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Mobile Home Bedroom Fire Studies: The Role of Interior Finish

Edward K. Budnick
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Center for Fire Research
National Engineering Laboratory
National Bureau of Standards
Washington, D.C. 20234

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Interim Report

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MOBILE HOME BEDROOM FIRE STUDIES: THE ROLE OF INTERIOR FINISH[1]

Edward K. Budnick, David P. Klein, and Robert J. O'Laughlin[2]

Abstract

A series of nine full-scale fire tests was conducted in the master bedroom of a typically constructed single-wide mobile home to (1) evaluate the effect of a variety of combinations of wall and ceiling materials on fire growth and spread and the production of smoke and toxic gases when exposed to an incidental fire, and (2) determine the relationship between the surface flame spread properties of the interior finish material as determined by the ASTM E-84 Tunnel Test and behavior of the materials under actual full-scale conditions.

The primary fire scenario selected was the exposure of the interior finish materials to an incidental fire from a burning upholstered chair in a corner in the master bedroom. Performance of the various combinations of wall and ceiling materials was evaluated on the basis of (1) whether and at what time flashover was reached, and (2) changes in the environment outside the bedroom which adversely affect life safety. Measurements included gas temperatures, irradiance, concentrations of carbon monoxide and carbon dioxide, oxygen depletion, and smoke densities.

Supplemental testing indicated that while the fire properties of the interior finish materials played a dominant role in spreading an incidental fire from a chair, the impact of the interior finish materials was less evident when the exposure fire was from the burning of a polyurethane mattress, which provided an exposure fire of greater intensity. When a bed was used instead of the chair as the initial burning item, flashover occurred in the room from involvement of the mattress and bedding materials, with no apparent contribution from the low flame spread interior finish.

Key words: ASTM E-84 Tunnel Test; fire growth; fire tests; flame spread; flashover; incidental fire; interior finish; life safety; mattress; mobile home; radiant heat flux; room fires; upholstered chairs.

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2 Currently with Union Carbide Corporation, Knoxville, TN

1. INTRODUCTION

This report is intended to provide technical data on an individual segment of the research conducted under the Mobile Home Fire Safety Project. A final report will be forthcoming in which this data will be analyzed along with data collected in other segments of the project, including full-scale fire tests in the kitchen, living room and corridor areas of a single-wide mobile home. Overall conclusions and recommendations will be provided.

1.1. Background

Examination of fire loss statistics [1][3] indicates that most residential fires are initially small and incidental in character; that is, they do not spread beyond the room of fire origin, and by themselves do not pose a serious problem. The fire loss statistics and experimental studies [2,3] indicate however, that the nature and quantity of combustibles around the fire and the geometry of the enclosure have a significant influence on the growth and spread of an incidental fire.

There is a reasonable concern that the adverse effects of burning many types of furnishings may incapacitate any occupant in the mobile home regardless of the interior finish materials [4,5]. However, as already mentioned, many incidental fires are initially small, generating low or moderate amounts of heat. When these fires occur, the threat to life and property damage due to fire buildup and spread beyond the room of origin is frequently a function of the nature of the interior finish materials.

While interior finish is not necessarily the first material ignited in a compartment, as the fire grows in intensity the interior finish can become involved and significantly influence the overall extent of the fire; due to its large exposed surface area it can have a high rate of heat production; in addition, the flames can spread rapidly over thin combustible materials. Therefore, within the room of fire origin, the interior finish, depending on its physical, thermal and fire properties, can contribute significant quantities of fuel to the fire [6] and play an important role in the occurrence of flashover.[4]

Once a fire has reached a certain magnitude, heat, toxic gases and smoke may move rapidly to adjacent areas. Fire growth to this size and the actual propagation of flame and smoke into these adjacent areas are significantly influenced by the type, amount, and location of the interior finish. This would indicate that proper selection of interior finish materials, based on measured fire properties, may provide an increased level of fire safety to the occupants and property from an incidental fire in a mobile home.

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

[4] Flashover is defined here as a fire phenomenon in which the upper level fire gases and ceiling radiate sufficient energy to the lower part of the room to cause rapid ignition and complete fire involvement of all combustible materials [7].

The involvement of interior finish materials has been generally recognized as a significant factor in the spread of fire within the room of fire origin, and in the spread to adjacent areas outside the room. Many building codes, including the Federal Mobile Home Construction and Safety Standard [8], have included criteria to regulate the use of interior finish materials on the walls and ceilings. The test upon which the criteria are based in most of these codes is the ASTM E-84 Tunnel Test [9]. The levels of acceptable performance appear to be based to a large extent on traditional materials, laboratory testing, and some experience with material performance in actual fires. However, it is not clear to what extent the conditions and test procedure in the tunnel simulate the environment in a room, or compartment, in which an incidental fire has occurred.

A major research project has been undertaken at the National Bureau of Standards (NBS) to examine some of the design and material characteristics which may affect fire growth and spread in a single-wide mobile home. As part of this project, full-scale tests were conducted to characterize the fire growth potential in the bedroom of a typical single-wide mobile home primarily as a function of the interior finish materials on the walls and ceiling. This report provides an examination of the results of nine full-scale experimental fire tests conducted in the master bedroom area of a 3.7 x 18.3 m (12 x 60 ft) mobile home constructed in accordance with NFPA 501B, Standard for Mobile Homes, 1972 Edition [10]. It should be noted that the spatial, structural and material elements of this mobile home, which influence fire growth and spread and therefore would impact any resulting evaluation of performance under full-scale room burn out tests, are identical to those in mobile homes constructed in accordance with the current Federal Mobile Home Construction and Safety Standard, effective June 1976.

1.2. Review of Previous Research

Whether or not a small incidental fire will stay small and confined to the initial burning item, or grow rapidly to a fully developed room fire depends on many factors. These factors include room geometry, ventilation, location and burning characteristics of the initial burning item and the proximity and arrangement of other combustibles including interior finish materials and furnishings. Mathematically based models are currently being developed to predict fire buildup as a function of these factors. However, it is not anticipated that these models will be available for some time.

While there is no complete methodology for determining the growth of fire in terms of the above key factors, information from experimental full-scale fire testing can provide an understanding of key mechanisms affecting fire growth and spread in a typically constructed room.

A key phenomenon in room fire buildup is radiation heat transfer from the heated surfaces [2,11,12] and the hot gas layer [13,14,15,16] in the upper part of the room. Based on experiments conducted in a full-scale enclosure at NBS, Fang [13] reported that an average upper room temperature ranging from 450 to 650°C provided a sufficient level of radiation transfer to result in flashover in the compartment. Three key factors which influence the attainment of temperatures in this range in the upper room are (1) the maximum burn rate of the initial item, (2) the duration of burning, and (3) the contribution of other combustibles which become involved. Based on results of past experiments, these three factors were carefully evaluated to provide guidelines in identifying key control variables for the experimental plan.

For example, in one series of enclosure experiments it was reported that a maximum burning rate of 40 g/s from involvement of combustibles in a 3.64 x 3.64 m (12 x 12 ft) enclosure, 2.43 m (8 ft) high, was reached or exceeded before room flashover occurred [17]. While this was determined for a particular set of controlled conditions it may approximate the necessary rate of burning for room flashover for fires in similar sized enclosures. Although items of furniture exist which could burn at a peak rate greater than 40 g/s, the peak burning rate of incidental items of furniture generally would not exceed this rate under similar conditions of room size and ventilation. Therefore, the initial assumption was made that the burning of a single upholstered chair (representing an incidental item of furniture) alone would not result in sufficiently high temperatures in the upper room to result in flashover. This assumption was validated during the conduct of the tests.

The contribution of other combustibles in the room, including furniture items and interior finish depends primarily on the proximity of these items to the burning item. Results of experiments by Fang [18] on low intensity fires from the burning of incidental combustible items indicated that inter-item spread of fire could occur only when combustibles are located within the hot air region surrounding the burning items (within approximately 0.15 m (0.5 ft)). For burning upholstered chairs of similar construction to those used in this test series, Klein [19] reported a maximum incident heat flux ranging from 1.2 to 1.8 W/cm^2 at a horizontal distance of 0.6 m (2 ft) and an incident heat flux of less than 1.0 W/cm^2 at a horizontal distance of 1.2 m (4 ft). Therefore, for incidental items such as upholstered chairs having moderate burning rates, adjacent combustibles must be located close to the burning item to result in inter-item fire spread.

If, however, the burning item is positioned in close proximity to a wall there is an increase in the severity of the fire. This exposure situation is even more severe when the burning item is in a corner of the room due to entrapment of radiation and the elongation of the flame from the restricted air flow in the corner behind the flame.

The previous research studies have indicated that the size and location of the burning item, the proximity of other combustibles, and the fire, thermal, and physical properties of the enclosure lining are key variables influencing the development of high temperatures in the upper room which result in sufficient radiation heat transfer to cause flashover of the enclosure.

1.3. Objectives

As previously noted, examination of fire loss statistics [1] indicated that most fires occurring in residences are initially small, and incidental in nature. The findings of other experimental studies including those dealing solely with mobile homes [2,3] indicated that the surface areas exposed and the fire properties of the interior finish materials on the walls and ceiling play a dominant role in fire buildup in a room. Therefore, the objectives of this particular segment of the project were:

(1) to provide quantitative data regarding the fire buildup process, primarily as a function of interior finish, resulting from an incidental fire in the bedroom of a typical single-wide mobile home, and

(2) to provide an evaluation of the extent to which the results of the presently required ASTM E-84 Tunnel Test can characterize the hazard of these interior finish materials when installed on the walls and ceiling in a bedroom of a mobile home.

1.4. Approach

A large full-scale test is intended to represent an actual real world condition. However, in order to provide experimental data on a variety of interior finish materials, tests must be conducted under a set of controlled conditions. Therefore, a single fire scenario must be selected; a fire scenario is a postulated probable occurrence of ignition, the subsequent chain of events, and the reasonable relationship of that occurrence to the nature of the occupancy.

The size of the initial burning item and its position in the room are key factors in selecting the scenario to evaluate interior finish materials. For example, the size of the initial burning item can be selected so that the influence of the interior finish materials appears insignificant. It can be very small or located such that the interior finish is not exposed during initial fire buildup, or it may be very large, thus masking the differential effects of the interior finish. Care was taken in the experimental design to avoid both these extremes so that the role of the interior finish materials could be properly evaluated.

Regardless of the size of the initial burning item selected in evaluating materials, a reasonably severe orientation consistent with practical usage, such as a corner configuration, is generally recommended. Therefore, the full-scale fire test procedure was designed based on the scenario that an ignition might occur resulting in an incidental fire in the corner of the bedroom. The effect of the fire properties of the interior finish materials on the growth and spread of the fire and the resulting severity was examined for this scenario.

In order to limit the number of variables in the full-scale fire tests, a standardized initial burning item, ignition location and room furnishing arrangement were used. Standardizing these factors enables a better comparison to be made of the fire performance of the interior finish materials in the bedroom area.

In eight of the nine tests conducted, the initial burning item was a medium sized upholstered chair positioned in the corner of the bedroom. A small polyethylene waste container was filled with ordinary newsprint and positioned adjacent to the right side of the chair; ignition of the newsprint was by remote electrical ignition of a typical book match. In these tests, the other combustible contents in the bedroom were a bed, floor covering, and curtains, providing a moderate moveable fuel loading of 9.8 kg/m^2 (2 lbs/ft^2). These furnishings were typical of those found in furnished mobile homes.

In one test the initial burning item was a bed, consisting of a polyurethane foam covered coil box spring and a polyurethane foam mattress. The bed included sheets, pillows and pillow cases, and was ignited by remote ignition of ordinary newsprint placed near one end of the mattress, partially exposing the mattress and the pillows. In this test there were no other combustible furnishings in the room.

The results of the full-scale tests were examined from two general viewpoints. First, an assessment of fire growth and spread in the room of origin was made, based on the various combinations of wall and ceiling materials tested. This assessment was based on measurements of incident heat flux and gas temperatures at strategic locations in the bedroom, and provided information on the rate of fire buildup and extent of room involvement from exposure of various lining materials to a standardized ignition source. The incident radiative heat flux resulting from the burning of the upholstered chair was measured at various distances outside the hot air region surrounding the burning chair in order to provide data on the potential for inter-item fire spread. Changes in concentrations of carbon monoxide and carbon dioxide and depletion of oxygen in the bedroom resulting from the fire buildup were also included. Secondly, changes in the levels of temperature, smoke density, carbon monoxide concentrations and oxygen depletion in adjacent areas outside the bedroom as a result of fire buildup were examined.

Standard and experimental laboratory fire tests were conducted to characterize some important fire properties of the various interior finish materials utilized in the full-scale testing. The results of these tests are systematically reported. The laboratory tests included the ASTM E-84 Tunnel Test [9], ASTM E-162 Radiant Panel [20], NFPA 258 Smoke Density Chamber [21], NBS ease of ignition test [22], and NBS rate of heat release calorimeter [23]. A qualitative evaluation of the relationship between the room fire buildup process and the laboratory measured surface flame spread classification of the wall and ceiling materials (ASTM E-84) is provided.

2. EXPERIMENTAL PROGRAM

2.1 Test Facility

The test facility was a conventional three bedroom single-wide mobile home approximately 3.7 x 18.3 m (12 x 60 ft) with the master bedroom (bedroom #1)[5] being selected as the room of fire origin (figures 1 and 2). The bedroom was approximately 3.5 m (11 ft 4 in) wide, and 2.8 m (9 ft 2 in) long, resulting in a floor area of 9.8 m^2 (105 ft^2), and had a ceiling height of 2.1 m (7 ft). The single opening into the bedroom was through a doorway 0.76 m (30 in) wide and 2.0 m (6 ft 8 in) high, connecting the bedroom with the corridor. The initial item to be burned was positioned in the southeast corner of the bedroom; figure 3 shows the location of the upholstered chair and the bed in the bedroom.

The construction of the bedroom was typical of mobile home construction. The exterior walls were constructed with 51 x 76 mm (2 x 3 in) nominal thickness hemlock studs, spaced 406 mm (16 in) on centers, with 64 mm (2.5 in) of single thickness glass fiber insulation between the studs and the aluminum exterior siding. The interior walls were constructed with nominal 51 x 51 mm (2 x 2 in) studs, 406 mm (16 in) on centers, with no insulation between the studs. The roof construction included an aluminum exterior sheeting attached mechanically to a system of wood bow-string trusses, spaced 406 mm (16 in) on centers, with 76 mm (3 in) of single thickness glass fiber insulation above a polyethylene vapor barrier. The floor was constructed of 19 mm (0.75 in) thick particle board. The bedroom had two 660 x 762 mm (26 x 30 in) windows. One each was located in the south and west walls. A detailed plan view of the mobile home is shown in figure 2.

[5] Hereafter referred to as the bedroom.

A sprinkler system was installed with small orifice open sprinkler heads located in the center of the bedroom and in the corridor (midway between bedroom and living room). The system was manually actuated to minimize fire spread outside the bedroom after flashover.

The interior finish materials were fastened with nails to the studs on the walls and the ceiling trusses in accordance with recommended practices for installation of the interior finish material. Assembly was completed at least 48 hours prior to the start of each test to allow time for conditioning.

2.2. Initial Burning Items

Based on the scenario previously described, for eight of the nine tests a medium sized upholstered chair was used as the primary source for the incidental fire. The chair, which weighed 16 kg (35 lbs), had a hardwood frame and was constructed with polyurethane foam and cotton batting materials and covered by a rayon fabric. The removable seat cushion was constructed completely of polyurethane foam and covered by rayon fabric material. The chairs were stored and conditioned to moisture equilibrium in a nearby test building where temperature and humidity are near constant at 75 ± 5°F and 35 ± 10% relative humidity.

In one test, the initial burning item was a 1.4 x 1.8 m (54 x 72 in) bed, comprised of a 16 mm (5/8 in) thick polyurethane foam covered coil box spring and a 102 mm (4 in) thick polyurethane foam mattress, having a total weight of 24.5 kg (54 lbs). The bed was not intended to represent an incidental sized ignition source, but rather the most severe situation likely to arise as a result of ignition of a single item of furniture in a mobile home bedroom. The bed was also stored in the adjacent building until tested.

2.3. Bedroom Furnishings

In the tests with the upholstered chair as the initial burning item, a bed 1.4 x 1.8 m (54 x 72 in) was located in the southwest corner of the bedroom at a distance of 0.6 m (2 ft) from the chair. The bed consisted of a 102 mm (4 in) thick polyurethane mattress and matching coil box spring, and included bedding (sheets, pillows, and pillow cases). Polyester fabric curtains were placed over both bedroom windows, and a vinyl asbestos floor covering, 3.3 mm (0.13 in) thick, was fastened to the 19 mm (0.75 in) thick particle board subfloor by staples. In the test with the bed as the initial burning item, there were no additional furnishings in the room.

2.4. Interior Finish Materials

The various interior finish materials used in these tests were selected to provide a range of materials having different surface flame spread properties. Table 1 lists the materials tested and some of the more pertinent measured properties obtained by conducting experimental laboratory and standard fire tests. The full-scale tests were designed to examine the performance of a number of combinations of wall and ceiling materials under a similar fire exposure. Table 2 identifies the materials used in each of the tests.

The three basic types of wall materials tested were untreated prefinished lauan plywood, intumescent coated lauan plywood, and printed paper finished gypsum board.

Two thicknesses of untreated prefinished lauan plywood were tested: 4 mm (5/32 in) thick plywood which was typical of the most common wall material used in conventional mobile home construction, and 6.4 mm (1/4 in) thick plywood. Both were purchased commercially.

Two types of fire retardant treated 4 mm (5/32 in) thick lauan plywood were tested. Both treatments were clear fire retardant intumescent coatings; one type was prepared on a proprietary basis by a manufacturer; the other coating was commercially available and applied at NBS in accordance with the manufacturer's instructions.

The printed paper faced gypsum board was 8 mm (5/16 in) thick and had a simulated wood grain vinyl surface.

Three types of ceiling materials were used in the construction of the various interiors tested in the mobile home. One type was 13 mm (1/2 in) thick prefinished wood fiberboard accoustical ceiling panels. The panels were 0.6 x 1.2 m (2 x 4 ft) in size and were purchased commercially. The second type of ceiling material used was 13 mm (1/2 in) thick unfinished wood fiberboard material in 1.2 x 3.7 m (4 x 12 ft) sheets. The third material was 8 mm (5/16 in) thick gypsum board with a finished surface, supplied in 1.2 x 3.7 m (4 x 12 ft) sheets.

One of the tests (test 8) was conducted to collect experimental data necessary to identify some of the key burning properties of the 16 kg (35 lb) upholstered chair when burned in an enclosure of this geometrical size having similar ventilation. In this test the walls and ceiling were constructed of 13 mm (1/2 in) thick sheets of inorganic marine board ($CaSiO_3$) installed over 13 mm (1/2 in) thick gypsum board.

In the test with the bed used as the initial burning item (test 13), the walls and ceiling were lined with 13mm (1/2 in) thick gypsum board, taped and spackled.

2.5. Ambient Measurements

Outside and inside temperatures and relative humidity, as well as wind velocity and direction, and barometric pressure were recorded prior to each test. In addition, the moisture content of the wall and ceiling materials were measured before each test using an electrical moisture meter (see table 3).

2.6. Test Measurements

A diagram illustrating the location where test measurements were taken is shown in figure 4. Table 4 also lists each instrument, the type of measurement, and location. Ranges and limits of error are listed in appendix C.

Forty-eight thermocouples were located throughout the mobile home to measure air temperatures during the tests. The thermocouples located in the corridor were commercial metallic-sheathed assemblies composed of 0.91 mm

(0.0359 in/20 gage) Chromel and Alumel[6] wires packed in mineral insulation and enclosed in a 3.15 mm (0.124 in) diameter inconel 702 sheath with a grounded junction. All other thermocouples were made from 0.61 mm (0.0239 in/24 gage) Chromel and Alumel wires enclosed in glass fiber insulation.

Combustion gas concentrations were sampled continuously in the bedroom and in the living room area. The samples were filtered through glass fiber to remove soot and particulate matter and chilled through an ice bath to remove the condensable vapors before being passed through non-dispersive infrared gas analyzers to determine concentrations of CO and CO_2. Concentrations of O_2 were measured by chemical oxygen cells. Concentrations of CO, CO_2 and O_2 were measured 1.5 m (5 ft) above the floor in the center of the bedroom. Concentrations of CO and O_2 were measured in the living room, also 1.5 m (5 ft) above the floor. In addition, oxygen depletion was measured 25 mm (1 in) below the door sill in the center of the door opening to the bedroom in selected tests.

Calibrated water-cooled Gardon type heat flux transducers were used to measure heat flux levels at the following locations: in the center of the bedroom on the floor, in the center of the door opening to the bedroom on the floor, and in the center of the corridor on the floor. The transducers had a calibrated measuring range of 57 KW/m^2 (5 Btu/ft^2 sec). Additional heat flux transducers were located on the wall and in the ceiling above the initial burning item in selected tests. The manufacturer's calibrated measuring range for these transducers was 114 KW/m^2 (10 Btu/ft^2 sec).

Light transmission through the smoke was monitored during the tests to determine the level of obscuration from the smoke which accumulated in the corridor and that which passed through the corridor and into the dining and living room areas. Horizontally aligned smoke meters were positioned 0.9 and 1.5 m (3 and 5 ft) above the floor at two locations: 1) in the corridor adjacent to bedroom #3 (with the light path positioned to measure approximately across the corridor width); and 2) in the living room, to provide some limited data on stratification of smoke outside the room of fire origin. The smoke was measured continuously by monitoring the attenuation of a collimated beam of light from a tungsten lamp impinging on a phototube. The housing of the phototube was shielded to prevent outside light from entering the receiver, and the optical path length of the light beams was 0.45 m (18 in).

A water-cooled, strain gage load cell was utilized to monitor the weight loss rate of the initial burning item during each test.

An A.C. powered ionization-type smoke detector having a sensitivity of 0.02 OD/m (1.48%/ft) when tested in a U.L. type 217 smoke box at an air flow rate of 0.15 m/s (30 f/m) was installed on the inside wall of the corridor, 229 mm (9 in) below the ceiling and 381 mm (15 in) from the corridor entrance to the living/dining room areas.

Graphical documentation of the fire tests was obtained with 35 mm color slides, 16 mm color movies, and black and white video tape. In addition, visual observations were recorded on a tape recorder and transcribed after each test.

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[6]Trademark - Hoskins Manufacturing Company

Data for each test were input to a multi-channel data acquisition system every 20 seconds and recorded on magnetic tape in order to be processed by computer. The data recorded in this manner included output signals from thermocouples, smoke meters, gas analyzers, heat flux transducers, and the load cell. The signals from 24 thermocouples and the gas analyzers were also simultaneously recorded either on strip chart or multipoint recorders.

3. TEST CRITERIA

3.1. General

Criteria for evaluating the test results were based on two related aspects of fire growth. First, the size of the fire in the room of origin affects the overall damage to the occupancy. Therefore the measurements of fire growth, and the attainment of flashover in the room of fire origin were selected as the primary criteria for assessment of property damage. Generally, flashover was assumed and reported to have occurred when ignition of the bed, the vinyl flooring, and all other combustibles located in the room was observed. The changes in temperature, incident heat flux, carbon monoxide, carbon dioxide and oxygen which occurred as the fire developed were recorded.

The second aspect of fire growth of importance in establishing fire safety criteria upon which to evaluate the results of these full-scale tests was the effect of the fire on the environment in adjacent areas outside the room of fire origin. By necessity, any approach to this must be pursued in terms of an assessment of the impact of the changes in the environment on the occupants. However, the current state-of-the-art does not permit a precise quantitatively based assessment of the direct hazard to humans associated with exposure to fires. Information concerning the clinical toxicology in humans of specific thermal decomposition products is at best meager [24]. Obviously, not until epidemiologic data from humans are available to supplement laboratory animal data and experimental data collection under physical fire testing could a true assessment of the hazards be made.

Notwithstanding the lack of epidemiologic information on human effects, the dominant adverse conditions occurring due to a fire can be measured. Dominant conditions present in building fires which are known to adversely affect human health include the development of high temperatures and carbon monoxide concentrations, and the depletion of atmospheric oxygen concentration [24]. While there are other concerns such as smoke particulate matter and other toxic gas species which may be generated in sufficient quantities to result in conditions which would adversely affect the life safety of the occupants before such levels of temperatures, CO, or O_2 are reached, these three dominant factors are the most reliably measured under full-scale experimentation.

Limiting criteria were selected to evaluate these principal factors affecting the life safety of occupants of the mobile home in the event of a fire originating in the bedroom. Performance of the various combinations of wall and ceiling materials installed in the living room was analyzed based on the changes in the environmental conditions along the normal paths of egress and in the living room in terms of the measured changes in temperature, CO and O_2. In addition to monitoring these conditions which have a direct impact on life safety, measurements were taken outside the living room to monitor the amount of visible smoke being produced by the fire. These data were collected to provide some information on the accumulation of smoke along the corridor and in the living room, which constitutes the principal path of egress.

Thresholds for limited conditions of temperature, CO and O_2 under a fire condition beyond which adverse physiological or psychological effects would result have not been established. Difficulties in pursuing this have arisen due primarily to the variation in 1) exposure times, 2) vertical and horizontal distribution of gases, 3) the activity rate of the occupant, 4) the general health of the occupant, and 5) the lack of clinical epidemiologic data as mentioned previously. However, for purposes of anlaysis there is sufficient information available to tentatively establish levels at which adverse effects begin to occur. Therefore, limiting conditions for life safety have been selected based on literature references available to the authors. In selecting these thresholds, no consideration has been given to either the synergistic effects or additive effects resulting when limiting conditions are exceeded for two or more of these measured conditions. Further, the thresholds suggested here are based on the levels of these elements which result in "incipient incapacitation" rather than death. Incipient incapacitation is defined as that point at which physiological and psychological effects are sufficient to impair thinking and influence physical efforts to escape. The criteria are based upon the assumption that these critical levels represent thresholds for human beings who are capable of normal physiological and psychological behavior. The thresholds should not be interpreted as precise boundaries but rather an approximation, based on the literature and the unique characteristics of the occupancy type being assessed, of the levels of conditions which would result in adverse effects.

3.2. Carbon Monoxide

Carbon monoxide (CO), while not the only toxic combustion gas, is produced in such large quantities in most fires that it is considered an important life safety factor [25]. Experimental full-scale testing has revealed that quantities of CO far in excess of amounts necessary to result in human incapacitation and death are often generated [16,26-32]. In addition, clinical studies of the causes of fire deaths have also lended support to this concern. For example, Zikria et al. [33-36], working with the clinical examination records and autopsy reports of fire victims in New York City, found that CO poisoning rather than respiratory tract damage was the significant factor with victims having post burn survival times less than 12 hours. In a fire fatality study currently being conducted at Johns Hopkins University [37,38] it has been reported that CO exposure resulted in sufficient carboxyhemoglobin in the blood to either directly cause or contribute to death in 80% of the cases cited.

A person's ability to function reliably can be significantly affected by exposure to CO. Progressive effects include dizziness, dimness of vision, nausea, increase pulse and breathing rates, loss of orientation, unconsciousness, convulsions and death [39,40]. How much CO a human being can tolerate is to a large extent a function of time, concentration, and physical activity. For example, the threshold limit for exposure to CO for an 8-hour period has been established as 50 ppm [41]. However, criterion based on exposures to high concentrations of CO is not as readily determined. In fires where ventilation is restricted, incomplete oxidation of carbon occurs leading to concentrations of CO as high as 138,000 ppm in short periods of time [42].

From a clinical standpoint CO poisons by asphyxiation; that is, CO is absorbed via the lungs into the blood resulting in a reduction in the amount of hemoglobin (Hb) available for oxygen transport because of hemoglobin's greater affinity for CO than for O_2. The level of reduction can be determined by measuring the carboxyhemoglobin (COHb) content in the blood resulting from the intake of CO, and can be demonstrated by the reaction:

$$CO + HBO_2 \overset{K}{\rightleftharpoons} COHb + O_2 \qquad [43]$$

To determine the COHb level from the CO concentration an uptake equation based on CO concentration and the time of exposure must be used. Stewart [44] has developed such an equation which is preferable to other available equations because it is based on experiments where human volunteers were subjected to very high CO concentrations such as might be expected under a fire exposure.

The equation is applicable for exposure times of less than 30 minutes, beyond which saturation and elimination can begin to take effect. The equation would also not hold beyond the time at which incapacitation occurs. Different equations would be used for low concentration-long duration exposures [45].

The amount of CO which can be tolerated (or, the amount of COHb content in the blood) also depends on factors including the individual's ventilation rate and the level of CO_2 exposure, which are difficult to assess under the rapidly changing conditions resulting from a fire. The CO uptake is directly proportional to the ventilation rate, which is around 6.5 ℓ/min for an individual at rest [46]. This rate can be increased by both an increase in activity and/or exposure to CO_2. For example, exposure to a 4% CO_2 concentration will more than double the ventilation rate [47]. In considering both stimuli, which are likely to be present in a fire, Babrauskas [48] selected 18 ℓ/min as the appropriate accelerated ventilation rate which could conservatively be attained by either a 5% CO_2 exposure or by light work. In selecting the same elevated ventilation rate for this study, the resulting uptake equation can be expressed in finite difference form:

$$\Delta COHb\ (\%) = 5.98 \times 10^{-4}\ (\Delta t)\ (CO)^{1.036} \qquad [48]$$

where Δt is the elapsed time (minutes) and CO is expressed in ppm; an initial value of COHb - 0.75% [46] is used. For this test series values were computed up to the time when the threshold for incipient incapacitation was reached. This threshold was selected at COHb = 25% based on a study by Kimmerle [49] in which this level resulted in symptoms associated with incipient incapacitation as defined for this study.

In addition to the threshold for the time rated concentration, another limit must be selected for CO exposure. Instantaneous doses of high levels of CO must also be considered due to the physiological effects such as cardiac arrythmia [50] which can occur independently of the effects of increased COHb. Claudy [39] reported on the effects of exposure to high concentrations of CO. The results of his work indicate that incipient incapacitation may occur with only a few short breaths at an exposure level of 10,000 ppm CO. And, at a slightly higher concentration of 12,800 ppm Claudy reported that unconsciousness could occur in 2 to 3 breaths, followed by death in 1-3 minutes. Based on this an instantaneous threshold of 10,000 ppm (1.0% by Vol) CO was selected as a criterion in addition to the time-rated exposure resulting in a COHb level of 25%.

3.3. Temperature

The most prominent characteristic of a fire is the increased temperature due to the release of thermal energy. In terms of human exposure to elevated temperatures this can result in dehydration, heat exhaustion, sloughing of the trachea lining and hemorrhaging in the respiratory tract, skin surface burns, and shock due to pooling of blood at the body surface [51,52].

Research has been conducted involving investigation of thresholds for exposure to temperature which results in adverse physiological effects. In the Los Angeles School Burns conducted in the 1950's, a temperature of 65°C (approximately 150°F) at the five-foot level was selected as the critical temperature for teachers and children to enter and leave through a corridor [53]. In fire tests conducted by the National Research Council of Canada, 150°C (approximately 300°F) was considered the maximum level for breathing.

Results of experiments conducted in 1947 by Moritz, et al. [54] on large animals having a surface area-mass relationship near that of humans indicated that the relationship between exposure time and temperature level is hyperbolic; that is, as the exposure temperature is increased the exposure time to reach a specified injury threshold is reduced. Further, Moritz, et al. reported that for exposure times on the order of two to five minutes, air temperatures of 100°C (212°F) represented the threshold for local burning and hypermia (general burning). In other animal studies (with smaller animal specimens) during that period Bond [55] reported that death occurred in two minutes when the exposure temperature was 100°C (212°F). While the differences encountered in these two studies may have been the result of the difference in the size of the animal specimens (significantly different surface area-mass relationship) it could also have resulted from variation in an unreported experimental variable such as humidity.

Increased humidity which is a common phenomenon in a fire, will result in injury thresholds being reached at somewhat lower temperatures. Work by Montgomery, et al. [56] in 1975 indicated that in humid air rapid skin burns would occur at 100°C (212°F), and 150°C (300°F) represented a temperature exposure level at which escape was not likely.

For this study, a temperature threshold of 100°C (212°F) was selected to represent the point of incipient incapacitation. Consideration was given not only to the studies reported herein, but also to the type of occupancy and to the likelihood that humidity would be present at increased levels (though a precise measure would not be made) througout the mobile home as a result of the fire. It was felt that an occupant might be expected to withstand this exposure level under moderate humidity levels for only a short period. And, as the humidity increased during the fire, the short exposure period before the onset of incipient incapacitation would be reduced even more.

3.4. Oxygen Depletion

Excessive reduction in oxygen is normally confined to the immediate environment of a fire. However, due to the geometry of a single-wide mobile home the possibility exists that oxygen depletion may be of great enough magnitude to affect life safety outside the bedroom area.

Extensive experimental research has been conducted to define tolerable ranges for the partial pressure of oxygen in the blood to insure satisfactory metabolic activities. Most of this research has been structured to provide specific information on reduced atmospheric pressure, and concentrations of oxygen ranging from 20.9 percent to 100 percent, as well as variation in the concentrations and mixtures of the inert gases. The results of these kinds of experimentation have provided well defined ranges for the partial pressure of oxygen from metabolic requirements under variations in controlled atmospheres [57].

While the amount of clinical information on reduction in the partial pressure of oxygen under normal atmospheric pressure (760 mm Hg) is limited, some information is available, based partly on experimental work on test animals and partly on analytical extrapolations from the extensive research conducted under auspices of the space program. As the partial pressure of the oxygen in the circulatory system is reduced, the movement through the body and the amount is altered. Reduction in the concentration of oxygen in the air breathed in will affect the partial pressure of the oxygen in the body, and to a proportionate amount affect the metabolic functions. The lack of sufficient oxygen for metabolic activities results in the occurrence of either "anoxia" or "hypoxia." Anoxia occurs when no oxygen is available, and is characterized by symptoms such as near immediate convulsions, paralysis and death. Hypoxia occurs due to a relative lack of sufficient oxygen, and depending on the severity, the symptoms may range from only subtle changes to those associated with anoxia [47].

Pryor, et al. [58] indicate the following symptoms resulting from progressive reduction in the concentration of oxygen in the air breathed in under normal atmospheric pressure:

Oxygen Concentration	Physiological Symptoms
17% O_2	Respiration volume increases, musclar coordination diminished, attention and clear thinking require more effort
14% O_2	Dizziness, shortness of breath, headache, numbness, quickened pulse, efforts fatigue quickly
11% O_2	Nausea and vomiting, exertion impossible, paralysis of motion
8% O_2	Symptoms become serious and stupor sets in; unconsciousness occurs

These symptomatic reactions to reduced levels of oxygen are reasonably agreed upon by other researchers, including Einhorn [59] and Kimmerle [49], with minor shifts in the groupings or ranges of percent concentration.

Studies conducted to examine the physiological effects of the rate at which the oxygen concentration in the air is depleted indicate that the physiological reaction may vary. When anoxia occurs slowly due to a gradual reduction in the oxygen concentration in the air, initial symptoms include dyspnea upon exertion and cyanosis. The effects are quite gradual and the individual may be unaware. The individual will gradually pass from a state of "stupor" to unconsciousness and total collapse. However, motor symptoms may be totally absent [60]. Kraines [61] reports, based on experimental and accidental incidents, that in gradual reductions in oxygen to as low as 10%, the subjects encountered these symptoms, the body and mind becoming gradually less responsive, with no apparent suffering.

However, under conditions resulting from fire development, the concentration of oxygen per unit volume of air is likely reduced rapidly. Studies by Henderson and Haggard [62] and reported by Pryor [63] suggest that when anoxia occurs rapidly, four distinct stages can be identified. In the first stage the respiration rate increases. In the second stage the respiratory rate becomes erratic, labored and convulsive, the inspiration rate is weakened, the expiration rate prolonged, and consciousness is lost. The third stage results in symptoms such as convulsions and collapse, shallow and infrequent respiratory movements, and a progressively slower and weaker pulse rate.

There is a fourth stage which is characterized by termination of respiration and heart arrest. The following diagram illustrates the ranges of oxygen concentrations associated with the various stages suggested by Henderson and Haggard [62]:

	$\%O_2$ by Vol.
	Normal
	21
	20
	19
	18
First Stage at 16-12%	17
Respiration volume increases	
Pulse quickens	16
Muscular coordination diminished	
Attention & clear thinking requires more effort	15
	14
Second Stage at 14-9%	
Resembles alcoholic inebriation,	13
headache, numbness, muscular	
efforts fatigue readily and cause	12
fainting, Cheyne-stokes respiration	
	11
Third Stage at 10-6%	
Exaggerates earlier symptoms	10
nausea and vomiting, exertion	
impossible, paralysis of motion	9
and sensation, unconsciousness	
	8
Fourth Stage	
Below 6%, respiration stops,	7
convulsive movements	
heart arrested 6-8 minutes	6
after the respiration	
	5
	4
Effects of reduced oxygen atmospheres	3
(reprinted from Pryor [63])	2
	1

Based on this information a value of 14 percent oxygen concentration has been selected to represent the threshold for incipient incapacitation for humans. While the various sources indicate slight differences of opinion in the types of symptoms occurring at 14 percent oxygen it is clear, particularly in light of the interpretation of the progress of anoxia in terms of stages of severity of symptoms by Henderson and Haggard [62], that concentrations of oxygen below 14 percent will result in serious physiological effects which may impair the judgment capabilities and physical movement of an individual.

3.5. Smoke Density

The presence of smoke can delay or prevent escape under fire conditions. In buildings where the occupants are unfamiliar with the escape routes or stairwell locations the reduction in visibility can involve strong psychologic factors as well as basic physiologic responses. Where the occupants might be familiar with the exit routes such as in a mobile home or other single family residences, they may be expected to some extent to negotiate smoke-laden pathways. However, even under familiar surroundings, when a certain perceived level of smoke is present people may be hesitant to pass through a corridor area and may completely refuse to, or at least proceed much more slowly through the smoke.

Extensive full-scale and laboratory research has been conducted to determine critical smoke levels under various occupancy types and under numerous combinations of conditions [64].

While references [65] and [66] cite critical smoke densities which are said to take account of eye irritation, the optical density of 0.0066 per meter derived from reference [65] is probably unreasonably low because it represents the onset of apprehension rather than a test of the limits of endurance of the observers. The optical density of 0.21 per meter derived by Malhotra [67] is said to be based on the Los Angeles School Burns number 2 [68]. However, nowhere in more recent studies is a critical value of 20% light transmission over a 10-foot path length to be found. As a matter of fact, the report on the Los Angeles School Burns [68] mentions only that 80% obscuration is the critical value for tenability, but identifies neither the location nor the length of the light path. From the information given in the two reports of the Los Angeles School Burns [68,69], it is possible to surmise that the light beams subject to 80% obscuration might have been as short as 3.3 meters or as long as 18.3 meters. It appears most probable that the light beam involved a double traverse of a corridor 3 to 5 meters wide or a path length of 6 to 10 meters. The critical optical density for that case would be 0.075 to 0.11 per meter. On this basis, it appears more reasonable to assign a critical optical density of about 0.1 per meter to the results of the Los Angeles School Burns. Rasbash [70] reassessed his earlier work as well as later work by Jin [71,72,73] and concluded that his original correlation [74] represents a useful worst condition which includes in an approximate way the effects of eye irritation. From a study of behavior of people in fires by Wood [75] he also judged that a minimum visibility for escape from fire is about 10 meters, and that this corresponds to an optical density of 0.08 per meter.

In the work by Jin [76,77] a smoke level which corresponded to a similar psychological effect as being blindfolded was developed. The walking speed of human volunteers was measured down a smoke filled corridor using "irritating" and "non-irritating" smokes. Walking speeds were also measured by the same volunteers down the same corridor with the volunteers blindfolded. The smoke level which resulted in the same walking speed as being blindfolded was then obtained. This work led Jin to establish an equation:

$$KV = 2$$

where K = extinction coefficient (m^{-1})

and V = visibility (m).

Jin further differentiated between the irritating and non-irritating smoke, recommending a limiting value of $K = 1.2\ m^{-1}$ for the former and $K = 0.5\ m^{-1}$ for the latter. The extinction coefficient can easily be expressed in terms of OD/m.

While review of these studies reveals a wide range of smoke densities selected to represent critical levels, a rough consensus from five of the studies [66,67,74,78,79] would suggest that an optical density of approximately 0.26 OD/m over a viewing distance of three to five meters can be used to represent the level of smoke at which impairment of physical features and possible disorientation of the individual might occur in an occupancy such as a mobile home. Approximately the same value was selected by Bukowski [80], Harpe [81] and Heskestad [82] for similar conditions. Therefore, a smoke concentration of 0.26 OD/m was selected to represent a level at which emergency escape along the normal paths provided in a typical single-wide mobile home would be impaired. This level of impairment should be distinguished from the thresholds selected for temperature, carbon monoxide, and oxygen which were selected to represent levels at which "incipient incapacitation" would likely occur. An optical density of 0.26 OD/m is intended to represent a concentration of smoke which might interfere with an occupant's movements by effecting his vision, but would not necessarily prohibit the individual from moving through it. It is expected that the more critical level of incipient incapacitation would be reached either at a somewhat higher concentration of smoke or a concentration of 0.26 OD/m in combination with the threshold for one of the other three conditions.

These conditions were monitored continuously during the tests, from the time of ignition of the initial fuel source until either flashover occurred or the instrumentation indicated a significant reduction in fire intensity and no additional fire growth, whichever occurred first.

4. PROCEDURE

4.1. Laboratory Evaluation of Materials

Laboratory test methods were utilized to measure the ignitability, surface flame spread, rate of heat release and smoke generation characteristics for the interior finish materials used in this series of full-scale fire tests. The tests utilized to ascertain these values were:

Characteristics		Laboratory Test Method
Ignitability	(1)	Ease of ignition test [22]
Surface Flame Spread	(2)	ASTM E-84, Standard Method of Testing for Surface Burning Characteristics of Building Materials [9]
	(3)	ASTM E-162, Radiant Panel Test [20]
Heat Release Rate	(4)	NBS rate of heat release calorimeter [23]
Smoke Generation	(5)	NFPA 258, Smoke Density Chamber [21]

4.2. Full-Scale Tests

The interior finish materials were mechanically fastened to the wall studding and ceiling trusses in accordance with recommended practices for installation of interior finish materials. Assembly was completed at least 48 hours prior to the start of the test. The moisture content of the interior finish materials was measured by an electrical moisture meter just prior to the test. Table 3 lists these measurements.

The conditions inside the mobile home were maintained to 23 ± 4°C (72 ± 7°F) and 52 ± 8% relative humidity. The measured moisture content of the walls and ceiling did not exceed 15%. The conditioning of the interior environment of the mobile home was difficult beyond these levels due to the high ambient temperatures and the high relative humidity during the period when the tests were conducted. The temperature, wind velocity and direction, and relative humidity were also recorded. Tests were not conducted during rainy periods or when relative humidity was exceptionally high. Table 3 lists the ambient conditions for each test.

In the eight tests with the upholstered chair as the initial item ignited, the arrangement of the furnishings, which is described in section 2.3., is shown in figures 3 and 5. The upholstered chair was positioned on the load cell in the southeast corner of the room at a distance of approximately 0.6 m (2 ft) from the bed. The polyethylene waste container, having a volume of 9l (9.5 qt) was filled with approximately 225 g (0.5 lb) of crumpled newspaper and placed adjacent to the right side of the chair. The tests were initiated by igniting the newsprint in the waste container by remote electrical ignition of a book match.

In the test with the bed as the initial item ignited (Test 13), there were no additional furnishings. The bed was positioned in the room as illustrated in figure 5. Figure 5 also illustrates instrumentation modifications; in particular additional heat flux transducers. An apparatus was designed and constructed to suspend the bed from a water-cooled load cell located above the roof line of the mobile home (figure 6). In this test, the mattress was exposed to a flaming fire resulting from remote electrical ignition of a typical section of ordinary newsprint, folded once, and positioned near the end of the mattress, exposing the pillows and the mattress bedding. The newspaper weighed approximately 280 g (0.6 lb).

As shown in figure 5, the upholstered chairs and the bed were positioned at a distance of 25 mm (1 in) from the corner walls. Prior to ignition, all exterior windows and doors were closed but not sealed, providing an initial static atmosphere. In addition, the doors to bedrooms #2 and #3 and the door to the bathroom were closed; the door to bedroom #1 remained open. Visual observations and photographic records were made of the development of the fire and measurements were continuously recorded from the time of ignition until the test was terminated.

5. RESULTS: LABORATORY SCALE TESTS

Table 1 provides a tabulation of the results of the laboratory tests conducted to measure some of the properties of the interior finish materials. While the results of other measured fire properties are included in table 1, particular attention will be given in the discussion of the full-scale test results to the surface flame spread characteristics of the materials as measured by the ASTM E-84 Tunnel Test.

6. RESULTS: FULL-SCALE TESTS

Review of the mass of data collected for these tests resulted in the selection of a number of specifically located measurements to characterize the average process of fire growth in the bedroom and the effects of this fire growth on the environment outside the bedroom. Specifically, analysis of the growth of the fire within the bedroom itself is based on 1) temperature 25 mm (1 in) below the surface of the ceiling, and 2) the levels of incident heat flux at the floor. In addition, plots of carbon monoxide, carbon dioxide and oxygen are provided to illustrate the effects of fire growth on the environment in the bedroom. All of these measurements were taken along the vertical center of the bedroom.

In considering the hazard to the occupants of the mobile home, it is assumed that anyone in the room of fire origin is alert and capable of reacting. Limiting conditions adverse to life safety are reached in the room rather quickly, providing little time to escape unless egress is begun immediately.

However, time should be available for occupants outside the room of fire origin to take corrective action and/or exit the mobile home. Since movement in a direction away from the fire is most likely, the primary route for most of the occupants outside the master bedroom would be along the corridor, through the living room and out the front door. In order for anyone attempting to exit the mobile home by this route to reach the front door, limiting conditions must not be reached along this route.

Even under adverse conditions, an occupant fleeing the fire may be expected, under some circumstances, to continue for a few steps. Therefore, to the extent that conditions in the living room remain tolerable, occupants may reach the front door even though a limiting condition of temperature, gas or smoke concentration may have been reached in the corridor. However, if limiting conditions are reached in the living room, similar or more severe conditions likely exist all along the primary escape route to the front door of the mobile home. Therefore, the effects of the fire on environmental conditions outside the bedroom are analyzed primarily by examining, in the center of the living room, 1) carbon monoxide 1.5 m (5 ft) above the floor, 2) oxygen 1.5 m (5 ft) above the floor, 3) temperature 1.3 m (52 in) above the floor, and smoke density 0.9 and 1.5 m (3 and 5 ft) above the floor. Table 5 provides a tabulation of the measured values of selected test conditions at approximately the time at which flashover occurred in the bedroom; table 6 lists peak measured values of the same conditions.

6.1. Fire Growth and Spread in the Bedroom

In typical mobile home construction, fire propagation beyond the room of origin will generally occur from full room involvement (flashover). To the extent that a fire does not reach the magnitude of full room involvement the overall damage to the mobile home and the changes in the environment throughout the mobile home which adversely affect the life safety of the occupants will be substantially reduced.

Chronological observations of the fire development for each of the tests is provided in appendix A.

Variations occurred in the development of the fire from the burning contents of the waste container and subsequent exposure of the upholstered chair. While the elapsed time to ignition of the chair covering material ranged from 55 to 86 seconds (due to variation in flame exposure time from the waste container fire), a more significant variation occurred in the erratic development of the fire in the chair itself. The elapsed time from ignition of the chair to the point when flame development resulted in impingement on the wall material ranged from two to twelve minutes (table 7). The longest period occurred in test 6 where the fire slowly progressed along the front of the chair, resulting in small flames attached to the front of the chair and no exposure to the wall along the right arm of the chair. The development of the chair fires was similar beyond the point of flame impingement on the wall.

The growth of the room fire beyond the burning chair depended significantly on the extent of involvement of the materials on the walls and ceiling. Ignition of the walls occurred after involvement of the seat cushion on the chair, spreading flames up the wall toward the ceiling. With the exceptions of tests 2 and 8, the flames progressed along the ceiling surface, heating the upper room. This was followed by flashover.

Ignition of the bed, vinyl flooring, and other combustibles occurred during flashover. At this time the intensity of the fire was of sufficient magnitude that flames entered the corridor along the ceiling. The fires were extinguished shortly after flashover to minimize the damage outside the bedroom.

In test 13, with the bed as the initial burning item, the burning newspaper ignited the sheets and the two pillows. At approximately two minutes into the test, both pillows and the mattress were involved and within another minute flames impinged on the ceiling. The fire progressed rapidly beyond this point, involving the entire top surface of the bed and flashing over the room.

6.1.1. Temperature and Incident Heat Flux

Figure 7 illustrates the temperature rise 25 mm (1 in) below the ceiling in the center of the bedroom. Six of the eight chair tests were characterized by very rapid temperature rise following involvement of the interior finish material, and peak upper room temperatures of sufficient magnitude to result in flashover. Test 13, with the polyurethane mattress as the initial burning item, was characterized by the most rapid temperature rise.

In tests 2 and 8, temperature rise was primarily the result of the burning of the chair. The interior finish materials on the walls and ceiling did not propagate the fire or contribute significant fuel to the fire. Both tests were characterized by gradual temperature rise, with peak temperatures of 300°C and 372°C, respectively. These peak temperatures were considerably below those reached in the seven tests in which flashover occurred.

In the remaining six tests with the upholstered chairs, there was considerable variation in the times at which rapid temperature rise occurred. However, in all six tests the temperature increased very rapidly once the fire spread beyond the chair to the interior finish, resulting in temperatures ranging from 634 to 734°C at flashover.

In test 13, with the polyurethane mattress and low flame spread interior finish materials, the early rapid temperature rise was similar to that which occurred in the six chair fires in which flashover was observed. The more gradual decline in temperature after flashover was the result of a longer delay in manual activation of the sprinkler system. The temperature at flashover was 700°C which was within the range of flashover in the chair fires.

Incident heat flux (figure 8) was measured at the floor in the center of the bedroom. As would be predicted, increases in incident flux occurred as the temperature increased in the upper room, with maximum levels of both incident flux and temperature occurring at approximately the same time. In those tests in which flashover occurred, the incident flux recorded at flashover ranged from 1.5 W/cm^2 (test 4) to 3.6 W/cm^2 (tests 3 and 6). The minimum level of 1.5 W/cm^2 recorded in test 4 corresponds to the minimum heat flux measured at flashover in previous full-scale mobile home fire tests at NBS [2].

6.1.2. Rate of Burning of Upholstered Chairs and Mattress

In general, the rate of burning for the initial item can be considered to consist of two regimes: a period of low burning rate during the time of initial fire development, and a period of high burning rate during the time of active burning of the item. The second period is usually characterized by a sharp rise in the rate of burning leading to a peak which is maintained for only a brief time before the rate of burning falls off sharply.

This trend is illustrated in figure 9 which shows time histories of the rate of burning for six of the eight chair tests and the mattress. The weight loss data for tests 1 and 6 were unreliable due to equipment malfunction and therefore not included. It can be seen that the initial period of low burn rate lasts for a variable length of time, even though all of the chairs were of similar design and were tested under similar conditions. The shortest period of fire buildup occurred with the mattress (test 13) where the maximum burning rate (measured over a 20 second interval) occurred at 4 min 10 sec. The time of maximum burning rate for the chairs ranged from 7 min 20 sec (test 3) to 14 min 10 sec (test 8). Peak (maximum) mass burn rates for each test are tabulated in table 6.

The burning rate, which is determined from the weight loss over finite time intervals, provides the basis for an approximation of the rate of heat generated from the burning items. While the actual heat release rate depends on the heat of combustion and rate of involvement of each of the various materials in the chairs or mattress, a number of important points are obtained from the burning rate histories in figure 9. In tests 2 and 8, in which flashover did not occur, the burning rate of the chairs rose sharply to peaks of 61 and 42 g/s, respectively, and then declined rapidly. The shape of the curves and the peak burning rates were consistent with results from similar tests conducted by Klein [19] in which he examined the burning rates of upholstered chairs in the living room of a mobile home with noncontributing walls. In tests 2 and 8 of the current study, the interior finish materials contributed little fuel, and the resulting peak temperatures in the bedroom were only 300 and 372°C, respectively. These values were far below the temperatures which occurred in those tests in which flashover was observed.

In test 13, the involvement of the polyurethane mattress resulted in a burning rate curve of similar shape to that of the chairs, but with a peak burning rate of 84 g/s, which was considerably higher. Again, the fuel contribution from the interior finish was low, but the peak temperature in the bedroom which occurred during this higher burning rate period of the mattress was 734°C, and flashover was observed.

In tests 3, 4, 5 and 7 in which flashover occurred, the maximum rate of burning for the chairs ranged from 18 to 27 g/s which was considerably lower then the range of 62 to 84 g/s associated with room flashover. The additional heat energy necessary to result in flashover in the bedroom in these four tests resulted from involvement of the interior finish materials. The peak burning rates for these four tests were limited by actuation of the sprinkler system. That is, at a burning rate ranging from 18-27 g/s there was sufficient contribution from the interior finish to reach upper room temperatures ranging from 688-776°C and flashover. Had the sprinkler system not been actuated, the burning rate for these chairs would probably have approached the levels measured in tests 2 and 8.

6.1.3. Oxygen Depletion and Generation of Combustion Gases

As would be expected, the fire severity directly affected the amount of CO and CO_2 generated. Oxygen depletion, as a result of the demand for oxygen in the combustion process, paralleled the growth of the fire. Figures 10, 11 and 12 illustrate the concentrations of CO, CO_2 and percent change of O_2 (O_2 depletion), respectively, for all nine tests.

In the seven tests characterized by rapid fire growth and flashover, high levels of CO and CO_2 were generated, and were accompanied by rapid O_2 depletion in the bedroom. The generation of CO_2 and the corresponding drop in O_2 were near mirror images as can be seen in figures B10 - B18 which illustrate the changes in CO, CO_2 and O_2 for each separate test.

Tests 2 and 8, in which the fire did not spread beyond the chair, were characterized by relatively minor changes in gas concentrations. Peak levels of CO_2 were below 5%, and those for CO were 0.3% or less for both tests. The corresponding reduction in O_2 was 3.2% in test 2 and 5.7% in test 8, corresponding to actual O_2 levels of 17.8% and 15.3%, respectively.

While the CO_2 data for test 13 is included, it appears questionable due to its extremely low peak value. The actual cause of the low CO_2 values could not be determined. Based on the other data collected in this test, it would appear that the peak CO_2 level should have reached 15-17%.

6.1.4. Residential Smoke Detector Response

A single station ionization type smoke detector was installed on the inside corridor wall near the entrance to the living/dining room area for each of the upholstered chair tests. Generally, the detector responded prior to extensive involvement of the upholstered chair and the interior finish materials. The times for response of the detector ranged from 34 to 86 seconds elapsed time (table 7). No detector was installed in test 13.

The single data point provided by one smoke detector should not be misconstrued as demonstrating detector response to a fire in a mobile home. Detector response varies as a function of many variables including environmental conditions such as relative humidity and ventilation rate, as well as the design of the sensing chamber, type of sensing mode and the reliability of the detector components. The experimental design for this series of tests was not intended to delineate among these. Any effort to assess state-of-the-art detection performance would require consideration of these as well as other technical variables.

6.2. Environmental Changes Outside the Bedroom and the Impact on Life Safety

In the experimental setup for the eight tests with the upholstered chair as the initial burning item, the incidental fire resulted in flame impingement on the interior wall surface; however, as previously discussed, there was significant variation in the time to flame impingement on the wall due to the erratic development of the chair fires. To assess the effect of the individual wall and ceiling systems, the influence of the variation in initial fire growth prior to exposure of the wall surface must be normalized. Therefore, in table 8, the data from the chair tests is tabulated based on the elapsed time from flame impingement on the wall surface to flashover and to limiting conditions of temperature, carbon monoxide and oxygen. This normalization of the data provides a more meaningful comparison of the performance of various combinations of wall and ceiling materials when exposed to similar incidental fires.

In test 13, the flames from the burning mattress did not impinge on the wall. Therefore, while the conditions outside the bedroom during test 13 are included in the discussion, the elapsed time is from the beginning of the test and is not normalized to the point of flame impingement on the wall as is done with the upholstered chair tests.

6.2.1. Temperature

In the tests in which flashover occurred, a limiting temperature of 100°C was exceeded 1.3 m (52 in) above the floor in the bedroom, along the corridor, and in the living room. In the six chair fires in which flashover occurred, the limiting temperature level was the first limiting condition reached in the living room, and as illustrated in figure 13, the temperature continued to increase beyond the 100°C criterion. The maximum temperatures reached prior to actuation of the sprinkler system in these tests ranged from 145 to 188°C. Flashover in the bedroom occurred at approximately the same time or not more than 40 seconds after this temperature was reached in the living room.

In test 13, the development of the fire in the mattress resulted in attainment of 100°C in the living room after 3 min 35 sec had elapsed. This was approximately ten seconds before flashover was observed in the bedroom. The temperature continued to increase after flashover to a peak of 159°C where it remained nearly constant for the period until the sprinkler system was actuated.

In tests 2 and 8 in which flashover did not occur, the 100°C criterion was still reached in the living room. In test 2, it occurred 2 min 45 sec after flame impingement on the wall (see table 8). And, in test 8, the temperature reached a maximum of 98°C at 9 min 40 sec elapsed time after flame impingement on the wall. Because of expected spread of data for a given set of test conditions, the peak temperature of 98°C was considered close enough to be considered a failure of the temperature criterion for purposes of discussion.

However, while 100°C was reached in both tests 2 and 8, in comparing them with the tests characterized by flashover, it appears that both tests are borderline cases. Figure 13 illustrates a very gradual temperature rise for tests 2 and 8, with peak temperatures of 109 and 98°C, respectively. These peak temperatures were considerably below the peak temperatures in the other seven tests. Further, in all tests except 2 and 8, the temperature in the living room was increasing rapidly as the 100°C criterion was exceeded, with the peak temperatures being limited solely by the actuation of the sprinkler system.

In addition to this, the greatest time periods from flame impingement on the wall to 100°C in the living room occurred in tests 2 and 8. Therefore, while flashover in the bedroom resulted in a limiting condition of temperature in the living room, the results of these tests indicate that if flashover does not occur in the bedroom 100°C may or may not be reached in the living room, but if it is reached the delay in reaching this temperature will provide additional time for escape.

Temperature levels of 100°C were not reached in any of the nine tests in the two bedrooms which had the doors closed. Since this temperature never exceeded 80°C in these tests, the closed doors successfully impeded the passage of hot combustion gases and flames into these rooms for the period of fire growth up to room flashover. However, the closed bedrooms should not be considered a sanctuary for occupants. These tests were terminated at flashover, but a post-flashover fire can be expected to result in inter-room fire spread. Many of the interior finish materials tested would not provide a barrier of any significance against fire penetration under such severe conditions.

6.2.2. Carbon Monoxide and Oxygen

As discussed in Section 3., the thresholds for limiting levels of CO were either 1) a time-rated accumulation of 41,800 $(ppm)^{1.036}$ (min) which is approximately equivalent to 25% COHb, or 2) an instantaneous concentration of 1.0% CO by volume. A minimum level of O_2 of 14% (7% maximum O_2 depletion) was also selected as a limiting condition.

Limiting levels of CO and O_2 were reached in the living room in six of the upholstered chair tests - those in which flashover occurred. While in some of the tests the thresholds were exceeded just prior to flashover, the difference in elapsed time was marginal (less than 20 sec). For the most part the thresholds were exceeded after conditions in the room of fire origin reached flashover (table 8).

In all six tests in which flashover occurred the 1.0% instantaneous concentration was the determining threshold for CO. However, in test 8 in which flashover did not occur, the threshold of 41,800 $(ppm)^{1.036}$ (min) was exceeded rather than the instantaneous level of 1.0%. This would not be unexpected. Under fire development as flashover was approached the measured conditions changed rapidly, by orders of magnitude. Under such a situation the instantaneous threshold was exceeded very quickly. As can be seen in table 5, at flashover the volume of CO was quite high but the time-rated accumulations based on the uptake equation were still relatively low. The plots in figures B19-B27 illustrate the dominance of the direct measurement of CO as flashover was approached.

While it would be expected that the threshold based on the time-rated accumulation would also be exceeded this occurred only in tests 8 and 13. However, failure to reach the time-rated threshold for CO in the six chair tests in which flashover occurred was most likely the result of experimental limitations. First, the chair tests were terminated shortly after flashover, but the duration of test 13 with the polyurethane foam mattress was extended almost two minutes beyond flashover, allowing for the additional buildup of CO. Secondly, the maximum range of the CO analyser was 2%. Therefore, the peak values of the time-rated accumulations for CO tabulated in table 6 are at most approximations since increases in CO concentration beyond 2% could not be measured.

The use of the uptake equation was expected to reflect those cases where rapid fire buildup did not occur, but a level of CO adverse to occupant safety was generated anyway. The fact that 41,800 $(ppm)^{1.036}$ (min) was exceeded in test 8 demonstrated this very point. A gradual buildup of time-rated CO due to an extended exposure time to a low level of CO resulted in exceeding the 41,800 $(ppm)^{1.036}$ (min) level. However, the threshold was not exceeded until 21 min 40 sec after flame impingement on the wall which was considerably longer than in the six chair tests characterized by flashover in which the threshold for instantaneous CO concentration was exceeded within two to three minutes after flame impingement on the wall.

In test 1, a window in the bedroom broke out during the test, providing additional ventilation. This occurred at 5 min 50 sec into the test and affected the minimum level of O_2 which was 15.7%. However, as can be seen in figure 15, the maximum slope of the O_2 depletion curve was similar to other tests in which the O_2 level was reduced far below the 14% threshold. It is likely that had the window not broken out, the O_2 level in the room would have continued to be rapidly reduced below 14%. Therefore, the limiting condition was assumed to have been reached.

As previously mentioned, the maximum level of CO in the living room exceeded the maximum range of the 2% infrared analyzer in all of the tests in which flashover occurred, with the exception of test 1 due to the additional venting through the broken window (figure 14).

As illustrated in the data plots in figures B19-B27, and in table 8, with the exception of test 1, limiting conditions of CO and O_2 occurred at nearly the same time, and shortly after 100°C was reached. In tests 1, 4, 5 and 7, the elapsed time from flame impingement on the wall to 1% CO ranged from 1 min 45 sec to 2 min 25 sec; similarily, elapsed time to reduction of O_2 to 14% ranged from 1 min 35 sec to 2 min 5 sec. The range of elapsed times was only 40 and 30 seconds respectively for CO and O_2.

The results of tests 3 and 6 indicate a noticeable increase in elapsed time from flame impingement to limiting conditions of CO and O_2 (table 8). However, as previously indicated, the behavior of the chair fire in test 6 varied considerably from the other seven chair fires and interpretation of the results in terms of elapsed times was limited.

In tests 2 and 8, with walls and ceiling which did not contribute significantly to the growth of the fire, a limiting condition of O_2 was not reached. And, while the time-rated threshold for CO of 41,800 $(ppm)^{1.036}$ (min) was reached in test 8, it occurred at a much later point in the test than any of the others where the CO threshold was exceeded. However, in test 13, limiting conditions of CO and O_2 were reached in the living room immediately after the mattress fire reached flashover in the bedroom even though the interior finish materials were similar to those used in tests 2 and 8.

6.2.3. Smoke Generation

An optical density of 0.26 OD/m was identified as corresponding to a level of smoke density at which obscuration of physical features and disorientation of the occupant may occur. While this level of optical density does not correspond to incipient incapacitation as do the levels selected for temperature, carbon monoxide and oxygen, it does represent a level of smoke accumulation at which impairment of emergency evacuation along the normal exit routes in the mobile home may occur.

In the nine tests conducted in this series, the four smoke meters located 0.9 and 1.5 m (3 and 5 ft) above the floor in the corridor and in the living room were oriented in a horizontal position. This orientation provided sensitivity to smoke stratification. Figures B28-B36 illustrate the optical density per meter as a function of elapsed time for the four smoke meters. The optical density of 0.26 OD/m corresponds to 76% light transmission over the 0.46 m light meter path used in these tests.

The results indicated that 0.26 OD/m occurred first at the 1.5 m level in both the living room and the corridor, and that the optical density was always higher at the 1.5 m level indicating stratification of the smoke throughout the mobile home. In all nine tests, 0.26 OD/m was reached and exceeded at all four measurement locations. With the exception of test 8, an optical density of 0.26 OD/m was reached prior to flame impingement on the wall. This would indicate that the time to reach 0.26 OD/m optical density at the locations selected for these tests does not depend on the interior finish material when the initial burning item is a typical upholstered chair.

While development of the chair fires alone resulted in high levels of optical density, the results of tests 2, 4 and 8 indicate a more gradual generation of smoke than in the other fire tests. In addition, the maximum optical density per meter reached in tests 2 and 8 which had low flame spread walls and ceiling was 2.0 OD/m, while maximum optical densities in the other tests exceeded 4.0 OD/m. Actually, in tests 4, 6, 7 and 13, the optical density exceeded 6.0 OD/m. (The reliability of the calculated values of optical density greater than 6.0 OD/m is reduced due to the accuracy of the instrumentation.) Therefore, the maximum rate of smoke generation prior to flashover depended significantly on the contribution of the interior finish materials when the initial burning item was a typical upholstered chair.

6.2.4. Fire Growth and the Impact on Life Safety

Figure 16 provides a graphical summary of the occurrence of limiting conditions of temperature, carbon monoxide and oxygen in the living room as a function of elapsed time from flame impingement on the wall for full-scale fire tests with the upholstered chairs. This technique provides a means of examining the performance of a variety of wall and ceiling systems assuming similar initial development of the chair fire. In addition, the times from the beginning of the test to attainment of limiting conditions are included for test 13 where the polyurethane mattress was used as the initial burning item.

The time available for emergency evacuation prior to reaching limiting conditions within the mobile home under this test scenario can be estimated based on the information included in figure 16. For example, if a fire requires 4 min 25 sec before initial flame impingement on the wall occurs, and an additional 1 min 20 sec to reach flashover (e.g., test 1) then the maximum time available before survival becomes unlikely and damage is extensive is 5 min 45 sec.

However, changes in conditions prior to flashover may significantly affect the occupants' ability to egress from the mobile home. Though not considered a limiting condition for human incapacitation, when 0.26 OD/m optical density is reached it becomes more difficult for an occupant to move. This difficulty is due in part to the decreased visibility and in part to the discomfort (i.e., coughing, eye irritation, etc.) caused by the smoke. The occupant may also have difficulty thinking clearly because of confusion and fear frequently associated with decreased visibility. The test data indicate that 0.26 OD/m optical density was reached very early in each of the tests, primarily as a result of the burning chair or mattress.

Difficulty in exiting the mobile home through an entrance door will be increased considerably once a limiting condition of CO, O_2 or temperature is reached. Limiting conditions of these elements will directly affect the capacity of the occupant to move. In addition, it cannot be assumed that persons will crouch or crawl along the floor where conditions may be more tolerable. Survival along the egress passages and in any room not closed to the fire is extremely questionable under these conditons. Finally, flashover is reached in the room of fire origin, and with it, as mentioned above, somewhat doubtful probability that one can survive any longer in the environment.

While the information in figure 16 can be used to determine the maximum time an occupant has to escape, other factors to be considered in an exercise of this nature would be the expected time for initial fire development prior to flame impingement on the wall, and the likelihood that the occupants are aware of the fire or are alerted to its existence by automatic detection.

In the six tests in the upholstered chair series in which flashover was observed, limiting conditions of temperature, CO and O_2 were reached in the living room which was located at the opposite end of the mobile home. These conditions were reached in the living room and flashover occurred in the bedroom for these tests from 1 min 20 sec to 3 min 15 sec elapsed time after flame impingement on the wall.

In the two tests in which flashover was not observed, the temperature and CO criteria were reached, but after a much longer period of time. This further indicates that the attainment of flashover in the bedroom may be a critical factor for life safety as well as property damage.

7. SURFACE FLAMMABILITY OF INTERIOR FINISH MATERIALS

The test results showed that fire growth and spread depended to a large extent on the temperature rise of the air (gases) in the upper part of the room. The attainment of high temperatures in the upper part of the room was primarily a function of the amount of heat released from the burning materials, including the initial burning item and the walls and ceiling. Therefore, a simple heat balance could be applied.

The tests demonstrated that the surface flame spread classification (FSC) of the interior finish materials influence at least in part the rate of flame propagation over the material surface and the total surface area of involvement, and therefore should be considered when examining the heat generation and resulting upper room temperature in the room. Since the Tunnel Test is the laboratory test upon which requirements are based in the Federal Mobile Home Construction and Safety Standard, it is essential to examine the extent to which surface flame spread as measured by this test can provide information on the performance of these materials when exposed to an incidental fire under full-scale conditions. Therefore as part of this segment of work, the surface flame spread classification determined in accordance with the ASTM E-84 Tunnel Test for each interior finish material was compared with the performance of the materials under full-scale test conditions. It should be noted that this comparison was complicated by the interaction between the wall and ceiling materials during the fire. For example, the individual contribution from the walls and ceiling could not be delineated. Therefore, it was necessary to consider the performance of the combination rather than that of an individual wall or ceiling.

In test 8, with walls and ceiling having FSC of zero, the heat generated in the room was primarily from the initial fire, which did not spread beyond the burning chair. However, in other chair tests the extent of flame propagation along the interior finish materials increased the amount of heat, resulting in higher upper room temperatures and flashover.

As previously discussed, the most severe conditions occurred in those tests in which flashover was observed; the thresholds for limiting conditions of temperature, CO and O_2 were reached at the measurement location in the center of the living room at approximately the same elapsed time after flame impingement on the wall as was flashover in the bedroom. Further, the thresholds were exceeded by a considerable amount, indicating continued rapid decay of the environment in the areas outside the bedroom.

In the tests in which flashover did not occur, the rise in temperature and CO and the depletion of oxygen in the living room were quite different; the changes were more gradual, with the threshold for temperature being the only limiting condition reached in test 2, and temperature and CO in test 8. It should also be noted that the temperature threshold was only marginally exceeded indicating borderline cases; and, the elapsed time to reach the temperature and CO thresholds were noticeably longer than in the tests which flashed over.

This analysis of the test data indicated that when considering life safety and property damage from fires similar to those in this experimental setup, flashover is a critical point in fire development. Therefore, the surface flame spread properties of the wall and ceiling material combinations, based on the FSC from the ASTM E-84 Tunnel Test, were evaluated comparatively based on the attainment of flashover under the actual full-scale conditions.

In the six upholstered chair tests resulting in flashover in the bedroom, the time from flame impingement on the wall to flashover varied from 80 to 195 seconds. Since all test conditions were nominally the same, and the adjusted times provide for a similar exposure of the interior finish in each test, the variation in time to flashover is predominantly a function of the fire properties of these materials.

The shortest period of elapsed time from flame impingement on the wall to flashover occurred in test 1 with prefinished lauan plywood walls and a wood fiberboard ceiling; these materials had FSC of 206 and 119, respectively, in accordance with the ASTM E-84 Tunnel Test.[7] However, in test 6 with a similar wall material used in conjunction with a gypsum ceiling (FSC 11), the elapsed time to flashover was extended by 88 seconds (figure 17a).

A similar comparison of tests 3 and 7 is shown in figure 17b. In these tests, the walls were constructed of fire retardant treated lauan plywood (FSC 60) and the ceiling was a wood fiberboard ceiling with a moderate FSC of 81 (test 3) and a gypsum ceiling with FSC 11 (test 7) to further illustrate the effect of different ceiling materials on fire growth. The difference in elapsed times to flashover was 80 seconds, which was slightly less than the difference which occurred between tests 1 and 6. However, the lower FSC of the wood fiberboard ceiling in test 7 may have accounted for this.

When comparing the temperature rise in all four tests, it appears that little change occurred in fire buildup for this group of materials when the FSC of the wall material was changed from 60 to 182 with the same (FSC 11) ceiling material. Figure 18a illustrates similar temperature development for tests 3 and 6 in which a fire retardant treated wall (FSC 60) and an untreated prefinished lauan plywood wall (FSC 182) were each tested with the same ceiling material. Similar results are indicated when comparing tests 4 and 5.

In test 7, the wall (FSC 60) and ceiling (FSC 81) materials were selected to provide a combination of interior finish materials of intermediate FSC. The results indicate that the elapsed time from flame impingement on the wall to flashover was extended an additional 35 seconds beyond the time in test 1 with prefinished lauan plywood walls (FSC 206) and a wood fiberboard ceiling (FSC 119).

The plots for tests 3 and 4 in figure 18a illustrate a difference in temperature rise as a function of elapsed time from flame impingement on the wall between the two tests. Both tests were conducted with gypsum board ceilings which contributed little fuel. However, while the walls in both tests had a FSC of 60, the lauan plywood was treated with different intumescent coatings. This indicates that while in the end the peak severity may be the same, some variation in the time for fire development can be expected when using different types of intumescent coatings, even when a similar FSC is obtained.

The results of tests 5 and 6 indicate that there is no advantage in increasing the thickness of prefinished lauan plywood from 4 to 6.4 mm (5/32 to 1/4 in) in conjunction with a gypsum ceiling.

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7 Flame spread calculated by George Williams - Leir (GWL) Method. This method was adopted by ASTM in April 1976 and replaces the method previously used to determine flame spread [9].

The most significant change in fire development occurred in test 2 with gypsum walls (FSC 24) and ceiling (FSC 11). This was the only combination of materials, other than the calcium silicate board (test 8), in which flashover was not reached. This indicates that while the fire properities of the ceiling material can affect the time to reach flashover, the fire properties of both the walls and the ceiling are significant if flashover from an incidental fire in the bedroom is to be avoided.

In order to specify the range of FSC of combinations of wall and ceiling materials which will not result in flashover from an upholstered chair fire in the bedroom of a mobile home, a matrix was developed based on the results of the full-scale tests (see figure 19). The region in the matrix depicted by diagonal lines represents those combinations of wall and ceiling materials which either resulted in flashover or are judged to have the potential for flashover from exposure to an incidental fire. Judgements are based primarily on the concepts that 1) materials having lower FSC will contribute less to fire buildup, and 2) small differences in FSC, without significant changes in the the thermo-physical properties of the materials themselves will not significantly alter fire growth.

In figure 19, three categories or regions of performance are identified. One region includes combinations of FSC in which flashover did not occur; another region includes all of the combinations in which flashover did occur; the remaining separates the other two and represents those combinations in which, due to lack of data, no determination was made. The size of this region of uncertainty is dependent upon the number of combinations of FSC actually tested.

Additional full-scale tests would provide information to determine the potential hazard of a combination of materials having FSC's located in the untested region of the matrix. Such tests would reduce the size of the region of uncertainty within the matrix.

The times recorded in the matrix are the measured elapsed times from flame impingement on the wall to flashover for those tests in which flashover was observed. These values indicate that the elapsed time from flame impingement on the wall to flashover generally increased with decreasing FSC of the ceiling material. Therefore, the rate of fire buildup as well as the maximum intensity were influenced by the surface flame spread characteristics of the interior finish materials, particularly those on the ceiling.

Flashover occurred in all of the tests conducted with the upholstered chair fires with the exception of test 2, constructed with a wall material of FSC 24 and a ceiling material of FSC 11, and test 8 with noncontributing walls and ceiling (FSC zero).

The matrix in figure 19 can provide guidance in identifying the potential for particular combinations of wall and ceiling materials to contribute sufficiently to a fire originating in an upholstered chair in the master bedroom of a single-wide mobile home. In those tests in which environmental conditions approached or exceeded flashover, high levels of carbon monoxide and temperature, the dominant causes of physical incapacitation, occurred. Therefore, the matrix provides a useful tool in assessing the impact of the FSC of the walls and ceiling on the potential hazard to occupants as well as on the potential property damage.

There are important limitations in interpreting the results in the matrix. The degree of hazard for a given combination of wall and ceiling materials may be expected to diminish with increased room size and decreased size of the initial burning item. Therefore, application of the results in the matrix apply only to the master bedroom in this case, to the specific test parameters, and to an incidental fire with a severity similar to that of the upholstered chair fire. A modified matrix may be more appropriate for another combination of room size, type of initial burning item, etc. However, use can be made of the fact that the region of demonstrated flashover potential will increase with increasing size of the initial burning item and decreasing room size, while the region of no flashover potential will increase with increasing room size and decreasing size of the initial burning item. The use of the matrix should be limited to "conventional materials". Materials with widely divergent thermo-physical and fire properties including foam plastics and composites should be subjected to full-scale tests prior to making judgements regarding fire growth.

Figure 18b provides an illustration of temperature development in the bedroom after flame impingement on the wall for tests 1 and 2. In addition, temperature rise from time of ignition is plotted for test 13. Two key points are illustrated in this figure which confirm the limitations regarding the use of the matrix. First, for incidental fires of moderate intensity, the fire properties of the interior finish can dominate the resulting extent of fire growth, fire spread, and the hazard to occupants. Second, as the size of the exposure fire is increased, a point will be reached where the significance of the interior finish materials may no longer dominate. This is consistent with the material hazard matrix concept. If a matrix were created involving a polyurethane mattress exposure fire similar to the one tested in this series, the region of flashover potential would occupy the entire matrix, indicating that flashover will occur regardless of the interior finish.

8. SUMMARY AND CONCLUSIONS

Nine full-scale fire tests were conducted in the master bedroom of a typical single-wide mobile home. The primary experimental scenario was the exposure of various combinations of wall and ceiling materials to an incidental fire from a burning 16 kg (35 lb) upholstered chair located in one corner of the room. For one test (test 13), the scenario was altered to examine the characteristics of fire growth and spread resulting from the ignition of a polyurethane foam mattress and bedding materials.

Test conditions were as follows: (a) all exterior windows and doors were closed, but not sealed; (b) all doors along the corridor except the door to the master bedroom (bedroom #1) were closed; (c) the mobile home was conditioned to 23 ± 4°C (72 ± 7°F) and 52 ± 8% relative humidity.

The results indicate that a fire in an upholstered chair in the corner of a bedroom of a typical single-wide mobile home will not by itself generate sufficient heat and flames to result in flashover, and a fully involved room fire. The results of test 8, with essentially noncontributing walls and ceiling (flame spread zero) indicate that a maximum upper room air temperature of 372°C and a maximum incident heat flux of 0.2 W/cm^2 at the floor were reached. These levels are considerably lower than the peak range of temperatures (634 - 734°C) and incident heat flux (1.5 - 3.6 W/cm^2) which occurred in those tests which flashed over.

The results of the tests with each combination of wall and ceiling material indicate that the rate of development and the resulting severity of an incidental fire in the bedroom of a typical single-wide mobile home are affected by the fire properties of the interior finish materials exposed to the fire.

The horizontal spread of fire from the initial burning item to other items of furniture is primarily the result of convective heat transfer. However, the amount of convected heat transferred is usually small for the typical horizontal separations between furnishing items. Other combustible items such as the bed were located within 0.6 m (2 ft) of the burning chair, but involvement of these combustible furniture items only occurred when radiant energy was transferred at a sufficient rate from the upper part of the room. The minimum incident heat flux measured at the floor at the point in time when this occurred was approximately 1.5 W/cm^2; the upper room temperature 25 mm (1 in) below the ceiling was 634°C.

Early fire development was mostly the result of the fuel contribution from the chair. At the point at which the wall became involved the rate of change of the measured variables in the bedroom increased abruptly. The involvement of the upper walls and ceiling had the most influence on the growth of the fire beyond this point. In these tests, when the upper walls and ceiling contributed fuel at a high enough rate to raise the upper air temperature to a minimum of 634°C (test 1), total room involvement occurred. In tests 2 and 8, where the walls and ceiling did not become extensively involved, the maximum temperature in the upper room did not approach the level necessary to result in room flashover.

The results of test 13 indicate that flashover can occur in the room as a result of the burning of a polyurethane foam mattress and bedding, with essentially no contribution from the interior finish materials.

The following is a summary of the findings of the nine tests conducted in the bedroom of a typical single-wide mobile home:

1. Initial fire buildup varied considerably among the eight tests with the upholstered chairs due to the variation in spread of the flames along the surface of the chairs. Flame impingement on the wall surface varied from 3 min 10 sec in test 8 to 13 min 6 sec in test 6.

2. Flashover, observed to have occurred as a result of radiative heat transfer from the heated gas layer and the surfaces in the upper part of the room to the combustibles in the lower part of the room, occurred in those tests in which the upper air temperature reached a minimum of 634°C. Lateral (horizontal) heat transfer and flame propagation were not of sufficient levels to involve other combustibles prior to flashover.

3. The occurrence of flashover was accompanied by conditions that exceeded limits established for occupant incapacitation in both the bedroom and the living room.

4. Limiting conditions of temperature were not reached in the rooms along the corridor with the doors closed in any of the nine tests up to the time that flashover occurred. However, the closed bedrooms should not be considered a sanctuary for occupants. These tests were terminated at flashover, but a post-flashover fire can

be expected to result in inter-room fire spread. Many of the interior finish materials tested would not provide a barrier of any significance against fire penetration under such severe conditions.

5. In the eight tests with the upholstered chair, fire spread beyond the chair occurred only when there was involvement of the adjacent wall and ceiling materials. The fire buildup, including the rate of fire growth and spread beyond the point of flame impingement on the wall, the ultimate severity of the fire, and the resulting effects on life safety depended on the fire properties of the wall and ceiling materials.

6. The most rapid fire buildup to room flashover for the chair tests occurred in test 1 with the 4 mm (5/32 in) thick prefinished lauan plywood walls and 13 mm (1/2 in) thick wood fiberboard ceiling materials. The elapsed time from flame impingement on the wall to flashover ranged from 80 seconds in test 1 to as long as 195 seconds in test 3. The times increased with decreasing ASTM E-84 flame spread ratings of the ceiling material.

7. With the exception of test 8 with calcium silicate board walls and ceiling, the only chair test in which flashover did not occur was test 2, with gypsum walls and ceiling. This test (test 2) resulted in the least severe fire in terms of fire growth and the resulting hazard to occupants. Temperature was the only threshold for incipient incapacitation that was reached in this test; this occurred at 2 min 45 sec after flame impingement on the wall which was the longest period of time provided from flame impingement on the wall to a limiting temperature level for the upholstered chair tests. The test data further indicated that the temperature criterion was barely exceeded in this test, and therefore represents at best a borderline case for temperature criterion failure.

8. Increasing the thickness of the prefinished lauan plywood from 4.0 mm (5/32 in) to 6.4 mm (1/4 in) in conjunction with a gypsum ceiling did not appreciably change the rate of fire growth or the attainment of flashover and limiting conditions.

9. Flashover and limiting conditions were reached in less than 4 minutes from the ignition of a polyurethane mattress and bedding with no apparent involvement of the unpainted gypsum board interior finish.

10. The ASTM E-84 flame spread classification (FSC) rating provided an indication of the potential fire hazard resulting from a chair fire in the mobile home bedroom under the conditions established and for the materials used in this test series.

The following general conclusions regarding the impact of the interior finish materials can be drawn from the data discussed in this report.

1. Given an upholstered chair fire in the corner of the master bedroom in a single-wide mobile home, in the absence of other combustible furnishings near enough to be ignited by flame contact, the attainment of flashover requires the involvement of the interior finish materials. Flashover is likely to occur if the FSC of the wall lining material is greater than 60 (by ASTM E-84) regardless of the FSC of the ceiling material. However, the time from flame impingement on the wall to flashover will increase with decreasing FSC of the ceiling material.

2. Given a polyurethane mattress and bedding fire in the corner of the master bedroom of a single-wide mobile home, flashover is likely to occur regardless of the FSC of the interior finish materials. However, it should be noted that bedding fire involving mattresses constructed of other materials such as cotton batting or neoprene [48] may not pose as serious a hazard as the mattress used in this series.

3. Limiting conditions adverse to life safety are reached in the living room at the remote end of the mobile home from the bedroom where the fire was started at approximately the same time that flashover occurs in the bedroom. To the extent that flashover does not occur, limiting conditions of carbon monoxide and oxygen are reached in the living room only after an extended period of time, or not at all.

4. A smoke level of 0.26 OD/m will generally be exceeded throughout the mobile home during development of the chair fire, prior to involvement of the interior finish materials. Therefore, while the type of interior finish material will affect the total amount of smoke generated, the interior finish will have minimum impact on the time at which 0.26 OD/m optical density is reached.

This report provides experimental data on an individual segment of the research conducted under the Mobile Home Fire Safety Project. A summary report is planned in which data will be included along with the data collected in other segments of the project including full-scale fire testing in the kitchen, living room and corridor areas of a single-wide mobile home.

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Figure 1. Photographs of Typical Single-Wide Mobile Homes Used in Conducting Full-Scale Fire Tests

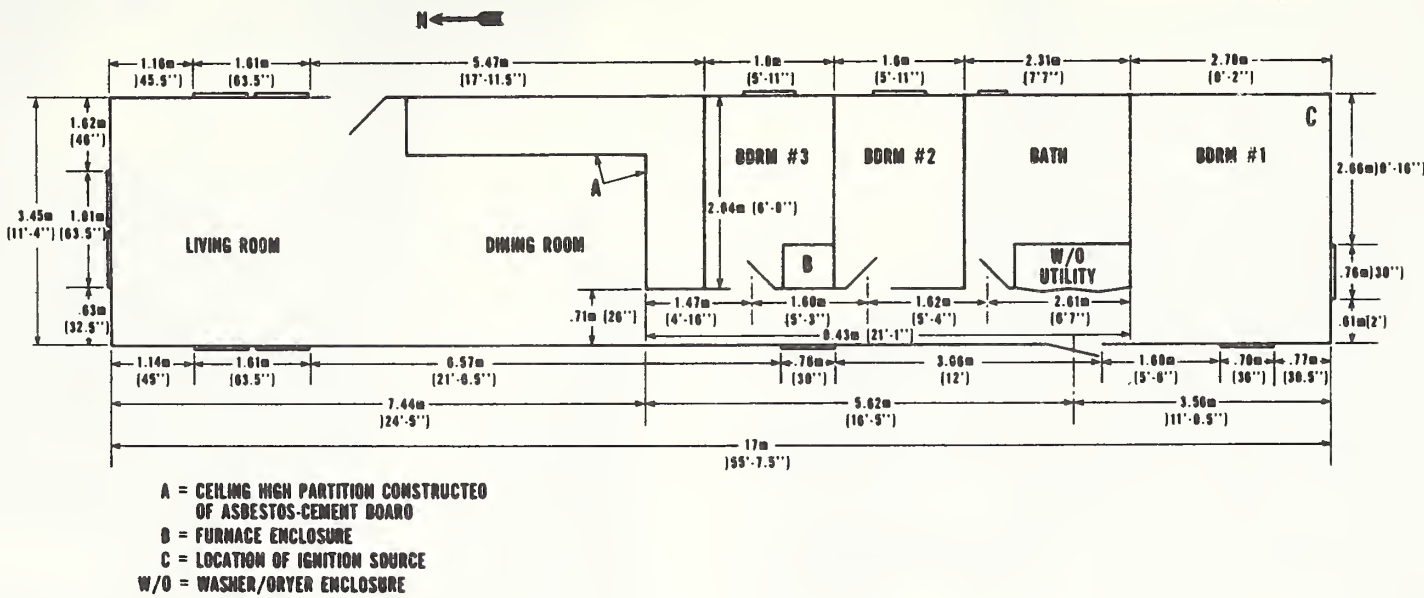


Figure 2. Plan View of Mobile Home Test Unit

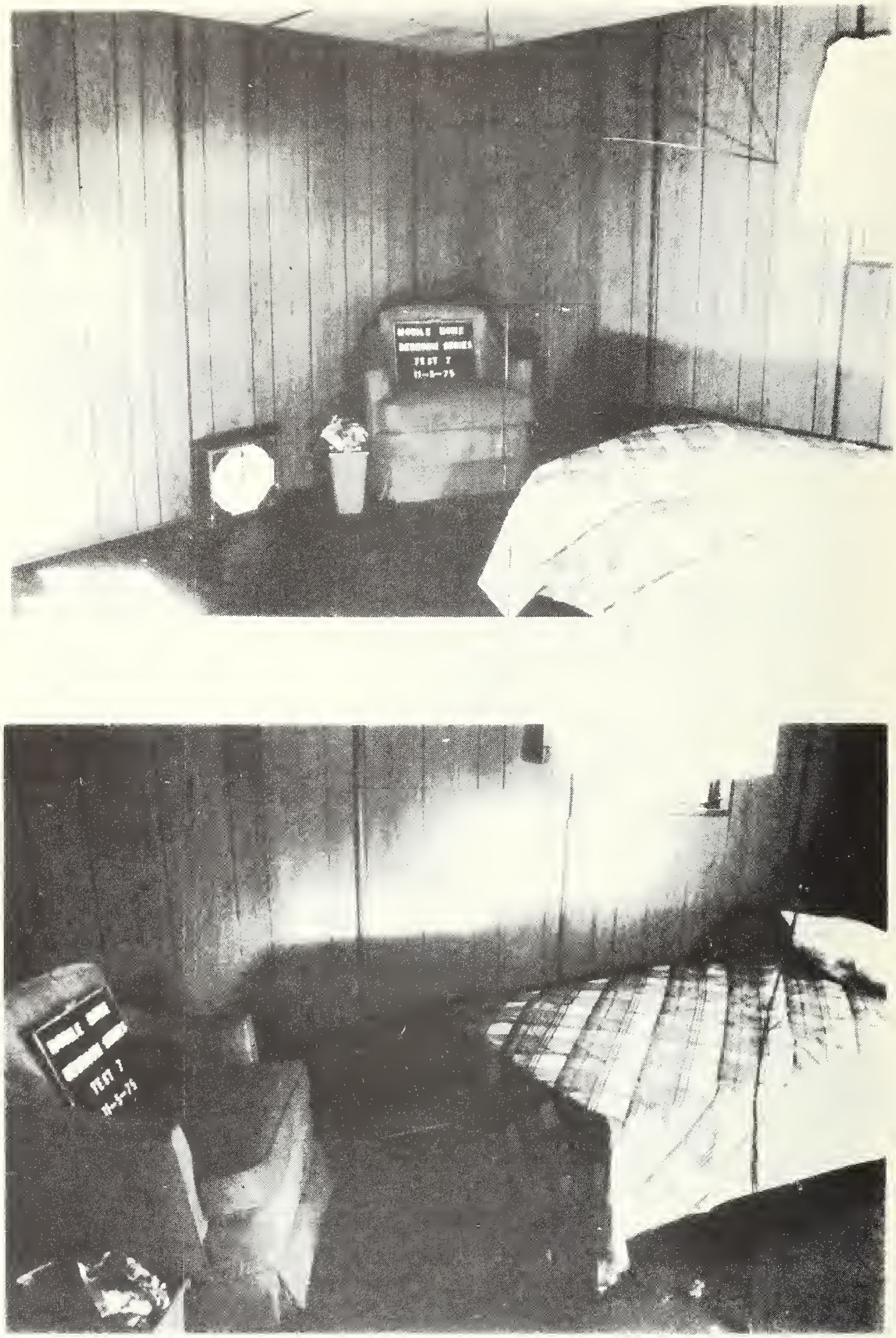
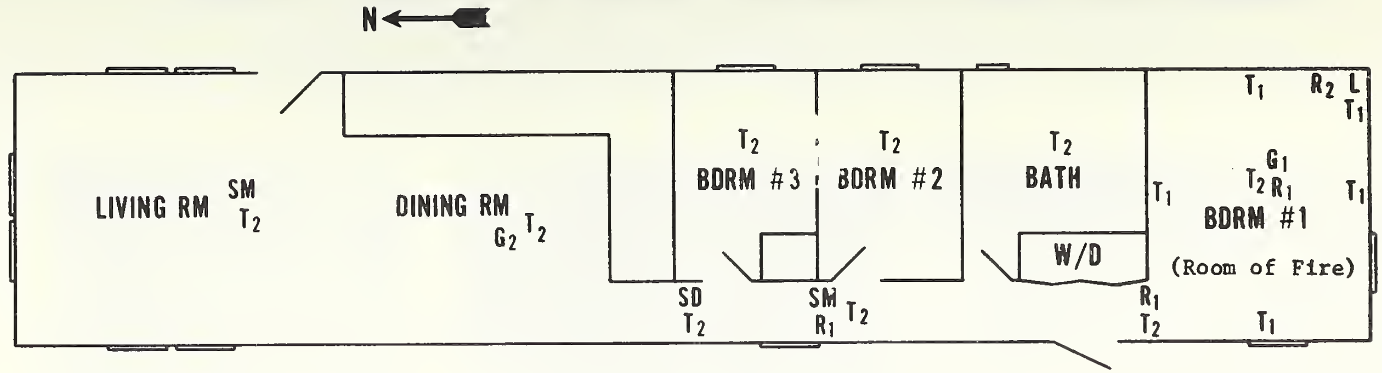


Figure 3. Photographs Showing Upholstered Chair Positioned in Southeast Corner of Bedroom



<u>Temperature</u>

T_1 - Thermocouples located 211, 188, and 132 cm above floor
T_2 - Thermocouples located 211, 188, 132, and 122 cm above floor

<u>Incident Heat Flux</u>

R_1 - Transducer located at floor level
R_2 - Transducer located above chair on East wall

<u>Weight Loss of Ignition Source</u>

L - Strain gage load cell

<u>Combustion Gases</u>

G_1 - CO, CO_2 and O_2, 1.5 m above floor
G_2 - CO, and O_2, 1.5 m above floor

<u>Smoke Generation</u>

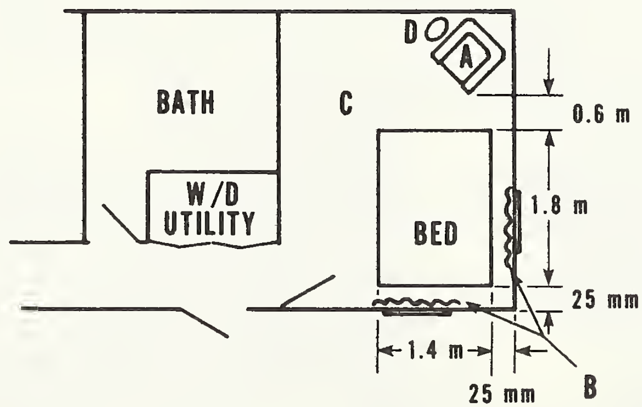
SM - Horizontally aligned photometers, 0.9 and 1.5 m above floor; light path of 0.46 m

<u>Smoke Detector</u>

SD - Commercial ionization type smoke detector positioned 229 mm below ceiling on inside corridor wall

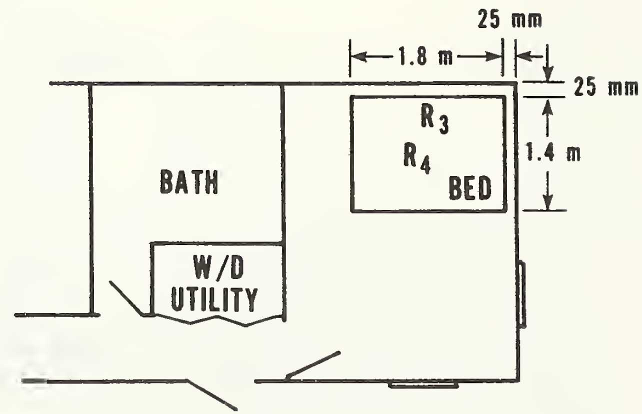
Figure 4. Plan View of Mobile Home Test Unit Illustrating General Location of Experimental Measurements

Figure 5a. Test Set-up Utilizing the Upholstered Chair Ignitions



A = Upholstered Chair
B = Curtains
C = Floor Covering, 3.2 mm thick
D = Waste Container

Figure 5b. Test Set-up Utilizing the Bed as the Ignition Source (Test 13)



Additional Instrumentation for Test 13

R_3= Heat flux transducers located at 0.9 and 1.8 m above the floor on the wall surface

R_4= Heat flux transducer located in ceiling above center of bed, flush with ceiling surface

Figure 5. Plan View of Bedroom Illustrating the Fuel Load Arrangement for the Two Test Configurations

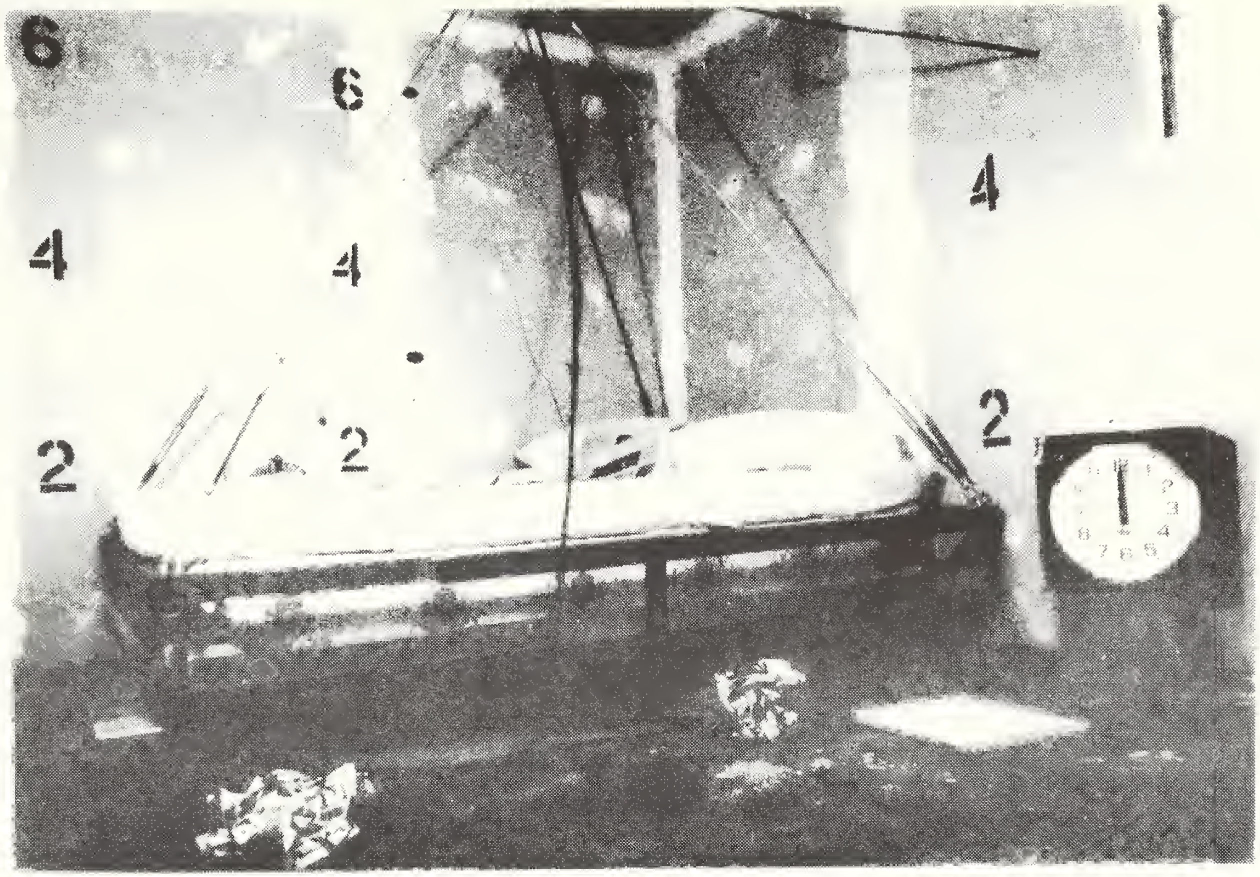


Figure 6. Photograph Illustrating the Weighing Platform and Suspension System for Measuring Weight Loss in Bed Test

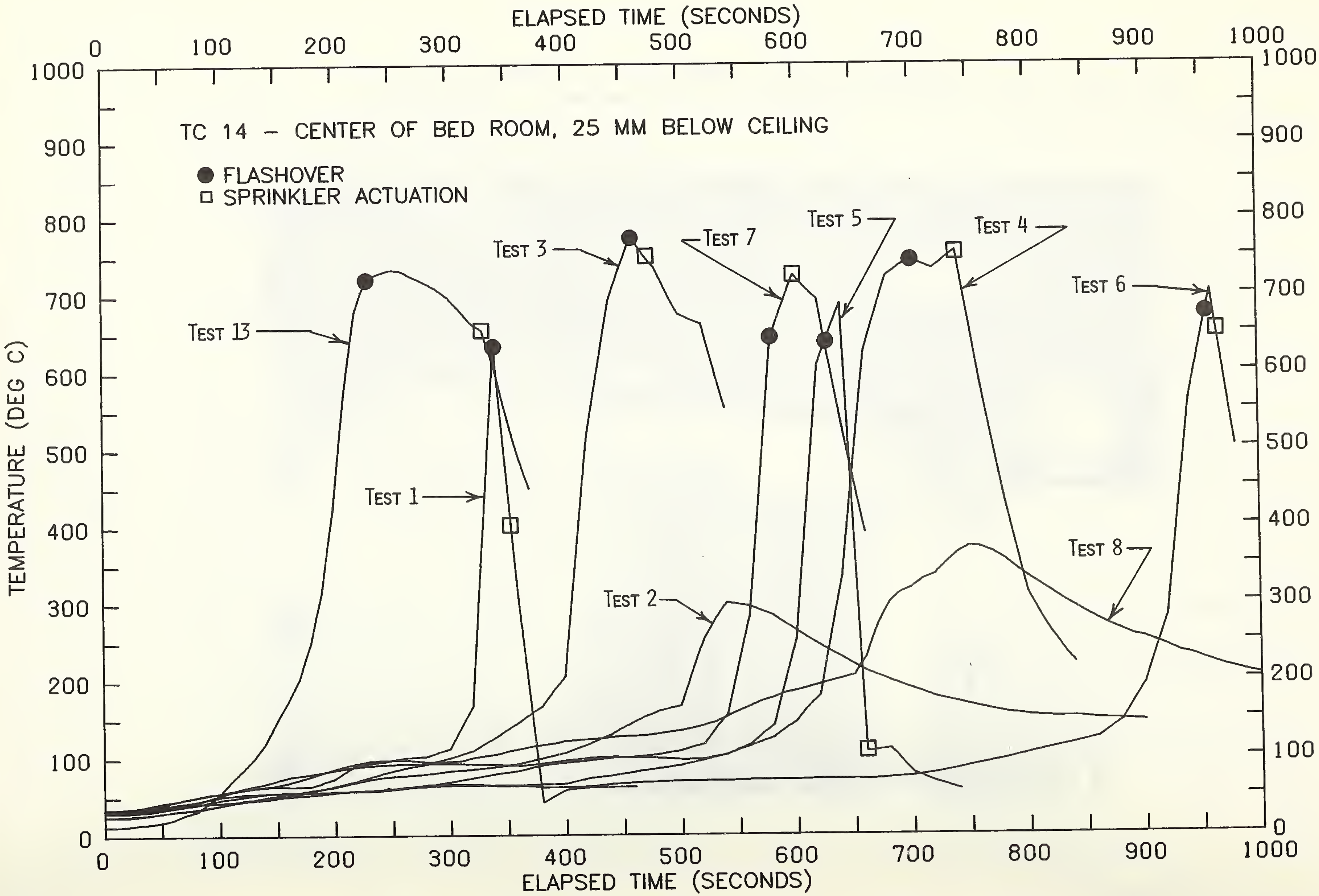


Figure 7. Temperature 25 mm Below Ceiling in Center of Bedroom (Bedroom Series)

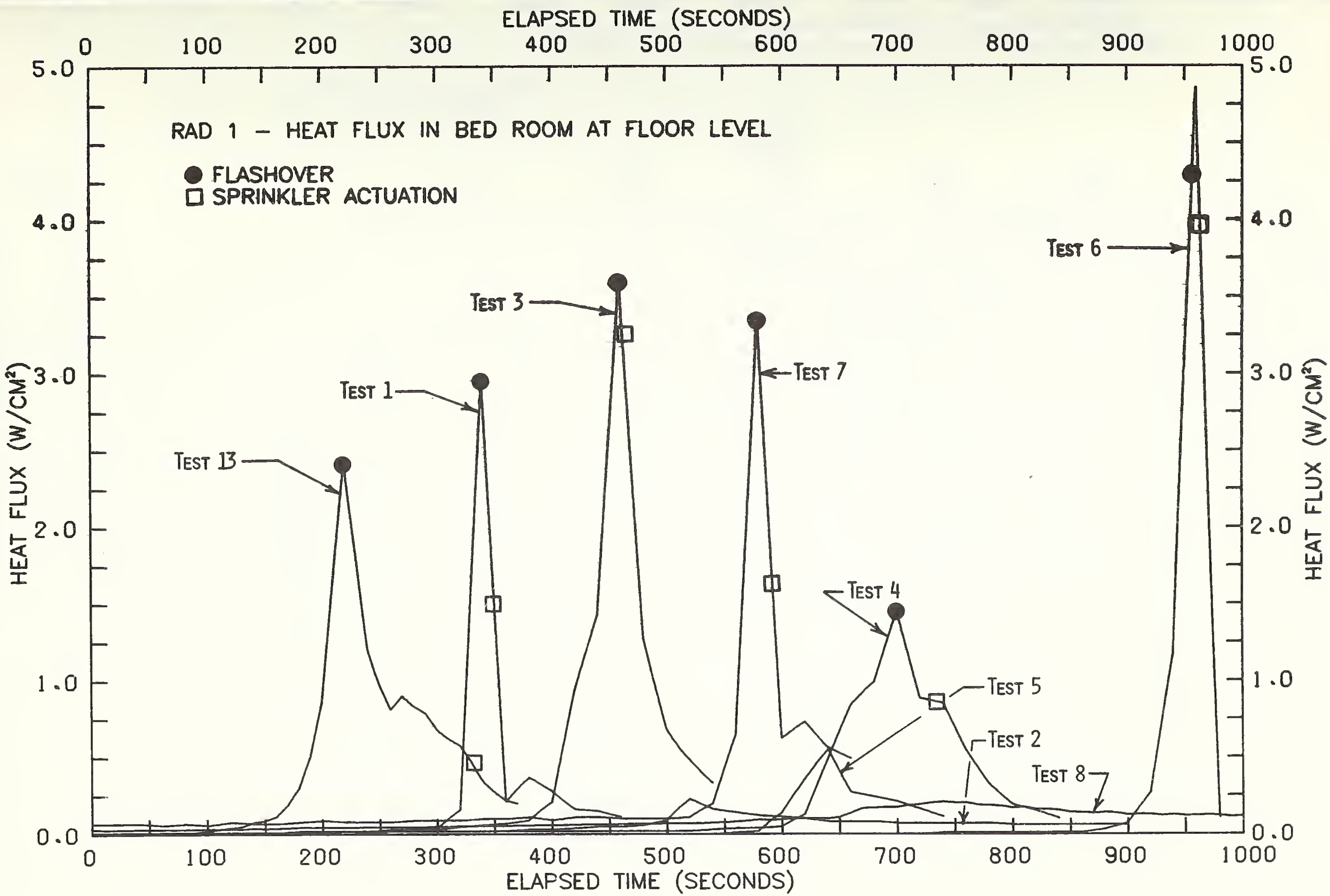


Figure 8. Total Incident Heat Flux at Floor in Center of Bedroom (Bedroom Series)

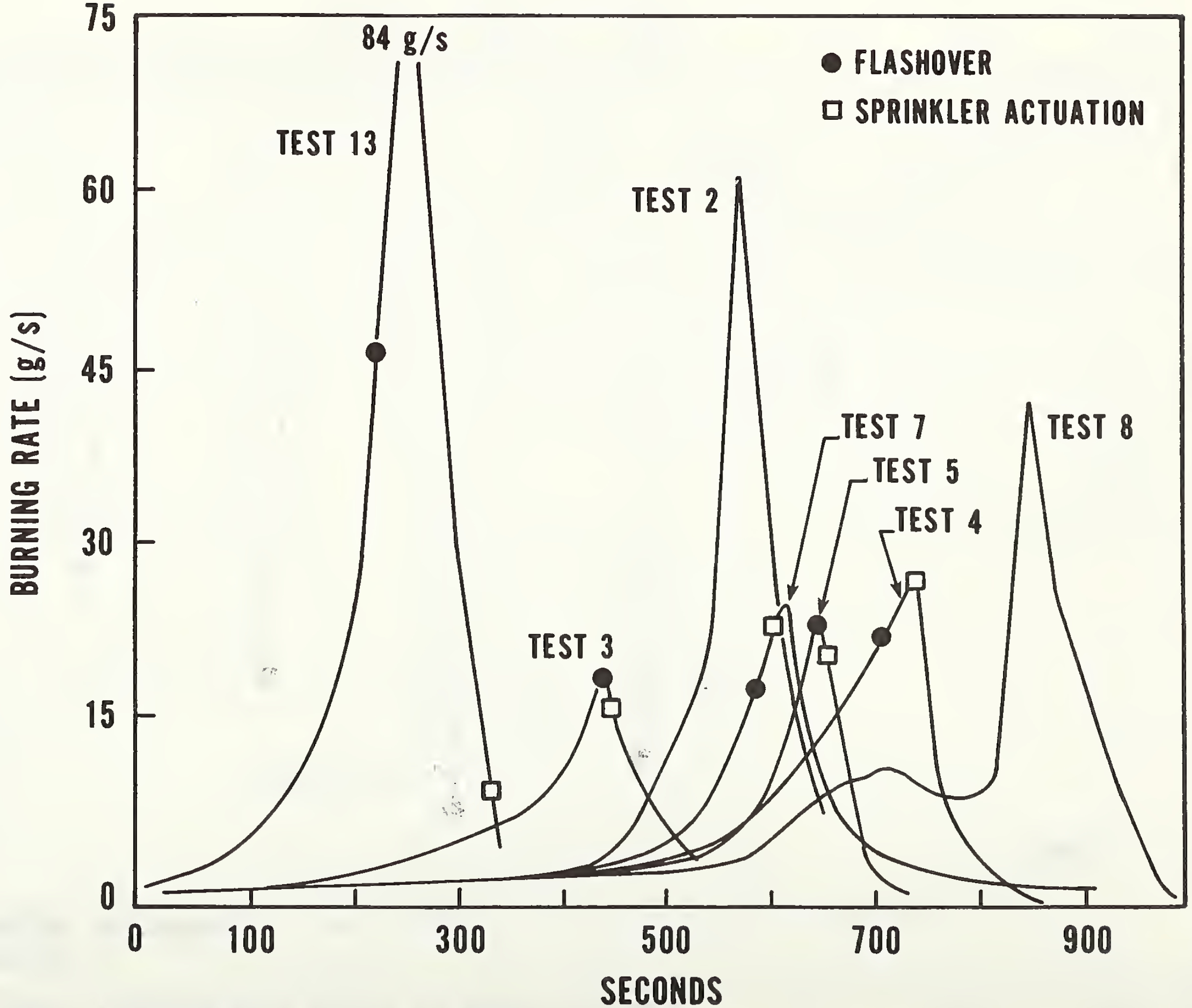


Figure 9. Time Histories for Rate of Burning (20-second intervals) of Upholstered Chairs and Mattress (Bedroom Series)

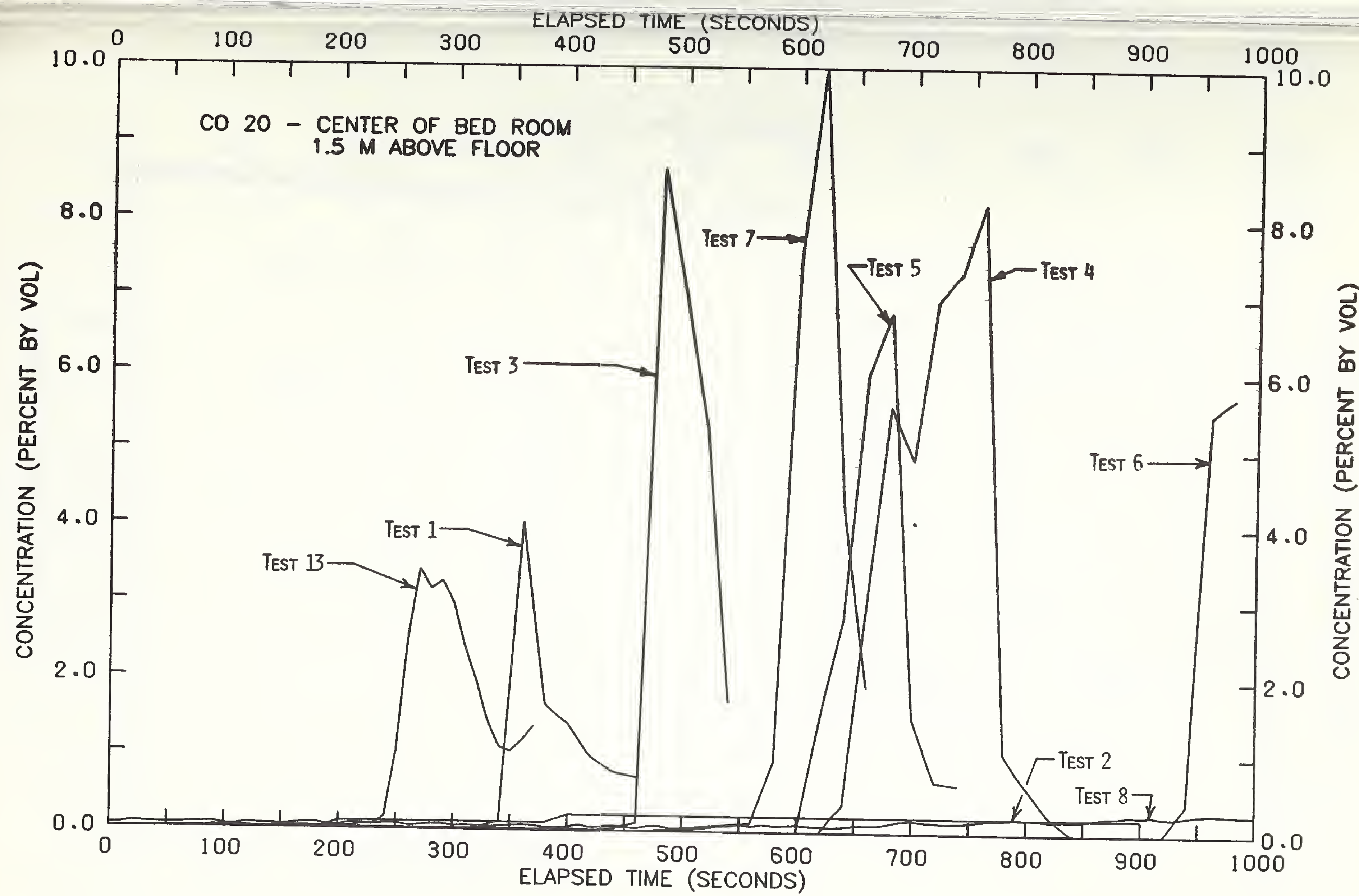


Figure 10. Percent Carbon Monoxide Concentration 1.5 m Above Floor in Center of Bedroom (Bedroom Series)

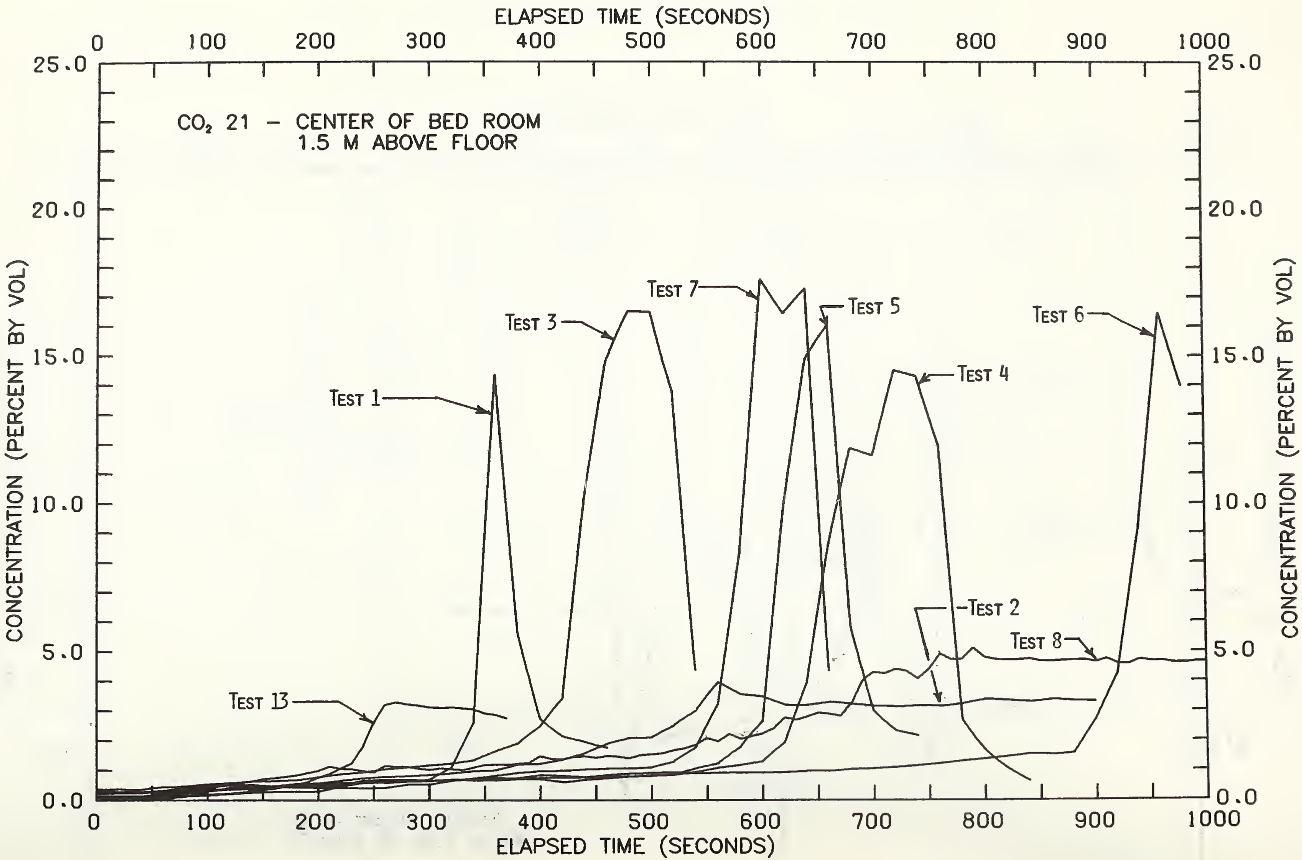
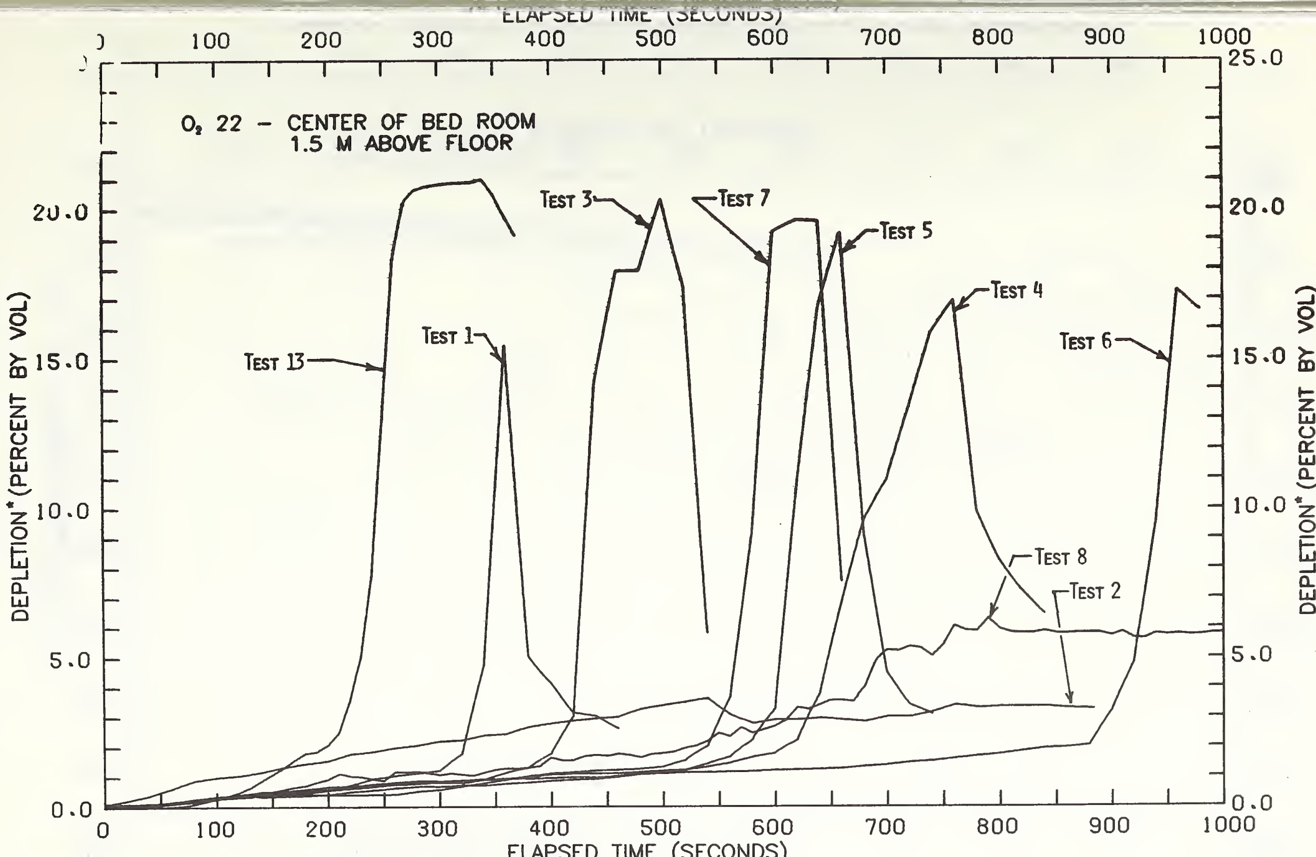


Figure 11. Percent Carbon Dioxide Concentration 1.5 m Above Floor in Center of Bedroom (Bedroom Series)



* %DEPLETION = 20.9% - %O_2 CONCENTRATION

Figure 12. Percent Oxygen Depletion* 1.5 m Above Floor in Center of Bedroom (Bedroom Series)

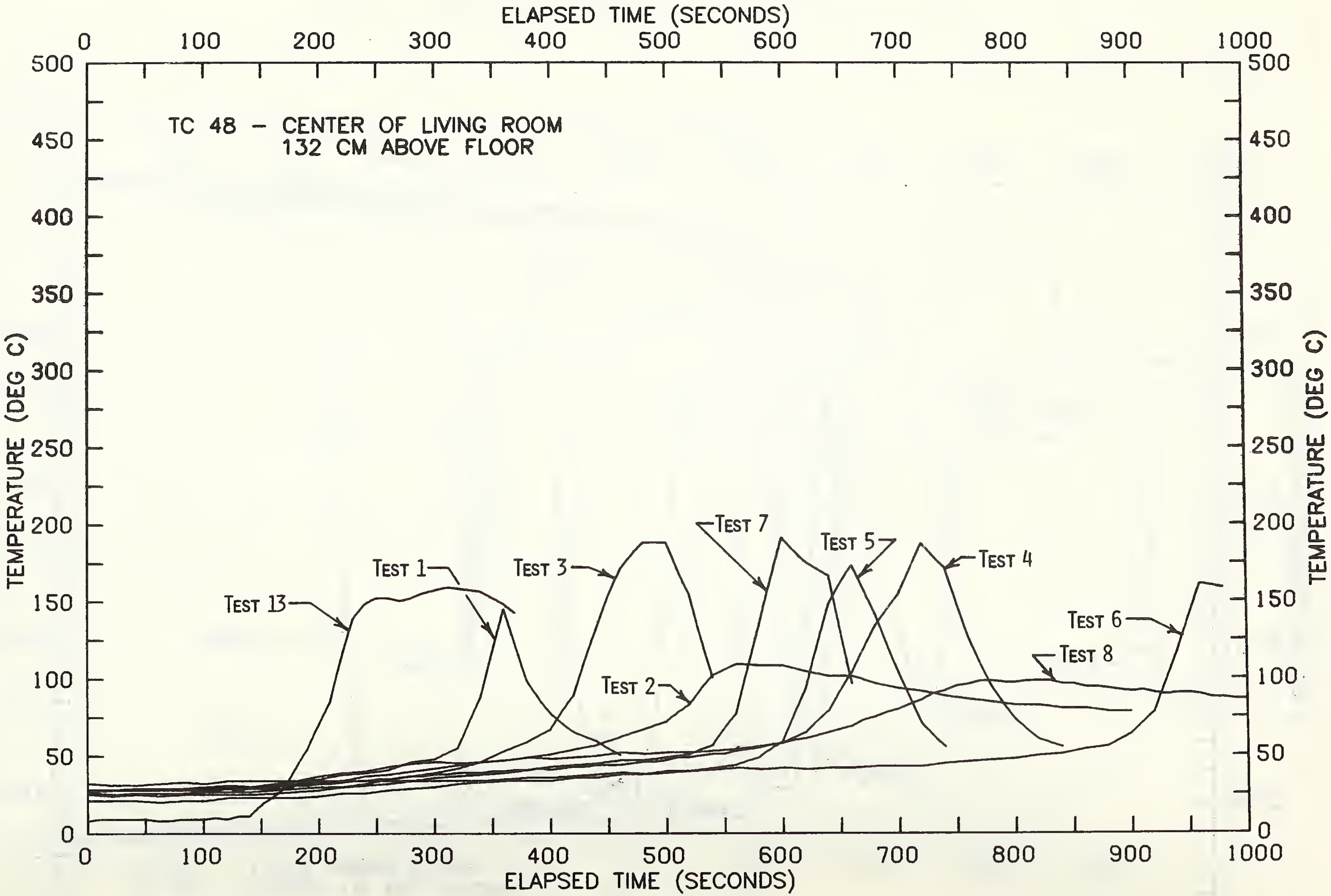


Figure 13. Temperature 1.3 m Above Floor in Center of Living Room (Bedroom Series)

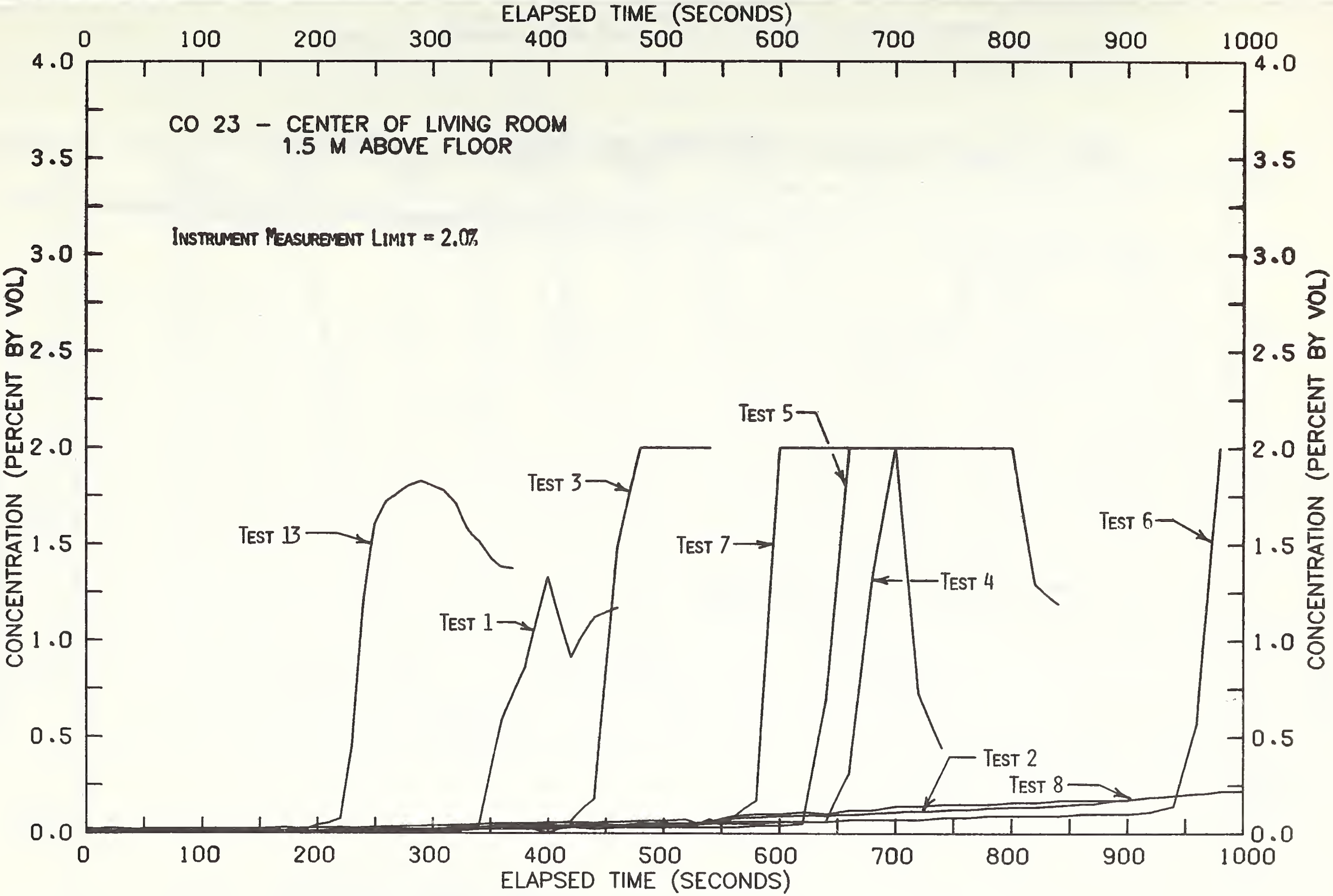
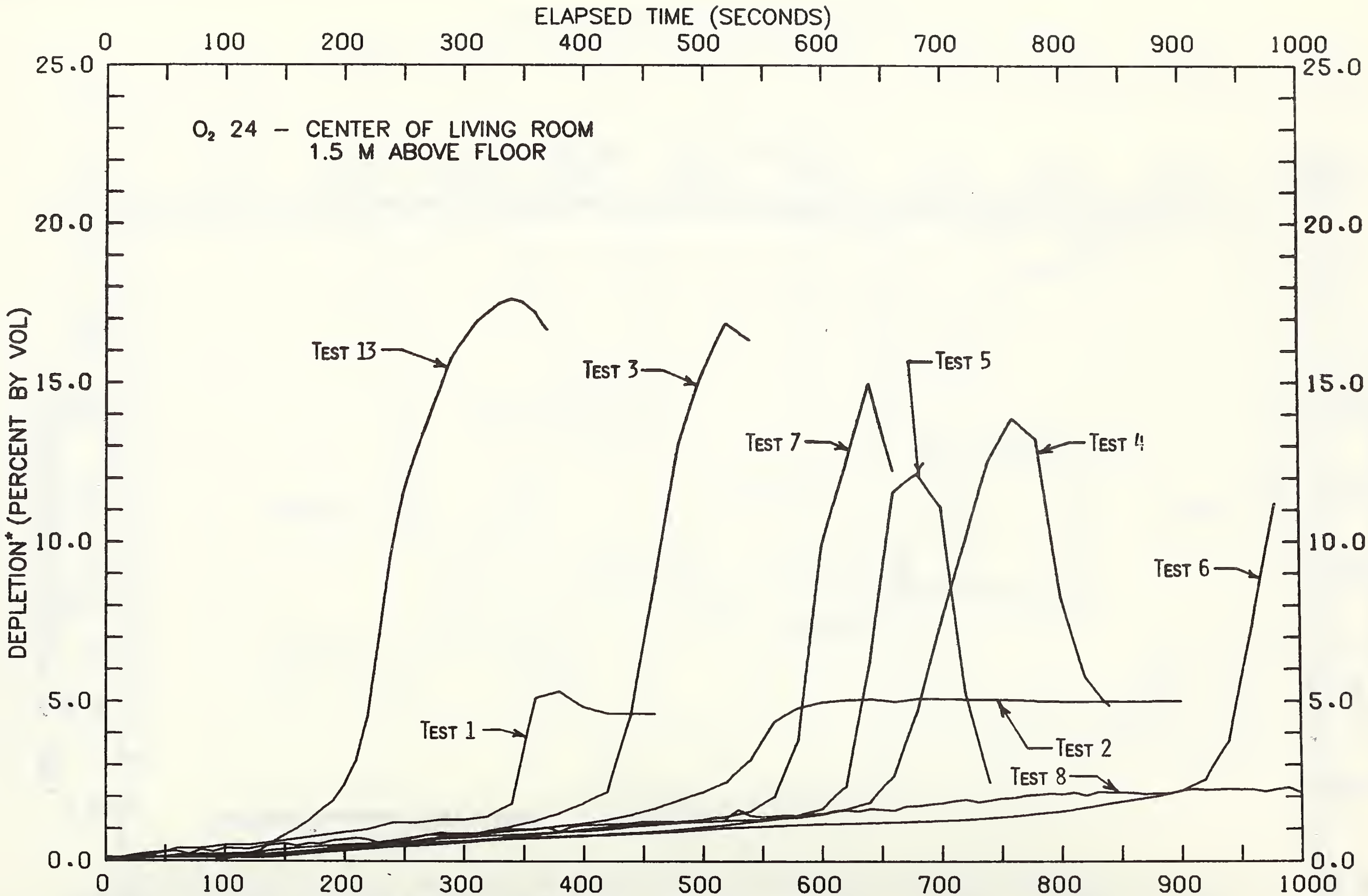
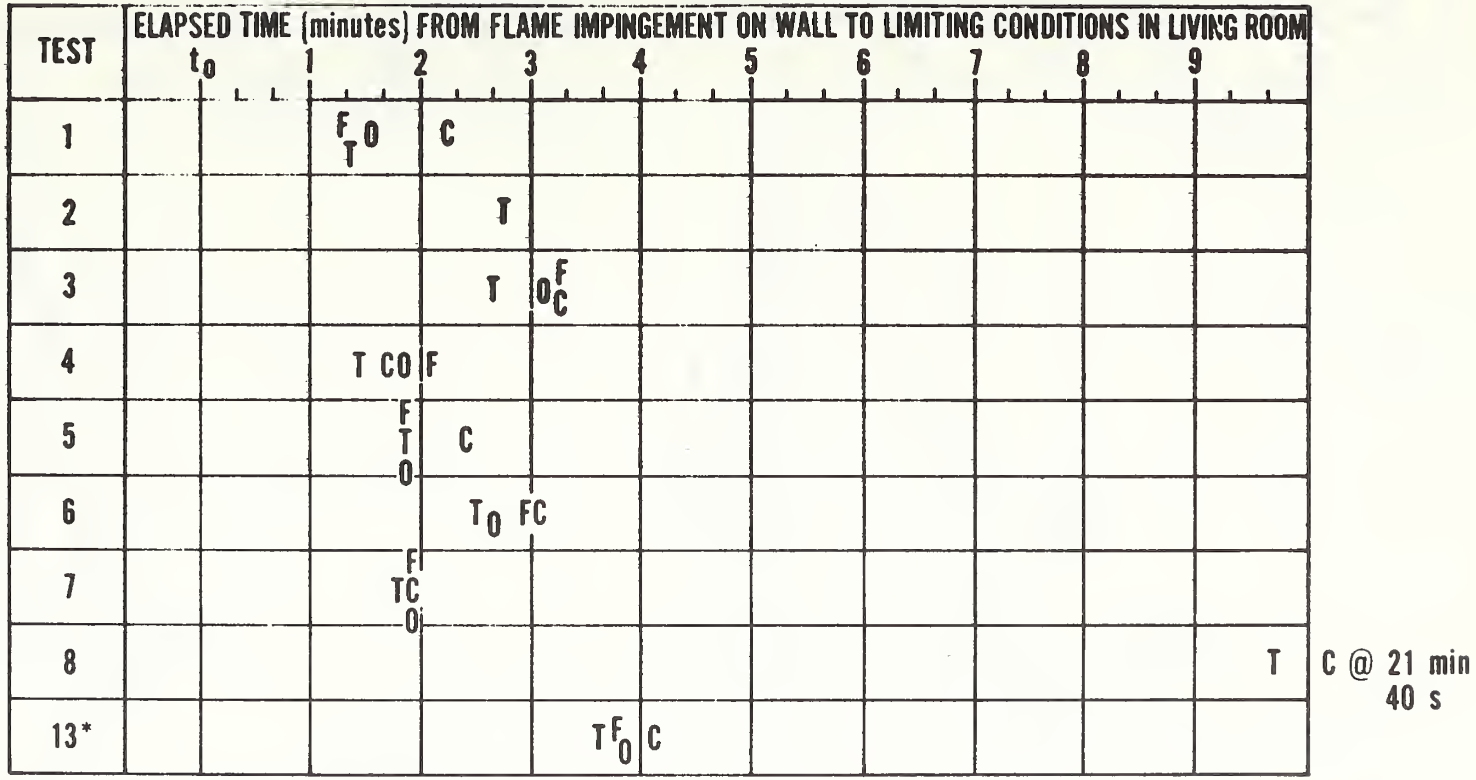


Figure 14. Percent Carbon Monoxide Concentration 1.5 m Above Floor in Center of Living Room (Bedroom Series)



* %DEPLETION = 20.9% - %O_2 CONCENTRATION

Figure 15. Percent Oxygen Depletion* 1.5 m Above Floor in Center of Living Room (Bedroom Series)



t_0 = TIME OF FLAME IMPINGEMENT ON WALL

* TABULATED BASED ON TIME FROM IGNITION FOR TEST 13

T = 100°C
C = 1% CO or 41,800 $[(PPM)^{1.036}(MIN)]$
O = 14% O_2
F = FLASHOVER

Figure 16. Elapsed Time From Flame Impingement on the Bedroom Wall to Limiting Conditions of Temperature, Carbon Monoxide, and Oxygen in the Living Room (Bedroom Series)

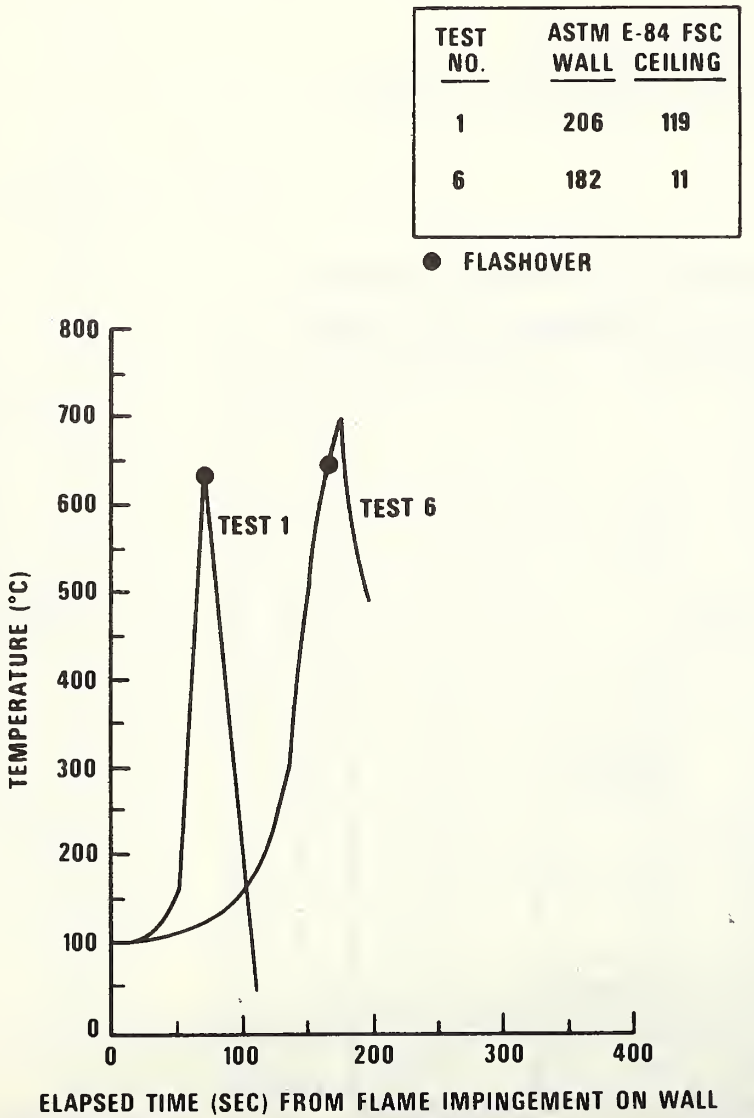


Figure 17a. Temperature 25 mm Below Ceiling in Center of Bedroom vs. Elapsed Time From Flame Impingement on Wall (Bedroom Series)

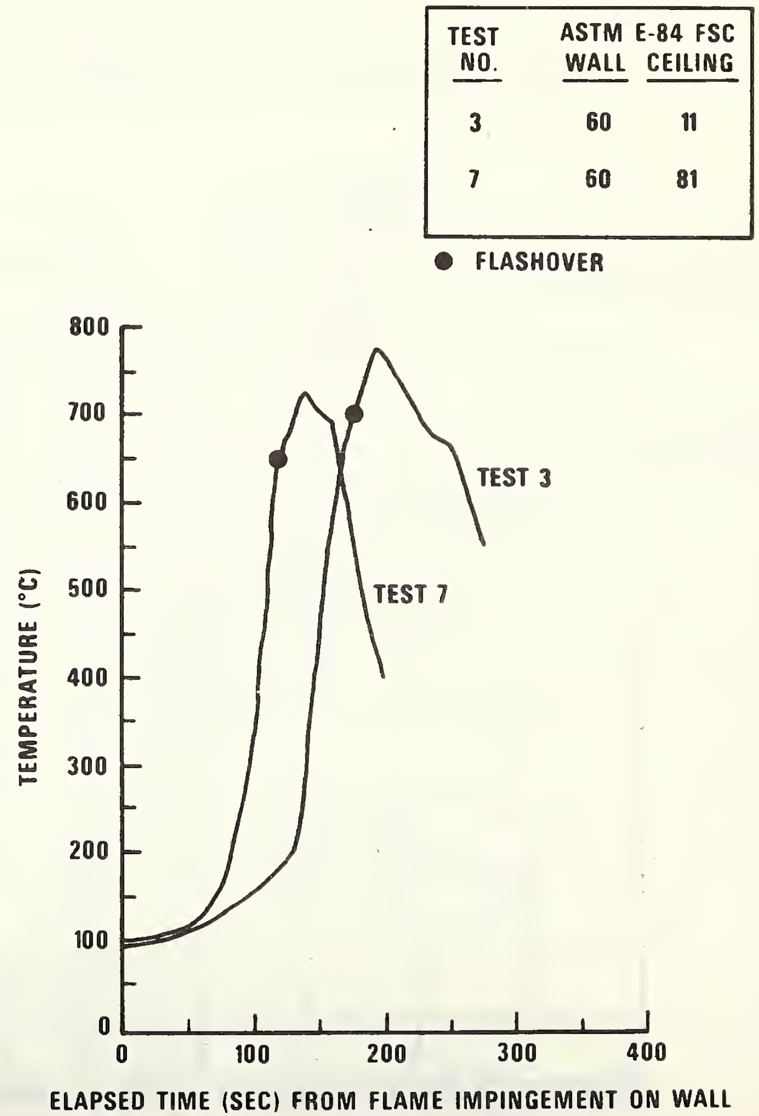


Figure 17b. Temperature 25 mm Below Ceiling in Center of Bedroom vs. Elapsed Time From Flame Impingement on Wall (Bedroom Series)

TEST NO.	ASTM E-84 FSC WALL	ASTM E-84 FSC CEILING
2	24	11
3	60	11
4	60	11
5	127	11
6	182	11

● FLASHOVER

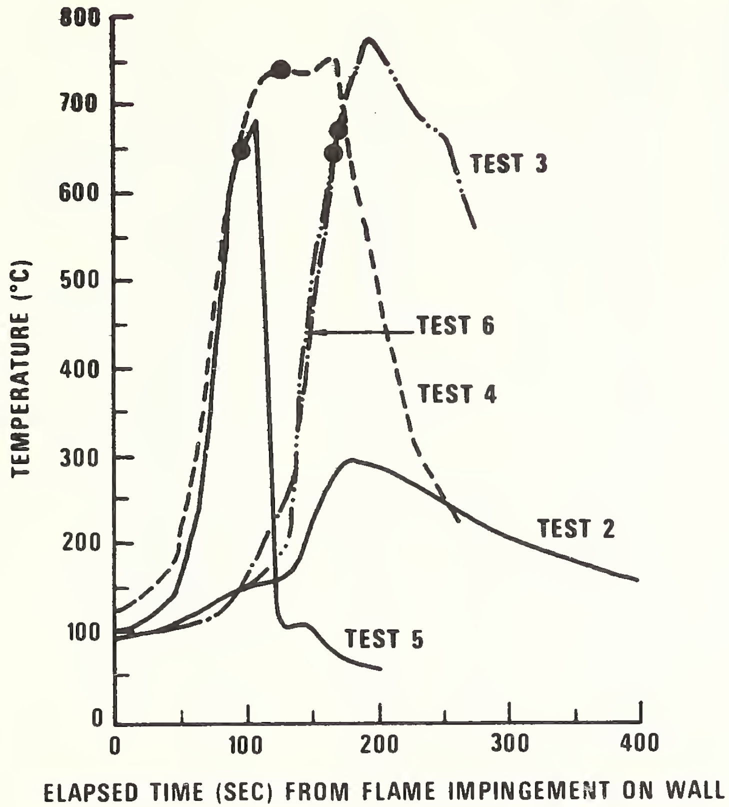


Figure 18a. Temperature 25 mm Below Ceiling in Center of Bedroom vs. Elapsed Time From Flame Impingement on Wall (Bedroom Series)

TEST NO.	ASTM E-84 FSC WALL	ASTM E-84 FSC CEILING
1	206	119
2	24	11
13	15	15

● FLASHOVER

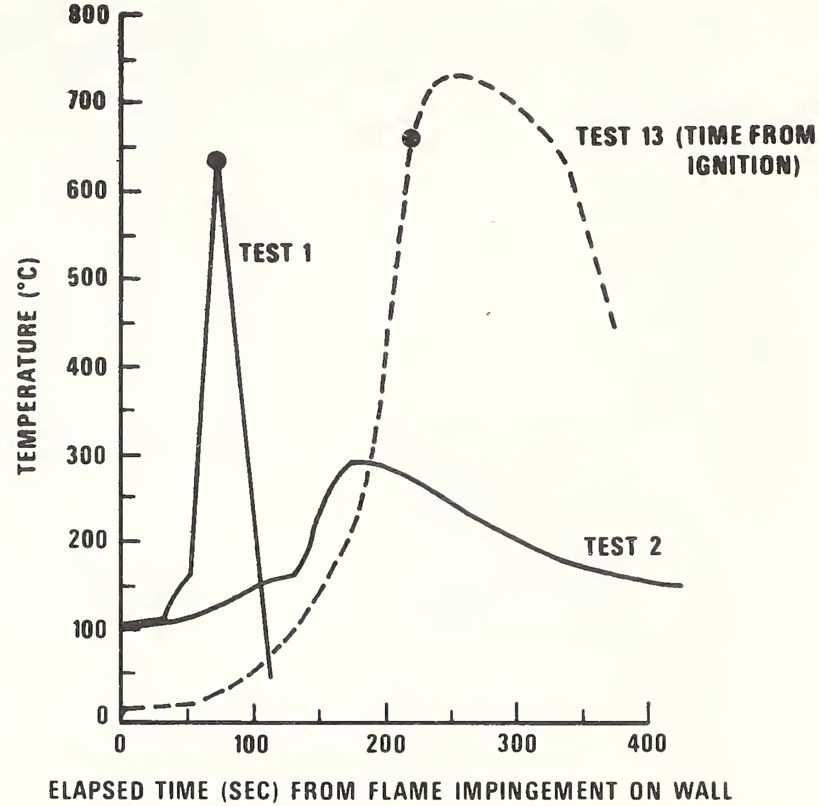


Figure 18b. Temperature 25 mm Below Ceiling in Center of Bedroom vs. Elapsed Time From Flame Impingement on Wall (Bedroom Series)

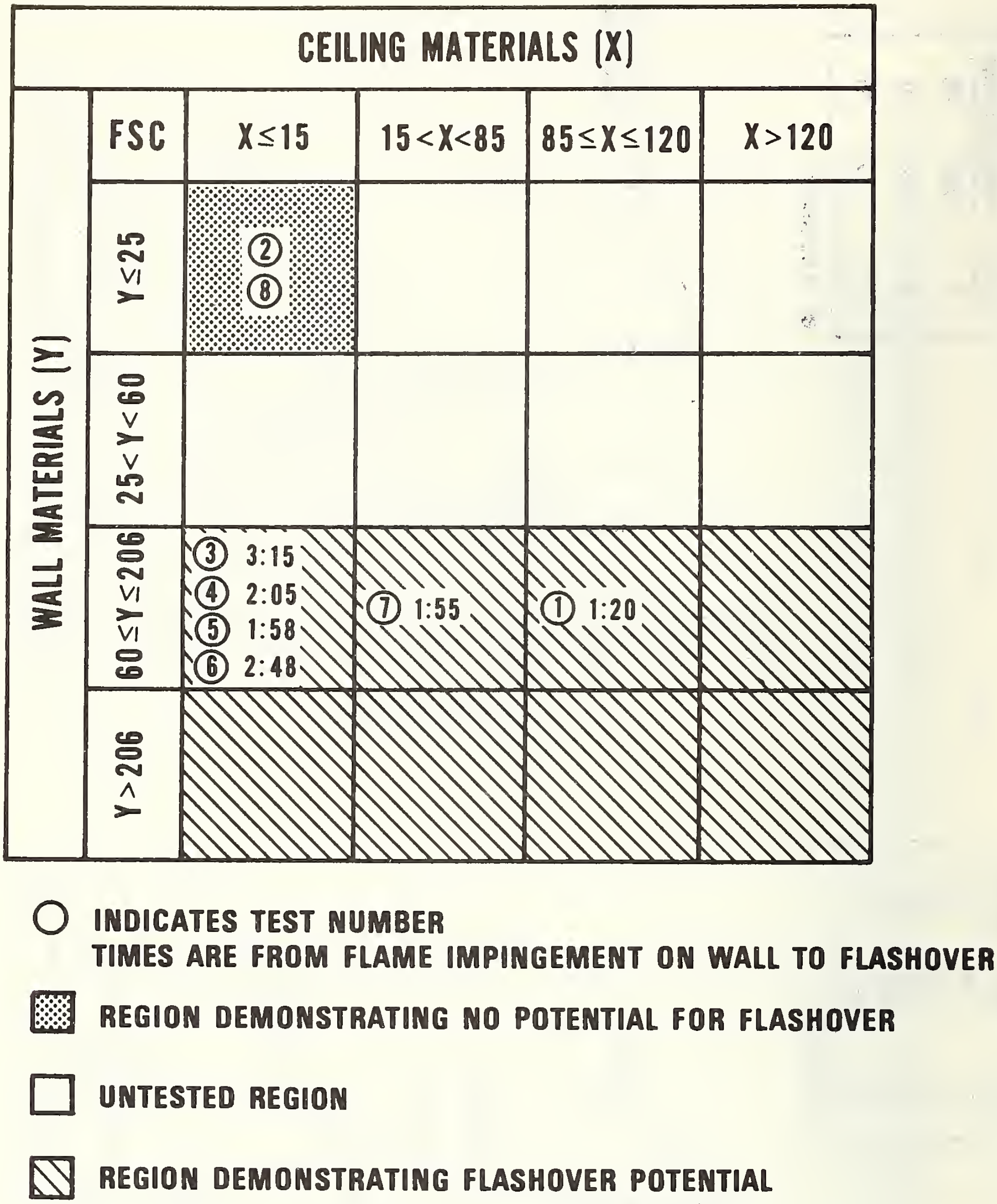


Figure 19. Material Hazard Matrix Based on ASTM E-84 FSC for an Upholstered Chair Exposure Fire (Bedroom Series)

Materials				Ease of Ignition		Surface Flame Spread			Smoke Generation		Heat Release Rate (W/cm^2) (Highest 1-Minute Average)		
						ASTM E-84			NFPA Smoke Density Chamber		N.B.S.- R.H.R. Calorimeter		
N.B.S. ID Code	Description	Thickness (mm)	(in)	Flame Attachment (sec)	Fuel Contribution (sec)	FSC	GWL[a]	ASTM E-162	Flaming	Non-Flaming	Exposure 2 W/cm^2	Exposure 4 W/cm^2	Exposure 6 W/cm^2
W-1	Prefinished Gypsum Board	8	5/16	89	∞	24	24	27	46	40	1	4	5
W-5	Prefinished Lauan Plywood	4	5/32	67	69	202	182	159	33	251	12	17	17
W-6	Prefinished Lauan Plywood	4	5/32	63	67	206	206	193	36	226	15	17	18
W-7	Intumescent Fire Retardant Treated Lauan Plywood	6	1/4	80	128	67	60	29	106	129	6	12	20
W-8	Intumescent Fire Retardant Treated Lauan Plywood	6	1/4	119	175	70	60	29	127	257	3	7	14
W-15	Prefinished Lauan Plywood	6	1/4	48	52	120	127	115	89	435	18	20	23
C-2	Unfinished Wood Fiberboard	13	1/2	32	41	70	81	152	134	481	6	7	8
C-4	Prefinished Gypsum Board	8	5/16	∞	∞	14	11	1	35	38	0	2	4
C-7	Prefinished Wood Fiberboard	13	1/2	31	37	128	119	76	203	250	6	11	17

[a] GWL indicates flame spread calculated by the George Williams-Leir method, which was adopted in April 1976 and replaces the previously used method designated here as FSC

Table 1. Physical and Fire Properties of Interior Finish Materials

Test No.[a]	Wall Material Description	NBS ID Code	Ceiling Material Description	NBS ID Code	Ignition Source
1	4 mm (5/32 in) thick prefinished Lauan plywood	W-6	13 mm (1/2 in) thick prefinished wood fiberboard	C-7	Chair
2	8 mm (5/16 in) thick prefinished gypsum board	W-1	8 mm (5/16 in) thick prefinished textured finished gypsum board	C-4	Chair
3	6 mm (1/4 in) thick prefinished Lauan plywood; fire retardant treated with intumescent coating-manufacturing application	W-7	8 mm (5/16 in) thick prefinished textured finished gypsum board	C-4	Chair
4	6 mm (1/4 in) thick Lauan plywood, fire retardant treated with intumescent coating; applied at NBS	W-8	8 mm (5/16 in) thick prefinished textured finished gypsum board	C-4	Chair
5	6 mm (1/4 in) thick prefinished Lauan plywood	W-15	8 mm (5/16 in) thick prefinished textured finished gypsum board	C-4	Chair
6	4 mm (5/32 in) thick prefinished Lauan plywood	W-5	8 mm (5/16 in) thick prefinished textured finished gypsum board	C-4	Chair
7	6 mm (1/4 in) thick prefinished Lauan plywood; fire retardant treated with intumescent coating-manufacturing application	W-7	13 mm (1/2 in) thick unfinished wood fiberboard	C-2	Chair
8	13 mm (1/2 in) thick calcium silicate over 13 mm (1/2) thick unfinished gypsum board	W-16	SAME AS WALLS	W-16	Chair
13	13 mm (1/2 in) thick unpainted gypsum board, taped and spackled joints	W-20	SAME AS WALLS	W-20	Bed

[a] Tests 9-12 were conducted to examine the burning characteristics of a number of standardized wood cribs. The results were not germane to this study and therefore were not included.

Table 2. Description of Interior Finish Materials Used in Each Full-Scale Test

Test	Exterior Conditions			Interior Conditions			Ignition	Moisture Content	
	Temperature		Humidity	Temperature		Humidity	Source	Walls	Ceiling
No.	°C	°F	%	°C	°F	%	Type	(%)	(%)
1	24	75	54	23	73	54	Chair	9.5	8.5
2	23	74	79	22	72	60	Chair	12.5	15.0
3	23	74	62	20	66	58	Chair	9.0	13.0
4	26	78	67	23	74	60	Chair	8.5	13.0
5	15	58	60	24	75	55	Chair	8.6	13.0
6	23	74	51	21	70	54	Chair	8.0	13.0
7	27	80	38	25	76	46	Chair	7.4	7.0
8	26	79	77	27	81	44	Chair	12.0	12.0
13	11	52	48	11	52	44	Bed	11.0	11.0

Table 3. Test Conditions for Full-scale Mobile Home Fire Tests (Bedroom Series)

INSTRUMENTATION AND LOCATION	
Average air temperature 25 mm below ceiling in bedroom No. 1	
TC-2	Bedroom 1, south wall, 211 cm above floor
TC-3	Bedroom 1, south wall, 188 cm above floor
TC-4	Bedroom 1, south wall, 132 cm above floor
TC-5	Bedroom 1, east wall, 211 cm above floor
TC-6	Bedroom 1, east wall, 188 cm above floor
TC-7	Bedroom 1, east wall, 132 cm above floor
TC-8	Bedroom 1, north wall, 211 cm above floor
TC-9	Bedroom 1, north wall, 188 cm above floor
TC-10	Bedroom 1, north wall, 132 cm above floor
TC-11	Bedroom 1, west wall, 211 cm above floor
TC-12	Bedroom 1, west wall, 188 cm above floor
TC-13	Bedroom 1, west wall, 132 cm above floor
TC-14	Bedroom 1, center of room, 211 cm above floor
TC-15	Bedroom 1, center of room, 188 cm above floor
TC-16	Bedroom 1, center of room, 132 cm above floor
TC-17	Bedroom 1, center of room, 91 cm above floor
TC-18	Corridor, entr. to bdrm 1, 211 cm above floor
TC-19	Corridor, entr. to bdrm 1, 188 cm above floor
TC-20	Corridor, entr. to bdrm 1, 132 cm above floor
TC-21	Corridor, entr. to bdrm 1, 91 cm above floor
TC-22	Corridor, entr. to bdrm 2, 211 cm above floor
TC-23	Corridor, entr. to bdrm 2, 188 cm above floor
TC-24	Corridor, entr. to bdrm 2, 132 cm above floor
TC-25	Corridor, entr. to bdrm 2, 91 cm above floor
TC-26	Corridor, entr. to bdrm 3, 211 cm above floor
TC-27	Corridor, entr. to bdrm 3, 188 cm above floor
TC-28	Corridor, entr. to bdrm 3, 132 cm above floor
TC-29	Corridor, entr. to bdrm 3, 91 cm above floor
TC-30	Bathroom, center of room, 211 cm above floor
TC-31	Bathroom, center of room, 188 cm above floor
TC-32	Bathroom, center of room, 132 cm above floor
TC-33	Bathroom, center of room, 91 cm above floor
TC-34	Bedroom 2, center of room, 211 cm above floor
TC-35	Bedroom 2, center of room, 188 cm above floor
TC-36	Bedroom 2, center of room, 132 cm above floor
TC-37	Bedroom 2, center of room 91 cm above floor
TC-38	Bedroom 3, center of room, 211 cm above floor
TC-39	Bedroom 3, center of room, 188 cm above floor
TC-40	Bedroom 3, center of room, 132 cm above floor
TC-41	Bedroom 3, center of room, 91 cm above floor
TC-42	Kitchen, center of room, 211 cm above floor
TC-43	Kitchen, center of room, 188 cm above floor
TC-44	Kitchen, center of room, 132 cm above floor
TC-45	Kitchen, center of room, 91 cm above floor
TC-46	Living room, center of room, 211 cm above floor
TC-47	Living room, center of room, 188 cm above floor
TC-48	Living room, center of room, 132 cm above floor
TC-49	Living room, center of room, 91 cm above floor
RAD-1	Heat flux - center of bdrm 1, floor level
RAD-2	Heat flux - corridor at entrance to bdrm 1 - floor level
RAD-3	Heat flux - corridor at entrance to bdrm 3 - floor level
HSM-13	Horizontal smoke meter - 0.9 m above floor in corridor
HSM-14	Horizontal smoke meter - 1.5 m above floor in corridor
HSM-18	Horizontal smoke meter - 0.9 m above floor in living room
HSM-19	Horizontal smoke meter - 1.5 m above floor in living room
CO_2-21	Center of bedroom 1, 1.5 m above floor
CO-20	Center of bedroom 1, 1.5 m above floor
O_2-22	Center of bedroom 1, 1.5 m above floor
CO-23	Center of living room, 1.5 m above floor
O_2-24	Center of living room, 1.5 m above floor
Load cell	

Table 4. Mobile Home Full-Scale Bedroom Series Instrumentation Locations

Test No.	BEDROOM					LIVING ROOM			
	TC 14[b]	RAD 1	ΔO_2-22	CO-20	CO_2-21	TC 48	ΔO_2-24	CO-23	
	°C	w/cm^2	%	%	%	°C	%	%	$(PPM)^{1.036}x(MIN)$
1	634	3.0	15.4	4.0	14.3	100	5.2	0.9	1,498
2[a]	--	--	--	--	--	--	--	--	--
3	734	3.6	3.1	8.0	16.5	188	10.0	1.6	4,179
4	732	1.5	10.1	4.9	11.6	121	7.4	≥2.0	9,360
5	660	--[c]	14.5	2.4	13.2	129	7.0	0.7	4,653
6	653	3.6	14.9	3.7	13.9	146	7.3	0.6	6,294
7	650	3.3	9.3	4.1	8.2	134	3.7	1.0	2,569
8[a]	--	--	--	--	--	--	--	--	--
13	700	2.4	4.9	0.1	1.2[c]	120	6.9	0.4	22,100

[a] Tests 2 and 8 did not reach flashover.

[b] Reference Table 4 for instrument locations.

[c] Unreliable data

Table 5. Measured Values of Test Variables at Flashover (Bedroom Series).

Test No.	BEDROOM						LIVING ROOM			
	$\dot{m}$ [a]	TC 14 [b]	RAD 1	ΔO_2-22	CO-20	CO_2-21	TC 48	ΔO_2-24	CO-23	
	g/s	°C	w/cm^2	%	%	%	°C	%	%	$(PPM)^{1.036}x(MIN)$
1	[c]	634	3.0	15.4	4.0	14.3	145	5.2	1.3	14,060
2	61	300	0.2	3.2	0.2	4.0	109	5.0	0.2	7,495
3	18	776	3.6	>20.0	8.7	16.5	188	10.0	≥2.0	22,580
4	27	756	1.5	15.8	7.3	14.3	122	12.4	≥2.0	39,960
5	23	688	[c]	16.6	6.0	14.9	148	11.2	≥2.0	20,270
6	[c]	703	4.9	17.2	5.5	16.5	161	11.1	≥2.0	9,699
7	25	650	3.3	19.1	7.5	17.6	175	9.9	≥2.0	19,380
8	42	372	0.2	5.7	0.3	5.1	98	2.2	0.2	53,190
13	84	734	2.4	>20.0	3.4	3.3 [c]	159	17.5	1.8	54,470

[a] $\dot{m}$ = mass burning rate

[b] Reference Table 4 for instrument locations

[c] **Unreliable data**

Table 6. Peak Measured Values of Test Variables (Bedroom Series).

Test	Detector Alarm	Ignition of Chair (I_c)	Flame Impingement on Wall (I_w)	Elapsed Time I_w-I_c	Ignition of Wall	Flashover	Activation of Sprinkler System	Final Data Record	Termination of Test Observations	ASTM E-84 FSC Wall/Ceiling
	(min:sec)	(min:sec)	(min:sec)	(min:sec)	(min:sec)	(min:sec)	(min:sec)	(min:sec)	(min:sec)	
1	1:11	2:15	4:25	2:10	5:10	5:45	5:50	7:40	5:55	206/119
2	1:12	1:30	6:10	5:40	7:20	NR	NR	15:00	15:00	24/11
3	1:26	0:55	4:25	3:30	5:00	7:40	7:45	9:00	8:20	60/11
4	1:19	1:27	9:35	8:08	10:20	11:40	12:27	14:00	13:00	60/11
5	1:19	1:05	8:55	7:50	10:00	10:53	11:10	12:40	11:15	127/11
6	1:15	1:00	13:05	12:05	14:35	15:53	16:05	16:20	16:10	182/11
7	0:55	0:55	7:45	6:50	8:35	9:40	9:45	11:00	9:55	60/81
8	0:34	1:10	3:10	2:00	NR	NR	NR	27:30	25:00	0/0
13	--	--	NR[a]	--	3:45	3:45	6:10	5:40	6:15	15/15

[a]NR = not reached

Table 7. Tabulation of Key Events Observed in the Full-Scale Tests (Bedroom Series)

Test	Elapsed Time to 0.26 OD/m Optical Density At: HSM 14	HSM 19	Elapsed Time to Flame Impingement on Wall	Elapsed Time from Flame Impingement on Wall to: Flashover	100°C at TC 48	14% O_2 in Living Room	CO[e] in Living Room	Maximum Optical Density (OD/m) at HSM 14	HSM 19	ASTM E-84 FSC	Ease of Ignition Fuel Contribution Time (sec)	NBS Heat Release Rate Calorimeter 2 W/cm^2 Exposure
	min:sec	min:sec	min:sec	min:sec	min:sec	min:sec	min:sec			Wall/Ceiling	Wall/Ceiling	Wall/Ceiling
1	3:30	4:00	4:25	1:20	1:20	1:35	2:15	3.8	4.2	206/119	67/37	15/6
2	4:50	4:40	6:10	NR[b]	2:45	NR	NR	1.6	1.6	24/11	∞/∞	1/0
3	4:00	4:50	4:25	3:15	2:40	3:05	3:10	>6.0	>6.0	60/11	128/∞	6/0
4	4:50	5:50	9:35	2:05	1:25	1:55	1:45	>6.0	>6.0	60/11	175/∞	3/0
5	5:40	6:20	8:55	1:58	1:55	1:50	2:25	>6.0	>6.0	127/11	52/∞	18/0
6	5:50	7:50	13:05	2:48	2:30	2:35	3:05	>6.0	>6.0	182/11	69/∞	12/0
7	7:30	8:30	7:45	1:55	1:45	2:05	1:55	>6.0	>6.0	60/81	128/41	6/6
8	4:15	4:00	3:10	NR	9:40[c]	NR	21:40	1.2	1.8	0/0	∞ ∞	0/0
13[a]	2:00	2:15		3:45	3:35	3:45	4:00	>6.0	>6.0	15/15	-[d]	-[d]

[a] Recorded times from beginning of test for #13

[b] NR = Not reached

[c] Maximum temperature - 98°C

[d] Data unavailable

[e] 1.0% or 41,800(ppm$^{1.036}$ x min)

Table 8. Tabulation of Selected Measurements (Bedroom Series)

APPENDIX A

Chronological Tabulation of Test Observations

Appendix A: Chronological Tabulation of Test Observations

MHBED #1

TEST CONDITIONS

Date: 7-31-75
Time: 10:30 a.m.

Exterior Weather Conditions
- Temperature - 24°C (75°F)
- Relative Humidity - 54%
- Barametric Pressure - 760 mm (29.9 in) Hg
- Wind - 8 mph (W-SW)
- Generally clear, sunny

Interior Conditions
- Temperature - 23°C (73°F)
- Relative Humidity - 54%

Interior Finish Material
- Walls: 4 mm (5/32 in) thick lauan plywood, moisture content 9.5%
- Ceiling: 13 mm (1/2 in) thick wood fiberboard, moisture content 8.5%

Ignition Source - polyethylene waste container with 225 gm (1/2 lb) newsprint, adjacent to 16 kg (35 lb) polyurethane foam upholstered chair

OBSERVATIONS

Time (min:sec)	
0:00	Ignition of newsprint
0:01	Sustained burning of newsprint
0:45	Flame height - 0.3 m (1 ft) above waste container
1:00	Flame height - 0.46 m (1-1/2 ft) waste container ignited
1:11	Single station smoke detector #1 alarmed
1:20	Single station smoke detector #2 alarmed
1:30	Waste container melting and dripping onto floor
1:35	Flame height - 0.6 m (2 ft) above floor, exposure of chair
2:15	Side of chair ignited
2:25	Flame reduced to 0.3 m (1 ft) in height
2:45	75% of waste container destroyed
3:00	Increased involvement of chair
3:15	Flames emitted from arm and back of chair
3:20	Excessive smoke production
4:25	Intermittent flame impingement on wall
4:40	30% to 40% involvement of chair - flames are not lengthening excessively
5:00	Stratification of smoke 0.9 - 1.2 m (3 to 4 ft) down from ceiling
5:10	Ignition of wall behind waste can and chair
5:15	Flame front flashed to ceiling level
5:45	Flashover
5:50	Failure of bedroom windows - flames extended 0.9 - 1.2 m (3 to 4 ft)horizontally from window openings
5:50	Operation of sprinkler system
5:55	Termination of visual observations
7:40	Last data record

Post Test Observations

1) High level of irritants in combustion by-products
2) Heavy smoke accumulation
3) Walls in bedroom sustained burning from ceiling down to 0.3 m (1 ft) from floor
4) Ceiling in bedroom charred throughout
5) Walls charred in corridor 0.6 - 0.9 m (2 to 3 ft) down from ceiling; 2.4 m (8 ft) into the corridor
6) Pyrolysis of vinyl flooring in bedroom
7) Wall behind chair in corner did not sustain char below level of the chair
8) Failure of both bedroom windows

MHBED #2

TEST CONDITIONS

Date: 8-12-75
Time: 10:30 a.m.

Exterior Weather Conditions
- Temperature 23°C (74°F)
- Relative Humidity - 79%
- Barametric Pressure 763 mm (30.02 in) Hg
- Wind - 7-10 mph (N)
- Clear, humid

Interior Conditions
- Temperature 22°C (72°F)
- Relative Humidity - 60%

Interior Finish Material
- Walls: 8 mm (5/16 in) thick printed paper gypsum board; moisture content 12.5%
- Ceiling: 8 mm (5/16 in) thick textured gypsum board; moisture content 15%

Ignition Source - polyethylene waste container with 225 gm (1/2 lb) newsprint, adjacent to 16 kg (35 lb) polyurethane foam upholstered chair

OBSERVATIONS

Time (min:sec)	
0:00	Ignition of newsprint
0:30	Flame height 0.6 m (2 ft) from floor
0:45	Reduction in flaming mode
1:12	Single station smoke detector alarmed
1:30	Ignition of fabric cover on chair
2:00	Right arm and back of chair involved
2:20	Smoke being emitted from burning chair
3:00	Burning limited to chair
4:00	Waste container melting and dripping
4:25	Slight increase in heat at observation window
5:50	Flame height lengthening to 0.9 m (3 ft)
6:00	Intermittent flame impingement on wall

6:30	Clear visibility from floor to ceiling
6:45	Intermittent flame height at 1.2 m (4 ft) above
7:00	Cushion on chair ignited - smoke generation
7:20	Ignition of wall; intermittent flame height at 1.5 - 1.8 m (5 to 6 ft) above floor
7:25	Extensive burning of chair
7:30	Low visibility
8:00	Significant increase in heat at window
8:30	Flame height at ceiling - chair fully involved
8:50	Visibility negligible
10:00	No significant observations - temperatures are dropping
15:00	Termination of observations/last data record

Post Test Observations

1) Paper burned on the two wall panels comprising the corner; no indication of any further contribution from walls or ceiling
2) Floor covering unaffect
3) Slight charring of curtains
4) No contribution from any furnishings except the test chair
5) Minimum heat transmission to exterior
6) 75% of chair burned

MHBED #3

TEST CONDITIONS

Date: 8-19-75
Time: 9:30 a.m.

Exterior Weather Conditions
- Temperature - 23°C (74°F)
- Relative Humidity - 62%
- Barametric Pressure 765 mm (30.11 in) Hg
- Wind 5-8 mph (S-SW)
- Clear

Interior Conditions
- Temperature - 20°C (66°F)
- Relative Humidity - 58%

Interior Finish Materials
- Walls: 6.4 mm (1/4 in) thick lauan plywood, intumescent treated by manufacturing process, moisture content 9%
- Ceiling: 8 mm (5/16 in) thick textured surface gypsum board, moisture content 13%

Ignition Source - polyethylene waste container with 225 gm (1/2 lb) newsprint, adjacent to 16 kg (35 lb) polyurethane foam upholstered chair

OBSERVATIONS

Time (min:sec)	
0:00	Ignition of newsprint
0:15	Sustained burning of newsprint
0:50	Flame height - 0.6 m (2 ft) above floor
0:55	Ignition of synthetic fabric chair cover
1:15	Waste container melting and dripping onto floor
1:20	Flame height - 0.76 m (2-1/2 ft) above floor
1:26	Single station smoke detector alarmed
1:43	Flame height - 0.9 m (3 ft) above floor
1:50	Increased involvement of chair
2:40	Noticeable production of irritants
3:00	Rate of burning of chair increasing
3:40	Flame height - 1.2 m (4 ft) above floor.
3:45	Right arm and back of chair involved
4:10	Slight increase in heat at observation window
4:15	Synthetic chair cover fabric melting and dripping onto floor
4:25	Flame impingement on wall
4:30	Stratification of smoke 0.5 m (1.5 ft) below ceiling
4:50	Walls adjacent to chair are charring/intumescing
5:00	Ignition of wall; no further contribution from waste container
5:30	Excessive dripping of fabric covering chair
5:40	Significant increase in heat at observation window
5:50	Extensive smoke production
6:00	20-25% involvement of chair
6:30	Flame impinging on ceiling
6:35	Excessive smoke production minimum visibility
7:15	Flame spread across ceiling to corridor entrance
7:20	Smoke extremely acrid
7:30	Failure of bedroom windows
7:40	Flashover observed
7:45	Operation of sprinkler system
8:20	Termination of observations
9:00	Last data record

Post Test Observations

1) High level of irritants in combustion by-products
2) Excessive smoke accumulation
3) Walls charred/burned from ceiling to floor in bedroom
4) Failure of ceiling along joints
5) Walls charred 0.6 - 0.9 m (2 to 3 ft) down from ceiling throughout corridor
6) Pyrolysis of vinyl flooring in bedroom
7) 90% of cover fabric of chair destroyed; right arm, back, and cushion of chair consumed
8) Extensive burning behind partitions

MHBED #4

TEST CONDITIONS

Date: 9-11-75
Time: 11:00 a.m.

Exterior Weather Conditions
- Temperature 26°C (78°F)
- Relative Humidity 67%
- Barametric Pressure 762 mm (30.01 in) Hg
- Wind 10 mph (S)
- Clear, humid

Interior Conditions
- Temperature - 23°C (74°F)
- Relative Humidity 60%

Interior Finish Materials
- Walls: 6.4 mm (1/4 in) thick lauan plywood, treated with intumescent fire retardant treatment, moisture content 8.5%
- Ceiling: 8 mm (5/16 in) thick textured surface gypsum board, moisture content 13%

Ignition Source - polyethylene waste container with 225 gm (1/2 lb) newsprint, adjacent to 16 kg (35 lb) chair constructed of cotton and polyurethane foam

OBSERVATIONS

Time (min:sec)	
0:00	Ignition of newsprint
0:45	Flame height 0.6 m (2 ft) above floor
1:19	Single station smoke detector alarmed
1:27	Ignition of chair - right arm
1:35	Waste can melting and dripping
2:00	Involvement of right arm and seat cushion of chair
3:00	Reduction in flaming mode
3:50	Slight increase in heat at observation window
4:10	Flames moving up back of chair
4:20	Smoke concentration in upper part of room
4:45	Intermittent impingement of flames on wall
5:15	Increased smoke accumulation in upper part of room, but no noticeable stratification
5:35	Increase in heat at observation window
6:15	Flame height 1.2 m (4 ft) above floor
6:35	Increased involvement of chair, slight increase in rate of fire growth
6:45	No further contribution from waste container or newsprint
7:00	Visibility reduced at the ceiling level; neutral plane appears to be 1.5 m (5 ft) above floor
7:45	Slight decrease in rate of burning
8:45	Rate of burning of chair increasing - polyurethane cushion is affecting burn rate
9:00	Extensive smoke accumulation at ceiling level
9:30	Fire still confined to chair
9:35	Flame impingement on wall
10:00	Rate of fire growth increasing - radiation level increasing
10:10	Flame height approaching ceiling level

10:20	Full involvement of chair
10:20	Ignition of wall
10:25	High radiation at window
11:00	Windows in burn room failed
11:15	Corridor involved
11:18	Extensive burning of gases throughout room
11:40	Flashover
12:27	Actuation of sprinkler system
13:00	Termination of observations
14:00	Last data record

Post Test Observations

1) Walls intumesced and burned from ceiling to floor
2) Failure of walls, burning extended into stud cavities and ceiling space
3) Flashover involved walls, ceiling, furnishings and 50% of the vinyl flooring
4) Burning of corridor walls 0.3 - 0.6 m (1 to 2 ft) down from ceiling
5) Burning above ceiling in corridor

MHBED #5

TEST CONDITIONS

Date: 9-30-75
Time: 11:00 a.m.

Exterior Weather Conditions
- Temperature 15°C (58°F)
- Relative Humidity 60%
- Barametric Pressure 737 mm (29.01 in) Hg
- Wind negligible
- Sunny, clear

Interior Conditions
- Temperature - 24°C (75°F)
- Relative Humidity - 55%

Interior Finish Material
- Walls: 6.4 mm (1/4 in) thick lauan plywood; moisture content 8.6%
- Ceiling: 8 mm (5/16 in) thick textured surface gypsum board; moisture content 13%

Ignition Source - polyethylene waste container with 225 gm (1/2 lb) newprint, adjacent to 16 kg (35 lb) chair constructed of polyurethane foam cotton

OBSERVATIONS

Time (min:sec)	
0:00	Ignition of newsprint
0:33	Test terminated due to clock malfunction

0:00	Ignition of newsprint
0:45	Flame height 0.6 m (2 ft) above the floor
1:05	Ignition of chair

1:19	Single station smoke detector alarmed
1:28	Chair burning on the side adjacent to the waste can
2:30	The polyethylene waste can melting and dripping
3:20	Flame height 0.76 m (2-1/2 ft) above the floor - very little smoke development
4:00	The arm of the chair adjacent to the waste can involved; flame spread to the back of the chair
4:24	Flame front regressing
5:35	Noticeable smoke stratification occurring above the 1.2 m (4 ft) level
6:13	Noticeable increase in smoke obscuration
6:27	The waste can totally consumed
7:08	Flame propagating up the back of the chair
7:15	The polyurethane chair cushion ignited
7:30	The flame front progressed to the front of the chair
7:54	Noticeable heat increase observed at the observation window
8:10	Involvement of chair increasing rapidly
8:18	Visibility above the 1.2 m (4 ft) level negligible
8:25	Flame impinging on the wall
8:55	Constant flame impingement on wall
9:23	Flame 1.8 m (6 ft) above floor
9:30	Rapid heat build-up at observation window
9:44	Stratification continued with dense, dark smoke in the upper half of the room
10:00	Ignition of wall
10:25	Flame propogation across the ceiling
10:53	Flashover occurred - bed ignited
11:03	Vinyl floor covering ignited
11:10	Manual sprinkler system was activated
11:15	Termination of test observations
12:40	Last data record

MHBED #6

TEST CONDITIONS

Date: 10-15-75
Time: 11:30 a.m.

Exterior Weather Conditions
- Temperature - 23°C (74°F)
- Relative Humidity - 51%
- Barametric Pressure - 760 mm (29.90 in) Hg
- Wind 5 mph (SW)
- Clear

Interior Conditions
- Temperature - 21°C (70°F)
- Relative Humidity - 54%

Interior Finish Materials
- Walls: 4 mm (5/32 in) thick printed paper surface lauan plywood; moisture content 8%
- Ceiling: 8 mm (5/16 in) thick textured surface gypsum board; moisture content 13%

Ignition Source - polyethylene waste container with 225 gm (1/2 lb) newsprint, adjacent to 16 kg (35 lb) chair constructed of polyurethane foam cotton

OBSERVATIONS

Time (min:sec)	
0:00	Ignition of newprint
1:00	Ignition of side of chair
1:10	Flame height 0.6 m (2 ft) above floor
1:15	Single station smoke detector alarmed
1:25	Flame height approximately 0.9 m (3 ft) above floor
2:10	Waste container beginning to melt and drip onto floor
2:40	Flame height receding
4:00	Flame Spread laterally towards back of chair
4:20	60-70% of waste container destroyed
4:30	Increased involvement of right side of chair
5:50	Smoke stratification to approximately 1.2 m (4 ft) above floor
6:20	Flame height nearly constant
7:00	Noticeable increase in heat level at observation window
7:05	Material in waste container no longer contributing to fire
8:00	Approximately 30% of front of chair burning
8:45	Visibility above 1.2 m (4 ft) from floor negligible
9:30	Increase in heat at observation window
10:40	Visibility above 0.3 m (1 ft) from floor negligible
11:30	High amount of smoke generation
12:45	Sustained burning of chair cushion
13:05	Flame impingement on wall
14:00	Noticeable increase in rate of fire growth
14:35	Ignition of wall adjacent to chair
14:50	Flame impingement at ceiling
15:05	Lateral flame spread across ceiling
15:25	Ignition of curtains
15:45	Vinyl asbestos floor burning
15:50	Bed ignited
15:53	Flashover
16:00	Failure of windows
16:05	Actuation of sprinkler system
16:10	Termination of test observations
16:20	Last data record

Post Test Observations

1) Fire growth characterized by excessive generation of grey/black smoke; high quantity of irritants
2) Evidence of slight charring in the corridor
3) 80% of vinyl flooring charred
4) Walls charred from floor to ceiling throughout test compartment
5) Burn-through of wall panel behind chair
6) No evidence of extensive burn-through of walls

MHBED #7

TEST CONDITIONS

Date: 11-5-75
Time: 2:45 p.m.

Exterior Weather Conditions
- Temperature - 27°C (80°F)
- Relative Humidity - 38%

- Barametric Pressure - 767 mm (30.18 in) Hg
- Wind - 10 mph (S-SW)
- Clear and warm

Interior Conditions
- Temperature - 25°C (76°F)
- Relative Humidity - 46%

Interior Finish Materials
- Walls: 6.4 mm (1/4 in) thick lauan plywood, intumescent treated by manufacturing process, moisture coontent 7.4%
- Ceiling: Backside of 13 mm (1/2 in) thick fiberboard, moisture content 7%

Ignition Source - polyethlyene waste container with 225 gm (1/2 lb) newsprint, adjacent to 16 kg (35 lb) chair constructed of polyurethane foam and cotton

OBSERVATIONS

Time (min:sec)	
0:00	Ignition of newsprint
0:30	Flame height at level of arm of chair
0:45	Initial melting of waste container
0:55	Ignition of arm of chair
0:55	Single station smoke detector alarmed
1:10	Flame height 0.3 m (1 ft) above chair
1:30	Fire confined to right side of chair
2:30	Fuel contribution from waste container reduced
2:45	Flame height 0.76 m (2-1/2 ft) above floor
4:00	Melting and dripping of waste container - 80% destroyed
4:15	Burn-through of fabric cover on chair
4:30	Noticeable increase in fire growth
5:20	Flame height 0.9 - 1.1 m (3 - 3-1/2 ft) above floor, fire has spread to back of chair
6:00	Cushion ignited
7:20	Increase in heat flux at observation window
7:45	Flame impingement on wall; dense smoke accumulation in upper part of room
8:35	Ignition of wall adjacent to chair
8:55	Flame impingement at ceiling
9:10	Lateral flame spread behind chair
9:30	Propagation across ceiling
9:40	Flashover
9:45	Actuation of sprinkler system
9:50	Flame spread down corridor
9:55	Termination of test observations
11:00	Last data record

Post Test Observations

1) Fire growth characterized by excessive smoke generation
2) A significant pressure increase was detected around the windows just prior to flashover (the windows were closed), all windows failed
3) The right arm of the chair was burned through; 30% of the urethane cushion was destroyed
4) Failure of the ceiling assembly resulted in propagation of the fire above the ceiling into adjacent compartments
5) The surfaces of the interior finish materials were burned down to the floor level
6) The panel adjacent to chair was burned through as well as the wall

panels along the ceiling in the corridor
7) 80-90% of the vinyl asbestos flooring was charred
8) Surface flame spread 10-12 feet down the corridor

MHBED #8

TEST CONDITIONS

Date: 8-17-77
Time: 9:35 AM

Exterior Weather Conditions
- Temperature - 26°C (79°F)
- Relative Humidity - 77%
- Barametric Pressure - 758 mm (29.86 in) Hg
- Wind - 12 mph (SW)
- Overcast

Interior Conditions
- Temperature - 27°C (81°F)
- Relative Humidity - 44%

Interior Finish Material
- Walls: 13 mm (1/2 in.) thick marinite XL (moisture content 12%) over 13 mm (1/2 in) thick gypsum board (moisture content 23%)
- Ceiling: Same as walls

Ignition Source - polyethylene waste container with 225 gms of newsprint positioned adjacent to right arm of 16 kg (35 lb) polyurethane foam upholstered chair; corner configuration

OBSERVATIONS

Time (min:sec)	
0:00	Ignition of newsprint
0:25	Fabric along right arm of chair beginning to char
0:34	Single station smoke detector alarmed
1:10	Initial burn-through of fabric covering chair; surface area of chair involved is approximately .09 m^2 (1 ft^2)
1:15	Polyethylene waste container beginning to melt and drip
1:40	Flame progress along right arm of chair
2:19	Some burning (slight) observed on the corner of the seat cushion
2:50	Flame progress continued toward back of chair
3:00	Flame height approximately 1.2 m (4 ft)
3:10	Flame impingement on wall
3:45	Waste container burned down; melted polyethylene continued to contribute fuel
4:20	Area of burn-through of right arm of chair has increased in size
5:00	Fire intensity increased; burn-through of the right arm has provided some venting
6:10	Fire still localized to right side of chair; flames continue to impinge on wall
8:00	Flames began to move towards front of chair; area of burning on cushion increased slightly
9:00	Flames have progressed behind back of chair; some involvement of the polyurethane foam in the cushion was observed

9:25	Flames were approximately 0.9 mm (3 ft) in height from burning cushion
9:40	Flame spread across cushion and back of chair
10:20	Flame height greater than 1.2 m (4 ft); some burning observed under chair
11:00	Most of the exposed surface area of the cushion and right arm of chair involved
11:15	Flame impingement on ceiling
11:25	Fire spread along right arm of chair
12:00	Visibility reduced considerably
12:30	Continued flame impingement on ceiling
13:15	Flames no longer impinging on ceiling; continued rigorous burning of cushion
14:30	Burn-through of right arm and back of chair; flame height reduced to approximately 1.2 m (4 ft) in height
15:20	Intensity of fire reduced
18:00	Chair fire burning down; visibility negligible; instrumentation indicated reduction in temperature levels in bedroom
23:40	Fire appeared confined to underside of chair
25:00	Termination of observations Chair fire extinguished
27:30	Final data record

MHBED #13

TEST CODITIONS

Date: 10-13-77
Time: 9:30 a.m.

Exterior Weather Conditions
- Temperature - 11°C (52°F)
- Relative Humidity - 48%
- Barametric Pressure 767 mm (30.18 in) Hg
- Wind - 12 mph (N)
- Partly cloudy

Interior Conditions
- Temperature - 11°C (52°F)
- Relative Humidity - 44%

Interior Finish Material
- Walls: 13 mm (1/2 in) thick unpainted gypsum board with taped and spackled joints; moisture content 11%
- Ceiling: Same as walls

Ignition Source - 24.5 kg (54 lb) bed, consisting of 102 mm (4 in) thick polyurethane foam mattress over a coil box spring. Bed included typical bedding accessories: sheets, pillows; and was ignited by remote ignition of 280 gm of newsprint placed on the pillows and sheet (ordinary newspaper folded once). Bed positioned in southeast corner of room.

OBSERVATIONS

Time (min:sec)	
0:00	Ignition of newsprint
0:30	One pillow has ignited; flame spreading across surface of pillow and newsprint

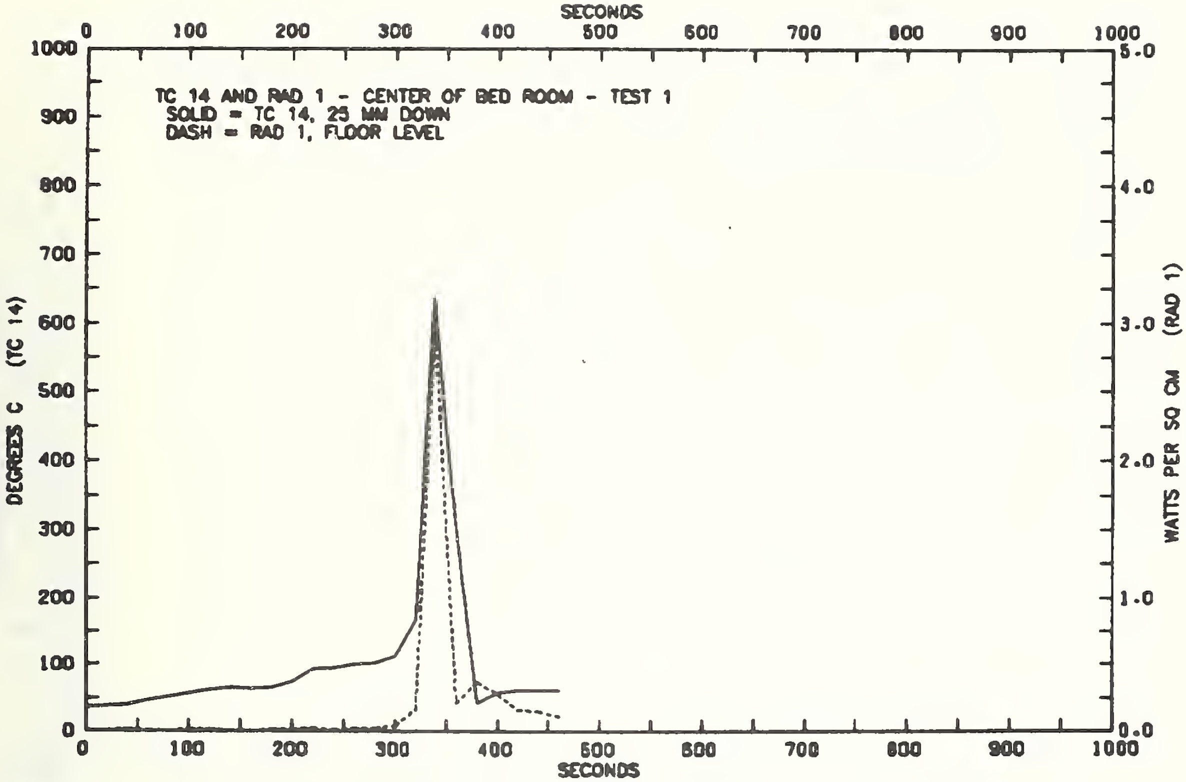
1:00	Pooling of liquid from melting polyester
1:45	Flames are contained to the pillows; some black colored smoke being emitted
1:50	Mattress involved; flames 1.5 m (5 ft) above floor
2:15	Flames have spread across the entire exposed surface of both pillows; dense black colored smoke has accumulated at the ceiling.
2:30	Intermittent flame height has reached 1.8 m (6 ft) above floor
3:00	Constant flame impingement on ceiling; some lateral flame spread across ceiling
3:15	Flame spread across ceiling more extensive
3:30	Ignition of crumbled newspaper located at foot of bed
3:40	Top surface of bed fully involved - radiant ignition of the lower part of the bed occurred
3:43	Ignition of the two pieces of crumbled newspaper located on the floor in front of the bed
3:45	Flashover
4:00	Burning of combustion gases down to the level of the observation window, approximately 0.6 m (2 ft) above floor
4:10	Windows in bedroom cracked; observation windows have become distorted
4:20	Visibility negligible with the exception of the flames from the burning bed
4:30	Visibility zero
5:15	Apparent reduction in fire intensity, bed still burning
5:40	Actuation of sprinkler system
6:10	Last data record
6:15	Termination of test observations

Post Test Observations

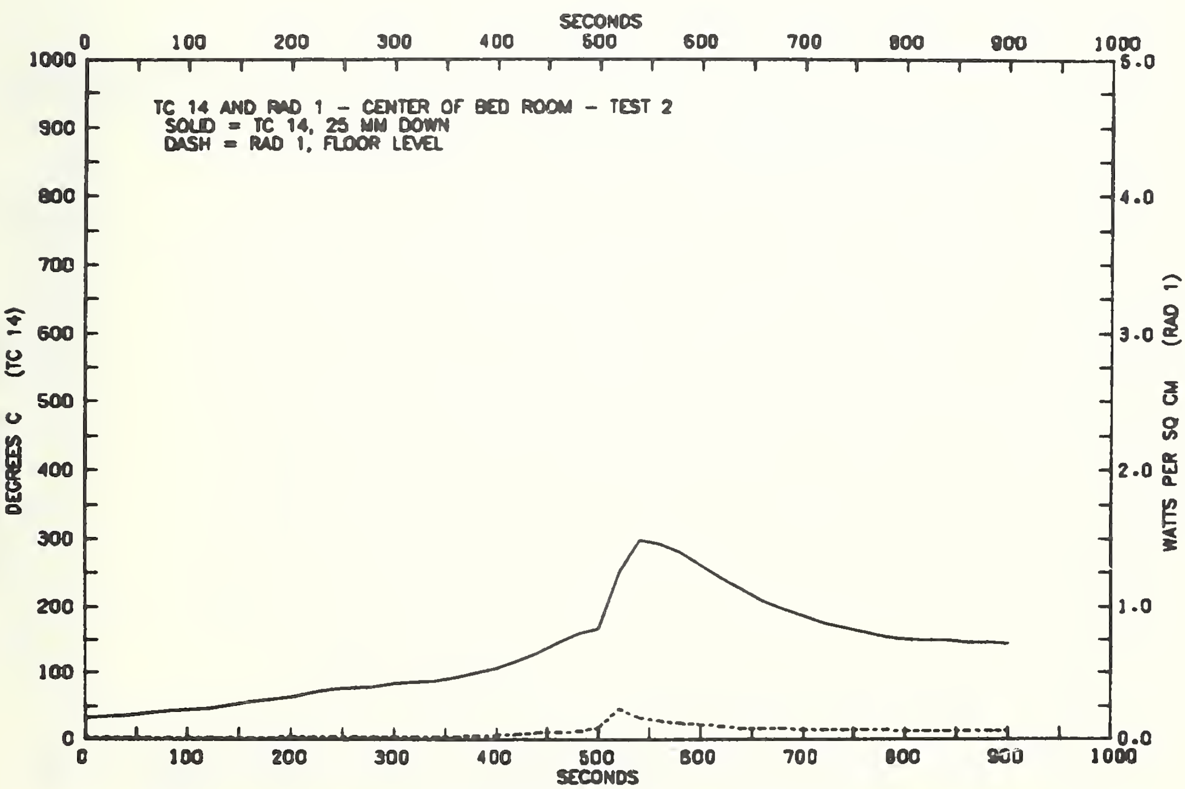
1) Walls and ceiling charred throughout room
2) Mattress consumed, most of coil box spring consumed
3) Crumbled newspaper located on floor in doorway showed no indication of char.
4) Some damage to wall and ceiling surface just outside room in corridor, no indication that damage extended significantly down the corridor

APPENDIX B

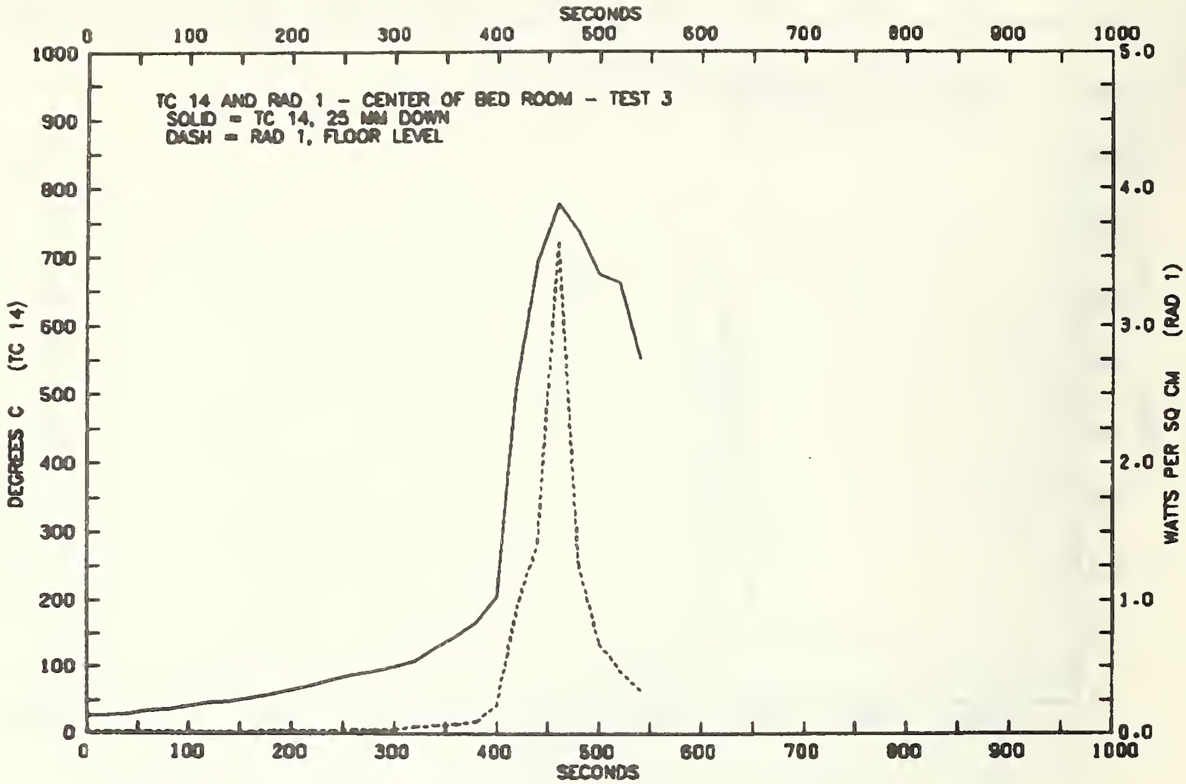
Plotted Test Data Illustrating Key Changes in Measured Conditions



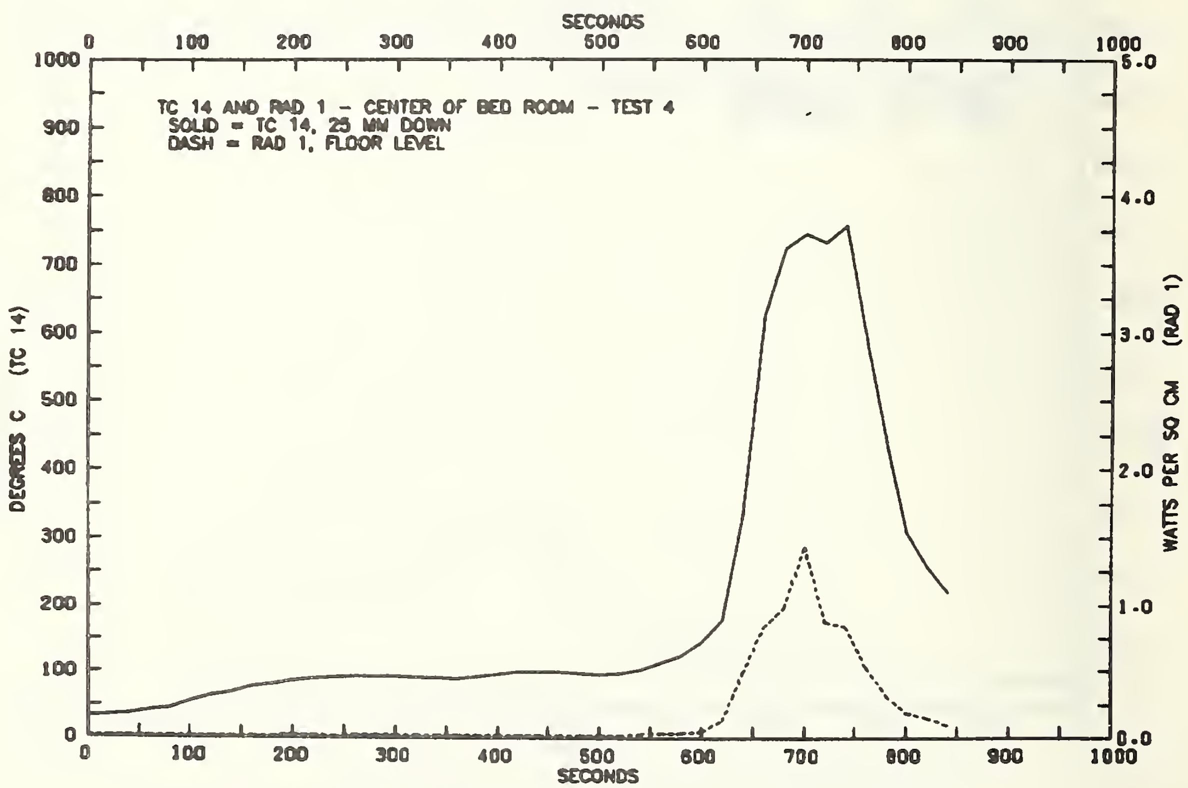
B1. Gas Temperature and Incident Heat Flux Measured in Center of Bedroom



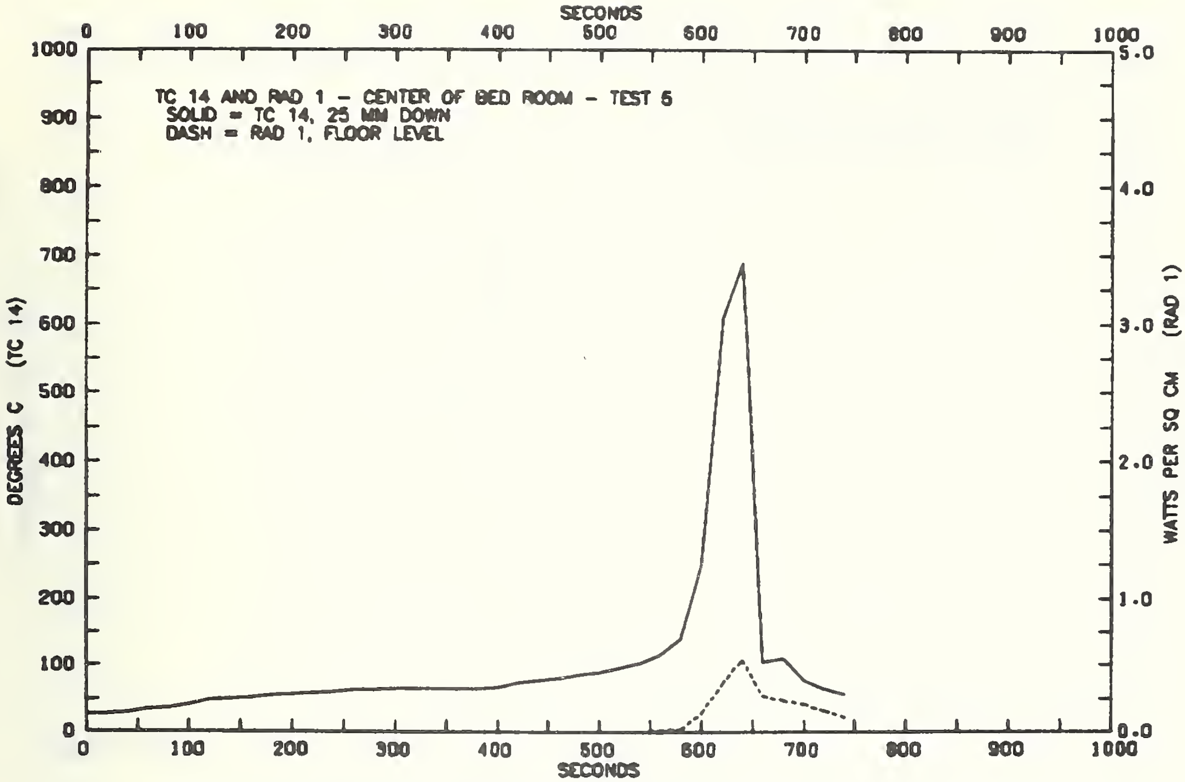
B2. Gas Temperature and Incident Heat Flux Measured in Center of Bedroom



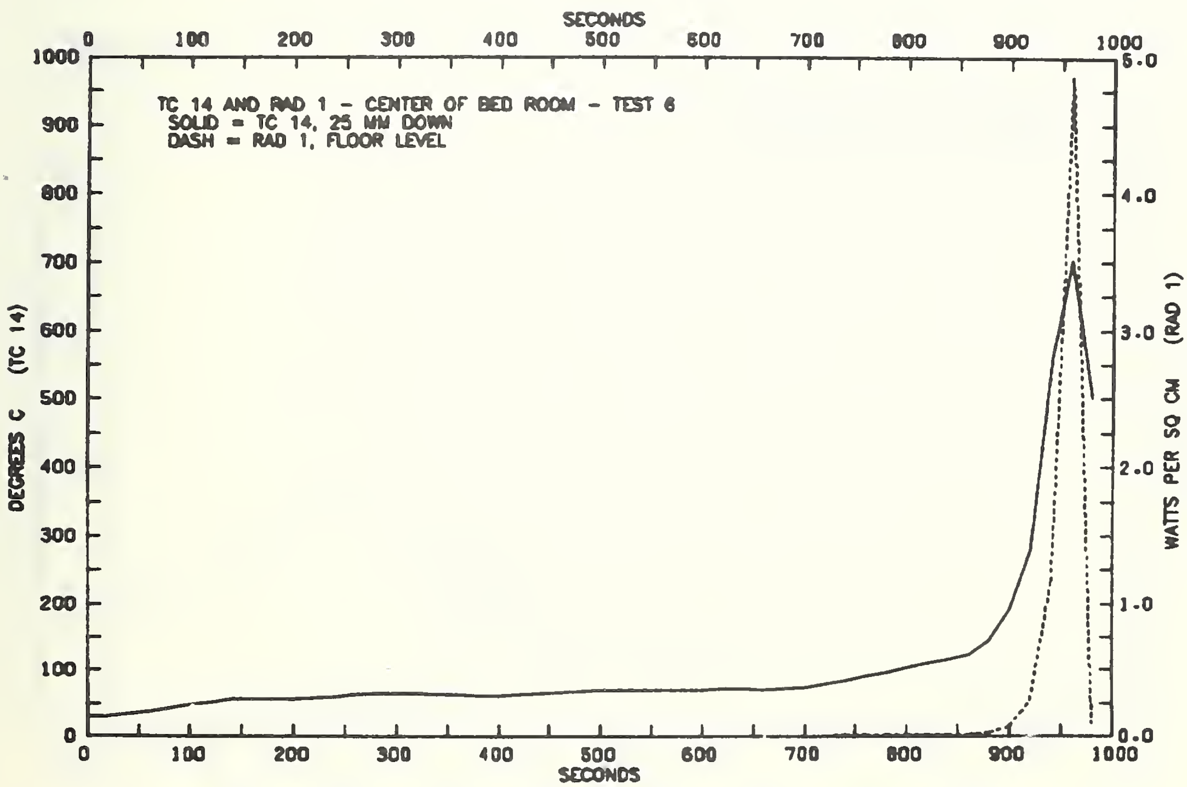
B3, Gas Temperature and Incident Heat Flux Measured in Center of Bedroom



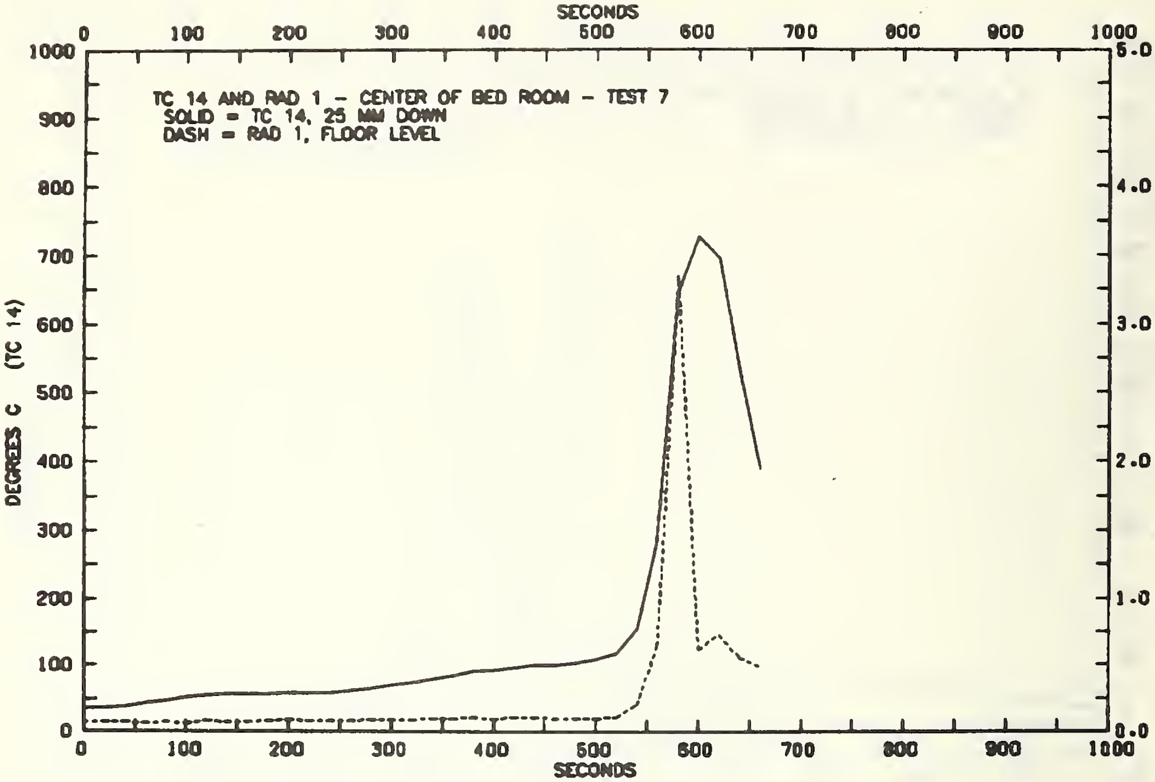
B4, Gas Temperature and Incident Heat Flux Measured in Center of Bedroom



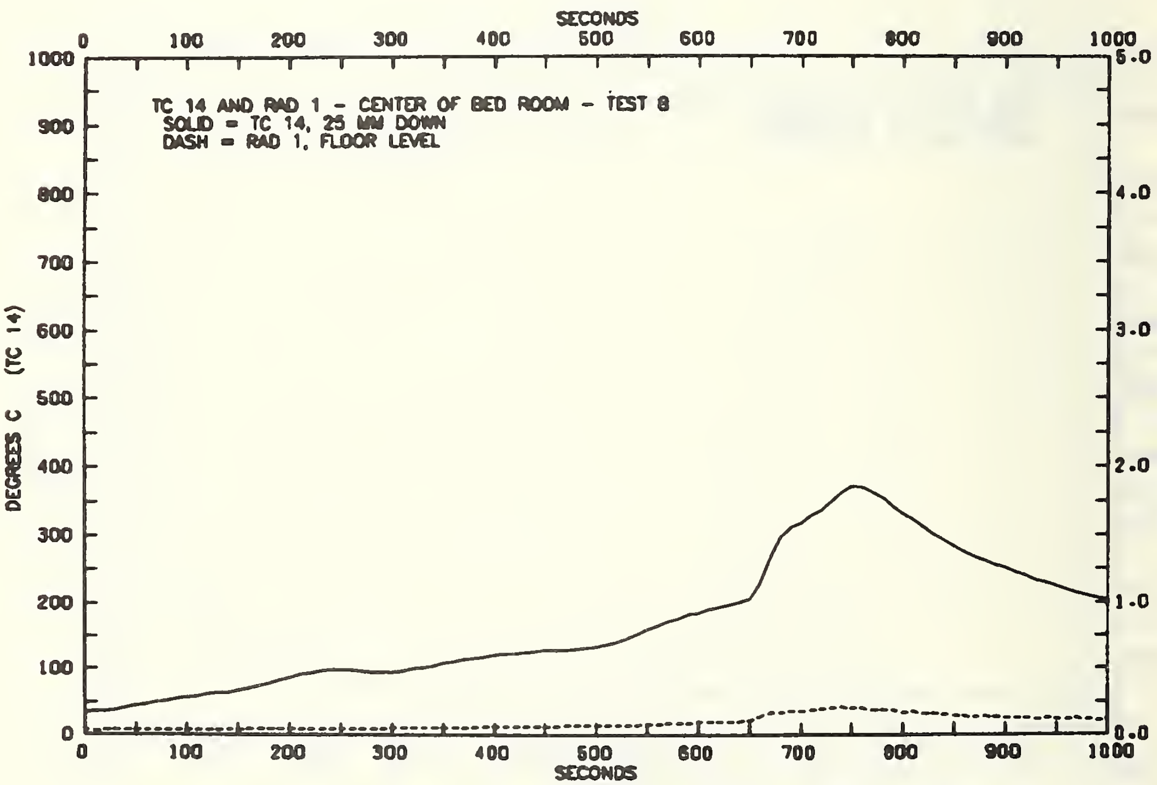
B5. Gas Temperature and Incident Heat Flux Measured in Center of Bedroom



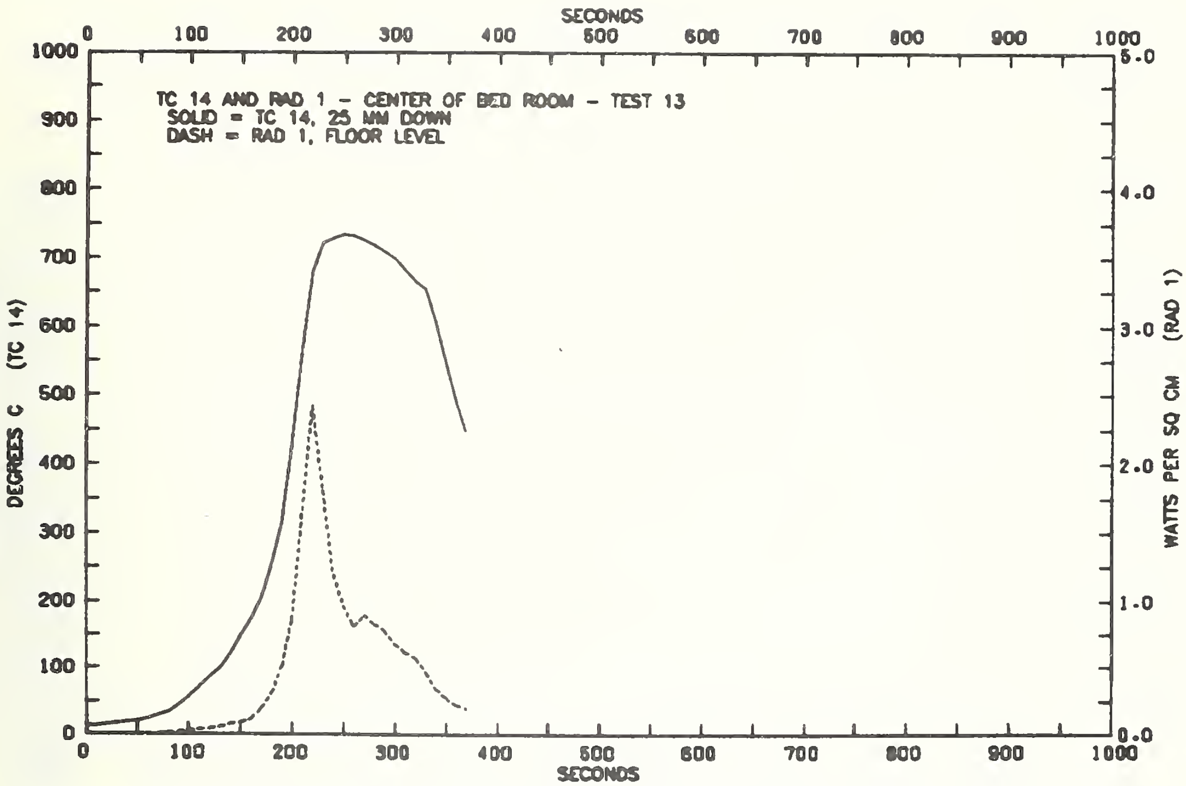
B6. Gas Temperature and Incident Heat Flux Measured in Center of Bedroom



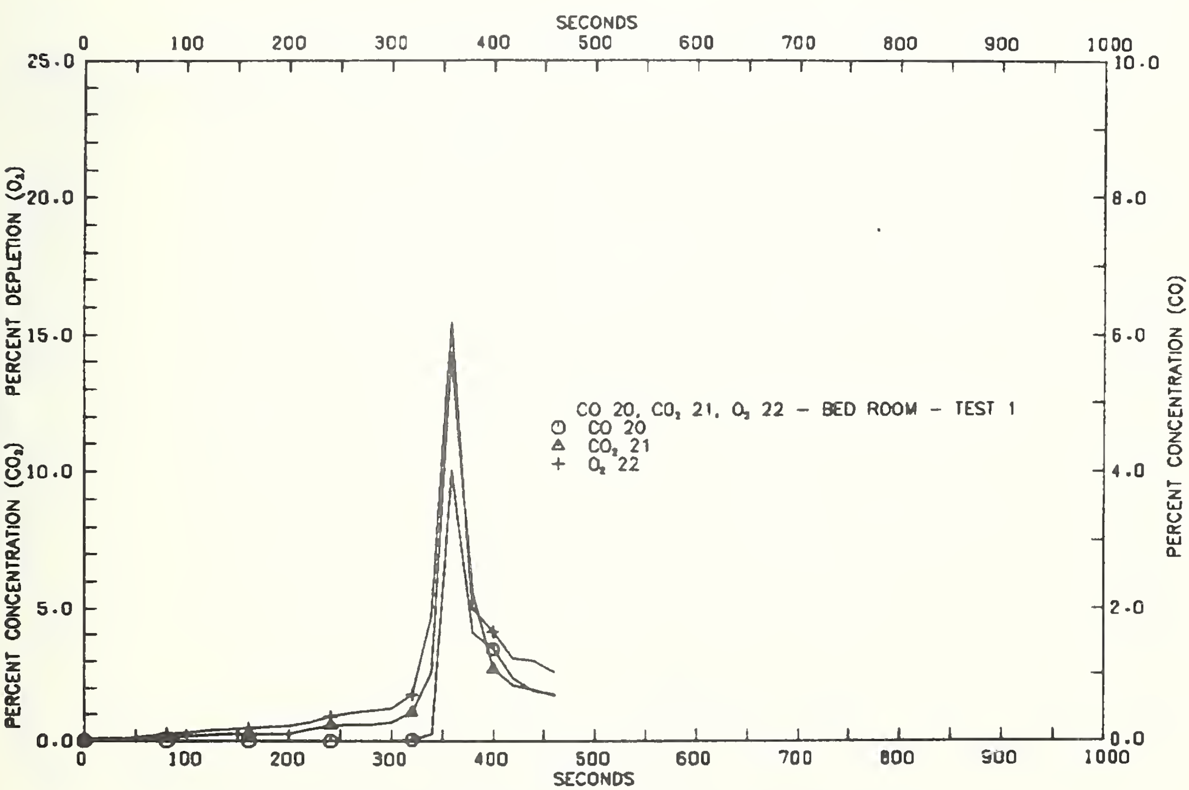
B7. Gas Temperature and Incident Heat Flux Measured in Center of Bedroom



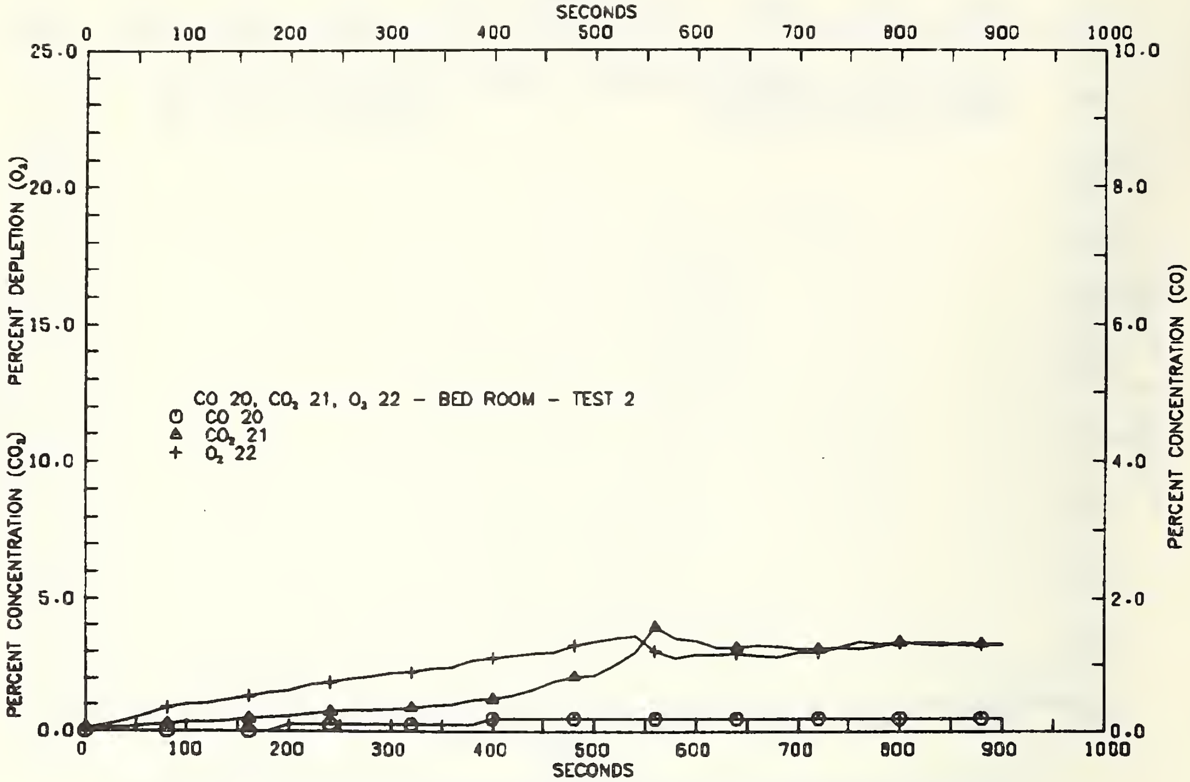
B8. Gas Temperature and Incident Heat Flux Measured in Center of Bedroom



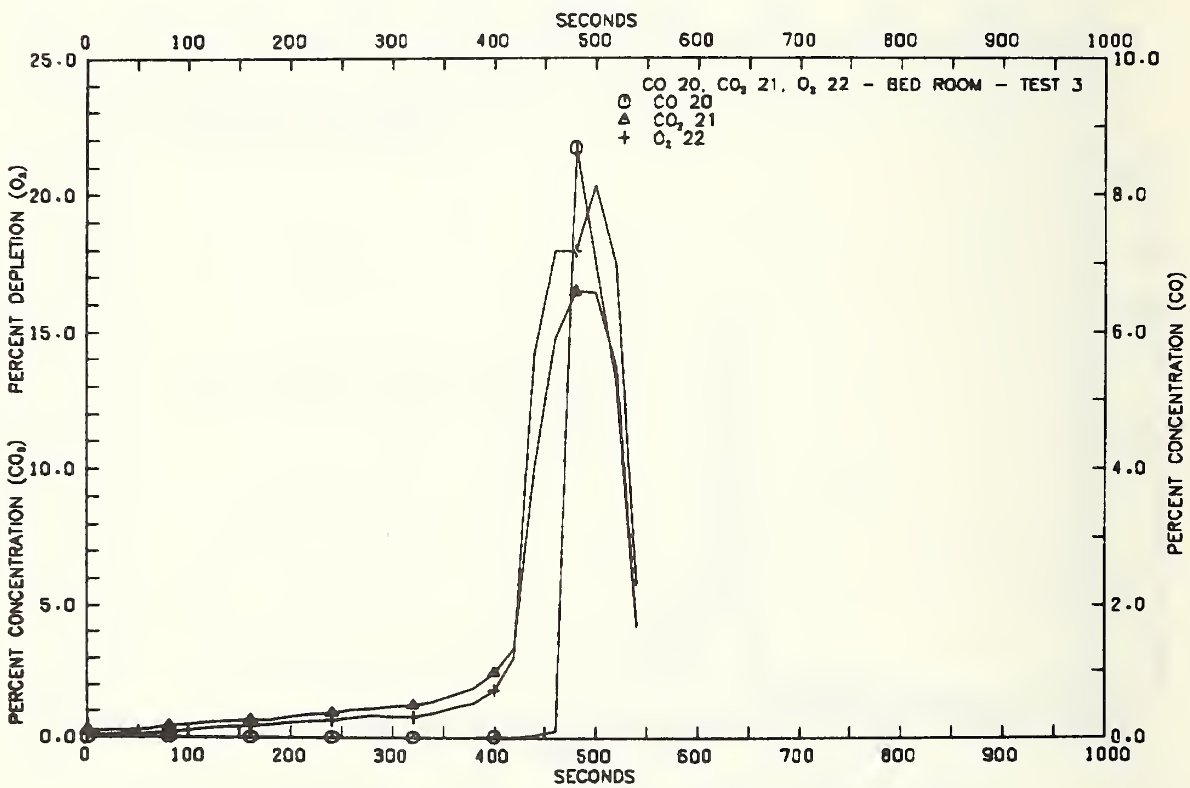
B9. Gas Temperature and Incident Heat Flux Measured in Center of Bedroom



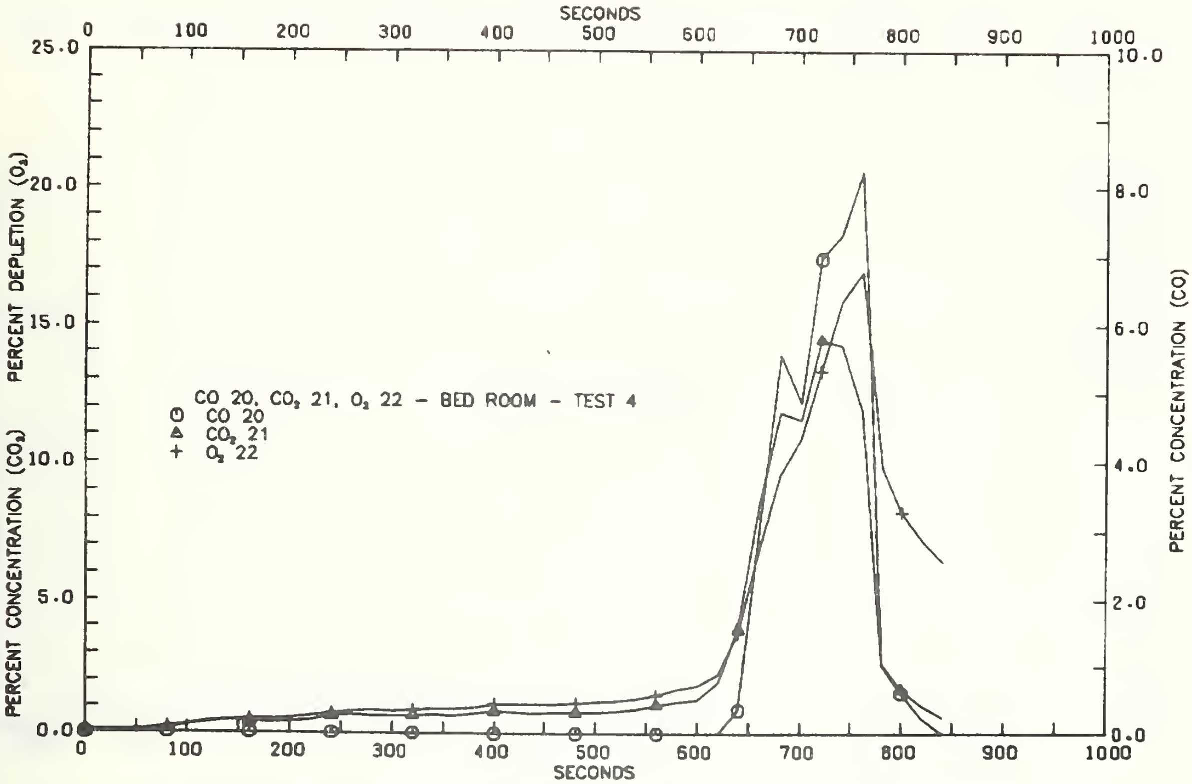
B10. CO and CO_2 (% concentration) and O_2 (% depletion) Measured in Center of Bedroom



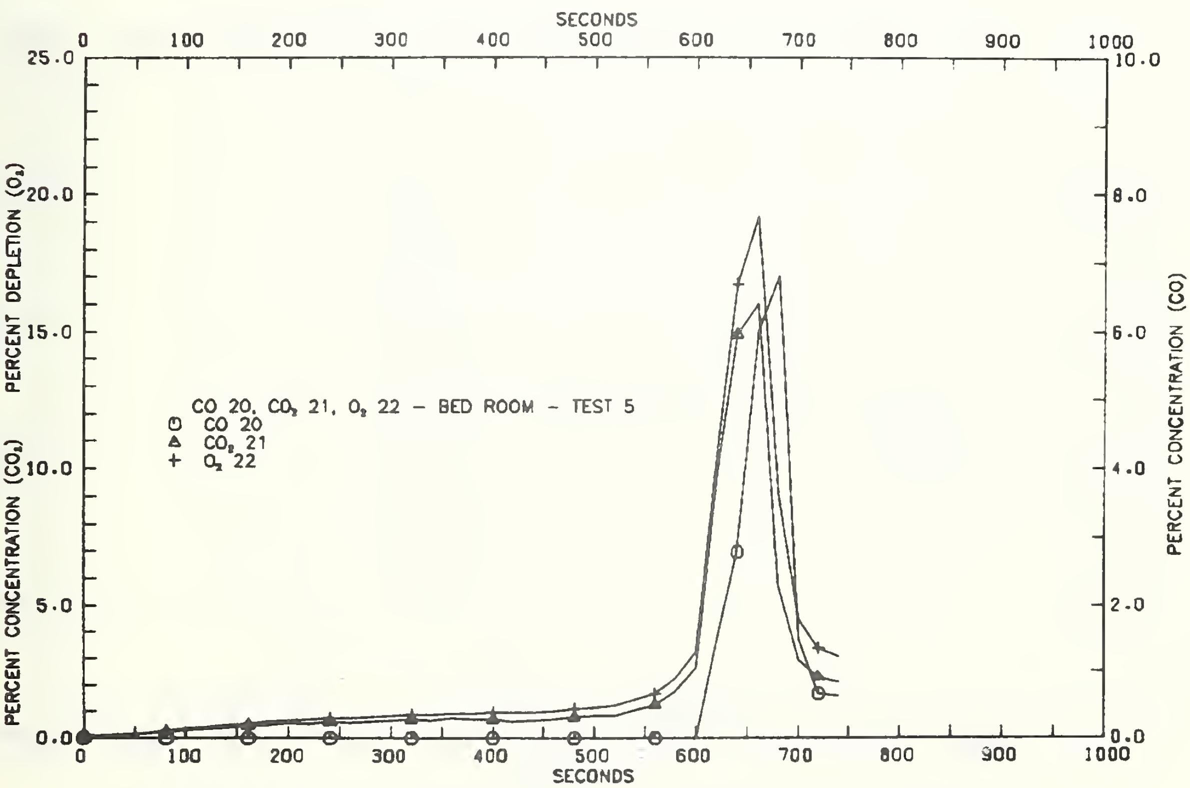
B11. CO and CO_2 (% concentration) and O_2 (% depletion) Measured in Center of Bedroom



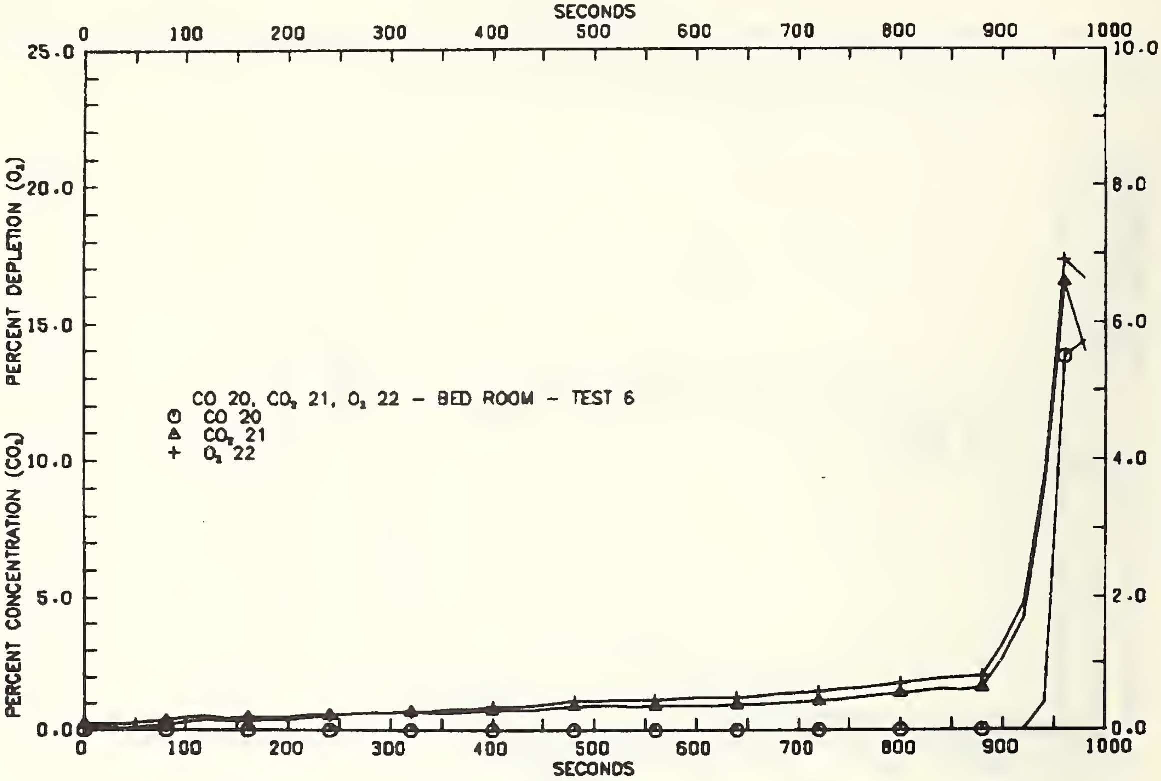
B12. CO and CO_2 (% concentration) and O_2 (% depletion) Measured in Center of Bedroom



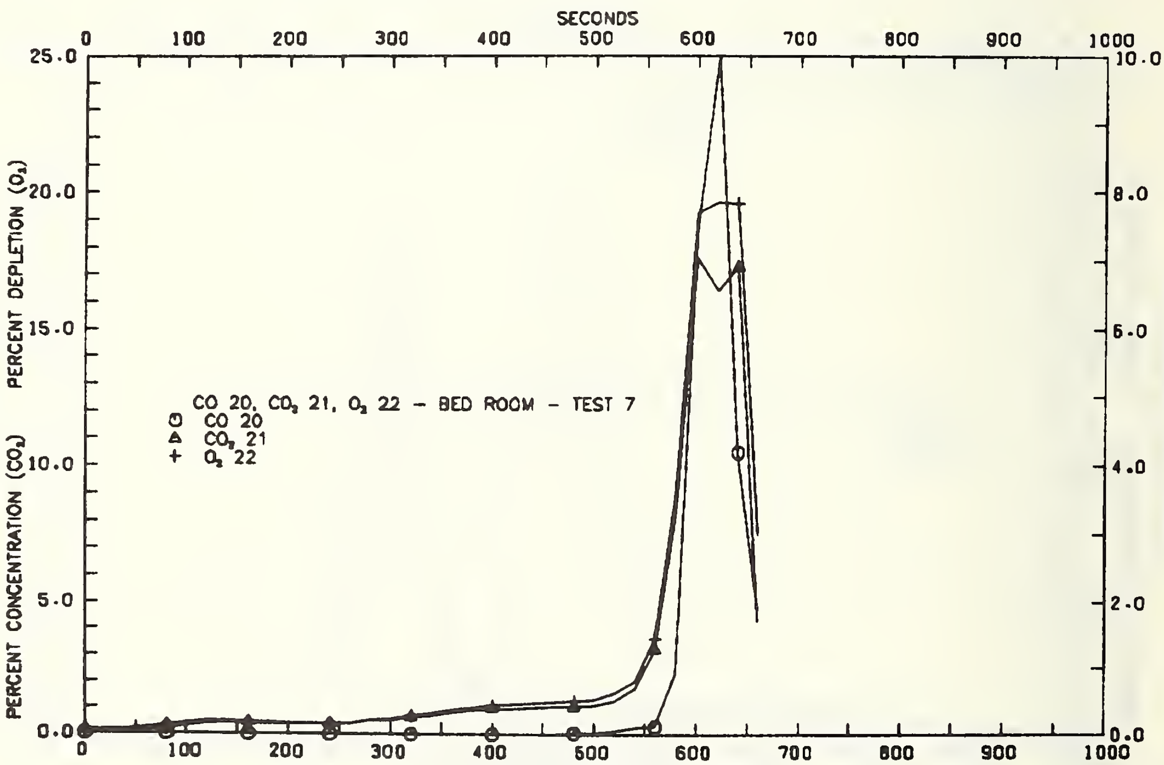
B13. CO and CO_2 (% concentration) and O_2 (% depletion) Measured in Center of Bedroom



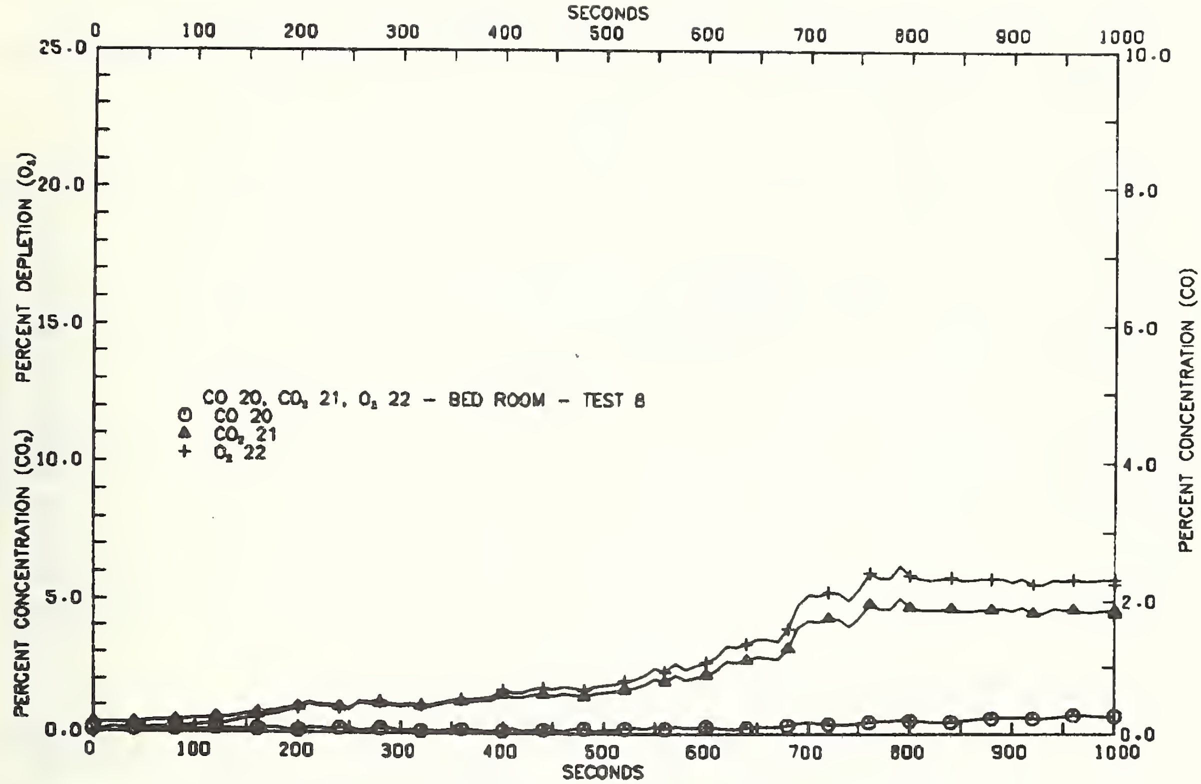
B14. CO and CO_2 (% concentration) and O_2 (% depletion) Measured in Center of Bedroom



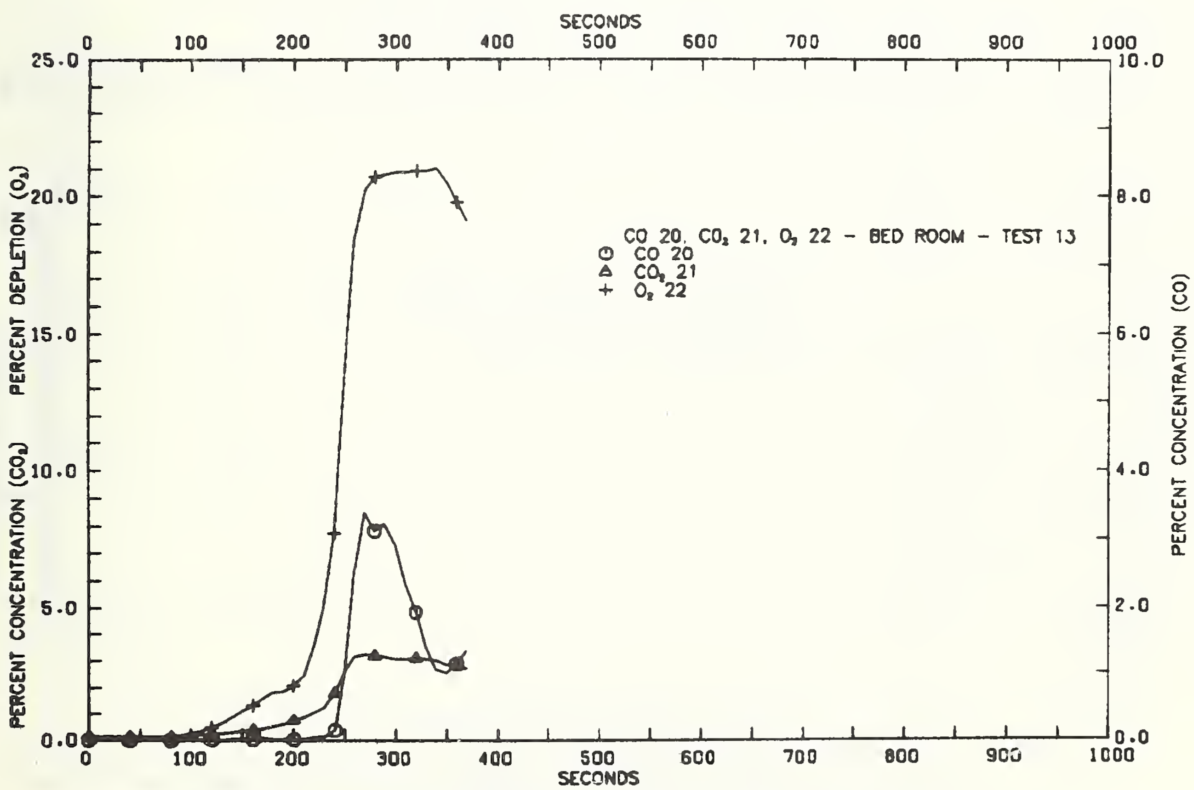
B15. CO and CO_2 (% concentration) and O_2 (% depletion) Measured in Center of Bedroom



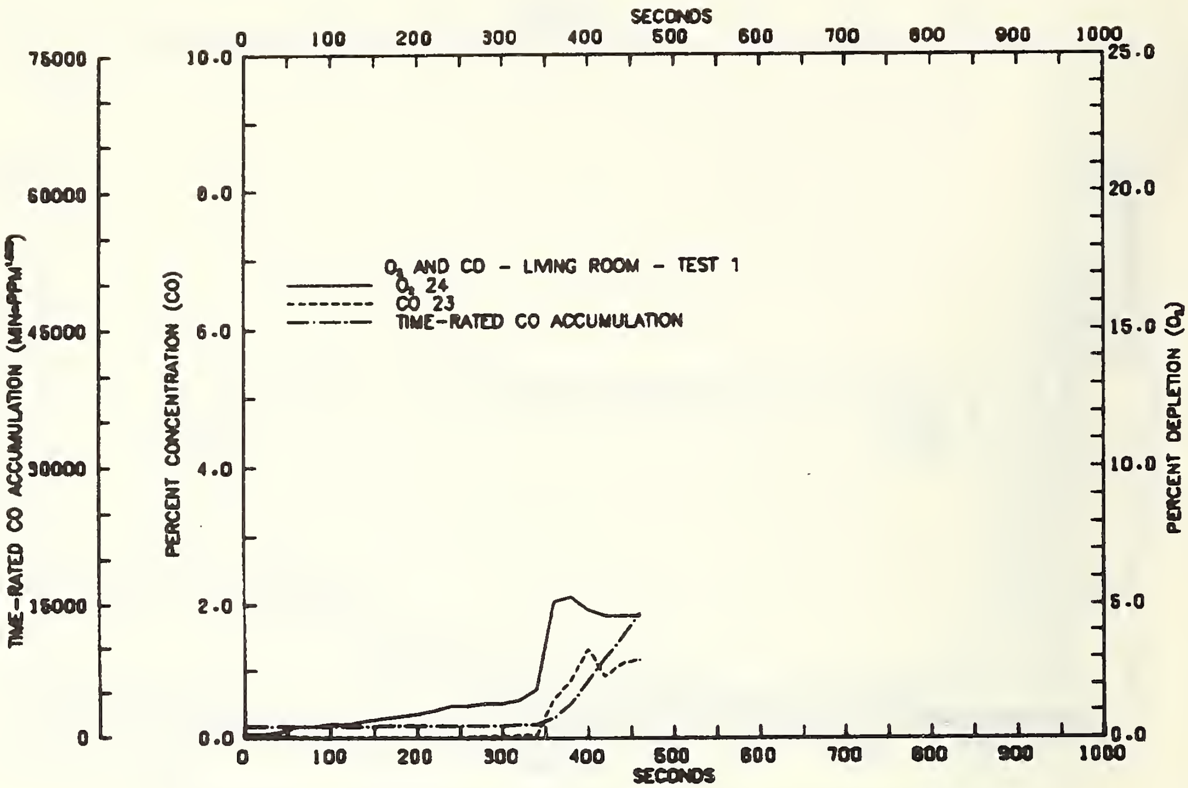
B16. CO and CO_2 (% concentration) and O_2 (% depletion) Measured in Center of Bedroom



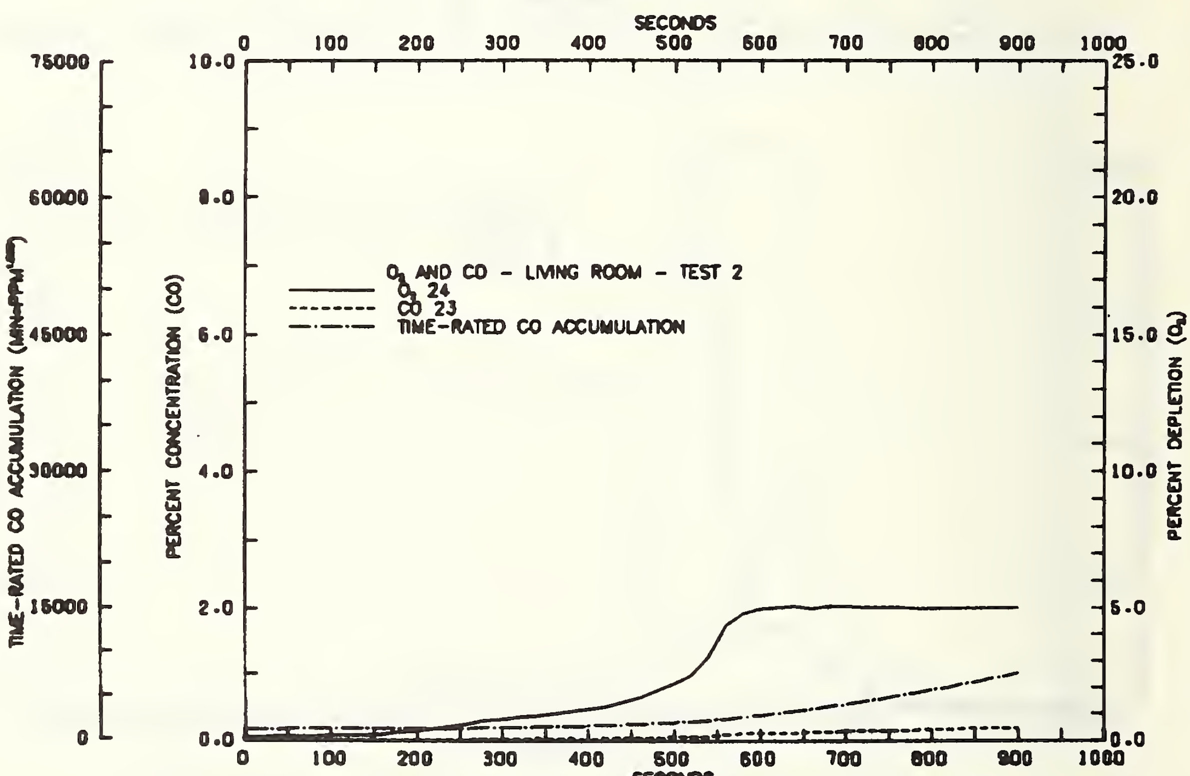
B17. CO and CO_2 (% concentration) and O_2 (% depletion) Measured in Center of Bedroom



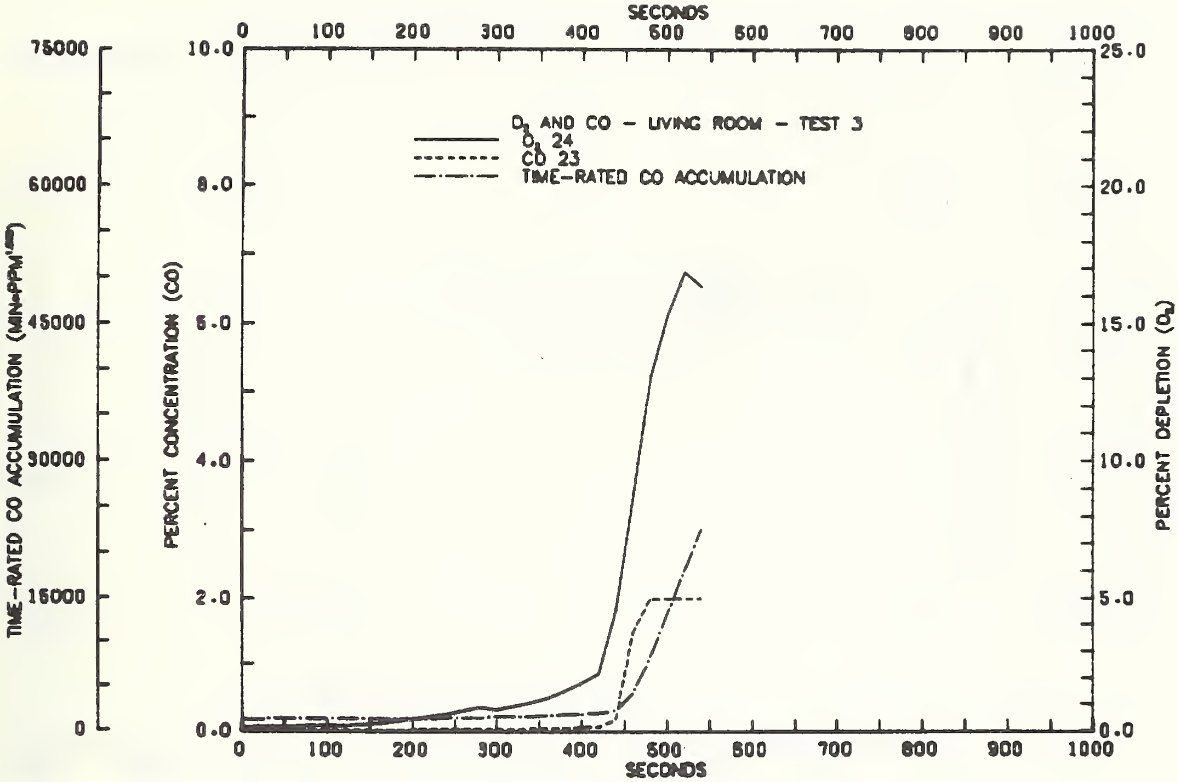
B18. CO and CO_2 (% concentration) and O_2 (% depletion) Measured in Center of Bedroom



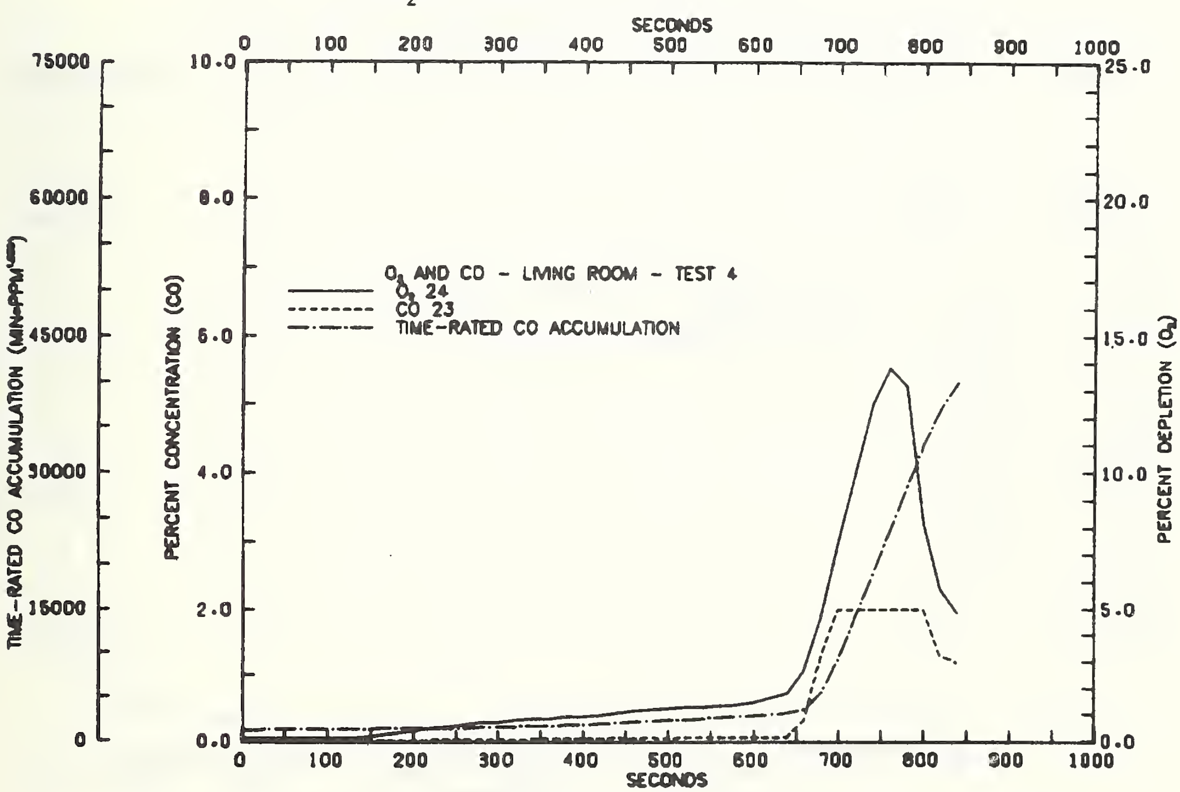
B19. CO (% concentration), Time-Rated CO Accumulation ($ppm^{1.036}$ min), and O_2 (% depletion) Measured in Center of Living Room



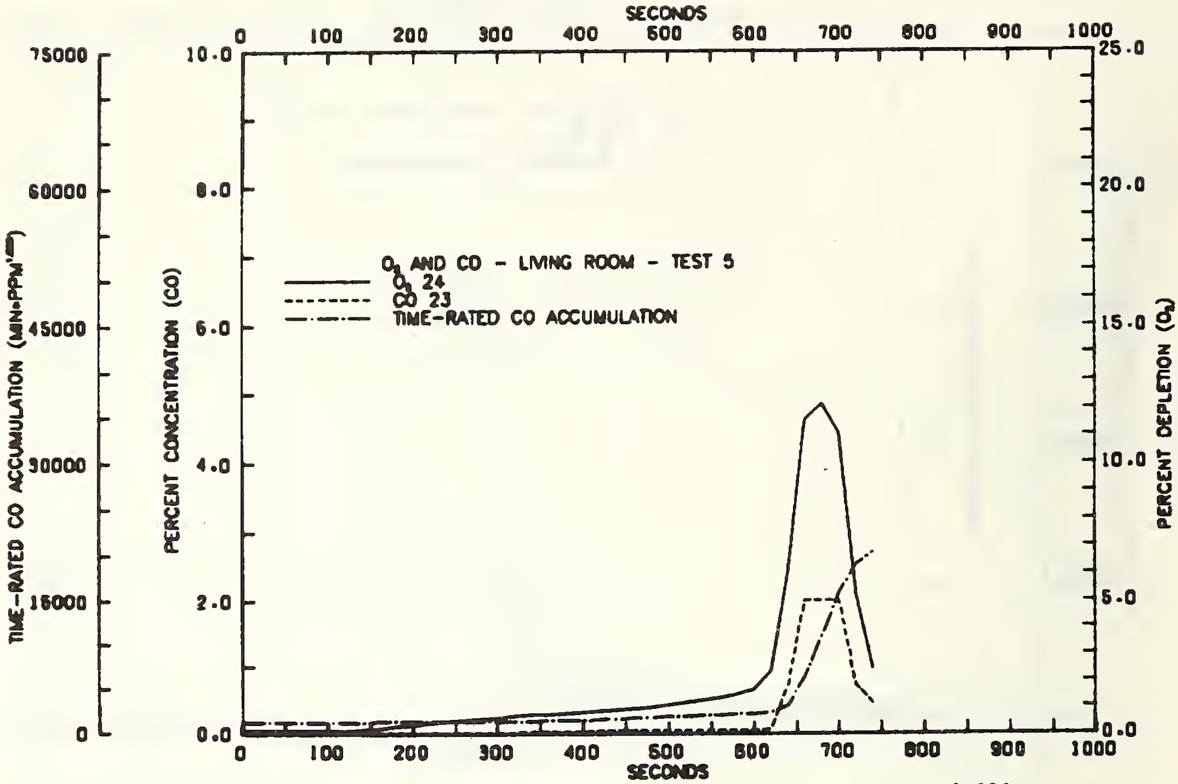
B20. CO (% concentration), Time-Rated CO Accumulation ($ppm^{1.036}$ min), and O_2 (% depletion) Measured in Center of Living Room



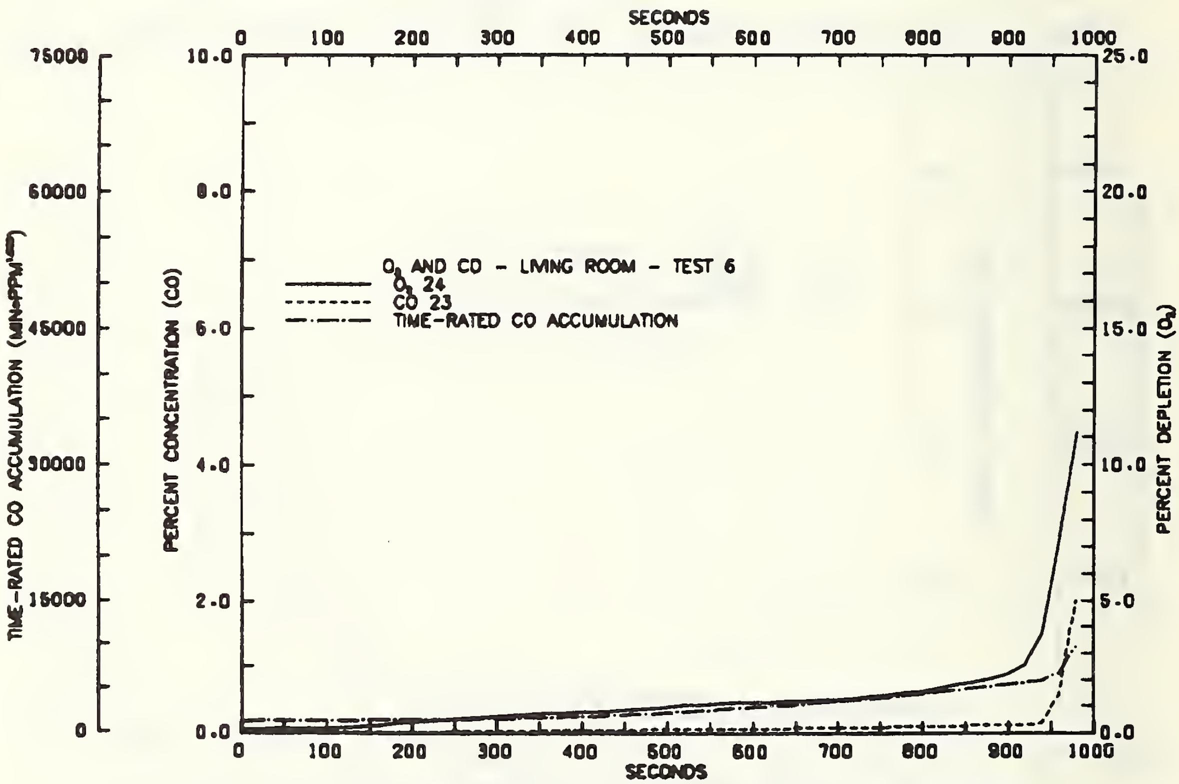
B21. CO (% concentration), Time-Rated CO Accumulation ($ppm^{1.036}$ min), and O_2 (% depletion) Measured in Center of Living Room



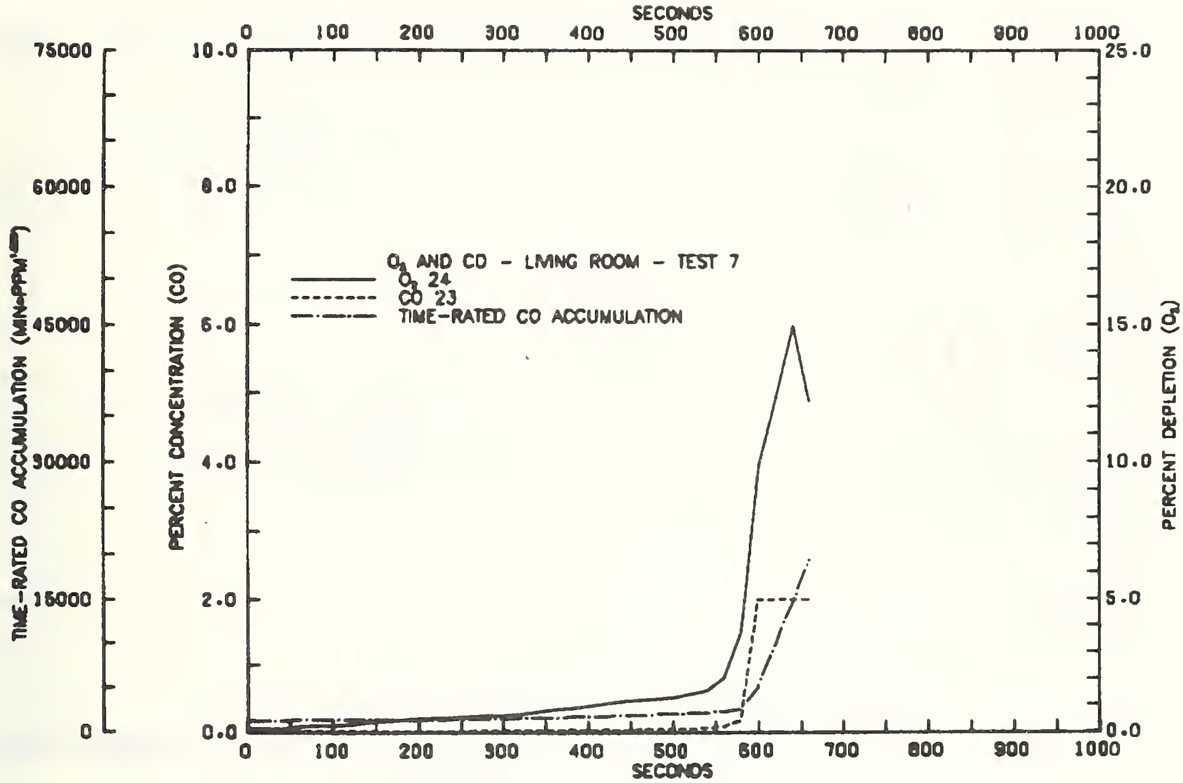
B22. CO (% concentration), Time-Rated CO Accumulation ($ppm^{1.036}$ min), and O_2 (% depletion) Measured in Center of Living Room



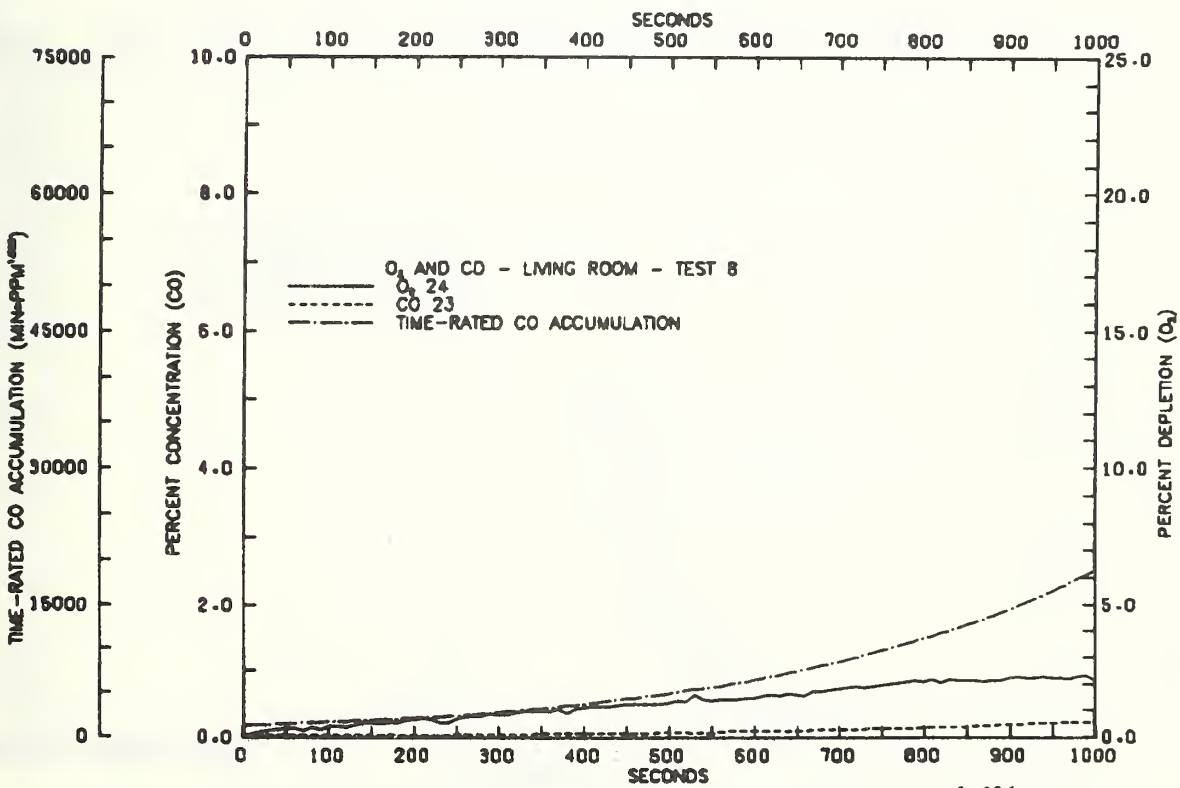
B23. CO (% concentration), Time-Rated CO Accumulation ($ppm^{1.036}$ min), and O_2 (% depletion) Measured in Center of Living Room



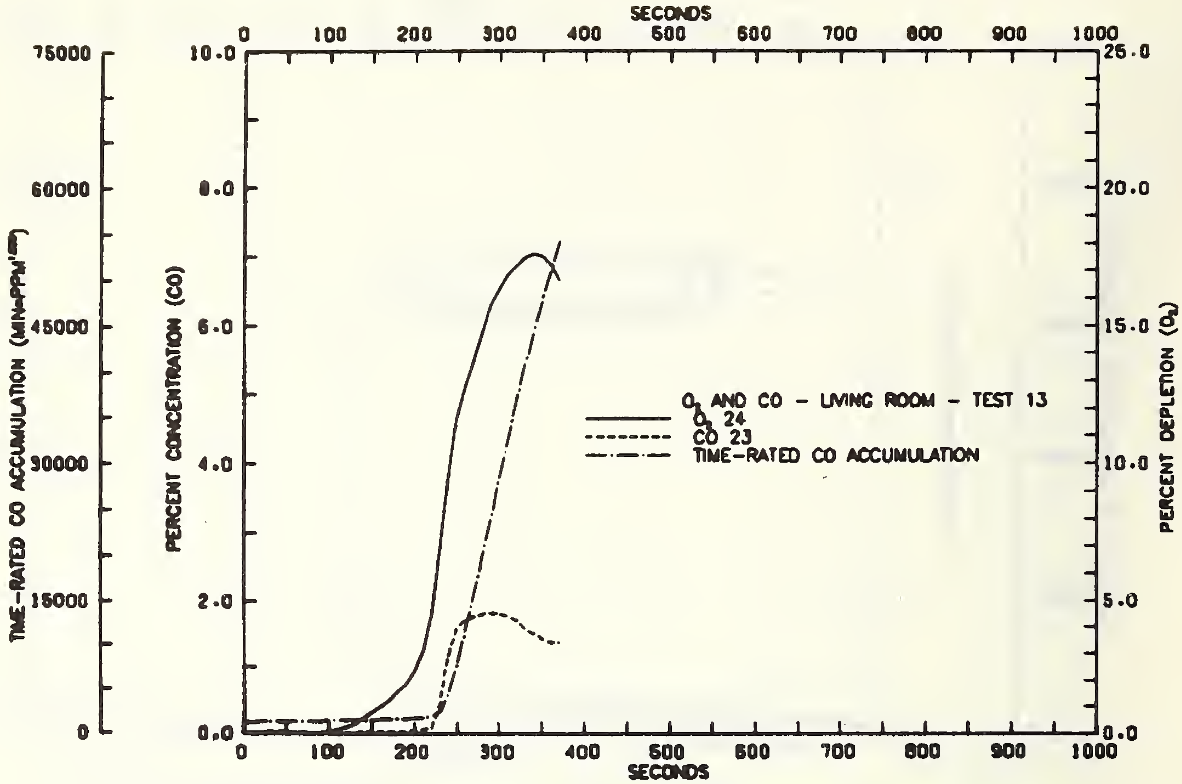
B24. CO (% concentration), Time-Rated CO Accumulation ($ppm^{1.036}$ min), and O_2 (% depletion) Measured in Center of Living Room



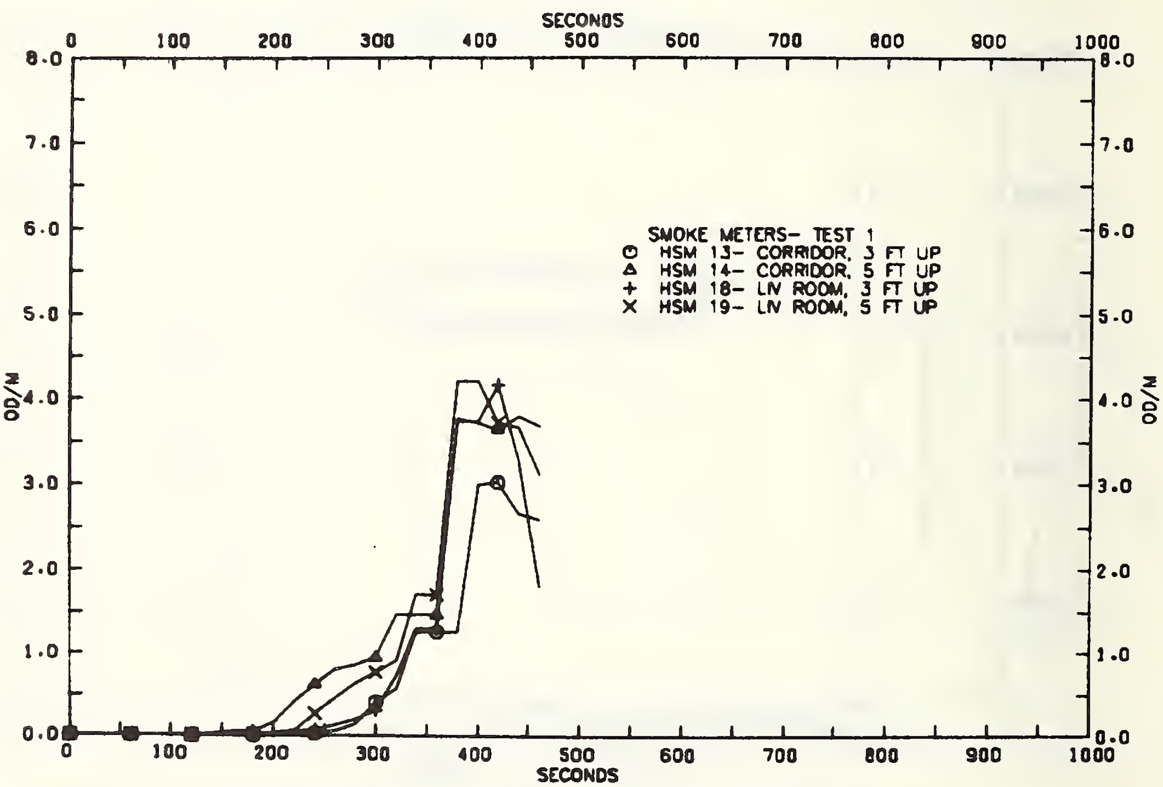
B25. CO (% concentration), Time-Rated CO Accumulation (ppm$^{1.036}$ min), and O_2 (% depletion) Measured in Center of Living Room



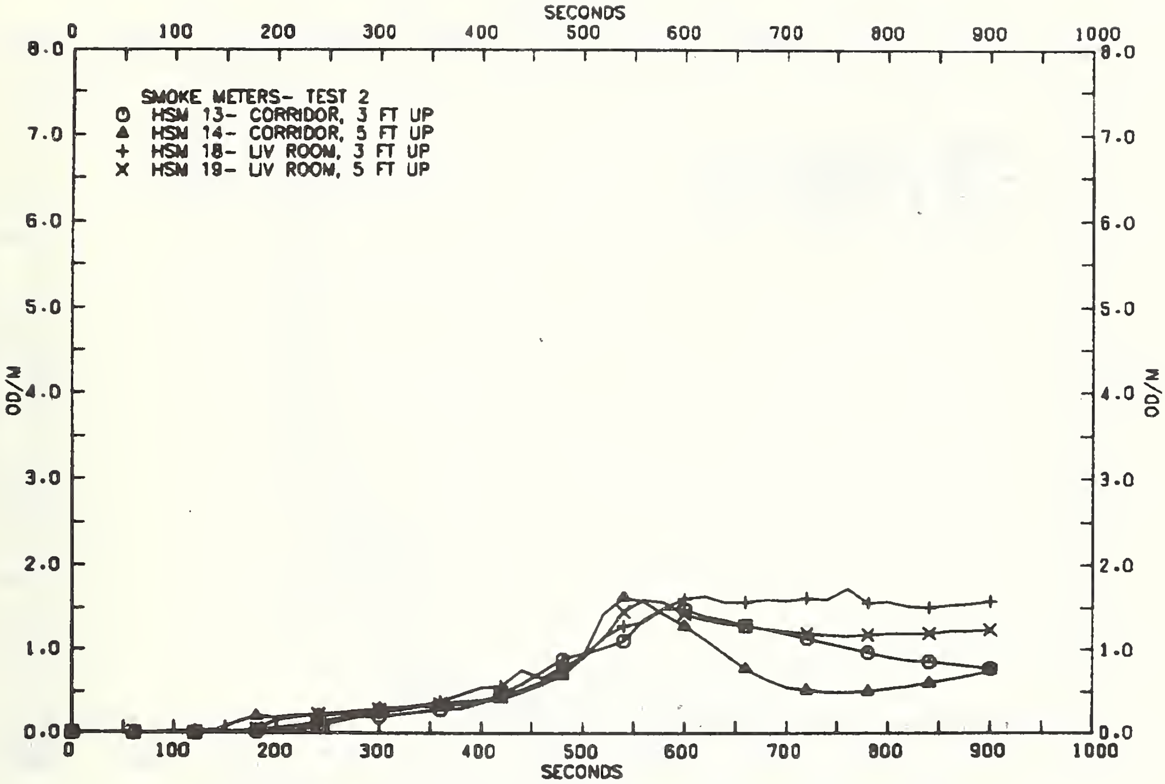
B26. CO (% concentration), Time-Rated CO Accumulation (ppm$^{1.036}$ min), and O_2 (% depletion) Measured in Center of Living Room



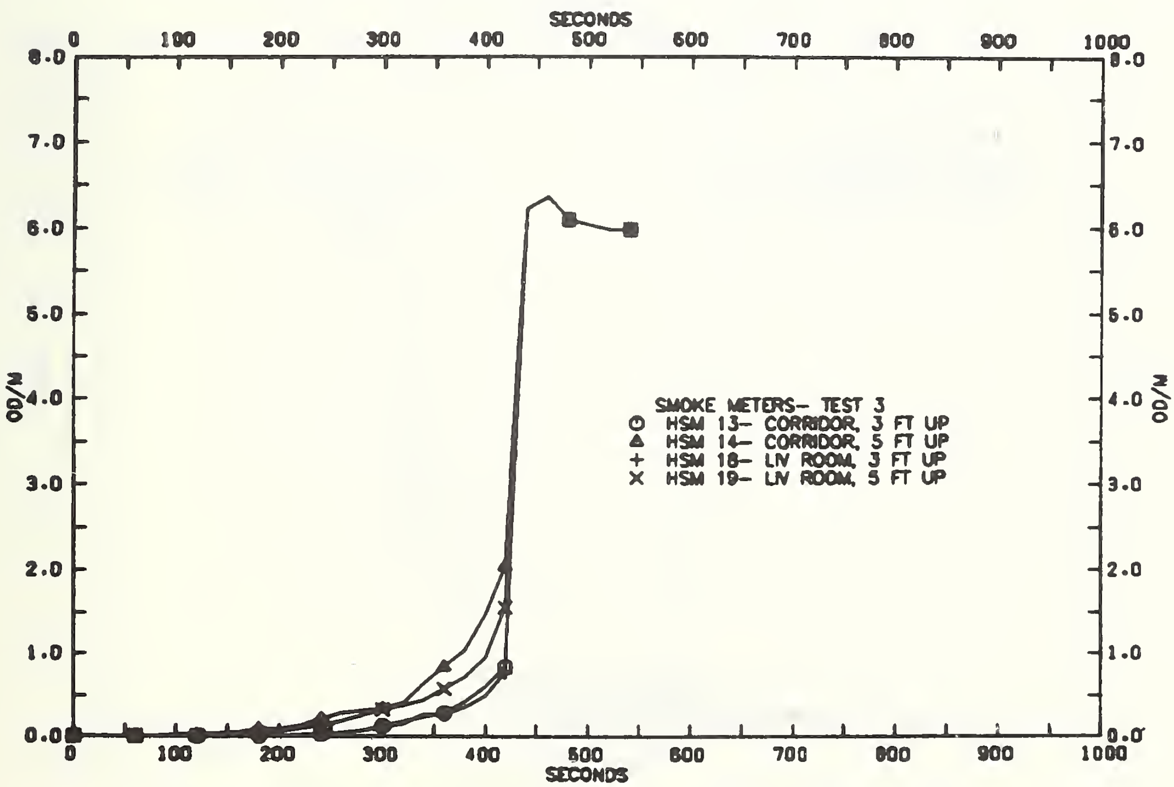
B27. CO (% concentration), Time-Rated CO Accumulation ($ppm^{1.036}$ min), and O_2 (% depletion) Measured in Center of Living Room



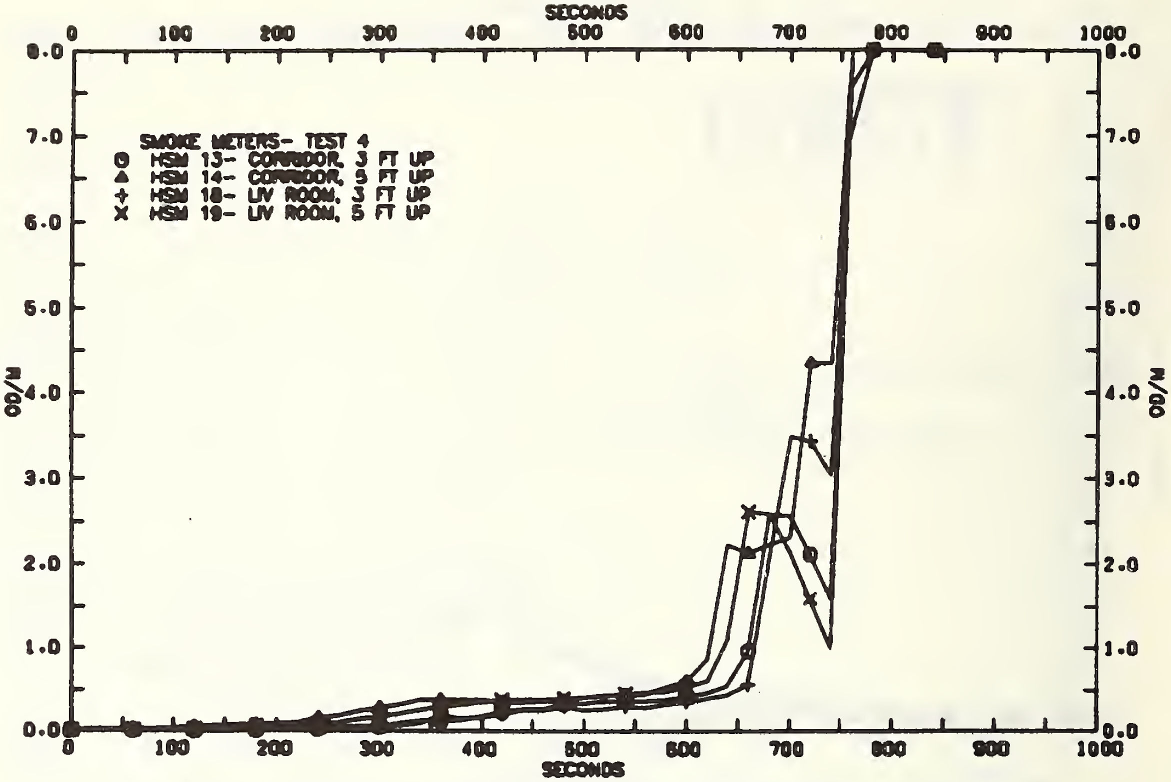
B28. Smoke Density (OD/m) Measured in the Center of the Corridor and in the Living Room



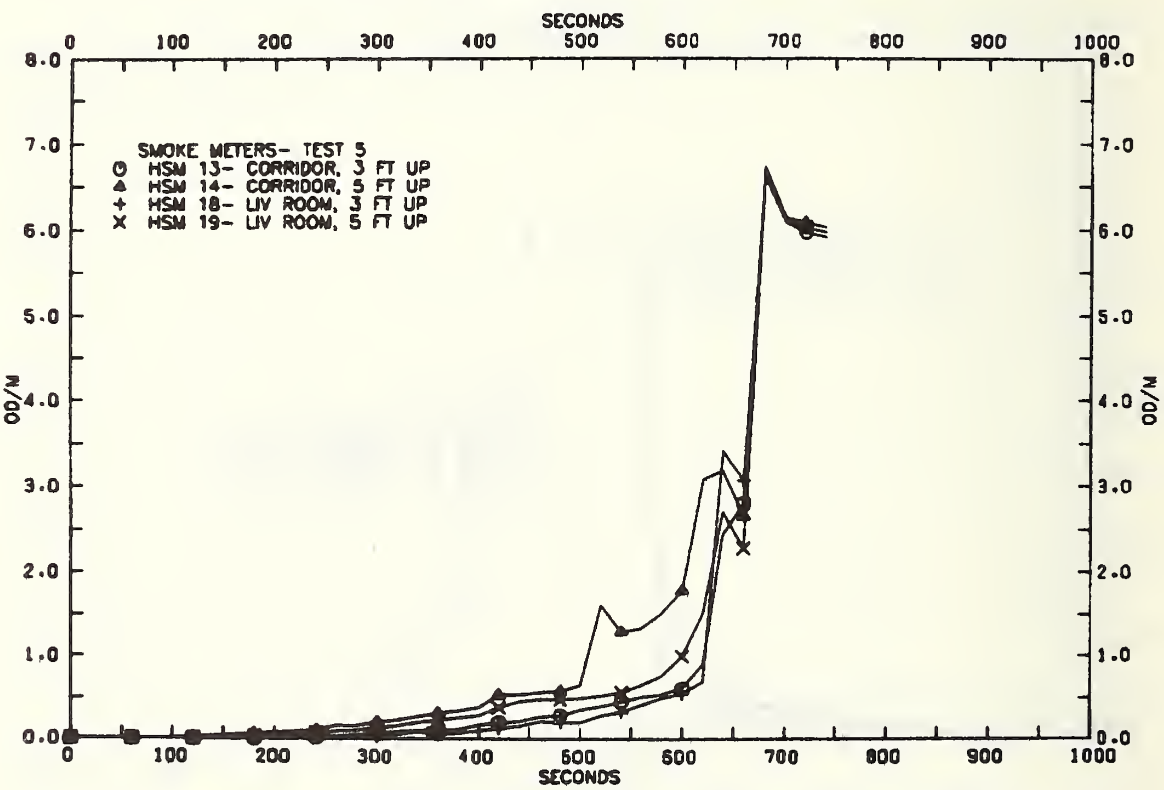
B29. Smoke Density (OD/m) Measured in the Center of the Corridor and in the Living Room



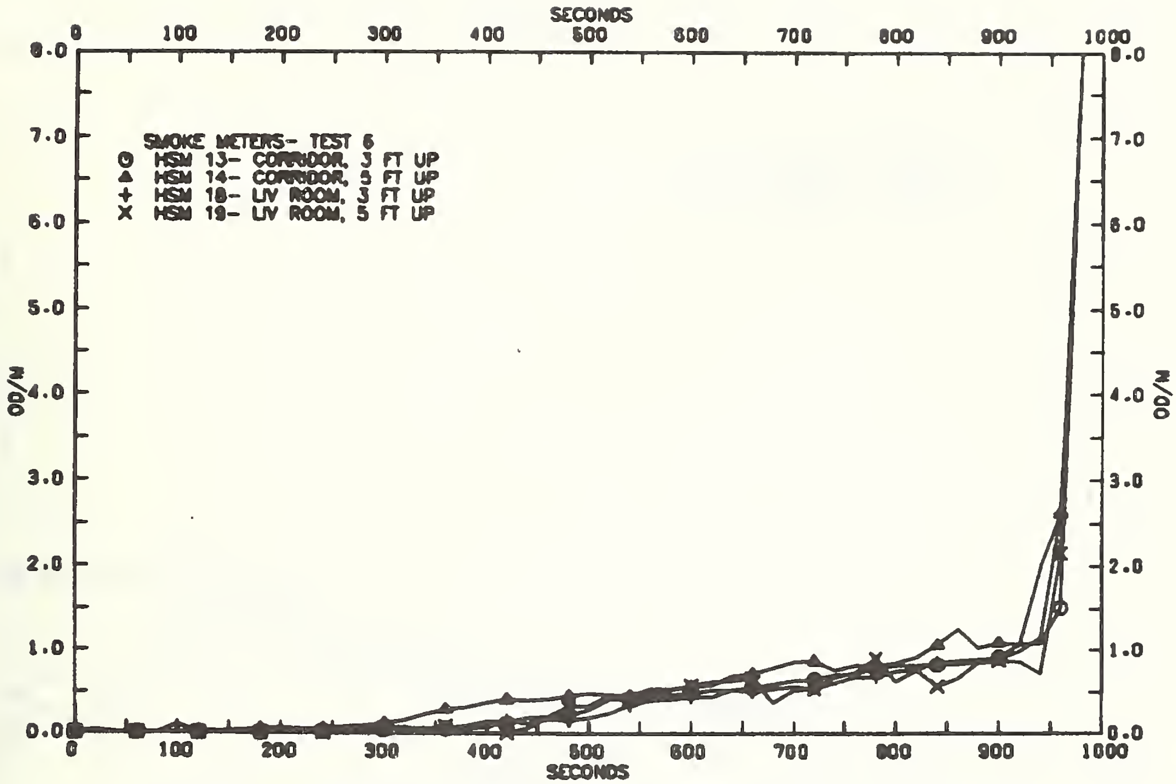
B30. Smoke Density (OD/m) Measured in the Center of the Corridor and in the Living Room



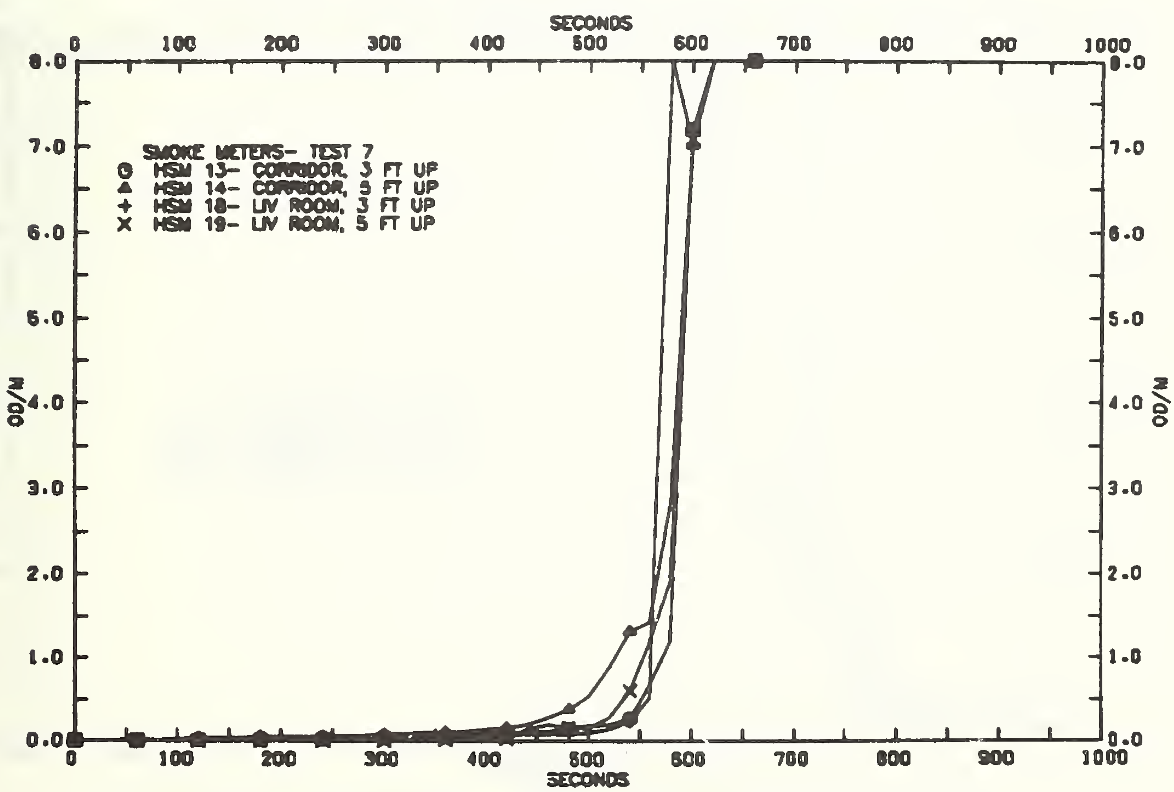
B31. Smoke Density (OD/m) Measured in the Center of the Corridor and in the Living Room



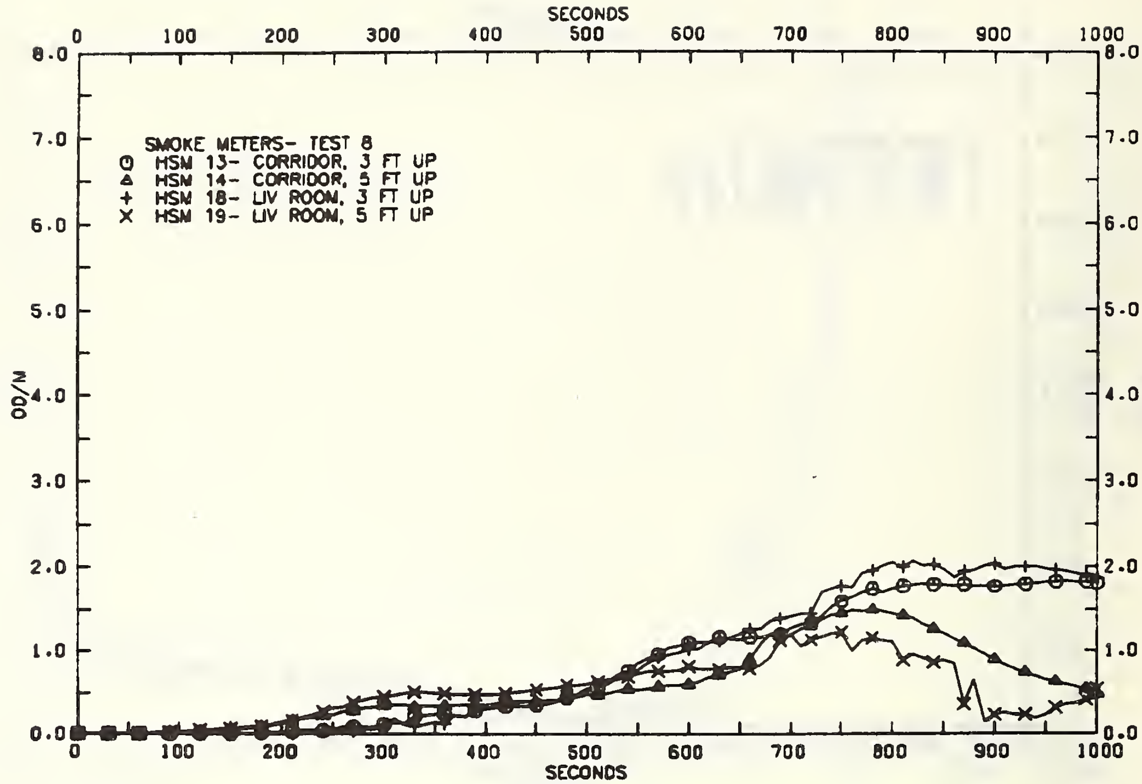
B32. Smoke Density (OD/m) Measured in the Center of the Corridor and in the Living Room



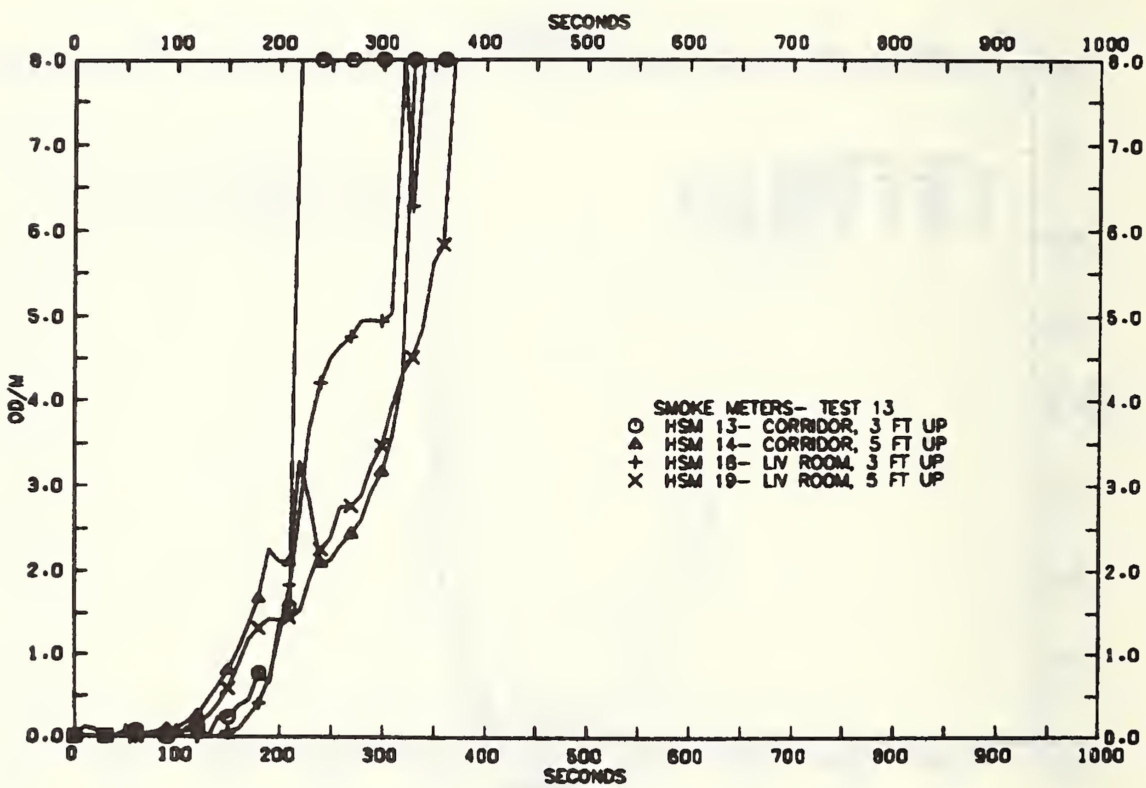
B33. Smoke Density (OD/m) Measured in the Center of the Corridor and in the Living Room



B34. Smoke Density (OD/m) Measured in the Center of the Corridor and in the Living Room



B35. Smoke Density (OD/m) Measured in the Center of the Corridor and in the Living Room



B36. Smoke Density (OD/m) Measured in the Center of the Corridor and in the Living Room

APPENDIX C

Range and Limits of Error for Instrumentation

APPENDIX C. RANGE AND LIMITS OF ERROR FOR INSTRUMENTATION

Instrument	Range	Limits of Error
Thermocouples	0 to 277°C	±2.2°C
	277 to 1260°C	±.75% of output reading
Heat Flux Transducers		
RAD 1	5.7 W/cm^2	
RAD 2	5.7 W/cm^2	
RAD 3	22.3 W/cm^2	10% of output reading
RAD 4	22.3 W/cm^2	
Gas Analyzers		
CO-20 [#30759]	10%	±2% of range
CO-23 [#32062]	2%	±5% of range
CO_2-21 [#32371]	20%	±2% of range
O_2-22	0-20.9%	±1% of reading
O_2-24	0-20.9%	±1% of reading
Smoke Meters		
HSM 13, 14, 18, 19	0-10 mv	±10% of reading
Load Cell	-225 to +225 kg	±0.1% of reading

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7. AUTHOR(S) E. K. Budnick, David P. Klein and Robert J. O'Laughlin	8. Performing Organ. Report No.
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15. SUPPLEMENTARY NOTES

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.)* A series of nine full-scale fire tests was conducted in the master bedroom of a typically constructed single-wide mobile home to (1) evaluate the effect of a variety of combinations of wall and ceiling materials on fire growth and spread and the production of smoke and toxic gases when exposed to an incidental fire, and (2) determine the relationship between the surface flame spread properties of the interior finish material as determined by the ASTM E-84 Tunnel Test and behavior of the materials under actual full-scale conditions.

The primary fire scenario selected was the exposure of the interior finish materials to an incidental fire from a burning upholstered chair in a corner in the master bedroom. Performance of the various combinations of wall and ceiling materials was evaluated on the basis of (1) whether and at what time flashover was reached, and (2) changes in the environment outside the bedroom which adversely affect life safety. Measurements included gas temperatures, irradiance, concentrations of carbon monoxide and carbon dioxide, oxygen depletion, and smoke densities.

Supplemental testing indicated that while the fire properties of the interior finish materials played a dominant role in spreading an incidental fire from a chair, the impact of the interior finish materials was less evident when the exposure fire was from the burning of a polyurethane mattress, which provided an exposure fire of greater intensity. When a bed was used instead of the chair as the initial burning item, flashover occurred in the room from involvement of the mattress and bedding materials, with no apparent contribution from the low flame spread interior finish.

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)* ASTM E-84 Tunnel Test; fire growth; fire tests; flame spread; flashover; incidental fire; interior finish; life safety; mattress; mobile home; radiant heat flux; room fires; upholstered chairs.

18. AVAILABILITY	19. SECURITY CLASS (THIS REPORT)	21. NO. OF PAGES
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