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Mobile Home Living Room Fire Studies: The Role of Interior Finish

Edward K. Budnick

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

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Interim Report

Sponsored principally by:

Division of Energy, Building Technology and Standards
Office of Policy Development and Research
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EXECUTIVE SUMMARY

Title VI of the Housing and Community Development Act of 1974 provided for the development of a Federal mandatory standard for mobile home construction and safety. Statutory responsibility for development and promulgation of such a standard was delegated to the Secretary of the Department of Housing and Urban Development (HUD). Title VI explicitly authorized HUD to undertake mobile home safety research and development in order to improve the mobile home construction and safety standards, particularly in those areas which impact personal injuries and deaths and property damage in mobile homes.

A key area identified as a potential problem in mobile homes was fire safety. Various statistical sources indicated that while the incidence rate was approximately the same, the injury and life hazard and the extent of property damage were three to five times greater than that of conventional residences [1-11][1].

Most residential fires are initially localized and small in size, but the design characteristics inherent in mobile homes such as fire load density, room geometry, and combustible finishes may provide the potential for rapid fire development, resulting in higher temperatures, smoke, and toxic gas generation in a relatively short period of time. While various design and structural features appear to be possible contributors to this problem, interior finish materials used on walls and ceilings have been cited as one of the most important contributors to fire spread in mobile homes. No organized research studies have been performed to evaluate this thesis. Therefore, in 1975, within the statutory power under Title VI, the Office of Policy Development and Research of HUD requested that the Center for Fire Research at NBS expand and accelerate the activities of an ongoing research project. The purpose of this ongoing project was to provide experimental data on the potential growth and spread of fire in mobile homes.

The Federal Mobile Home Construction and Safety Standard was promulgated, effective June 15, 1976. This mandatory standard adopted many of the provisions contained in the existing Standard for Mobile Homes (NFPA 501B, ANSI A119.1), a voluntary consensus standard previously utilized by many mobile home manufacturers and state and local regulatory officials. Included in the provisions adopted from NFPA 501B was a surface flame spread criterion for interior finish materials based on the ASTM E-84 Tunnel Test Method. (The ASTM E-84 test method is a nationally recognized method for evaluating the surface flame spread characteristics of interior wall and ceiling materials.) In addition, results from initial segments of the Mobile Home Fire Safety Project were evaluated and criteria based on this evaluation were incorporated into the Standard.

Work has continued at NBS in the area of fire safety in mobile homes since promulgation of the standard. This report includes the results and analysis from a segment of the work completed to date. This work encompassed sixteen full-scale fire tests conducted in a living room under a controlled set of conditions, in which various combinations of wall and ceiling interior finish materials were exposed to small incidental fires represented by upholstered chairs and wood cribs. These fires were conducted in a typical single-wide mobile home constructed in accordance with the NFPA 501B Standard for Mobile Homes in effect in 1972 and which had comparable structural, material and spatial characteristics to mobile homes presently being constructed to comply with the current Federal standard. Analyses of these tests were directed at evaluating the extent of the potential hazard to life and property damage occurring in each of the sixteen tests.

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

The criteria used to evaluate the hazard to life were selected based on available reference literature, and included temperature, carbon monoxide, and oxygen deficiency. The criteria used to evaluate the extent of property damage were the rate of fire growth and the attainment of flashover in the living room which was the room of fire origin. Flashover is defined for this report as a fire phenomenon in which the upper level fire gases and ceiling radiate sufficient energy to the lower half of the room to cause ignition and rapid, complete fire involvement of all combustible materials.

Standardized laboratory fire tests were also conducted to characterize some of the more critical fire properties of the various interior finish materials utilized in the full-scale testing. Correlations between behavior under full-scale conditions and comparative ratings or measurements in small-scale or standard laboratory tests have not been fully established. Therefore, an evaluation was made to determine the extent to which the results of the presently required ASTM E-84 Tunnel Test can characterize the performance of these materials when installed on the walls and ceiling in a full-scale mobile home fire test.

Analysis of test results indicate similarities to previously established experimental findings regarding key factors in the fire buildup process in compartments. Two significant factors which qualitatively identify these similarities are:

(1) Total room involvement occurred primarily as a result of radiative heat transfer from the heated gas layer in the upper part of the room to the combustibles in the lower part of the room. Lateral heat transfer and direct flame contact were not sufficient to involve other combustibles.

(2) Variations in fire buildup occurred, depending on the fire properties of the interior finish materials. These variations directly affected the rate of fire growth and spread, the severity of the fire, and the resulting effects on life safety.

MOBILE HOME LIVING ROOM FIRE STUDIES: THE ROLE OF INTERIOR FINISH[2]

Edward K. Budnick

Abstract

A series of sixteen full-scale fire tests was conducted in the living room of a typically constructed single-wide mobile home. These tests were designed (1) to 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) to determine the relationship between the surface flame spread properties of the interior finish materials as determined by the ASTM E-84 Tunnel Test and the behavior of the materials as installed under actual full-scale conditions.

The test procedure was based on a fire scenario in which the interior wall surface was exposed to an incidental fire from a standardized 6.4 kg (14 lb) wood crib or a 16 kg (35 lb) upholstered chair positioned in a corner in the living room.

Performance of the various combinations of wall and ceiling materials was evaluated based on (1) the rate of fire buildup and extent of living room involvement, and (2) changes in the environment in the corridor and bedroom areas which may adversely affect the life safety of the occupants. Measurements utilized in the evaluation of changes in the environment due to fire growth and spread included gas temperatures, irradiance, concentrations of carbon monoxide, carbon dioxide and oxygen, and smoke densities. Under this set of conditions it was found that the fire properties of the interior finish materials directly affected the rate of fire growth and spread, the severity of the fire, and the resulting effects on life safety.

Key Words: ASTM E-84 Tunnel Test; carbon dioxide; carbon monoxide; fire growth; fire tests; flame spread; flashover; interior finishes; life safety; mobile homes; radiant heat flux; room fires.

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1. INTRODUCTION

This report provides 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 testing in the kitchen, bedroom and corridor areas of a single-wide mobile home. Recommendations will be included in the final report.

1.1. Background

A major research project is ongoing at the National Bureau of Standards to examine some of the characteristics which may affect fire growth and spread in a single-wide mobile home. An area of significant emphasis in this project is the conduct of full-scale fire tests to provide experimental data on fire growth and spread. As part of this full-scale testing, tests were conducted to characterize the fire growth potential in a living room area 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 sixteen full-scale experimental fire tests conducted in the living room area of a 3.7 x 18.3 m (12 x 60 ft) single-wide mobile home constructed in accordance with the NFPA 501B, 1972 Edition, Standard for Mobile Homes. The structural, material and spatial characteristics of the mobile home were comparable to those in mobile homes constructed to the current Federal standard.

Examination of fire loss statistics [1] indicates that most residential fires are initially small in character, do not spread beyond the room of fire origin, and by themselves do not pose a serious problem. It appears, however, that the nature and quantity of combustibles around the fire and the geometry of the enclosure are among principle factors having a significant influence on the growth and spread of this incidental fire. Past research has indicated that combustible compartment linings can contribute to the spread of an unwanted fire. Therefore, the interior finish materials on the walls and ceiling in a typical mobile home may provide surfaces for the possible spread of a small fire, as well as increased production of heat, smoke and potentially toxic gases. The proper selection of the finish materials, based on measured fire properties, and control of the location of installation of interior finish materials can potentially provide an increased level of fire safety to the occupants and a reduced fire severity from an incidental fire in a mobile home.

1.2. Review of Previous Research

A great deal of work has been done to provide information regarding the dynamics of the fire buildup process in enclosures. Much of this work has been directed toward the conduct of full-scale room tests to provide experimental data on fire development, and in particular, the growth and spread of small incidental fires.

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. Some of the more significant environmental factors include room geometry, thermal properties of materials, ventilation, location and burning characteristics of the initial burning item, and the proximity and arrangement of other combustibles including interior finish materials and furnishings.

Although sophisticated computer programs are under development to predict fire growth, at present there is no complete quantitative methodology for determining the growth of fire in terms of all of the above key factors. However, during the interim period a considerable amount of information has been developed which can provide an understanding of key mechanisms affecting fire growth and spread in a typically constructed room.

For instance, Waterman [12] identified the heating of combustibles by radiation as a key mechanism for flashover in a room fire. He further indicated that the radiation was primarily obtained from the ceiling and upper walls. Evidence of the significance of this phenomenon has subsequently been reported by Fang [13] and Quintiere [14] at NBS, and by Croce, Emmons and Modak based on work conducted at Factory Mutual Research Corporation (FMRC) [15-17].

The FMRC study was based on the measurements taken in three full-scale bedroom fires. They reported that the radiation heat transfer from the heated smoke layer beneath the ceiling contributed significantly to room flashover. Fang [13] reported that radiative energy from the heated upper room gas layer promoted flashover. He also indicated that full involvement of the room occurred when temperatures in the upper part of the room ranged from 450 to 650°C. (Flashover is defined as the rapid, complete fire involvement of all combustible materials resulting from the energy radiated from the high temperature of the fire gases, and upper wall and ceiling surfaces.)

Two key factors which seem to influence the attainment of temperatures in this range in the upper room are (1) the duration of burning and the maximum burn rate of the initial burning item, and (2) the contribution of the other combustibles which become involved. It has been reported that in one series of experiments in a 3.64 x 3.64 m (12 x 12 ft) enclosure 2.43 m (8 ft) high, a maximum burning rate of 40 g/s was reached or exceeded before room flashover occurred [18]. While this occurred under one set of controlled conditions it may approximate the necessary rate of burning for room flashover for fires in similar enclosures.

The peak burn rate of incidental items of furniture generally do not approach 40 g/s. Results of work conducted by Gross and Fang [19] indicated that a peak burn rate in excess of 15 g/s did not occur for a variety of low intensity fires from the burning of incidental combustible items such as waste containers. Although there do exist items of furniture which alone could burn at a peak rate of 40 g/s or more, both Fang [13] at NBS and Castino, et al. [20] at Underwriters' Laboratories (U.L.) conducted full-scale fire tests in enclosures in which exposure of various types of combustible interior finish materials to small combustible items with peak burning rates from 6 to 10 g/s resulted in room flashover. The additional energy beyond that produced from the burning combustible item necessary to flash over the enclosure was attributed to the involvement of the interior finish materials.

Fang [21], in subsequent work, indicated that fire buildup from the inter-item spread of fire could occur only when combustibles are located within a prescribed hot air region surrounding the burning item. For incidental items of moderate burning rates, adjacent combustibles must be located within 0.15 m (6 in) of the burning item to result in inter-item fire spread.

Bruce [22] indicated, based on six tests conducted at the Forest Products Laboratory, that interior finish materials did not affect fire development. However, in that series of tests, the ignition source, along with a considerable amount of fuel, was placed in the center of the room at a distance of 0.47 m (18.5 in) from the wall. The significance of the distance between other combustibles, including interior finish materials, and the burning item or items has already been identified as a critical factor in fire development. Involvement of the wall materials is not likely during initial fire buildup when an incidental fire occurs at distances on the order of 0.5 m (19 in) from the wall.

The involvement of interior finish materials in fire development has been generally considered as a significant factor in the spread of room fires. Many building codes, including the Federal Mobile Home Construction and Safety

Standard, have included criteria to regulate the use of interior finish materials on the walls and ceilings. The test upon which the primary criterion is based in most of these codes is the ASTM E-84 Tunnel Test. However, it is not clear to what extent the conditions and test procedure in the tunnel rationally simulate the environment in an enclosure in which an incidental fire has occurred [23].

Lee and Parker [24] in investigating the potential development of fire safety criteria for naval operations (shipboard fire safety) expressed concern for the difficulties which may arise when assessing fire hazards based "solely on laboratory tests." They indicated the need to better understand the fluid dynamics, thermal, physical and chemical factors influencing fire buildup; they also reported the need for an improved interpretation, understanding, and application of existing laboratory test methods and the development of better ones which provide information that correlates with the key factors in room fire buildup.

As previously stated, work is being done to develop mathematically based models to predict fire buildup depending on the factors such as room geometry, interior finish, furnishings, and ventilation. While these models would potentially identify the key properties of combustibles which could be measured by laboratory testing, their availability for use in analyzing fire hazards in varying occupancies is not anticipated for some time. In the meantime, additional experimental data must be collected to provide insight into the potential control of fire growth in residential occupancies such as mobile homes in order to limit damage and prevent deaths.

1.3. Objectives

The objectives of this particular segment of the project were:

(1) to provide quantitative technical data regarding the fire buildup process resulting from an incidental fire in the living room of a typically designed single-wide mobile home, primarily as a function of interior finish; 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 the living room of a mobile home.

1.4. Approach

A large 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 was selected; a fire scenario is a postulated probable occurrent of ignition, the subsequent chain of events leading to a fire loss or injury, and the reasonable relationship of that occurrence to the nature of the occupancy.

A key in selecting the scenario to evaluate interior finish materials is the size of the initial burning item and its position in the room. The size of the initial burning item can be so selected 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 can be too large, thus masking the effects of the interior finish. Both of these extremes have appeared in some tests and can result in inconclusive information, indicating that the interior finish materials are incidental to fire development and should not be considered in evaluating fire hazards.

But, 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 room. For this case the interior finish materials on the walls and ceiling were studied to determine if they significantly influence the growth and spread of the fire, and the resulting severity. Formulation of this scenario was based on statistical evidence that most fires occurring in residental occupancies are initially small in size; and, in a high number of mobile home fires the spread of fire from the initial burning item occurs via the wall and ceiling lining [1,3,4,5,6,7,25].

The results of the full-scale tests were examined from two 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 room of origin, 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. Further assessments included examination of smoke generation and changes in concentrations of carbon monoxide, carbon dioxide and oxygen resulting from the fire buildup.

Secondly, changes in the environment in adjacent areas outside the room of origin as a result of fire buildup were examined. This effect of fire buildup on conditions in the corridor at the back exit door and in a remote location bedroom was based on changes in the levels of temperature, smoke density, carbon monoxide concentrations and oxygen depletion.

Laboratory tests conducted on the materials included the standard tests: ASTM E-84 Tunnel Test, ASTM E-162 Radiant Panel Test, NFPA 258 Smoke Density Chamber Test, and experimental tests: NBS ease of ignition test, and NBS rate of heat release calorimeter. 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. In addition, the test data derived from the other laboratory tests is provided for additional edification.

2. EXPERIMENTAL PROGRAM

2.1. Test Facility

The test facility was a conventional single-wide mobile home approximately 3.7 x 18.3 m (12 x 60 ft) with a living/dining room, kitchen, bathroom, and three bedrooms (reference figures 1 and 2). The living/dining room, which was approximately 3.5 m (11 ft 4 in) wide, 7.5 m (24 ft 5 in) long, and had a ceiling height of 2.1 m (7 ft 0 in) resulted in a net usable floor area of 22.7 m^2 (244 sq. ft). The initial burning item was positioned in the northwest corner of the living room for each of the sixteen tests. A ceiling-high partition, constructed of asbestos cement board, was placed in front of the kitchen area to prevent damage from the test fires. The partition was covered with whichever wall material was being tested. During all tests, the exterior doors and windows were closed, but not sealed, to provide an initial quiescent or calm air condition. The doors leading into bedrooms No. 2 and No. 3 and the bathroom were also closed. The doorway to bedroom No. 1 remained open.

2.2. Living Room Construction

The construction of the living room was typical of mobile homes. The exterior wall system was composed of nominal 51 mm x 76 mm (2 x 3 in) hemlock studs, 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 glass fiber insulation contained a paper vapor barrier adjacent to the back side of the interior wall finish material.

Interior partitions 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 was constructed of painted aluminum exterior sheeting mechanically fastened to a system of wood bow-string trusses, 406 mm (16 in) on centers, insulated by 76 mm (3 in) of glass fiber above a polyethylene vapor barrier. The floor covering was 3.3 mm (0.13 in) thick vinyl asbestos taken from a continuous 3.7 m (12 ft) wide roll, mechanically fastened to the 19 mm thick (0.75 in) particle board subfloor by staples. The living room was constructed with six windows, 660 x 762 mm each (26 x 30 in) in size. Two each were located in the west, north, and east walls. Figure 2 provides a detailed plan view of the mobile home.

The various interior finish materials used for wall and ceiling construction in these tests were selected to provide a range of materials which have different surface flame spread properties. The interior finish materials were mechanically fastened 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.

2.3. Living Room Furnishings

All furnishings used in the living room were of the type commonly found in a mobile home. For thirteen of the tests, the only furniture other than the ignition source was a sofa constructed of a wood frame, cushioning of polyurethane foam and cotton, and covered with a rayon fabric. The sofa was placed against the east wall, approximately 2.4 m (8 ft) from the corner where the initial burning item was located. In these tests the living room was considered to be sparsely furnished. This procedure was based on the premise that it is unnecessary to include other combustible furnishings when assessing the influence of the interior finish material on initial fire growth when exposed to an incidental fire from a single burning item - the primary objective.

In order to examine the reliability of this premise, a higher fuel loading was selected for some of the tests. In these tests which were considered to be moderately furnished, the additional items of furniture used were a matching upholstered chair constructed of the same materials as the sofa, two end tables and a coffee table constructed of pine and particle board, a kitchen table constructed of vinyl-covered polyurethane foam with steel frames and legs (see figure 3 for diagrams of the sparsely and moderately furnished rooms). In fourteen tests there were curtains, made of a polyester fabric, over the six windows in the living room. Due to the nature of tests 15 and 16 the curtains were not installed. As indicated by figure 3b, the furnishings in the moderately furnished tests were located throughout the living/dining room area, providing an approximate fuel loading of 4.9 kg/m^2 ($\sim$ 1 lb/sq ft). Table 1 lists the individual items of furniture providing the moderate fuel loading.

2.4. Initial Burning Items

For eleven of the tests, identically constructed crossed-piled wood cribs were utilized as the initial burning item. The weight of the wood crib was approximately 6.4 kg (14 lb) with overall dimensions of 356 x 356 mm, 300 mm high (14 x 14 x 12 in). The wood crib was constructed of 28 pieces of 51 x 51 x 356 mm (2 x 2 x 14 in) nominal hemlock arranged in six 4-stick layers and two 2-stick layers, and conditioned at 70°F and 50% relative humidity until the moisture content and the resulting change in weight stablized.

The size and weight of the wood crib was selected based on experimental work conducted at the National Bureau of Standards to simulate a fire due to ignition of a small piece of incidental furture [20]. An incidental item of furniture is described as an item of furniture which if ignited and burning apart from other combustibles will not result in room flashover and will not pose a serious haaard to life safety. Test results based on this previous experimental work indicate that the essential characteristics of a typical incidental fire from a small piece of furniture such as temperature and heat flux levels, burning time, and the size and shape of the flame can be duplicated by the burning of a standardized 6.4 kg (14 lb) wood crib.

In tests 10,11,12,14 and 16, the initial burning item was a medium-sized upholstered chair. The chairs, weighing 16 kg (35 lbs), were alike in construction and produced by the same manufacturer; constructed of wood, polyurethane foam and cotton materials and covered by rayon fabric. The chairs were stored in a nearby test building where temperature and humidity are nearly constant at 75 ± 5°F and 35 ± 10% RH until the weight of the chair stabilized.

2.5. Interior Finish Materials

Table 2 lists all of the interior finish 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 3 identifies the materials used in each of the 16 tests.

2.5.1. Wall Materials

Three basic types of wall materials were tested: untreated prefinished lauan plywood; fire retardant treated lauan plywood; and printed paper finished gypsum board.

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

Lauan plywood specimens treated for fire retardance by two separate methods were tested. One method of treatment involved the application of two coats of a clear intumescent type fire retardant coating, covered by a clear varnish overcoating, to 4 mm thick prefinished lauan plywood. The fire retardant coating was commercially available and was applied in accordance with the manufacturer's instructions. Test 4 and 8 were conducted with walls constructed of this material. The other type of fire retardant treatment utilized was a chemically treated vinyl film surface, 0.38-0.46 mm (0.015-0.018 in) in thickness, glued to unfinished 4 mm thick lauan plywood. This material was tested in tests 5 and 7. While the material was experimental, it potentially could be made commercially available.

The printed paper faced gypsum board was 8 mm (5/16 in) thick and had a simulated wood grain surface; this material was also commercially available.

2.5.2. Ceiling Materials

Two types of ceiling materials were used in construction of the various interiors tested in the mobile home. One type was 13 mm (1/2 in) thick prefinished low density cellulosic fiberboard acoustical ceiling panels. The panels were 0.6 x 1.2 m (2 x 4 ft) in size and were available commercially. The other material was 8 mm (5/16 in) thick gypsum board with a prefinished surface. This material was obtained in 1.2 x 3.7 m (4 x 12 ft) sheets and is also commercially available.

2.5.3. Noncontributing Materials

Two of the sixteen tests (tests 15 and 16) were conducted to collect experimental data necessary to identify some of the key fire properties of the two types of initial burning items, e.g., the 6.4 kg (14 lbs) wood crib and the 16 kg (35 lb) upholstered chair. In these two tests, the walls and ceiling were constructed of 13 mm (1/2 in) thick sheets of marine board (hereafter referred to as calcium silicate-$CaSiO_3$), installed over 13 mm (1/2 in) gypsum board.

2.6. Full-Scale Test Criteria

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. Therfore, 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 sofa, 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 [26]. Obviously, not until epidemiologic data from humans are available to supplement laboratory animal data and experimental data collection under physical fire testing can a true assessment of the hazards be made.

Nothwithstanding 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 concentrations [26]. 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 temperature, 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 living room. 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 bedrooms 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 which is the principal path of egress.

Thresholds for limiting 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 analysis there is sufficient information available to tentatively establish levels at which adverse effects being to occur. Therefore, limiting conditions for life safety have been selected based on literature references available to the author. In selecting these thresholds, no consideration has been given to either the synergistic effect 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 then 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 threholds 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.

2.6.1. Carbon Monoxide

Carbon monoxide (CO), while not the only toxic combustion gas, is produced in such large quantitites in most fires that it is considered an important life safety factor [27]. 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 [17,28-34]. In addition, clinical studies of the causes of fire deaths have also lended support to this concern. For example, Zikria et al. [35-38], working with the clincal 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 [39,40] 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 [41]. 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 [42]. 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 [43].

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:

$$CO + HBO_2 \xrightleftharpoons{K} COHb + O_2 \quad [44]$$

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 [45] 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 [46].

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 [47]. 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 [48]. In considering both stimuli, which are likely to be present in a fire, Babrauskas [49] 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:

$$\Delta COHb(\%) = 5.98 \times 10^{-4} (CO)^{1.036} (\Delta T) \quad [49]$$

where CO is expressed in ppm and Δt is the elapsed time (minutes); an initial value of COHb = 0.75% [47] 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 [50] in which this level resulted in symptoms associated with incipient incapacitation as defined for this study.

In addition to the threshold for time-rated accumulation, 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 [51] which can occur independently of the effects of increased COHb. Claudy [41] reported on the affects 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 two to three breaths, followed by death in one to three 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 COHB level of 25%.

2.6.2 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 [52,53].

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 [54]. 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. [55] 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 [56] 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 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. [57] 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) throughout 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.

2.6.3. 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 a great enough magnitude to affect life safety outside the living room 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% to 100%, 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 [58].

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 the 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 [48].

Pryor, et al. [59] 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, muscular 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	Nause 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 [60] and Kimmerle [50], 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 [61]. Kraines [62] 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 [63] and reported by Pryor [64] 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 [63]:

	$\%O_2$ BY VOL. NORMAL
	21
	20
	19
	18
<u>FIRST STAGE AT 16-12%</u>	17
RESPIRATION VOLUME INCREASES	
PULSE QUICKENS	16
MUSCULAR COORDINATION DIMINISHED	
ATTENTION & CLEAR THINKING	15
REQUIRES MORE EFFORT	
	14
<u>SECOND STAGE AT 14-9%</u>	
RESEMBLES ALCOHOLIC INEBRIATION,	13
HEADACHE, NUMBNESS, MUSCULAR	
EFFORTS FATIGUE READILY AND CAUSE	12
FAINTING, CHEYNE-STOKES RESPIRATION	
	11
<u>THIRD STAGE AT 10-6%</u>	
EXAGGERATES EARLIER SYMPTOMS	10
NAUSEA AND VOMITING, EXERTION	
IMPOSSIBLE, PARALYSIS OF MOTION	9
AND SENSATION, UNCONSCIOUSNESS	
	8
<u>FOURTH STAGE</u>	
BELOW 6%, RESPIRATION STOPS,	7
CONVULSIVE MOVEMENTS	
HEART ARRESTED 6-8 MINUTES	6
AFTER THE RESPIRATION	
	5
	4
	3
	2
	1

EFFECTS OF REDUCED OXYGEN ATMOSPHERES
(Reprinted from Pryor [64])

Based on this information, a value of 14% 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% 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 [63], that concentrations of oxygen below 14% will result in serious physiological effects which may impair the judgement capabilities and physical movement of an individual.

2.6.4. Smoke Density

The presence of smoke can delay or prevent escape under fire conditions. In buildings were 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 [65].

While references [66] and [67] cite critical smoke densities which are said to take account of eye irritation, the optical density of 0.0066 per meter derived from reference [66] 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 [68] is said to be based on the Los Angeles School Burns number 2 [69]. 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 [69] 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 [69,70], 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 [71] reassessed his earlier work as well as later work by Jin [72-74] and concluded that his original correlation [75] 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 [76] 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 [77,78] 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 [67,68,75,79,80] 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 [81], Harpe [82] and Heskestad [83] 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 burning item until either flashover occurred or the instrumentation indicated a significant reduction in fire intensity and no additional fire growth, whichever occurred first.

2.7. Measurements

2.7.1. Ambient Measurements

In the tests conducted with the wood cribs, the moisture content of the wood crib and the wall and ceiling finish materials were measured and recorded for each test using an electrical moisture meter. Outside and inside temperatures and relative humidity were also recorded, as were wind velocity, wind direction, and barometric pressure. In those tests using the upholstered chair as the initial burning item, the moisture content of the chair materials could not reliably be obtained from use of the moisture meter and was therefore omitted.

2.7.2. Test Measurements

Figure 4 is a diagram illustrating the locations where measurements of changes in test conditions were taken. Table 5 lists each channel and the type of measurement taken. Ranges and limits of error are listed in appendix D.

Forty-eight thermocouples were located throughout the mobile home to measure changes in air temperature during the tests. The thermocouples located in the center of the room in bedroom No. 1, bedroom No. 3, the dining room and the living room were made from 0.61 mm (0.0239 in/24 gage) Chromel and Alumel wires enclosed in glass fiber insulation with bare beaded ends. All remaining thermocouples consisted of commercial assemblies of 0.91 mm (0.0359 in/20 gage) Chromel and Alumel wires packed in mineral insulation and enclosed in a 3.15 mm (0.124 in) diameter inconel 702 sheath with a grounded junction.

Calibrated commercial water-cooled total heat flux transducers were used to measure the incident heat flux levels on the floor in the center of the living room and on the floor at the north and south ends of the corridor. The transducers were positioned to provide a vertical view towards the ceiling to collect data on the heat flux at the floor as a result of the radiation from the hot gases and the high temperature surfaces in the upper part of the room. In addition, for several tests (tests 9-16), two transducers were placed in the north wall behind the initial burning item and one was placed in the ceiling in the center of the living room. The transducers located in the north wall provided data on the levels of incident heat flux exposure to the walls from the initial burning item. The transducer installed in the ceiling provided some limited information regarding the incident heat flux at the surface of the ceiling at a distance from the corner where the fire was started. The manufacturer's maximum specified range for the transducers installed in the floor was 5.7 W/cm^2 (5 BTU/ft^2-sec). The maximum for the remaining transducers was 23 W/cm^2 (20 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 along the corridor and which passed through the corridor and into the bedroom areas. A vertically aligned smoke meter was positioned midway between the walls at the north end of the corridor and measured the smoke moving into the corridor along the ceiling. An identically constructed smoke meter was installed in the south end of the corridor just beyond the back exit door at the entrance to bedroom No. 1 in the same configuration. The smoke was measured by monitoring the attenuation of a collimated 0.46 m (18 in) beam of light from a tungsten lamp impinging on a phototube; the path of the beam was vertically aligned from 610 mm (24 in) below the ceiling to 152 mm (6 in) below the ceiling.

The smoke density at various heights above the floor was monitored at the same locations at the north and south ends of the corridor. Horizontally aligned smoke meters were positioned at 0.6, 1.2, and 1.8 m (2, 4 and 6 ft) above the floor at these two locations to provide experimental data on stratification of smoke outside the room of fire origin along the corridor and at the entrance to bedroom No. 1. The smoke was measured continuously by monitoring the attenuation of a collimated beam of light from a tungsten lamp impinging on a photodiode. The beam of light was horizontally aligned across the corridor and had a path length of approximately 0.77 m (30 in).

Combustion gas concentrations were sampled continuously in the living room and at the south end of the corridor beyond the back exit door at the entrance to bedroom No. 1. These gases were filtered through glass fiber to remove soot and particulate matter and chilled through an ice bath to remove condensable vapors before being passed through an infrared gas analyzer to determine concentrations of CO and CO_2. Concentrations of O_2 were measured by a chemical oxygen cell. All three gases were sampled at 1.5 m (5 ft) above the floor.

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

A commercially available A.C. powered ionization-type smoke detector having a sensitivity of 6.4 OD/m (2%/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 north end of the corridor approximately 229 mm (9 in) below the ceiling and 381 mm (15 in) from the kitchen wall.

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

Data for each test were input to a high-speed multiple-channel data acquisition system every 10 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, the heat flux transducers, gas analyzers and the load cell were also simultaneously recorded either on strip chart or multipoint recorders.

3. PROCEDURE

3.1. 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 4 lists these measurements.

The air temperature in the mobile home was maintained as close as possible to 22 $\pm$ 4°C (72 $\pm$ 7°F). The moisture content of the walls and ceiling ranged between 5 and 10%. The conditioning of the interior environment of the mobile home within closer limits was not achieved because of the high ambient temperatures and relative humidity during the period when most of 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 4 lists these measured test conditions for each of the 16 tests.

In the tests using the 6.4 kg (14 lb) cross piled wood crib as the initial burning item, each wood crib was positioned on a load cell platform in order to measure its weight loss throughout the test. The crib was 254 mm (10 in) above the floor, and approximately 25 mm (1 in) from the adjacent walls forming the northwest corner. A 200 x 200 x 25 mm (8 x 8 x 1 in) metal pan containing 150 cm^3 of heptane was placed under the wood crib as an ignitor. The moisture content of the wood cribs was measured by an electrical moisture meter just prior to ignition.

In those tests using the upholstered chair as the initial burning item, the chairs, having an approximate weight of 16 kilograms (35 lbs) were positioned on the load cell platform, again in the northwest corner with the back of the chair approximately 25 mm (1 in) from the walls comprising the corner. The chairs were ignited by placing a commercially available 9ℓ (9.5 qt) capacity polyethylene waste container containing 225 gm (8 oz) of crumbled newspaper adjacent to the left arm of the upholstered chair and igniting the newsprint. (Figure 5 illustrates the two initial burning items and their position in the corner configuration.)

Prior to ignition, all exterior windows and doors were closed but not sealed, providing an initial quiescent atmosphere. In addition, the doors to bedrooms No. 2 and No. 3 and the door to the bathroom were closed; the door to bedroom No. 1 remained open.

The ignition of the 150 cm^3 of heptane in the tests using the wood cribs, and the ignition of the 225 grams of newsprint in the tests using the upholstered chairs was accomplished by remote electrical ignition of a wooden match.

Visual observations and photographic records were made of the development of the fire and all measurements were recorded from the time of ignition until the test was terminated.

3.2. Laboratory Evaluation of Materials

Laboratory test methods are frequently utilized to measure various material characteristics such as ignitability, surface flame spread, rate of heat release and smoke generation. For the interior finish materials used in this series of full-scale fire tests, the tests utilized were:

Characteristic	Laboratory Test Method
Ignitability	(1) ease of ignition test [84]
Surface flame spread	(2) ASTM E-84, Standard Method of Testing for Surface Burning Characteristics of Building Materials
	(3) ASTM E-162, Radiant Panel Test
Heat release rate	(4) NBS rate of heat release calorimeter [85]
Smoke Generation	(5) NFPA 258, Smoke Density Chamber

4. RESULTS

4.1. Full-Scale Fire Tests

In the eleven tests conducted using a 6.4 kg (14 lb) wood crib as the initial burning item, the initial development of the wood crib fire varied somewhat. Due to the rapid consumption of the 150 cm^3 of heptane, an initial period was characterized by a rapid lengthening of the flame towards the ceiling. Exhaustion of the heptane, which occurred within a range of 60 to 90 seconds after the beginning of the test, was accompanied by a reduction in flame height followed by a gradual buildup of the wood crib fire until a fairly stable burn rate was reached. Close observation during this period indicated that while there was some intermittent flame impingement on the wall, there was no involvement of the interior finish materials during the period of fire initiation resulting from the burning heptane.

In the five tests conducted using a 16 kg (35 lb) upholstered chair as the primary fire source the period of initial fire development was significantly longer than in those tests utilizing the wood crib. This occurred as a result of a less intense exposure of the chair to a low order fire from a waste container filled with burning newsprint. In addition, as in the case of the wood crib tests, there was variability in the time required for involvement of the chair, and the subsequent exposure of the wall and ceiling materials. The approximate time at which flames impinged on the wall in the eleven tests using the 6.4 kg (14 lb) wood crib ranged from 32 to 110 seconds; in the five tests using the upholstered chair the range was from 180 to 330 seconds.

The statistical variance (mean squared deviation) within the grouping of chair tests was greater than that for the crib tests. Further, the most rapidly developing chair fire nevertheless took more than a minute longer to expose the wall than any of the eleven crib tests. Aside from this variation in the rate of development of the initial fires, the general development of the room fires and the resulting changes in measured conditions were similar.

The tests varied in length depending on the development of the fire from the initial burning item and the extent of involvement of materials comprising the interior finish. The series of photographs in appendix C provide some illustration of the variation in fire growth observed for a number of tests. The tests ranged from just over 5 minutes in test 1 to approximately 20 minutes in test 16. The tests were terminated either when there appeared to be no further involvement of the interior finish materials or, when total room involvement occurred (flashover). The determination that no further involvement of the walls and ceiling would result from continuing the test was based on 1) a reduction in temperature levels at selected locations monitored continuously during the test, and 2) a noticeable reduction in the magnitude of the fire and the area exposed. As previously defined, flashover, or conditions suitable for total room involvement, was considered to have been reached when materials including the upholstery fabric on the sofa and the vinyl asbestos flooring were ignited. When this occurred, it was the result of radiation heat transfer from the hot gas layer and the heated surfaces in the upper part of the room.

Measurements of particular interest obtained in the full-scale tests are tabulated in tables 6, 7 and 8 for convenient reference. Table 6 includes measurements of maximum temperature at various locations in the upper part of the living room and incident heat flux measured at the floor level. Table 7 provides a tabulation of the concentrations of CO, CO_2 and O_2 in the center of the living room. Finally, table 8 lists the elapsed time to reach selected levels of temperature, CO, O_2 and smoke density at locations throughout the mobile home.

Appendix A includes the records of the visual observations for each of the sixteen tests. Appendix B is a compilation of plotted data illustrating key changes in measured conditions due to fire buildup. For example, the plotted data in figures B1 to B16 illustrate the changes in temperature 25 mm below the ceiling and 25 mm above the floor in the center for the living room for each of the sixteen tests. In addition, changes in incident heat flux at the floor level are plotted on the same set of coordinates providing comparative information in the living room.

Figures B17 through B32 provide illustrations of the changes in temperature, CO, CO_2 and O_2 in the center of the living room for each individual test. Figures B33 through B48 are plots of temperatures, CO concentration, time-rated CO accumulation, and O_2 depletion outside the living room in the corridor beyond the back exit door for each of the sixteen tests. Figures B49 through B64 are plots of the percent light transmission 1.2 m above the floor at two locations: the north entrance to the corridor and beyond the back exit door at the entrance to bedroom No. 1.

Figures B65 through B74 are plots of changes in temperature 25 mm below the ceiling in the center of the living room and at the north entrance to the corridor. Tests with similar wall materials are included on the same plots to assist the readers following the analysis of results.

4.2. Laboratory Test Results

Table 2 provides a tabulation of the results of the laboratory tests conducted to measure some of the properties of the interior finish materials.

5. ANALYSIS OF RESULTS

5.1. General

Review of the mass of data collected for these sixteen tests resulted in the selection of a number of specifically located measurements to characterize the process of fire growth in the living room and the effects of this fire growth on the environment outside the living room area. Specifically, analysis of the growth of the fire within the living room area was based on 1) the change in temperature 25 mm (1 in) below the surface of the ceiling (TC 13), and 2) the levels of incident heat flux measured at the floor. In addition, the effect of the fire buildup on the levels of carbon monoxide (CO), carbon dioxide (CO_2) and oxygen (O_2) were examined. All of these measurements were taken along the vertical center line of the living room.

In considering the hazard to the occupants of the mobile home from a fire in the living room, it must be assumed that persons in the living room are alert and capable of reacting to the fire. Limiting conditions are reached in the living room quickly from the incidental fire, and it is not likely that a significant escape period can be provided to the occupants of the room of fire origin. However, some time should be available for occupants outside the room of fire origin to take corrective action and/or escape the mobile home. Since movement in a direction away from the fire is most likely, the back exit door is a strategic location for escape for those persons outside the living room area. Anyone attempting to escape along the corridor and out the back exit door must not encounter limiting environmental conditions such as those defined in section 2.6. The test results show that when a limiting condition is reached at the back door, conditions are equally as serve (or worse) all along the corridor and in any rooms open to the fire. Therefore, the effects of the fire on environmental conditions outside the living room were analyzed primarily by examining the changes in 1) carbon monoxide 1.5 m (5 ft) above the floor, 2) oxygen 1.5 m (5 ft) above the floor, and 3) temperature 1.3 m (52 in) above the floor in the corridor just beyond the back exit door, at the entrance to bedroom No. 1. Other measurements are included in the analysis where helpful.

In order to analyze effectively the results of sixteen tests characterized by some variation in control variables (i.e., wood crib versus upholstered chair) and various interior finish materials on walls and ceiling, the results are separated into three distinct groups. The initial part will be devoted to a direct comparison of the two initial burning items based on the results of test 15 and 16. The second part will examine the results of the 10 tests using the wood crib and various combinations of wall and ceiling materials. The third part of the analysis addresses the series of four tests with the upholstered chair used as the initial burning item.

5.2. Wood Crib and Upholstered Chair Fires

5.2.1. Test 15: 6.4 kg (14 lb) Wood Crib

Test 15 was conducted to examine the fire growth and resulting changes in the measured conditions due to the burning of a 6.4 kg (14 lb) cross-piled wood crib in a corner configuration with walls and ceiling constructed from noncontributing materials. The living room and dining room walls and ceiling were constructed of 13 mm (1/2 in) thick gypsum board. Panels of calcium silicate, 13 mm thick (1/2 in), were installed over the gypsum board in the corner covering a horizontal distance of 2.4 m (8 ft) on both walls, and 6 m^2 ($\sim$64 ft^2) of ceiling space directly above the wood crib.

Ignition of the 150 cm^3 of heptane resulted in exposure of the wood crib. The heat released by burning the heptane and the subsequent initial involvement of the wood crib resulted in a rapid increase in temperature along the ceiling and an initial peak flame height of approximately 1.8 m (6 ft) above the floor in the corner. The maximum temperature reached above the crib at the ceiling due to this involvement of the heptane was approximately 325°C at 1 min 30 sec elapsed time. This was followed by rapid exhaustion of the heptane and a significant reduction in temperature. The initial peaks in figure 6a illustrate the early temperature rise at two locations in the room due to the burning of the heptane. Thermocouple 13 (TC 13) was located 25 mm (1 in) below the ceiling in the center of the living room, and thermocouple 4 (TC 4) was located 25 mm (1 in) below the ceiling directly above the wood crib.

After the heptane had been consumed, the rate of burning of the wood crib gradually increased as illustrated in figure 6b until a nearly constant peak burn rate was reached. This occurred after about two minutes, resulting in a flame height approximately 1.2 m (4 ft) above the floor. This near constant burning, resulting in a relatively stable flame, was observed to last for approximately 10 to 12 minutes with less than 10% variation before the crib fire began to decay. Figures 7a and 7b illustrate the shape of the early peak flame and the more stable flame resulting from the burning of this typical 6.4 kg wood crib.

The maximum temperature reached at TC 13 was approximately 150°C after 13 minutes elapsed time. The maximum temperature reached at TC 4 was 300°C. These maximum temperature levels remained nearly constant during the period of stable burning rate of the crib and somewhat beyond; the subsequent decay in the wood crib fire resulted in gradual reduction in temperature at these locations. The total weight loss of the wood crib was 4.8 kg (10.5 lb) or 63% of the initial weight.

Further examination of the temperature data revealed that the maximum average upper room temperature (average of TC 1, 7, 10, 13) was 142°C and the temperature of the heated gases entering the north end of the corridor along the ceiling reached a maximum of 114°C. The maximum level of incident heat flux measured at the floor level in the center of the room was less than 0.1 W/cm^2.

Measurements showed a very small change in concentrations of CO, CO_2 and O_2 in the living room. The data tabulated in table 9a showed that conditions in the room did not vary appreciably from the ambient conditions recorded at the beginning of the test, although the CO_2 concentration increased to nearly 1.9%. Therefore, it appears that the changes in concentrations of CO, CO_2 and O_2 in the living room occurring as a result of the burning of a 6.4 kg (14 lb) wood crib are of less significance than the increase in air temperature.

The changes in the environment in adjacent locations outside the living room were also of significance in this analysis. Table 8 provides a tabulation of measurements collected by strategically located instruments outside the living room along the corridor and in the bedrooms. These data were tabulated on the basis of criteria outlined in section 2.6. Review of the data indicated that temperatures 1.3 m (52 in) above the floor along the corridor and in the bedrooms did not reach 100°C; actually, the peak temperatures measured ranged from a maximum of 57°C at the north entrance to the corridor adjacent to the living room, to 49°C in bedrooms No. 1 and No. 3. This shows that the burning of a 6.4 kg wood crib will not result in temperatures in excess of the 100°C limiting level at 1.3 m (52 in) above the floor in this particular test configuration. Further, the data indicate that limiting concentrations of CO and O_2 were not reached 1.5 m (5 ft) above the floor along the corridor near the back exit door.

The measured reduction in percent light transmission reached a level equivalent to 0.26 OD/m optical density of smoke 1.2 m (4 ft) above the floor at 2 min 40 sec and 5 min 50 sec respectively, at the north entrance to the corridor (HSM #5) and beyond the back exit door (HSM #9).

5.2.2. Test 16: 16 kg (35 lb) Upholstered Chair

Test 16 provided information on the fire growth from a 16 kg (∿35 lb) upholstered chair in a corner configuration in the mobile home when the same noncontributing walls and ceiling were installed. In this test, the construction was identical to test 15, exposing walls and surfaces constructed of 13 mm (1/2 in) thick calcium silicate panels to the chair fire. The upholstered chair was exposed to a low intensity fire started in a 9ℓ (9.5 qt) capacity polyethylene waste container containing 225 gms (8 oz) of crumbled newsprint placed adjacent to the left arm of the chair (figure 5b). The newsprint was ignited on the top surface by remote electrical ignition of a wooden match.

The flame size from the burning newsprint and waste container was less than that from the 150 cm^3 of heptane. Therefore, the exposure was less severe and the chair fire developed much more slowly than the earlier crib fires. Exposure of the left arm of the chair resulted in gradual increases in temperature along the ceiling above the chair and in the center of the room. As illustrated in figure 8a, the significant rise in temperatures at TC 4 and 13 occurred initially as a result of the slow involvement of the polyurethane seat cushion. Later there was a more rapid buildup of fire along the left arm; this occurred after approximately 11 min 40 sec elapsed time. The peak temperature occurring at TC 4 was 418°C after 15 min 50 sec. The maximum temperature at TC 13 was 236°C after 15 min 30 sec. These maximum temperature levels corresponded to a maximum level of incident heat flux of 0.15 W/cm^2 at the floor level in the center of the room. As noted in the test observations, this was the period of most intense burning which resulted in intermittent flame impingement on the ceiling. Shortly after this peak level of burning, the burn rate began to decay, resulting in reduction in air temperatures and lower levels of radiative energy at the floor.

While the flame height and intensity of this fire resulted in higher peak temperatures than in test 15 (wood crib), only moderately higher changes in concentration of CO, CO_2 and O_2 occurred in the burn room. Table 9b provides a tabulation of peak levels of CO, CO_2 and O_2 which are moderate changes from the ambient concentrations measured at the beginning of the test.

Maximum temperature 25 mm (1 in) below the ceiling in the center of the room resulting from the burning upholstered chair was 236°C and the peak average temperature of the combustion gases along the ceiling in the living room was 215°C. These temperature levels were considerably below the conditions necessary to flash over the room. Further, the maximum temperature of the gases entering the corridor along the ceiling was 172°C.

The changes in the conditons outside the living room along the corridor and in the bedrooms at selected locations are tabulated in Table 8. Air temperature 1.3 m (52 in) above the floor at the entrance to the corridor (TC 25) adjacent to the living room exceeded the 100°C level established as the limiting condition for temperature. However, this did not occur at the other reported temperature measurement locations. The maximum concentration of CO just beyond the back exit door was <0.1% after 17 min 20 sec; the time-rated accumulation reached approximately 9,504 $(pmm)^{1.036}(min)$. The concentration of O_2 at this location did not drop below 18.4%.

Consistent with the results of burning the wood crib the threshold for smoke density was exceeded. A smoke density of 0.26 OD/m was reached 1.2 m (4 ft) above the floor at the north entrance to the corridor adjacent to the living room after 8 min 10 sec and just beyond the back exit door after 10 min 10 sec had elapsed.

5.2.3. Impact of Burning Wood Crib or Upholstered Chair on Fire Buildup

Previous experience indicated that involvement of other combustibles occurs when the incident heat flux is of a sufficiently high level. During initial fire buildup this occurs only in close proximity to the burning item. Therefore, the total incident heat flux was measured at selected distances from the wood crib or chair along a horizontal plane directed from the initial burning item to the front exit door in order to determine how incident flux varied with distance. This was measured with a total heat flux tranducer which measured combined radiation and convection.

Figure 9 illustrates the maximum levels of incident heat flux measured at selected horizontal distances from the wood crib and the upholstered chair in tests 15 and 16 with noncontributing walls and ceilings. The incident heat flux was primarily due to radiation from the flames and from the heated walls as a result of the intensity of the burning items. The maximum levels of incident heat flux dropped off rapidly as a function of distance both in the case of the burning wood crib and the burning upholstered chair. This indicated that ignition of combustibles, even a short distance away, would not likely occur without flame contact with the surface.

Based on this information, it appears that an incidental fire along the wall, and in particular in the corner, will expose the wall materials and possibly the ceiling materials to flames and radiative and convective energy of sufficient intensity to ignite combustibles. However, unless furnishings and other combustibles are placed in the immediate proximity of the initial burning item fire growth and spread will not be significantly influenced by the remaining contents in the room until flashover conditions are approached.

5.3. Tests with 6.4 kg (14 lb) Wood Crib

5.3.1. Tests 1, 2, 3, 9 [Prefinished Lauan Plywood Walls]

Four tests were conducted to examine the fire growth resulting from exposing prefinished lauan plywood walls to a burning 6.4 kg (14 lb) wood crib. Essentially, this group of tests provided data on (a) the effect of changing the thickness of lauan plywood walls, and (b) using plywood walls with two types of commercially available ceiling materials having significantly different fire properties. In tests 1 and 9 the lauan plywood walls were 4 mm (5/32 in) thick, and the ceiling was constructed of 13 mm (1/2 in) thick wood fiberboard. In test 2, the same type of lauan walls were used, but the ceiling was constructed of 8 mm (5/16 in) thick textured finish gypsum board. In test 3, the walls were constructed of 6.4 mm (1/4 in) prefinished lauan plywood, and the ceiling was the 8 mm (5/16 in) thick textured finish gypsum board.

Examination of the time-temperature curves for TC-13 (see figures B1 - B16) indicate that the highest maximum upper room temperature[3] levels reached were in tests 1 and 9. In test 1, a maximum temperature of 743°C was reached at 5 min 10 sec into the test. In test 9, the maximum temperature reached was 751°C after 5 min 40 sec. Flashover was observed to have occurred in both tests. In test 1, flashover occurred at 4 min 20 sec, corresponding to a temperature of 707°C. Fire growth in test 9 resulted in flashover at 6 min 30 sec into the test which corresponded with a 714°C temperature level. Some further verification of these results can be obtained by noting the levels of incident heat flux measured at the floor during the tests. In both tests, the maximum levels occurred at approximately the same time as flashover, and were on the order of 2 W/cm^2 or higher, which indicates sufficient levels of radiative energy to ignite combustible furnishings.

Appreciable changes in temperature development occurred when the ceiling material was changed. In tests 2 and 3, the ceilings were constructed with 8 mm (5/16 in) thick textured finish gypsum board. Further, the thickness of three prefinished lauan plywood was 4 mm (5/32) in test 2 and 6.4 mm (1/4 in)

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[3]In those tests where flashover occurred and the suppression system was activated, the maximum upper room temperature recorded prior to activation is referenced.

in test 3. In test 2 the maximum temperature reached was 429°C after 3 min 30 sec; in test 3, a maximum temperature of 520°C was reached at 4 min. Flashover was not observed in either test, and the maximum recorded level of incident heat flux at the floor in the center of the living room for both tests was less than 1.0 W/cm^2, considerably below the levels recorded in tests 1 and 9.

Rapid changes in concentrations of CO, CO_2 and O_2 occurred in both tests 1 and 9. At the point when flashover was observed in both tests, the concentration of oxygen in the living room had dropped below 12%. In addition, the levels of CO and CO_2 increased rapidly during the period of flashover, reaching maximum levels of 8.0% and 17.4% respectively in test 1 and 6.6% and 17.1%, respectively, in test 9. Minimum levels of O_2 were 7.8% and 2.6% for tests 1 and 9.

The initial fire development in tests 2 and 3 was similar to that occuring in tests 1 and 9. The graphical representations of changes in CO, CO_2 and O_2 illustrates similar rate of change for all four tests during the initial stages of fire development. However, the lower peak upper room temperatures reached in tests 2 and 3 indicate a less severe condition, and this is supported by the results of the measured changes in the gases. As the fire developed beyond the initial involvement of the walls, in tests 2 and 3 the rate of change of CO, CO_2 and O_2 decreased and lower peak concentrations of CO and CO_2 and higher concentrations of O_2 resulted. The minimum levels of O_2 measured in tests 2 and 3 were 17.7% and 14.5%, which were considerably higher than in tests 1 and 9. The maximum levels of CO reached in test 2 and 3 were 0.4% and 0.7%, respectively. The maximum levels of CO_2 reached were 3.8% in test 2, and 6.9% in test 3. These peak concentrations indicate significant changes in the environment in the living room as a result of the fire development. However, these changes are considerably lower than in tests 1 and 9.

In all four tests with the prefinished lauan plywood walls an optical density of 0.26 OD/m was reached in the corridor beyond the back exit door. In addition, in tests 1, 3 and 9, the thresholds for limiting levels of temperature, CO and O_2 were all exceeded. In test 2, the only limiting condition reached was the time-rated threshold for CO accumulation, 41 800 $(ppm)^{1.036}(min)$.

5.3.2. Tests 4, 5, 7, 8
[Fire Retardant Treated Lauan Plywood Walls]

This group of tests was designed to provide data on (a) fire growth and spread from exposure of two separate types of fire retardant treated lauan plywood walls from a burning 6.4 kg (14 lb) wood crib, and (b) the use of fire retardant treated walls with two types of ceiling materials having significantly different fire properties.

In tests 4 and 8, a clear fire retardant intumescent varnish was applied to the 4 mm (5/32 in) thick prefinished lauan plywood walls. In test 4 the ceiling was constructed of 8 mm (5/16 in) thick textured finished gypsum board, and in test 8, the ceiling was constructed of 13 mm (1/2 in) thick wood fiberboard.

In tests 5 and 7, a fire retardant vinyl film, 0.38-0.46 mm (0.015-0.018 in) in thickness, was glued to the 4 mm (5/32 in) thick lauan plywood walls. As in tests 4 and 8, the ceilings were different; in test 5 the ceiling was constructed of the textured finished gypsum board, and in test 7 the ceiling was constructed of the wood fiberboard.

Examination of temperature results showed that the most severe conditions occurred in tests 7 and 8. An important common denominator in these two tests was the ceiling material-wood fiberboard. The maximum upper room temperature in test 7 was 698°C which occurred at 5 min 20 sec into the test. The corresponding maximum average upper room tempeatures at 25 mm (1 in) and 250 mm (10 in) below the ceiling were 614°C and 617°C, respectively. Flashover was observed just prior to these maximum temperatures at 5 min 15 sec elapsed time. The temperature of the combustion gases entering the corridor along the ceiling after the room flashed over were similar to the gas temperatures incurred at the same location in tests 1 and 9.

The maximum upper room temperature in test 8 was 673°C at 7 min 40 sec. While this temperature level is normally considered indicative of conditions which result in total room involvement, it was maintained only briefly and flashover was not observed. Further, post-test examination of the living room did not reveal any indication that pyrolysis of the floor material or other combustibles located in the room had occurred. Reference to figure B66 indicates that the attainment of high temperatures along the ceiling took somewhat longer in test 8 than in test 7. Further examination of the test data revealed that the maximum average temperatures 25 mm (1 in) and 250 mm (10 in) below the ceiling (obtained by averaging the temperature measurements throughout the room at that height) in test 8 were 518°C and 402°C, respectively. These average temperature levels were considerably lower (over 100°C lower) than those measured in tests 1, 7 and 9 when flashover occurred.

The results of tests 4 and 5 indicate a significant effect on fire growth resulting from changing the ceiling material. The temperature data indicates a similarity in early fire development in test 5 and 7, most likely due to the initial exposure and involvement of the walls. And, altough a larger variance is evident between tests 4 and 8, the time-temperature curves also demonstrate a similar development of the fire and initial involvement of the walls.

The maximum temperature reached at TC 13 in test 4 was 311°C after 8 min 30 sec had elapsed; maximum temperature in test 8 was 673°C at 7 min 40 sec. And, the maximum temperature of the combustion gases entering the corridor along the ceiling was 308°C in test 8, but only 197°C in test 4. In comparing these results for test 4 and 8, it would appear that the influence of the ceiling material was quite significant with regards to fire development and the resultant change in temperature in these tests.

Comparable results occurred in tests 5 and 7 as indicated by similar temperature changes resulting from fire development for the initial 3 min 45 sec of both tests. But again, as in test 4, test 5 reached a lower maximum upper room temperature of 436°C after 3 min 50 sec.

The test results also indicated some variation in fire growth between the two types of fire retardant treated materials. Less exposure time was required in tests 5 and 7 for the walls to significantly contribute to the fire spread than in tests 4 and 8. This would indicate that variation in the fire properties of these two materials is of importance. It should also be noted that the rate of smoke generation was the highest in this group of tests.

As explained, test 7 was characterized by rapid fire growth, resulting in flashover in 5 min 20 sec. This resulted in maximum levels of CO and CO_2 in the center of the living room of 6.9% and 11% respectively. These maximum concentrations of CO and CO_2 were on the same order that were measured in tests 1 and 9. The minimum concentration of O_2 (4.6%) was reached at 5 min 40 sec.

In test 8, temperatures in excess of 670°C were reached in the upper part of the room but only for a short period. In addition the peak temperature was delayed as were the peak levels of CO, CO_2 and O_2 in the living room. The maximum concentrations of CO and CO_2 measured were 1.0% and 6.0%, respectively. The minimum concentration of O_2 in this test was 14%, somewhat higher than in tests 1, 7 and 9.

In tests 4 and 5, the absence of rapid fire growth and high temperatures resulted in lower and more gradual changes in concentrations of CO, CO_2 and O_2 in the living room.

From this group of tests the maximum size of the fire and the rate of fire buildup directly affected the measured conditions in the corridor. In all four tests in this group, 0.26 OD/m optical density was reached in the corridor. Further, limiting levels of carbon monoxide, temperature, and oxygen were reached in tests 7 and 8.

The results of test 7 indicated that the elapsed times to reach the thresholds selected as limiting levels of CO, O_2 and temperature were nearly the same as the times measured in test 1 using untreated prefinished lauan plywood walls. The results of test 8 indicated that a considerably longer period of time elapsed before limiting conditions were reached.

The significance of changing the ceiling material can be seen by examining the results of test 4 and 5. While smoke generation was similar in all four tests, in test 4 the thresholds for temperature, CO and O_2 were not reached. And, test 5 results indicate an increase in elapsed time over measured results in test 7 with a limiting level of O_2 not being reached.

An interesting observation from the results of this group of tests was that consistently 0.26 OD/m optical density was reached prior to ignition of the wall. This did not occur in any of the other tests using a wood crib.

5.3.3. Tests 6, 13 [Gypsum Board Walls]

Two tests were conducted to examine the fire growth resulting from exposing 8 mm (5/16 in) thick prefinished gypsum board walls with two types of ceilings to a burning 6.4 kg (14 lb) wood crib. In test 6 the ceiling was constructed of 8 mm (5/16 in) thick textured finish gypsum board, and in test 13 the ceiling was constructed of 13 mm (1/2 in) thick wood fiberboard.

The change in upper room temperature resulting from the development of the fire in test 6 was very gradual, reaching a maximum of 176°C after 11 min 30 sec elapsed time. This was the lowest maximum upper room temperature measured at TC 13 for any of the tests. The temperature development at this location did not vary significantly from that in test 15 in which a 6.4 kg (14 lb) wood crib was tested with noncontributing walls and ceiling. As one might expect, the maximum level of incident heat flux measured at the floor in the center of the room during test 6 was negligible.

The maximum temperature reached at TC 13 in test 13 was 316°C after 14 min 20 sec. However, conditions did not vary appreciably from those in test 6 for the first 10 to 11 minutes. The greater temperature can be explained based on events which occurred early in the test. The initial exposure of the wood crib ignited the paper surface on the walls after approximately 1 minute had elapsed. The fire propagated to the ceiling and ignited the wood batten strip installed to cover the ceiling joint. Although the fuel from the paper surface was exhausted rapidly and the flame envelope receded, the batten strip continued to burn. The heated gases collected above the ceiling and ignited the unexposed side of the ceiling material. The increase in temperature which occurred after 11 min 40 sec resulted from this burning of the ceiling.

Tests 6 and 13 were both characterized by gradual changes in concentrations of CO, CO_2 and O_2. In test 6, the maximum concentrations of CO and CO_2 were <0.1% and 1.8%, respectively. Both of these maximum measurements occurred after 11 min 40 sec. In test 13, the maximum concentration of CO_2 was 3.0% after 17 min 50 sec. Minimum levels of O_2 were 18.8% after 11 min 40 sec in test 6 and 17.4% after 17 min 50 sec in test 13.

These results indicate that while there was some variance in fire development between these two tests, the properties of the wall material did not provide sufficient extension of the fire to involve the exposed ceiling surface. It should be noted that in test 13, the easily ignited wood batten strip was more significant in propagating the fire than the exposed ceiling surface. The changes in concentrations of CO and O_2 and the increase in temperature at the back exit door were significantly lower in tests 6 and 13 than in the tests using prefinished or fire retardant treated plywood, with the exception of test 4.

As in some earlier tests, 0.26 OD/m optical density occurred at the back door location earlier than at the entrance to the corridor from the living room. This was most likely due to the cooling of the heated smoke as it traveled down the corridor along the ceiling in the heated gas layer. The cooling effect condensed some vapors, increasing the density of the smoke and the larger sized particles descended through the cooler gas layer towards the floor, increasing the smoke density at the instrument locations closer to the floor.

5.4. Tests with 16 kg (35 lb) Upholstered Chair

Four tests were conducted in which a low intensity fire from a typical household waste container filled with newsprint ignited the arm of an upholstered chair, exposing the walls and ceiling in the northwest corner of the living room. In three of the tests the living room and dining room were moderately furnished, as previously described, providing a fuel loading of approximately 4.9 kg/m^2 (1 lb/ft^2).

The interior finish materials were selected to provide two basic conditions. One combination of wall and ceiling materials was selected based on the most severe fire which occurred in the series of tests using the wood crib. The other combination of wall and ceiling materials was selected to duplicate the materials used in the test which resulted in the least severe fire in the series conducted with a wood crib.

In essence, these four tests were designed to provide experimental data regarding the selection of a number of basic control variables in the first series of tests. First, the selection of a wood crib as the primary fuel source to evaluate such a large number of combinations of wall and ceiling materials was done to provide some assurance of obtaining a reproducible fire of the same intesnity in each test. While the burning of an upholstered chair does not provide that same level of repeatability, it does represent a more visually realistic fire which one might encounter in a residential occupancy. Therefore, results of these four tests provide some indication of the validity of using a wood crib fuel source in this configuration to predict the relative influence of wall and ceiling materials on fire growth and spread from an incidental fire.

The other primary control variable requiring examination was the distribution of the fuel loading resulting from furnishings. The results of tests conducted with noncontributing walls and ceiling indicated that the radiation from burning sa wood crib or chair of these sizes decreased rapidly as a function of horizontal distance from the burning item. In fact, the data indicated that the radiation was too low to ignite other furnishings located at small distances from the burning crib or chair, and that it was most likely that the furniture and other combustible contents would only become involved as a result of radiation to the lower part of the room from the hot gas layer along the ceiling. These tests further indicated that the burning of the 6.4 kg (14 lb) wood crib or the 16 kg (35 lb) upholstered chair by themselves would not result in ceiling temperatures high enough to provide sufficient radiation levels to ignite the other combustibles in the lower part of the room.

The results of the three tests in which the rooms were typically furnished provided experimental data to validate the premise that the furniture, other than the initial burning item, would have little influence on the growth of the fire up to the point of flashover in this particular test configuration.

5.4.1. Tests 10, 12, 14 [Prefinished Lauan Plywood Walls]

Three tests were conducted with 4 mm (5/32 in) thick lauan plywood walls and 13 mm (1/2 in) thick wood fiberboard ceilings. Test 10 was conducted under similar conditions to the tests using the wood cribs, with the limited number of furniture items. In tests 12 and 14, the room was completely but moderately furnished as described in section 2.3. These three tests provided experimental data on (a) the significance of varying the amount of the fuel loading and (b) the fire severity resulting from the burning of an upholstered chair, and the effect of these elements on fire growth and spread in a mobile home constructed of conventional wall and ceiling materials.

In any series of full-scale fire tests there are limitations in achieving repeatability. To a large degree, this is due to the complexity of the phenomena and the number of variables. However, one would hope for some degree of repeatability, and the results of tests 12 and 14, conducted under identical conditions, indicate comparative fire development. While there was approximately 23 seconds difference between the recorded times for the walls to ignite in these two tests, the results illustrate similar temperature development along the ceiling in the middle of the living room.

The maximum recorded temperature levels at TC 13 were 748°C in test 12 and 736°C in test 14. In addition, the maximum average upper room temperatures reached were 656°C and 659°C in tests 12 and 14, respectively. These temperature levels corresponded with the occurrance of flashover which was observed at 8 min 20 sec in test 12 and 8 min 4 sec in test 14. The incident heat flux measured at the floor level in the center of the living room at the time of flashover was 2.14 W/cm^2 in test 12 and 2.18 W/cm^2 in test 14. This level of radiative energy flow from the hot gas layer to the lower part of the room is considered high enough to ignite combustibles; radiative ignition of the combustibles was observed in both tests.

In test 10, the fire in the upholstered chair developed somewhat sooner, igniting the wall materials after approximately four minutes had elapsed. This resulted in a shorter period of time to reach flashover conditions in the living room. The incident heat flux recorded at the floor during the period that the maximum temperature was reached at TC 13 ranged from 1.3 to 2.5 W/cm^2. The maximum temperature reached at TC 13 was 771°C, which was of the same order as in tests 12 and 14. However, this occurred after 5 min 40 sec had elapsed, which was approximately 2 min 30 sec sooner than in test 12 and test 14. This variation in the development of the chair fire was not totally unexpected. Regardless of this, the rate of temperature rise and the peak temperatures at TC 13 were similar for all three tests.

The maximum temperature of the gases entering the corridor, which provided some indication of the severity of the fire and the exposure of the areas in the mobile home outside the living room was 343°C in test 10. The maximum levels recorded in tests 12 and 14, were somewhat higher at 458°C and 481°C, respectively, and occurred after room flashover. The additional combustible furnishings to the room contributed to fire growth after flashover, and was possibly the reason for the attainment of higher peak temperatures in tests 12 and 14, which ran for a short period after flashover was observed.

Very rapid changes in concentrations of CO, CO_2 and O_2 were recorded in all three tests. At flashover, the concentration of oxygen in the living room had dropped below 12% in all three tests. The level of CO in all three tests at flashover was of the same order; 3.0%, 2.9%, and 3.0% in tests 10, 12 and 14, respectively. During this same period the measured levels of CO_2 were 10.1%, 10.1% and 12.1% for tests 10, 12 and 14.

In test 10, maximum measured levels of CO and CO_2 of 3.0% and 10.1% were reached at 5 min 40 sec elapsed time. A minimum concentration of O_2 of 9.0% was reached at the same time. In test 12, the maximum concentrations of CO and CO_2 of 5.5% and 15.7%, respectively, occurred after 8 min 50 sec elapsed time. The minimum concentration of O_2 of 3.8% occurred simultaneously. The maximum concentration of CO_2 in test 14 of 12.1% was measured at 8 min 20 sec into the test. The maximum level of CO (5.4%) and the minimum level of O_2 (8.8%) occurred shortly after this at 8 min 30 sec.

Limiting levels of CO, and temperature were reached at the back exit door in all three tests; limiting levels of O_2 were reached in tests 10 and 14, but in test 12 a limiting concentration of O_2 was not reached. This may be the result of extinguishment of the fire in test 12 immediately after flashover. In all three tests, 0.26 OD/m optical density was reached in the corridor.

The data in table 8 indicate, as one might expect, that the elapsed times to reach limiting levels of the measured conditions were similar for tests 12 and 14. The variation was less than one minute with the exception of O_2 concentration which did not reach 14% in test 12.

Similar levels of smoke density, O_2, CO and temperature were reached somewhat sooner in test 10 due to the more rapid initial development of the upholstered chair fire (on the order of 2-3 minutes). Despite the variation in development of the chair fires, the peak levels of CO, O_2, temperature and smoke density at flashover were similar in all three tests (with the exception of O_2 in test 12). This indicates that while a variation in time occurred, the actual fire growth and the effects on the environment in the mobile home outside the living room were similar in these three tests.

A comparison of the maximum temperatures reached, time to flashover, and gas concentrations between tests with the upholstered chair and those with the wood crib indicate that both items provide an exposure fire incidental in size, and that the fire growth is dominated by the extent of involvement of the walls and ceiling. Further, a comparison of the data among tests 10, 12 and 14 illustrate that (a) the tests are relatively reproducible, and (b) the effect of the furnishings beyond the single burning item may have little impact on fire growth in the room up to flashover. This supported the experimental procedure, confirming that it was not necessary to completely furnish a mobile home to study the impact of the interior finish materials.

5.4.2. Test 11
[Gypsum Board Walls]

In test 11, the walls were constructed of 8 mm (5/16 in) thick printed surface gypsum board and the ceiling was constructed of 8 mm (5/16 in) thick textured finished gypsum board. This test was conducted to examine the fire growth and spread resulting from ignition of an upholstered chair in a moderately furnished living room (furnished identically to test 12 and 14), but with wall and ceiling materials having different flame spread properties. This combination of wall and ceiling materials resulted in the least severe fire when tested with the wood crib ignition source (test 6). Figure B68 illustrates the rate of temperature change 25 mm (1 in) below the ceiling in the center of the living room for test 11. In comparing this time-temperature curve with those from tests 10, 12 and 14, a significant difference in fire development is indicated.

The variability in the initial development of the chair fire was observed again in test 11. Ignition of the wall surface occurred at approximately 4 min 55 sec into the test which was about one minute later than ignition of the wall in test 10 (3 min 58 sec elapsed) and approximately one minute sooner than in tests 12 and 14 (6 min 23 sec and 5 min 50 sec elapsed, respectively).

Fire development in test 11 was characterized by a somewhat slower rate of temperature rise at the ceiling. The paper surface on the walls provided a surface for sustained flame propagation for a short period of time. This, along with the attainment of the peak burn rate of the chair, resulted in a maximum temperature of 444°C, 25 mm (1 in) below the ceiling in the center of the room (TC 13). This temperature level was approximately 200°C above that obtained in test 16 (noncontributing walls). However, following this maximum temperature level the temperature began to drop off rapidly. This corresponded with the observation that the paper surface had been burned off the walls in the area exposed to the chair fire, and the walls were no longer involved in the fire buildup process.

Flashover was not observed in this test. The maximum temperature level of 444°C recorded at TC 13 was considerably lower than in tests 10, 12 and 14, and below the levels typically measured when approaching flashover. In addition, the maximum incident heat flux measured at the floor during this test was approximately 0.5 W/cm^2, which is considerably lower than the levels attained in the other tests.

Changes in concentrations of CO, CO_2 and O_2 during test 11 were similar in character to the temperature change measured along the ceiling (TC 13). A gradual increase in concentrations of CO, and CO_2 and a gradual depletion of O_2 occurred during initial fire growth. But, after the peak burn rate of the chair was reached (corresponding to a maximum temperature of 444°C at TC 13) the concentrations of CO, CO_2 and O_2 in the living room began to stabilize at relatively constant levels.

As indicated by the results of the other tests in this series, the size of the fire and the rate of fire buildup directly affected the change in the environment monitored beyond the back exit door at the entrance to bedroom No. 1. Since none of the other furniture items present became involved, the maximum level of fire intensity in test 11 resulted from the burning upholstered chair.

Smoke concentration reached a level corresponding to 0.26 OD/m at 9 min 40 sec into the test. Limiting temperature conditions were reached at this location after 11 min 30 sec had elapsed. (The maximum temperature measured at this location was about 20°C higher, and occurred approximately one minute later.) The elapsed time to reach 100°C was on the order of 3 to 3 1/2 minutes longer than under a similar test setup in tests 12 and 14. A limiting concentration of O_2 was reached at 11 min 50 sec into the test which was approximately four minutes longer than in test 14. (As noted, a limiting level of O_2 was not reached in test 12). A limiting concentration of CO was not reached at this location; a maximum percent concentration of 0.3% was measured at 18 min 20 sec elapsed time. The maximum time-rated accumulation of CO was also very low; 16 720 ((ppm)$^{1.036}$(min) at 18 min 30 sec elapsed time.

6. DISCUSSION

6.1. Fire Growth in Room of Origin

Once a room fire has progressed to the flashover stage dramatic changes take place in the environment, and the fire spread to adjacent areas is almost assured. This is of particular concern in a mobile home where this chain of events can result in total destruction of the room of fire origin and extensive damage to the adjacent areas. Generally, reconditioning of a mobile home after a fire of this magnitude is not pursued due to the extent of damage.

The experimental data reported herein indicate that a fire from an incidental ignition such as an upholstered chair or a simulated piece of furniture in the living room will not by itself generate sufficient heat and flames to result in a fully involved room fire. The results of tests 6 and 11 provide some information on the effect of the size of the initial burning item. In test 6, using a wood crib with an approximate maximum burn rate of 6 g/s, the peak temperature measured at TC 13 was 176°C. In test 11, using an upholstered chair with a maximum burn rate of 16 g/s the peak temperature at TC 13 was 444°C. This would indicate, as one might expect, that the larger the initial burning item, the more severe the exposure fire. And, there exists a maximum burning rate (estimated in previous studies with similar experimental setups to be on the order of 40 g/s [12]) at which the burning item alone may result in room flashover.

The effect of other furniture items on the fire growth up to flashover was considerably less significant under the fuel loading arrangements tested than the effect of the initial burning item and the subsequent exposure of the interior finish materials. Generally, ignition of other items of furniture from exposure to the burning item was primarily the result of heat transfer processes as the conditions in the upper room approached flashover. As previously indicated in the analysis, the radiative and convective heat flux dropped off quickly in the horizontal direction which indicated that it was difficult to ignite furniture at distances greater than 15 - 20 cm (6-9 in). As a result of this, involvement of the other combustible furniture items generally occurred when radiant energy was transferred at a sufficient rate from the heated smoke layer in 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, and corresponded to an average upper room temperature 25 mm (1 in) below the ceiling in excess of 600°C.

The results indicate that the likelihood that an incidental fire will develop into a fully involved room fire is significantly influenced by the fire properties of the exposed interior finish materials on the walls and ceiling. For example, in all four tests in which the interior finish was 4 mm (5/32 in) thick prefinished lauan plywood walls and 13 mm (1/2 in) thick wood fiberboard ceiling tile, regardless of which incidental burning item was used, temperatures in the upper room exceeded 600°C and flashover occurred.

Figure 10 compares the temperature rises at TC 13 for tests 6, 9, 10, 11, 12 and 14. It shows that the use of the wood crib (test 9) or the use of an upholstered chair (test 10), or increasing the amount of furnishings in the room (tests 12 and 14) did not appreciably change the fire severity when the interior finish materials were the same. However, examination of the temperature rise in tests 6 and 11 indicates that there was a change in fire development when the interior finish was changed to materials having different fire properties.

Early fire development was mostly the result of the fuel contribution from the initial burning item and the wall material. At the point at which the wall became involved the rate of change (indicated by the slope change in the plotted results in appendix B) of the measured conditions in the living room 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 above 600°C, total room involvement occurred. When the upper walls and ceiling did not become extensively involved, the maximum temperature in the upper room did not reach 600°C and flashover was not observed. Figure 11 provides a comparison of upper room temperature and incident heat flux at the floor. The range of upper room temperatures at which incident heat flux levels were high enough to involve other combustibles in the room is illustrated.

The results of the individual tests indicate that while there were some reversals in the ordering of the various measured conditions (temperature, CO, CO_2, O_2) the various combinations of wall and ceiling materials resulted in changes in measured conditions in the living room which fit qualitatively into three groups. One group consisted of those tests resulting in room flashover. Another group consisted of those tests in which peak temperatures at TC 13 did not approach the 600°C level. The third group consisted of those tests in which a low order change in measured conditions occurred (see table 10).

Group 1

The most severe fires occurred in the tests in which untreated prefinished lauan plywood and fire retardant treated plywood walls were used in combination with low density wood fiberboard ceilings. Maximum upper room temperatures ranged from 673 - 771°C in this group, and flashover was observed in each test. High levels of CO, and CO_2 and low levels of O_2 were reached.

Group 2

The tests in group 2 were characterized by lower maximum upper room temperatures, and lower peak concentrations of CO and CO_2, as well as less O_2 depletion. The maximum upper room temperatures in this group were below 600°C, ranging from 311°C to 520°C. The influence of the walls in fire growth can not be clearly delineated in this group with the exception that the contribution to fire growth was not sufficient for the fire to reach flashover. Tests 2 and 3, using untreated prefinished lauan plywood of different thicknesses, resulted in the highest upper room temperatures. One of the tests using fire retardant treated materials also resulted in temperatures in this range. However, the data from test 4 indicated that the use of the other fire retardant treated material with the same ceiling as used in tests 2, 3, and 5 resulted in a lower maximum upper room temperature (311°C).

While initial fire growth was primarily influenced by the extent of involvement of the walls the significant reduction in the severity of the fires in the second group appears to be the influence of both the upper wall and the ceiling materials in limiting upper room temperatures to below 600°C. The particular influence of the ceiling can be seen when comparing the results of tests in group 1 and 2 with the same wall material; a dramatic change in the character of the time-temperature curve for TC 13 is indicated when changing from the conventional wood fiberboard ceiling to a ceiling of limited combustibility.

It would appear that test 13 fell into group 2 rather than group 3 primarily as a result of the involvement of the wood fiberboard ceiling material, even though gupsum board walls were used. The paper surface on the gypsum provided an adequate fuel source to propagate the wood crib fire to the ceiling for a short period of time. As the fuel was depleted the flames receded, no longer impinging on the ceiling. However, the ceiling continued to smolder and the heated gases accumulated above the ceiling membrane, igniting the unexposed side.

Test 11, using gypsum board walls and ceiling, also resulted in changes which placed it in group 2. As previously described, the burning rate of the upholstered chair was nearly three times the burn rate of the wood crib. This, along with the fuel contribution from the paper surface on the walls, (though considered very low) increased the temperature in the upper part of the room to a maximum of 444°C.

A test was not conducted exposing gypsum walls and a combustible ceiling to an upholstered chair fire. However, there is some indication from the results of the other tests and the burning characteristics of the upholstered chair that a test of this configuration may have resulted in more extensive involvement. Whether or not the resulting radiative energy from the upper room to the combustibles in the lower part of the room would be of a sufficient level to initiate flashover can not be determined from these test results.

Group 3

The tests in group 3 resulted in the least severe fires in which only minor changes were measured. The third group consisted of tests 6, 15 and 16. Tests 15 and 16 were conducted with noncontributing calcium silicate panels on the walls and ceiling in order to examine the burning characteristics of the two initial burning items. Test 6 was conducted using gypsum board walls and ceiling.

The wood crib fire in test 15, with a maximum burn rate of 6 g/s, resulted in a maximum temperature of 149°C at TC 13. The properties of the walls and ceiling in test 6 resulted in a fire which was only moderately more severe than in test 15; that is, a maximum upper room temperature of 176°C. In addition, changes in measured concentrations of CO, CO_2, and O_2 were negligible in test 6.

6.2. Effects of Fire Growth and Spread on Attainment of Limiting Conditions

Interpretation of quantitative data regarding the actual time available for an individual to escape a typical mobile home, after being alerted to an ignition which would progress in a manner similar to those in this test series, is somewhat difficult. An analysis of the escape time under an emergency fire condition must include an evaluation of factors such as the size, location, and growth rate of the fire and the physiological and psychological condition of each of the occupants at the time they are alerted to the emergency condition. In addition, factors such as the number of occupants, the age of occupants, and whether the escape route from the mobile home involves moving toward the fire or away from it, are also important. A conservative estimate would exclude any fire suppression or fire-fighting activities.

In order to develop design criteria for life safety in a fire emergency, all possible fire situations should be considered. However, every possible fire situation cannot, from a practical standpoint, be examined by full-scale testing, nor can the physiological effects on every human being be clearly identified. In order to provide a reasonable description of the fire growth and its effect on life safety based on these tests, some subjective judgments must be made.

Experience has shown that once flashover has been reached in a room all of the combustible materials in the room will be contributing to the intensity of the fire. Upon reaching this level of fire intensity, the fire will probably be spreading to adjacent rooms. Therefore, the time required to reach flashover is a reasonable indicator of the transition point beyond which effective fire suppression can no longer be depended upon, and damage to the occupancy and furnishings can be expected to be extensive. Life safety is obviously in jeopardy beyond this transition point.

Regardless of age, physical capability and human tolerance, if occupants do not escape before flashover, survival is not expected. However, since tolerable conditions may deteriorate prior to flashover, escape may be prevented or seriously retarded. Therefore, the results were examined to determine whether or not the contribution of different types of interior finish materials when exposed to similar ignitions appreciably affect the change in environmental conditions considered necessary for continued safety of the mobile home occupants, and whether or not this occurred at a significantly earlier point in time than flashover.

The results of these sixteen full-scale tests confirm that in a typical single-wide mobile home, the rate of growth and maximum fire size can be used to determine whether or not limiting conditions are reached, and to some extent the time available for the occupant to respond to the situation. Ignition of an incidental item of furniture such as a waste basket or upholstered chair can be considered a typical fire incident in a residence. If the occupants are awake, or if they are aroused by an alarm and are alert, there should be time available to escape the mobile home prior to being overcome by the fire.

Under the experimental conditions established for this test series, the initial incidental fire resulted in flame impingement on the interior wall surface after a period of time. However, the exact time at which this occurred varied due to inherent variation in the initial fire development. For ten of the eleven tests with the wood crib, the extreme difference in the time to flame impingement was only 24 seconds. One of the tests (test 9) had a somewhat larger variation, which was 55 seconds longer than any of the other ten tests using a wood crib. In the five tests using the upholstered chair, the variability in the time for flames to impinge on the wall was considerably larger, ranging from 180 to 330 seconds. Figures 12 through 14 illustrate both the variation in the time to flame impingement on the wall, and the elapsed time from flame impingement on the wall to limiting conditions of temperature, carbon monoxide and oxygen for each of the sixteen tests.

The influence of the variation in initial fire growth prior to exposure of the wall surface must be adjusted in order to better compare the effect of the individual wall and ceiling systems when exposed to the same initial fire. Therefore, table 11 provides a tabulation of data based on the elapsed time from initial flame impingement on the wall surface to limiting conditions of temperature, carbon monoxide and oxygen. Discussion of these results follows.

6.2.1. Carbon Monoxide

As discussed in section 2.6., the thresholds for limiting levels of CO were either 1) a time-rated accumulation of 41 800 $(\text{ppm})^{1.036}(\text{min})$ which is approximately equivalent to 25% COHb, or 2) an instantaneous concentration of 1.0% CO by volume. One or both of the thresholds for CO was exceeded in ten of the sixteen tests, and was the first limiting condition reached in six of these (tests 1,2,7,9,10,12).

In the tests which flashed over, the 1.0% instantaneous concentration which was reached very quickly, and exceeded by a substantial amount, was the determining threshold for CO. However, in tests 2, 3, and 8, in which flashover did not occur, 1.0% CO was either not reached (test 3), or just barely exceeded (tests 2 and 8). In these three tests the time-rated accumulation of 41 800 $(ppm)^{1.036}(min)$ was also exceeded. Again, however, the threshold was either exceeded by only a small margin, or after a considerably longer test duration. In tests 3 and 8, the maximum time-rated accumulation was noticeably higher than the threshold. This was not due to excessive generation of CO, as can be seen in figures B35 and B40. Rather, it was the result of extended test durations.

A limiting level of CO occurred in all five of the tests conducted with prefinished lauan plywood walls and wood fiberboard ceiling, ranging from 2 min 20 sec to 3 min 5 sec. Tests 2 and 3 were conducted under similar conditions to tests 1 and 9 with prefinished lauan plywood walls, but in tests 2 and 3 the ceiling was gypsum board rather than wood fiberboard. The results show little change in CO generation when testing a gypsum ceiling. In test 2, a limiting CO concentration was reached after 2 min 30 sec elapsed, and while 1.0% CO was not reach in test 3, the maximum level recorded was 0.9%, and the time-rated accumulation exceeded the threshold of 41 800 $(ppm)^{1.036}(min)$.

In examining the results from the tests using fire retardant treated walls with a wood fiberboard ceiling, the significant variation in performance between the two types of fire retardant treatments under full-scale test conditions is again evident. In test 8 (intumescent coating), a limiting condition of CO was reached after 10 min 12 sec but in test 7 (vinyl film) it occurred in 2 min 56 sec. The results of tests 4 and 5 indicate a similar disparity when using a gypsum ceiling with the two different types of fire retardant treated walls.

A limiting condition of CO was not reached in any of three tests with gypsum walls. These included test 6 with a gypsum board ceiling and test 13 with a wood fiberboard ceiling, both using the wood crib exposure fire, and test 11 with gypsum board on both the walls and ceiling, using the upholstered chair exposure fire.

6.2.2. Temperature

Limiting temperature conditions were reached at TC 37, 1.5 m above the floor just beyond the back exit door, in ten of the sixteen tests. In five of the tests (tests 3, 5, 8, 11, 14) it was the first (or only) limiting condition reached. Table 11 illustrates the elapsed time from flame impingement on the wall to 100°C at TC 37 for this test series.

The results indicate that the shortest elapsed time from flame impingement on the wall to 100°C at TC 37 occurred in the tests using untreated lauan plywood walls and a wood fiberboard ceiling, ranging from 2 min 45 sec in test 12 to 3 min 20 sec in test 9. In tests 2 and 4 where untreated and fire retardant treated prefinished lauan plywood walls were tested with a gypsum board ceiling, limiting temperature conditions did not occur; in addition, in those tests using prefinished lauan gypsum board walls (tests 6, 13) limiting temperature conditions were not reached. However, the results of the four tests using two types of fire retardant treated plywood walls indicate considerable variation in temperature development under full-scale conditions with fire retardant treated plywood materials.

Examination of the temperature data specifically for those tests using the upholstered chair indicated that the limiting condition was reached in all four tests (with the exception of test 16 with noncontributing walls and ceiling). However, in tests 10, 12 and 14, 100°C was reached in three minutes or less. In test 11, using gypsum walls and ceiling, the elapsed time was 7 min 20 sec which was substantially longer. The results of these tests indicate that a limiting condition of 100°C can be reached at TC 37 in as little as 2 min 40 sec after initial flame impingement on the wall. Further, the use of a gypsum board ceiling may provide an appreciable advantage in limiting temperature development, specifically for the case of the wood crib exposure. For example, in test 1 (lauan plywood walls and wood fiberboard ceiling) and test 8 (intumescent coated lauan plywood walls and wood fiberboard ceiling), 100°C occurred after 3 min 15 sec and 7 min 56 sec, respectively. But in tests 2 and 4, in which the same wall materials were used, but the ceiling was changed from wood fiberboard to gypsum board, the 100°C limiting condition was not reached.

Finally, in those tests using gypsum board walls with the wood crib fire limiting temperature conditions were not reached. And, in the test using gypsum board walls and ceiling with the more severe upholstered chair fire, limiting conditions were reached 7 min 20 sec after flame impingement on the wall surface. Therefore, the use of gypsum walls and ceiling resulted in the longest period to attainment of 100°C at the back door for both the wood crib and upholstered chair fires.

6.2.3. Oxygen

Oxygen depletion measurements taken 1.5 m above the floor just beyond the back exit door indicate that in a typical single-wide mobile home a fire starting in the living room can potentially result in a reduction of oxygen in the environment in adjacent areas outside the living room to a level which would adversely affect life safety.

With the exception of test 12, a level of 14% O_2 concentration was reached in all of the tests using prefinished lauan plywood walls and a wood fiberboard ceiling, ranging from 2 min 50 sec to 4 min 5 sec elapsed time. The results of tests 2 and 3 indicate that some increase in time occurred when the ceiling was changed to gypsum board. In test 3, 7 min 18 sec elapsed from the time of flame impingement on the wall to 14% oxygen concentration, and in test 2, the limiting concentration was not reached.

The results of the four tests with fire retardant treated plywood walls indicated similarities in the attainment of limiting concentrations of O_2 and CO. In tests 7 and 8, 14% O_2 was reached after 3 min 6 sec and 9 min 56 sec, respectively. And, in tests 4 and 5, with a gypsum ceiling, the limiting concentration of O_2 was not reached.

In tests 6 and 13, using gypsum walls, a limiting concentration of O_2 was not reached. However, in test 11, using the burning upholstered chair, 14% O_2 was reached after 7 min 40 sec. It would appear that the lower intensity of the fire due to the limited propagation beyond the chair did not result in conditions which caused failure of any of the living room windows. Without the necessary ventilation, the chair fire was dependent to a greater degree on the oxygen available in the other areas of the mobile home. Therefore, eventually a reduction in oxygen to the 14% threshold occurred, although the elapsed time was considerably longer than in those chair tests with untreated prefinished lauan plywood walls and wood fiberboard ceilings.

6.3. Smoke Generation

As discussed in section 2.6.4, 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 the level of smoke accumulation which may begin to impair emergency escape along normal paths provided in the mobile home.

The results of tests 15 and 16 indicate that an accumulation of smoke corresponding to an optical density of 0.26 OD/m occurred as a result of the burning ignition source in approximately six minutes or less. However, this time was considerably reduced in the other tests due to the involvement of the interior finish materials.

The elapsed time from flame impingement on the wall to 0.26 OD/m ranged from 45 seconds in test 12 to six minutes in test 16. Figure 15 illustrates both the variation in the time to flame impingement on the wall and the time from flame impingement on the wall to 0.26 OD/m optical density for all sixteen tests. In the five tests conducted with untreated prefinished lauan plywood walls and a wood fiberboard ceiling (tests 1, 9, 10, 12, 14) 0.26 OD/m occurred in less than two minutes. In addition, in those tests (test 2, 3) where the ceiling was changed to prefinished gypsum board, there was no appreciable change. Therefore, while the involvement of the interior finish material did influence the rate at which smoke was generated, the lauan plywood wall materials and the single burning item together resulted in attainment of 0.26 OD/m in less than two minutes, regardless of the type of ceiling material used.

The results of the tests using fire retardant treated lauan plywood walls indicate that the combined use of fire retardant treated walls and a gypsum board ceiling (test 4) can provide a marginal increase in elapsed time from flame impingement on the wall to 0.26 OD/m optical density beyond the two minutes which occurred with untreated prefinished lauan plywood walls. However, of more significance in evaluating the smoke data from tests 4, 5, 7, and 8 was the indication that different methods of fire retardant treating interior finish materials result in significant variations in fire development and resulting smoke generation. In tests 5 and 7, using one type of fire retardant treatment with two different ceilings, 0.26 OD/m optical density was reached in less than one minute after flame impingement on the wall surface. Of the seven tests conducted with untreated lauan plywood walls, only two tests (12, 14) resulted in attainment of 0.26 OD/m in less than one minute. This indicates that different chemical formulations and application techniques for fire retardant finishes on interior finish materials may result in considerable variation in the generation of smoke under full-scale conditions.

The results of tests 6 and 11 using gypsum walls and ceiling indicated that a greater delay occurred in reaching an optical density of 0.26 OD/m compared to tests using untreated or fire retardant treated lauan plywood walls. In test 6, it was reached in 2 min 20 sec which represents an increase of 40 seconds over the longest period provided when testing untreated lauan plywood walls with the wood crib fire. In test 11, using an upholstered chair fire the elapsed time from flame impingement on the wall to 0.26 OD/m was 5 min 30 sec which was considerably longer than in the tests conducted with untreated lauan plywood and fire retardant treated walls, and only 30 seconds sooner than in test 16 using noncontributing walls and ceiling.

Inasmuch as smoke is difficult to measure, and a strong function of the initial burning item, ventilation, and geometry, and since the measured values would skew the results out of proportion, it has been decided to exclude smoke as a criterion at this stage and to base the following discussion on temperature, carbon monoxide and oxygen. However, smoke is a critical factor and the use of materials which generate little or no smoke is obviously desirable.

6.4. Fire Development-Impact on Life Safety

Figure 16 provides a summary of the occurrence of limiting conditions of temperature, carbon monoxide and oxygen in the corridor as a function of elapsed time from flame impingement on the wall for this series of full-scale fire tests. This technique provides a means of examining the performance of a variety of wall and ceiling systems assuming similar initial development of the fire.

The time available for emergency escape 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 55 seconds for initial flame impingement on the wall to occur, and an additional 205 seconds to reach flashover (e.g., test 1) then the maximum time available before survival becomes unlikely and damage is extensive is 260 seconds.

However, changes in conditions prior to flashover may significantly affect the occupants ability to escape from the mobile home. When an elevated smoke level is reached, it becomes difficult for an occupant to move either along the corridor or in any adjacent rooms in which the doors are not closed. 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.

Difficulty in exiting the mobile home through an entrance door may be increased considerably once an additional limiting condition is reached. Limiting conditions of temperature, CO and O_2 will directly affect the capacity of the occupant to move. Survival along the egress passages and in any room not closed to the fire is extremely questionable under these conditions. Finally, flashover is reached, and with it, as previously mentioned, a significantly reduced probability that one can survive any longer in that environment.

The information in figure 16 can be interpreted in a number of ways. For example, if the attainment of a single limiting condition (e.g., limiting conditions of temperature, CO, or O_2) is considered the point of incipient incapacitation for an occupant, then the time from flame impingement on the wall to the point at which this occurs can be determined for each of the sixteen tests. Other factors to be considered in an exercise of this nature would be the expected time for initial development prior to flame impingement on the wall as well as the likelihood that the occupants are aware of the fire, or alerted to its existence by automatic detection.

The present Federal Mobile Home Construction and Safety Standard requires the installation of a smoke detector in all newly constructed mobile homes. The reliability and effectiveness of automatic smoke detection is of consierable importance in assessing the benefits one would hope to obtain by inclusion of such a device. Tests conducted at NBS [86] showed that the performance of photoelectric type residential smoke detectors in mobile home test fires varied considerably for changes in test control variables such as location of the device, operation of the heating (or air conditioning) system, and the alarm threshold of the detector itself. Additional research in this area will be conducted at NBS in 1978 under the sponsorship of the Department of Housing and Urban Development.

6.5. Surface Flammability as a Fire Safety Criterion

6.5.1. ASTM E-84 Tunnel Test Method

The Federal Mobile Home Construction and Safety Standard references the ASTM E-84 Tunnel Test as the laboratory method for evaluating wall and ceiling interior finish materials for use in mobile home construction. Specifically, section 280.203 of the standard limits the surface flame spread of interior finish materials to a maximum flame spread classification (FSC) of 200 in accordance with the ASTM E-84 Tunnel Test. No requirements are included for "smoke developed" or "fuel contribution" which are also obtained from this test method. The limitation of interior finish materials to those having a surface flame spread value less than or equal to 200 was adopted based on a similar requirement in the voluntary consensus standard for Mobile Homes (NFPA 501B, ANSI 119.1) utilized extensively by mobile home manufacturers and the state and local regulatory authorities prior to the adoption of the Federal Mobile Home Construction and Safety Standard in June, 1976.

A literature search was performed by NBS to identify and evaluate the technical basis for the flame spread requirements presently referenced in the standard. Review of previous editions of the voluntary standard revealed that the 1963 and 1964 editions of NFPA 501B had a maximum surface flame spread requirement of 150 for interior finish materials. The surface flame spread requirements had been changed to 200 in the 1968 edition of NFPA 501B.

Review of available documents related to committee activities of NFPA 501B provided little relevant technical data regarding the rationale to support either requirement. Additional literature review of other technical works on the subject of surface flammability of materials indicated that little experimental work had been done on structures which resembled mobile homes in geometry. It is most likely that these requirements evolved from professional judgment and guidance based on other types of construction where similar requirements already existed.

Even though surface flame spread characteristics may not dominate fire growth under all situations, the flammability of interior finish materials can often determine the potential for fire spread beyond the initial burning item as well as the development of the fire within the enclosure. Technological advancements have been pursued to provide the building industry with methods of comparing the surface burning characteristics of materials. While there are at least three laboratory scale methods of testing for surface flame spread of materials[4], practically all of the building code requirements in the United States for control of the flammability of interior finish materials are based on the ASTM E-84 Tunnel Test method.

The purpose of the test is to determine the comparative surface burning characteristics of the material under test by evaluating (1) flame spread, (2) fuel contributed, and (3) smoke developed. The test establishes a basis on which surface burning characteristics of different materials may be compared.

A specimen 51 cm (20 in) wide by 7.3 m (24 ft) long, usually in three sections, is mounted and supported on the top ledge of a long test chamber. The chamber consists of a masonry (fire brick), insulated, horizontal tunnel having an inside width of 44.5 cm (17.5 in), a height of 30 cm (12 in) and a length of 7.6 cm (25 ft). The tunnel is open at both ends, the "fire" and

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[4]ASTM E-84 Test for Surface Burning Characteristics of Building Materials; ASTM E-162 Test for Surface Flammability of Materials Using a Radiant Heat Energy Source; FPL Eight Foot Tunnel Method (8 ft tunnel developed at U.S. Forest Products Labs.).

"vent" ends. The specimen, in a ceiling position with the side to be tested facing down, is subjected to a 1.4 m (4.5 ft) long diffusion flame fed by 139 ℓ/m (4.9 CFM) of methane delivered through two gas ports pointing upward at the fire end. Forced draft induced by a blower and damper system at the "vent" end of the tunnel pulls air through a small air inlet upstream from the burners into the fire end. A prescribed average velocity measured at the vent end prior to ignition is required. After ignition, a constant negative pressure (draft) is maintained and controlled by the damper system. The flame and draft serve to ignite the specimen and to induce flame spread along the ceiling of the tunnel. Windows located on the side of the tunnel allow an observer to record the extent of flame spread as a function of time over the last 5.9 m (19.5 ft) of the 7.3 m (24 ft) specimen. Test duration is 10 minutes. The flame spread classification (FSC) is based on a scale which has 0 for asbestos-cement board and 100 for a selected grade of red oak flooring. The FSC calculation is currently based on the area under the curve which depicts flame distance versus time.

6.5.2 Comparison of Full-Scale Results and ASTM E-84 FSC

The test results indicated that fire growth and spread depended to a large extent on the temperature rise in the upper room. For the scenario adopted in this test series the attainment of high temperatures in the upper room was a function of the amount of heat released from the burning materials, including the initial burning item and the walls and ceiling. This principle is in agreement with the basic concept that the amount of heat generated in a room fire is a function of the rate of heat release and extent of involvement of the combustible materials in the room.

The results presented in this report demonstrate that the rate of fire development and the attainment of high temperatures in the upper room depended at least in part on the surface flame spread characteristics of the interior finish materials. That is, as the flame propagated over the material surface, a larger area of involvement resulted, providing increased heating and additional fuel. Therefore, as a part of this series, the surface flame spread classification determined in accordance with the ASTM E-84 Tunnel Test for each of the interior finish materials 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 tests 15 and 16 with walls and ceiling of FSC 0, the heat generated in the room was primarily from the initial fire, which did not spread beyond the burning item. However, in other tests, the extent of flame propagation along the interior finish materials (to some extent a function of surface flame spread characteristics) affected the temperature rise in the upper room, the production of fire gases, and the attainment of flashover.

Examination of figure 16 shows that the most severe conditions occurred in those tests in which flashover occurred; the thresholds for limiting conditions of temperature, CO and O_2 were reached just beyond the back exit door at nearly the same elapsed time after flame impingement on the wall as did flashover in the living room. While these events did not occur at precisely the same time, the maximum range in elapsed time for all of these events to occur was 85 seconds (test 7) and was as low as 14 seconds (test 14). In addition, the thresholds were exceeded by a considerable amount (table 8) indicating that the environmental conditions continued to decay as the fire developed into the flashover stage, resulting in progressively more severe conditions.

In the tests in which flashover did not occur, the rise in temperature and CO concentration and the depletion of oxygen just beyond the back exit door was quite different. First of all, only in tests 3 and 8 were the thresholds exceeded for all three measured conditions. In tests 4, 6, 13, 15 and 16, none of the thresholds were reached; and, in the remaining three tests only one or two of the three measured conditions reached the selected thresholds. A second important point was that in most cases the thresholds were only marginally exceeded, indicating that for the threshold values selected, the rise in temperature and CO concentration and the depletion of O_2 either did not approach thresholds for limiting conditions, or barely exceeded them, indicating a borderline case. Noteable exceptions were tests 3 and 8 in which the accumulated CO exceeded the selected threshold by a substantial amount, but after an extended test duration. A final point of interest was that in the tests in which flashover did not occur, the periods of elapsed time from flame impingement on the wall to the attainment of the limiting conditions were substantially longer than in those tests in which flashover occurred, therefore, providing additional time to escape.

These results revealed that for fires similar to those in this experimental setup, the attainment of flashover in the room of origin is an important point in fire development, both from the standpoint of property damage and life safety. And, to the extent that flashover does not occur, the environmental conditions are less severe throughout the mobile home and fire damage is limited to the room of origin. Therefore, flashover was selected as the critical event in fire development, and the surface flame spread properties of the wall and ceiling materials based on the results of the ASTM E-84 (FSC) were examined to determine the relationship between the FSC and the behavior of the materials as installed under actual full-scale conditions.

In order to specify the range of FSC for combinations of wall and ceiling materials which will not result in flashover in the living room of a mobile home, a matrix was developed (figure 17) based on the results of the full-scale fire tests. The shaded region in the matrix represent those combinations of wall and ceiling materials which either resulted in flashover or were judged to have the potential for flashover from exposure to an incidental fire. Judgments are based primarily on the concepts that (1) material combinations having lower FSC generally result in lower fire spread rates under full-scale conditions, and (2) small differences in FSC, without significant changes in the thermo-physical properties of the materials themselves do not significantly alter fire severity. In addition, while flashover was not observed in test 8, the combination of a wall with FSC 41 and ceiling with FSC 73 has been included in the group of material combinations determined to have potential for flashover from an incidental fire. This was judged appropriate due to the high upper room temperatures measured in test 8 with a wood crib exposure fire. The temperature data indicated that the conditions in the living room were near flashover, and it is likely that the more intense upholstered chair fire would have resulted in flashover.

A number of key points can be drawn from the information in the matrix. For example, when a ceiling material of FSC 11 in combination with wall materials having FSC ranging from 24 to 182 were exposed to an incidental fire from the wood crib, flashover was not reached. However, flashover occurred in those tests where wall materials having a FSC of 56 and above were tested in combination with a ceiling material having a FSC of 73. And, based on the assumptions upon which the matrix was constructed, flashover was considered likely to occur from exposure to an incidental fire from the wood crib of any wall material having a FSC of 41 or higher in combination with any ceiling material having a FSC of 60 or higher.

Flashover occurred in all of the tests conducted with the upholstered chair exposure fire with the exception of test 11, constructed with a wall material of FSC 24 and a ceiling material of FSC 11, and test 16 with noncontributing walls and ceiling (FSC 0).

The test results in figure 17 are summarized by selected groupings in figure 18 to provide guidance in identifying the potential for particular combinations of wall and ceiling materials to contribute sufficiently to a fire from an upholstered chair or other incidental burning item to reach flashover. For the most part, high levels of carbon monoxide, one of the dominant causes of physical incapacitation, occurred only in those tests in which environmental conditions approached or exceeded flashover. In those tests which did not flashover, but resulted in high levels of CO, the CO thresholds were exceeded after a considerably longer period of time than in those in which flashover occurred. Therefore, the matrix in figure 18 provides a useful tool in assessing the impact of the FSC of the walls and ceiling on the potential for reaching flashover, and to some extent the subsequent hazard to occupants as well as the potential property damage.

In figure 18, three categories or regions of performance are identified: one region includes those combinations of FSC in which flashover did not occur; another region includes all of the combinations in which flashover did occur; the remaining region separates the two and represents those combinations along the boundary in which, due to lack of data, no determination can be made. The size of this boundary region is dependent upon the number of combinations of FSC actually tested.

In general, the potential for flashover for a specific sized burning item and a specific combination of wall and ceiling materials is reduced as the size of the enclosure or room is increased. Therefore, the matrix in figure 18 applies most reliably to a room and a single burning item of the same sizes as tested. The use of the matrix should be restricted to "conventional materials". Materials with widely divergent properties such as low density foam plastics or other exposed insulation materials would require additional full-scale testing in order to determine performance. Therefore, a reduction in fire losses through specification of interior finish materials using the matrix in figure 18 would be limited to those fires in which conventional interior finish is exposed to an incidental fire such as a burning upholstered chair or smaller item of furniture in a room of similar configuration.

It is important to note that while these restrictions in interpreting the matrix do exist, the ability to construct such a tool based on FSC illustrates some usefulness of the ASTM E-84 Tunnel Test as an indicator of the potential fire contribution of wall and ceiling interior finish materials to fire growth in mobile homes.

7. SUMMARY

Sixteen full-scale tests were conducted in the living room of a typical single-wide mobile home. The experimental scenario established for this test series involved the exposure of a number of combinations of interior wall and ceiling finish materials to an incidental fire resulting from burning of a 6.4 kg (14 lb) wood crib or a 16 kg (35 lb) upholstered chair located in one corner of the room.

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 bedroom No. 1 were closed; (c) the mobile home was conditioned to 22 ± 4°C[5] and a maximum relative humidity of 45%.

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[5] In the tests 11 and 12 the interior temperature was somewhat higher due to extended periods of warm weather.

The tests showed that an incidental fire in the living room resulting from the burning of a 6.4 kg crossed pile wood crib (simulating a small item of furniture, a waste container filled with combustibles, or a magazine stand) or a medium sized upholstered chair by itself, without further contribution from the interior finish or other furnishings, will not result in room flashover or attainment of conditions of temperature, carbon monoxide, and oxygen deficiency which would incapacitate occupants along the path of egress at the back exit door of the mobile home.

Further, moderately furnishing the room with typical combustible furnishings did not appreciably alter the fire development unless and until flashover occurred. In these tests the burning of a single incidental item of furniture did not result in sufficient heat transfer to ignite other items of furniture, even in relative close proximity to the burning item. Involvement of other furnishings did not occur until conditions conducive to room flashover were approached.

The type of interior wall and ceiling finish material was found to significantly affect the growth and spread of an incidental fire. A heated gas layer from the initial burning item developed in the upper part of the room. However, as the results indicated, a single chair or wood crib did not produce temperatures high enough to result in room flashover. In specific instances, the contribution of the wall and ceiling finish materials provided the additional energy to heat the gas layer beyond 600°C and to transfer sufficient radiative energy to the lower room to result in flashover.

The rate of fire growth and the resulting severity directly affected the attainment of limiting conditions for life safety. Those fires characterized by rapid flame spread along the interior wall and ceiling finish beyond the incidental burning item resulted in rapid deterioration of all of the experimentally measured conditions for human tenability.

Based on these sixteen tests in the living room area of a mobile home some specific conclusions are drawn:

1. Flame size and exposure temperature during initial fire buildup in those tests utilizing a standardized wood crib were sufficiently repeatable to be used for comparisons of the contribution of wall and ceiling finish materials. In only one of 11 tests did the fire remain localized in the center of the wood crib for an extended period of time, thus affecting repeatability.

2. In those tests using the upholstered chair there was considerable variation in initial fire buildup. This appeared to be due to variation in the sequential involvement of portions of the chair.

3. Fire spread beyond the initial burning item occurred as a result of involvement of the wall and ceiling finish materials near the burning item. Variation in fire buildup, including rate of fire growth and spread, the severity of the fire, and resulting effects on life safety occurred, depending on the thermo-physical and fire properties of the wall and ceilng finish materials.

4. Flashover, observed to have occurred as a result of radiative heat transfer from the heated gas layer and the surfaces in the upper room to the combustibles in the lower part of the room, occurred in those tests in which the upper room temperature exceeded 600°C. Lateral heat transfer and flame propagation were not of sufficient levels to involve other combustibles.

5. A rapid rate of fire growth and the attainment of flashover always resulted in exceeding all of the selected limits established for occupant incipient incapacitation at the back exit door.

6. Flashover and limiting conditions of temperature, carbon monoxide and oxygen deficiency occurred in those tests in which prefinished lauan plywood or fire retardant treated lauan plywood walls were installed in conjunction with a wood fiberboard ceiling. The most rapid fire buildup to room flashover occurred in those tests using 4.0 mm thick prefinished lauan plywood walls and a 13 mm thick prefinished wood fiberboard ceiling. Time from flame impingement on the wall to flashover for these tests ranged from 2 min 18 sec (test 10) to 3 min 40 sec (test 9).

7. Flashover did not occur in those tests in which prefinished lauan plywood or fire retardant treated lauan plywood walls were installed in conjunction with an 8 mm (5/16 in) thick textured surfaced gypsum panel ceiling and exposed to the wood crib fire.

8. The use of prefinished gypsum walls and a textured surface gypsum ceiling resulted in the least severe fire in terms of fire growth and resulting life hazard in the test series conducted with the wood crib and in the series with the upholstered chair.

9. No appreciable quantitative differences were observed in performance in tests involving lauan plywood walls of 4.0 mm and 6.4 mm thickness in conjunction with a textured surface gypsum ceiling. The wall thickness of 6.4 mm was not tested with a wood fiberboard ceiling.

10. While 0.26 OD/m optical density was reached in all sixteen tests, presumably from the burning wood crib or upholstered chair, the extent of involvement of interior finish on the wall affected the time at which 0.26 OD/m was reached. The shortest elapsed times, less than 2 minutes after ignition, occurred in the tests with prefinished lauan plywood walls and in the tests with the lauan plywood walls treated with a fire retardant vinyl film. While this level of optical density does not correspond to incipient incapacitation as do the levels selected for temperature, CO and O_2, it does represent the level of smoke accumulation which may begin to impair emergency escape along the normal paths provided in the mobile home.

11. Limiting conditions of temperature were not reached in bedroom No. 3 with the door closed in any of the sixteen tests up to the time that flashover occurred. However, the closed bedroom 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. The post-test examination of damage indicated that many of the interior finish materials would not provide a barrier of any significance against fire penetration under such severe conditions.

12. The use of the ASTM E-84 flame spread rating provides some indication of the potential contribution of interior finish materials when exposed to an incidental fire under the conditions established in this test series.

This is a report of work in progress, intended to provide experimental data on a single segment of the research conducted under the Mobile Home Fire Safety Project. Additional full-scale living room tests are planned to provide supplemental data that will reduce the size of the boundary region in the matrix (figure 18). A summary report will be forthcoming in which these data will be included along with data collected in other segments of the project including full-scale fire testing in the kitchen, bedroom and corridor areas of a single-wide mobile home. Recommendations will be included.

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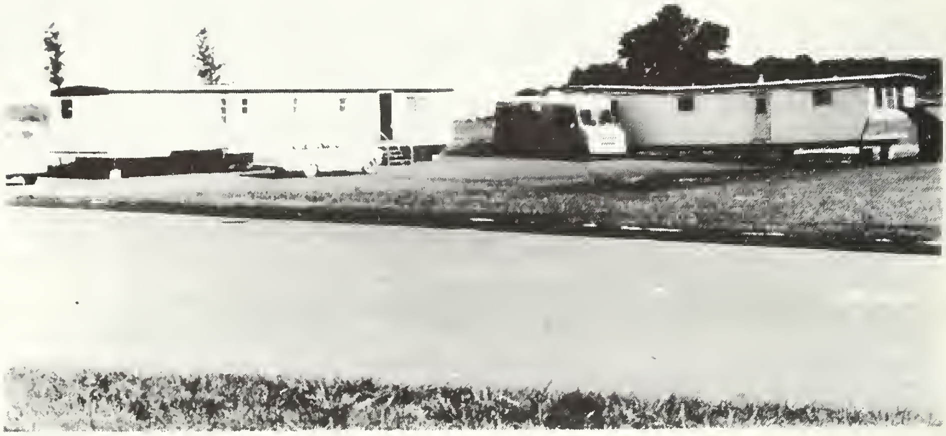


Figure 1. Illustrations of Typical Single-Wide Mobile Homes Used in Conducting Full-Scale Fire Tests.

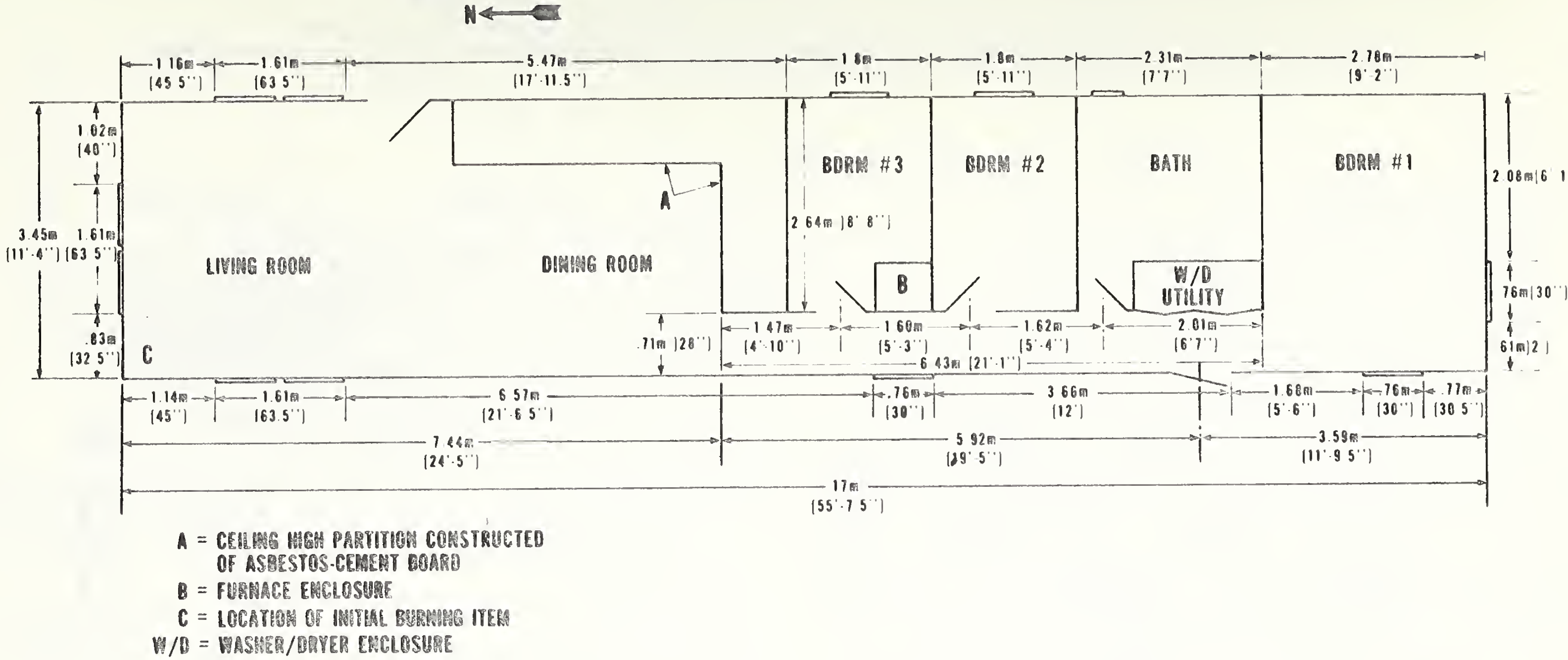
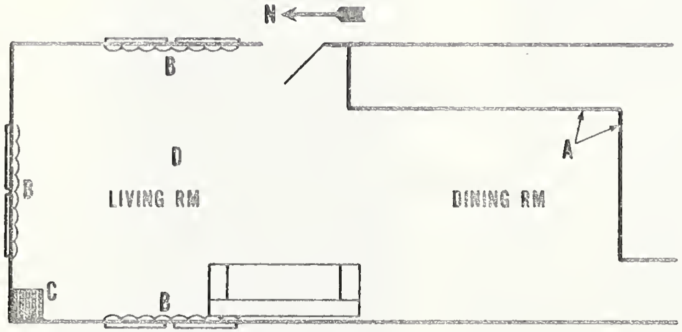


Figure 2. Plan View of Mobile Home Test Unit.

Figure 3a. Test set-up with low fuel load density.



A = CEILING HIGH PARTITION CONSTRUCTED OF ASBESTOS-CEMENT BOARD
B = CURTAINS (POLYESTER FABRIC)
C = IGNITION SOURCE POSITIONED 25mm FROM WALLS ON STRAIN GAGE LOAD CELL
D = FLOOR COVERING - 3.2mm THICK VINYL ASBESTOS

Figure 3b. Test set-up with moderate fuel density.

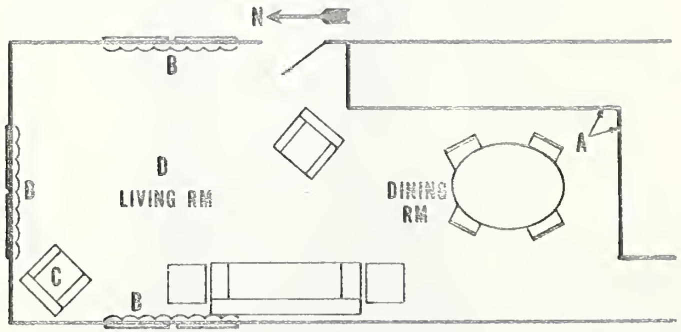
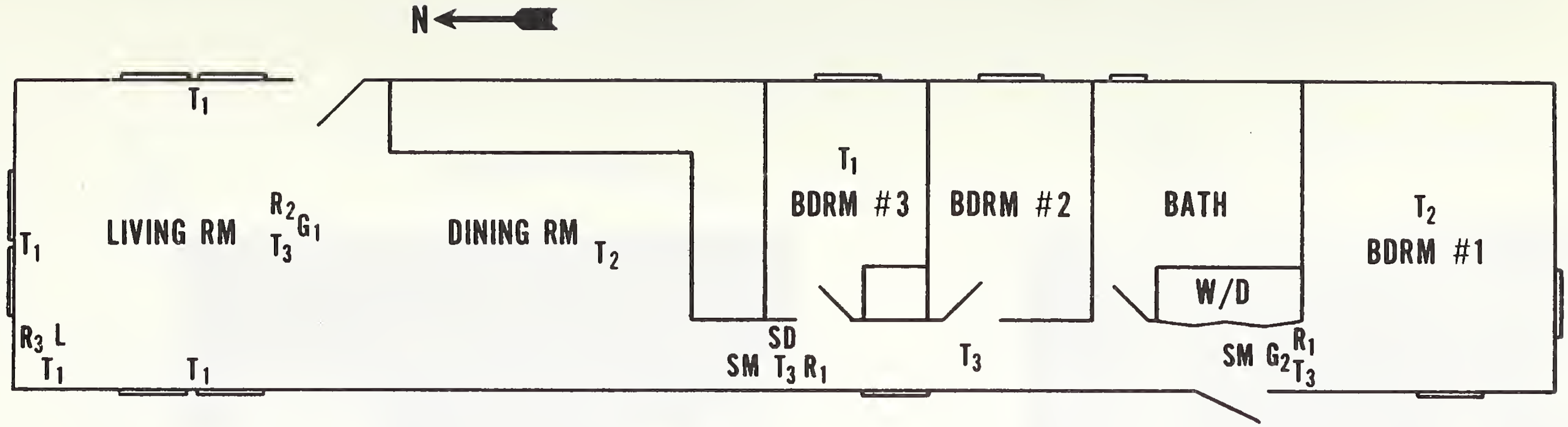


Figure 3. Plan View of Test Location in Mobile Home Illustrating Two Fuel Loading Densities Based on Removeable Contents.



<u>Temperature Measurements</u>
T_1 - thermocouples located 211, 188, and 132 cm above floor
T_2 - thermocouples located 211, 188, 132, and 91 cm above floor
T_3 - thermocouples located 211, 188, 132, 91, 46, and 2.5 cm above floor

<u>Incident Heat Flux</u>
R_1 - transducer located at floor level
R_2 - transducers located at floor and ceiling
R_3 - transducers located 0.9m and 1.8m above floor at wall surface, horozontally centered with respect to burning item

<u>Weight Loss of Initial Burning Item</u>
L - high temperature strain gage load cell

<u>Combustion Gas Measurements</u>
G_1 - CO, CO_2, and O_2, 1.5m above floor
G_2 - CO, and O_2, 1.5m above floor

<u>Smoke Generation Measurements</u>
SM - vertically aligned photometer located at ceiling; path length of light beam 0.46m
- horozontal path photometers 0.6, 1.2, and 1.8m above floor; light path 0.71m measured across corridor

<u>Smoke Detector</u>
Commerically available ionization type smoke detector positioned 178mm below ceiling on inside corridor wall

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

Figure 5a. Wood Crib

Figure 5b. Upholstered Chair

Figure 5. Illustration of Typical Test Set-Up; Location and Positioning of Initial Burning Items.

Figure 6a. Temperatures in upper part of room.

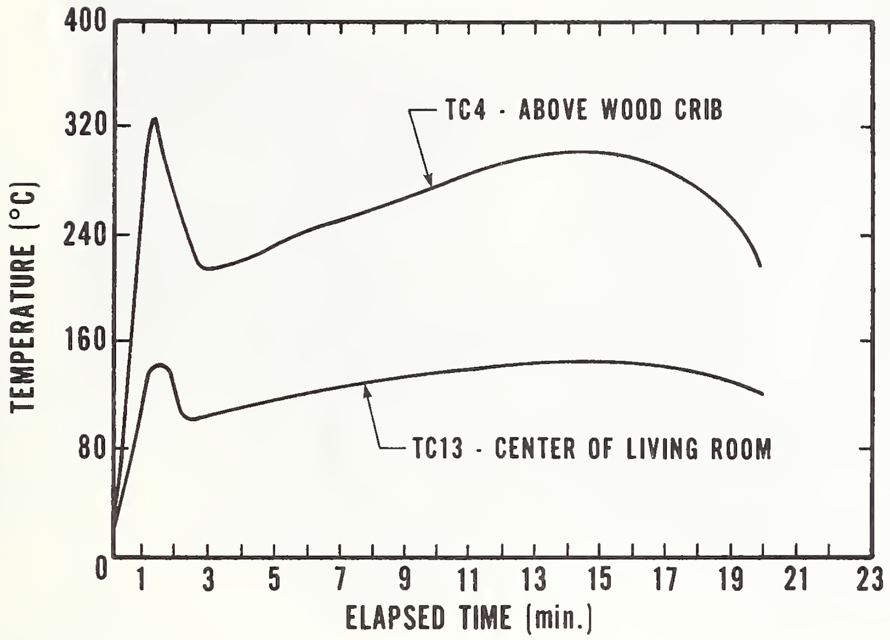


Figure 6b. Burning rate.

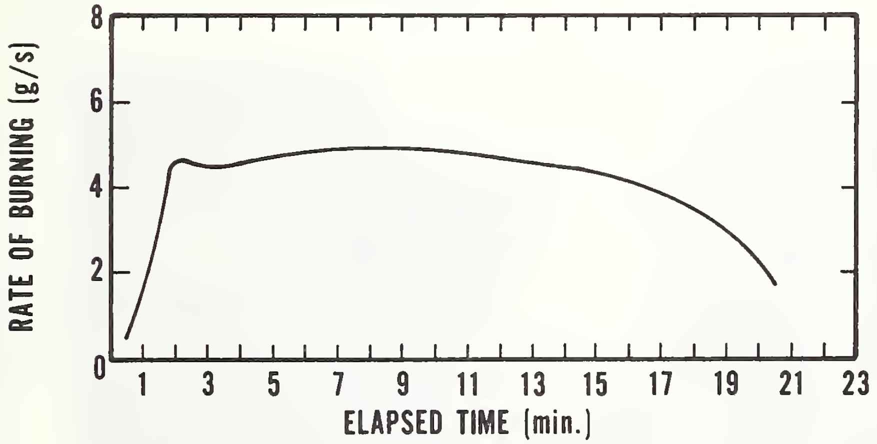


Figure 6. Burning Rate of a 6.4 kg (14 lb) Cross-piled Wood Crib and the Resulting Temperature Rise in the Upper Room.

Figure 7a. Initial Peak Flame Due to Burning Heptane

Figure 7b. Flame Resulting From Near Constant Burning

Figure 7. Illustration of Characteristic Shape and Height of Flame From a Burning 6.4 kg (14 lb) Wood Crib.

Figure 8a. Temperatures in upper part of room.

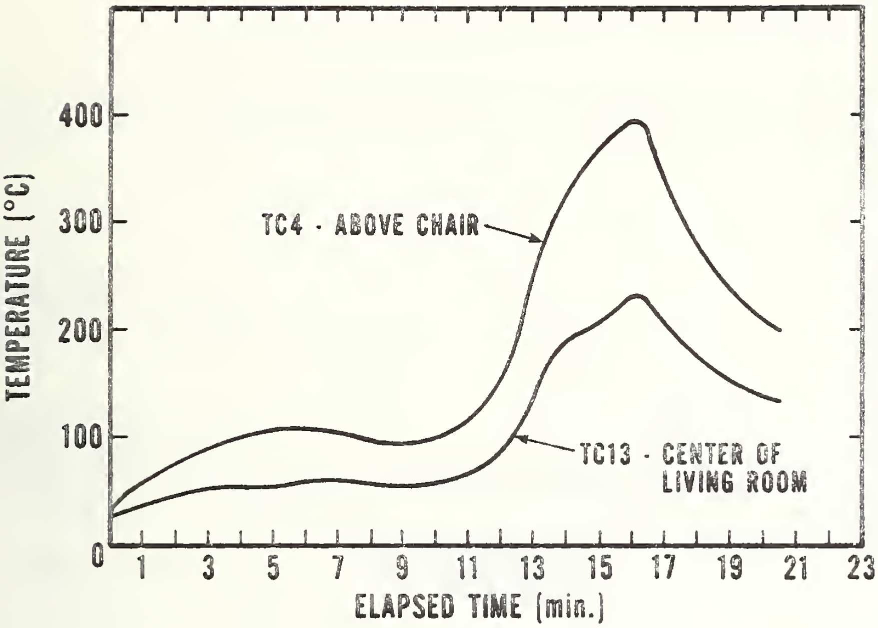


Figure 8b. Burning rate.

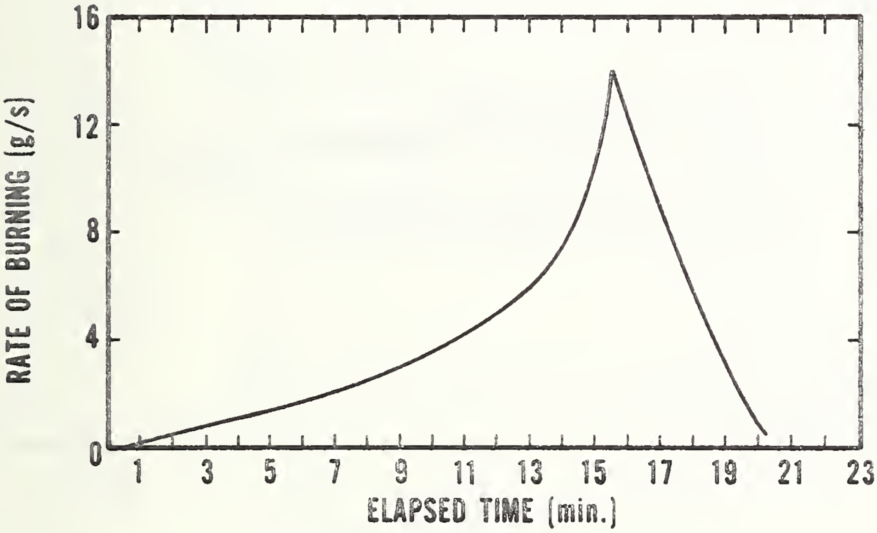


Figure 8. Burning Rate of a 16 kg (35 lb) Upholstered Chair and the Resulting Temperature Rise in the Upper Room.

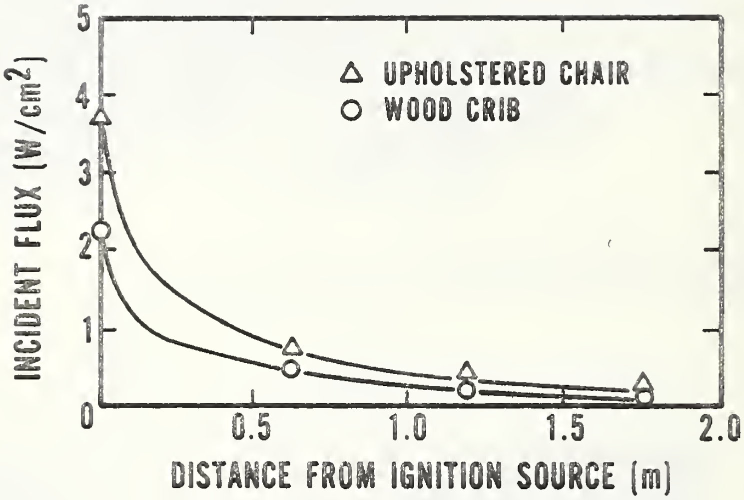


Figure 9. Maximum Levels of Incident Flux.

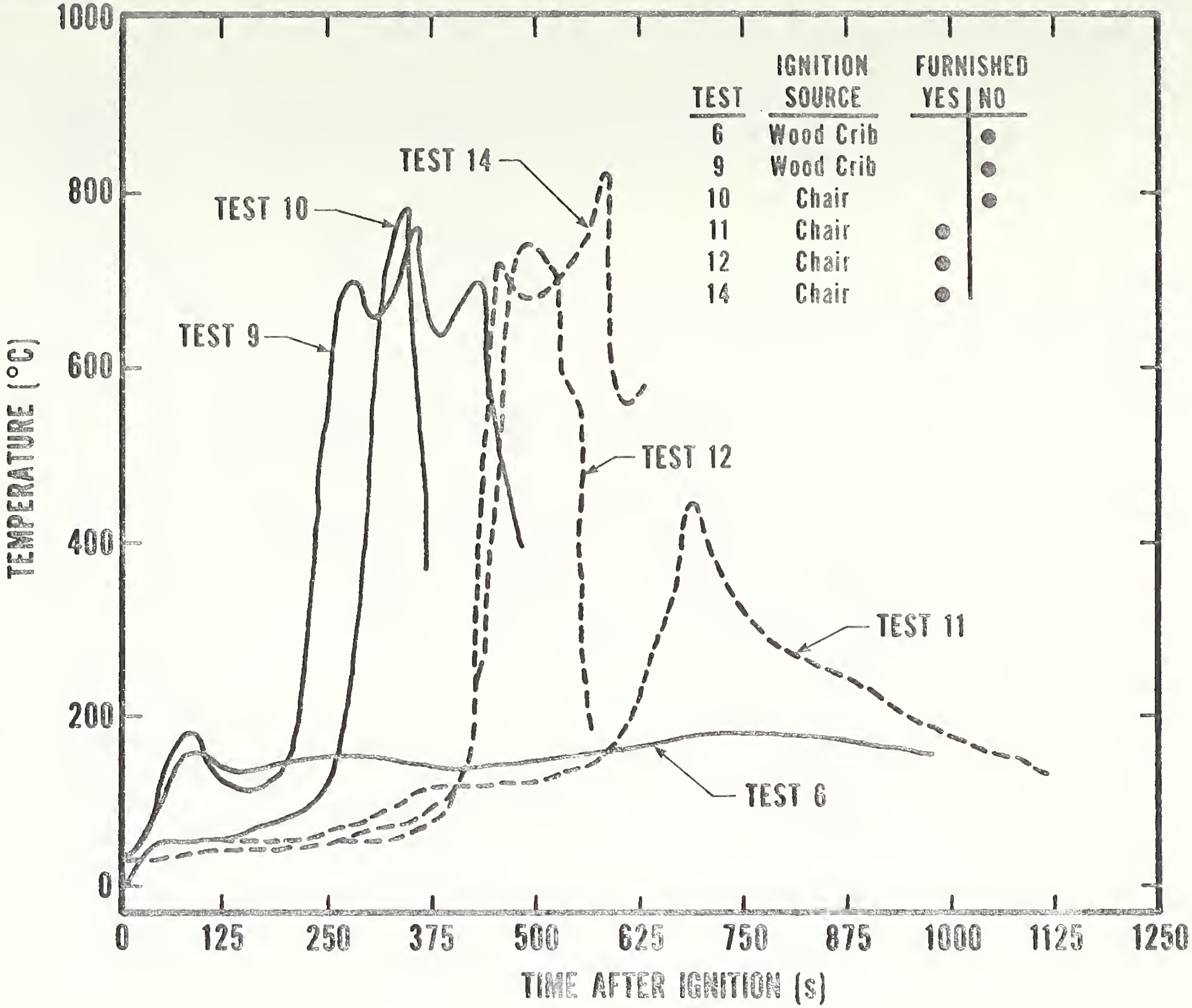


Figure 10. Temperature 25mm Below Ceiling in Center of Living Room For Selected Tests.

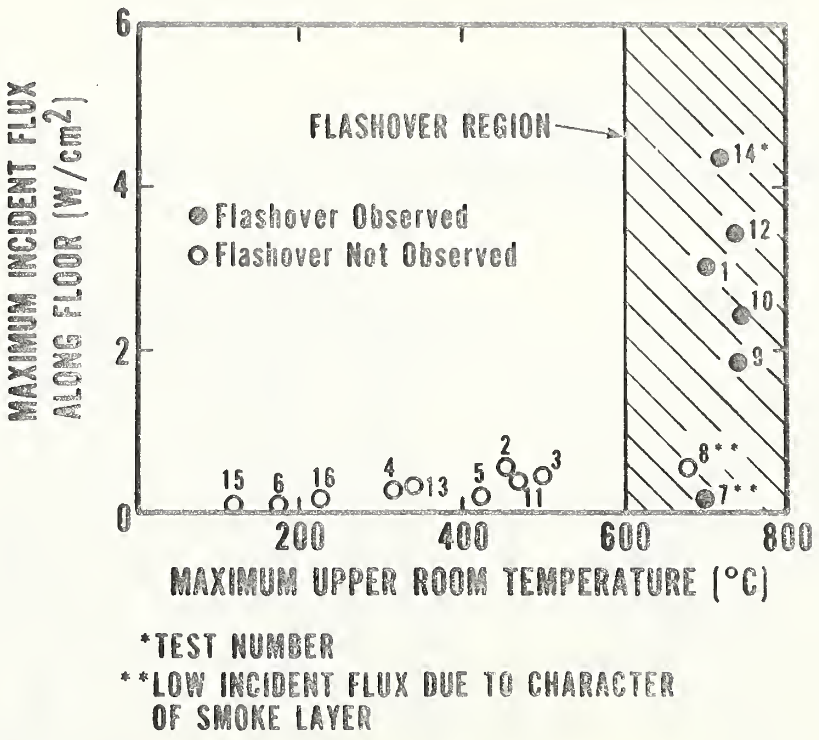


Figure 11. Comparison of Maximum Upper Room Temperature With Maximum Incident Flux at Floor Level.

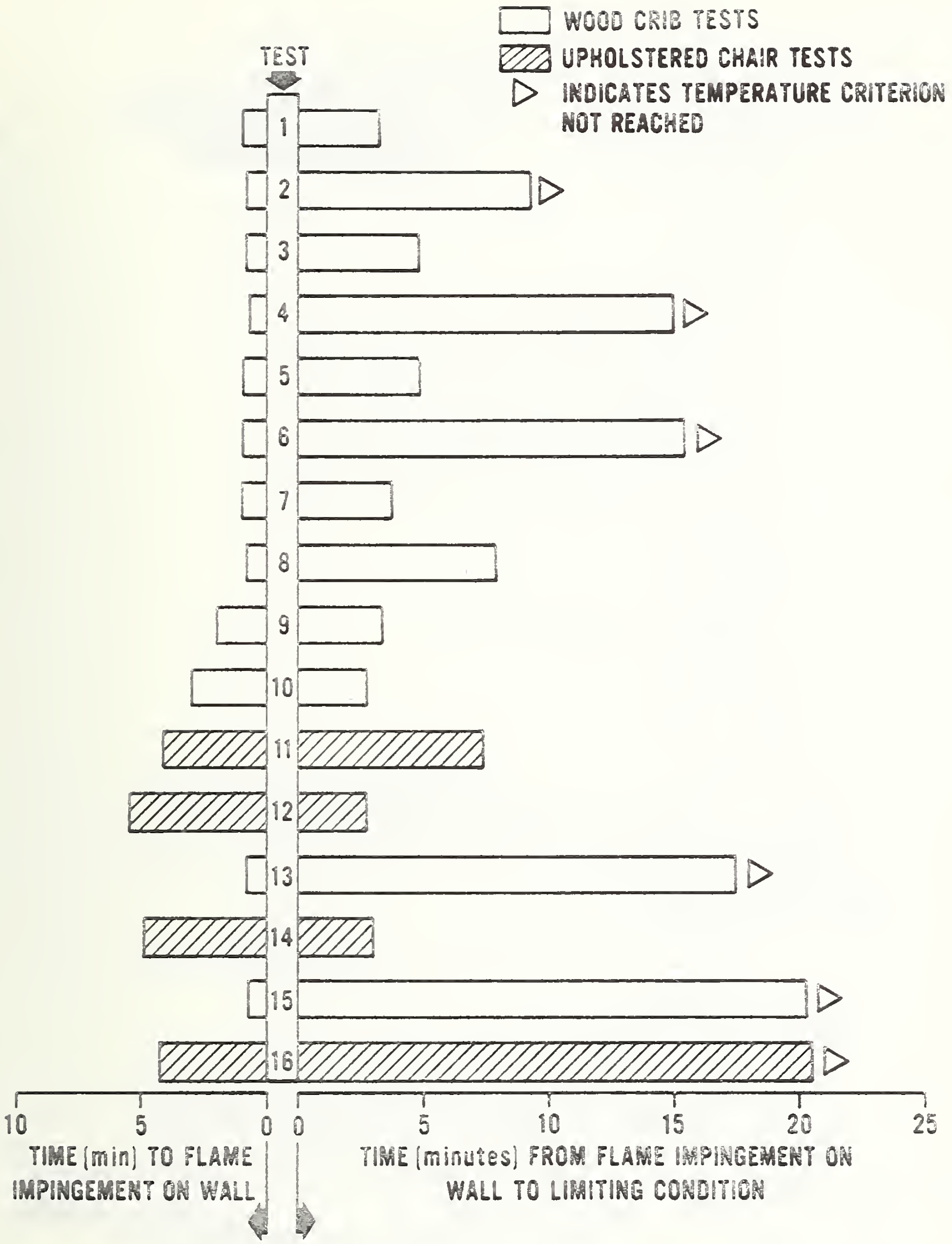


Figure 12. Illustrates Time From Intermittent Flame Impingement on the Wall Surface to 100°C, 1.5 m Above Floor Beyond Back Exit Door Near Entrance to Bedroom #1.

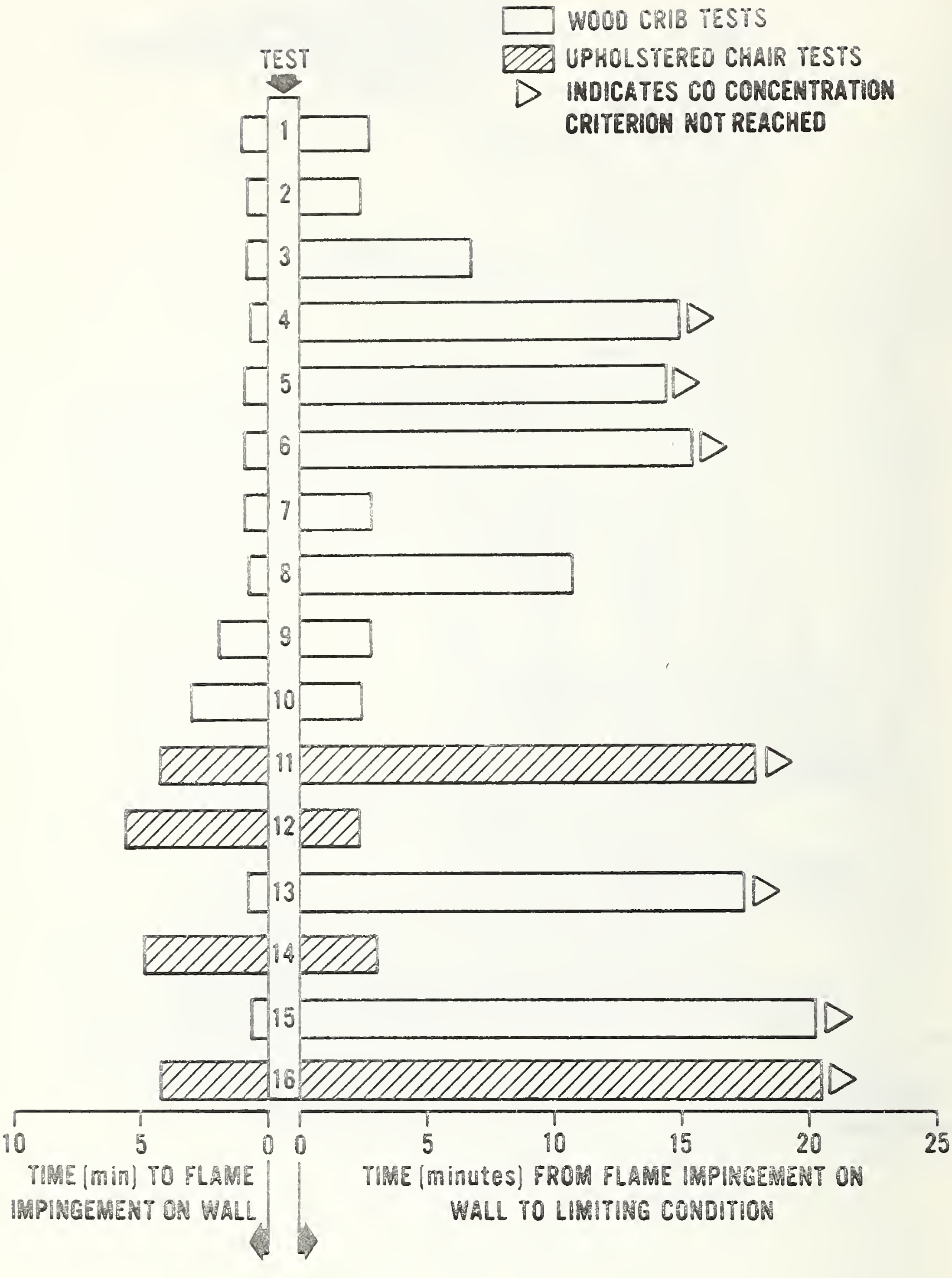


Figure 13. Illustrates Time From Intermittent Flame Impingement on the Wall Surface to 1% (vol) CO Concentration or 41,800 ($ppm^{1.036}$x min), 1.5 m above the Floor Beyond Back Exit Door Near Entrance to Bedroom #1.

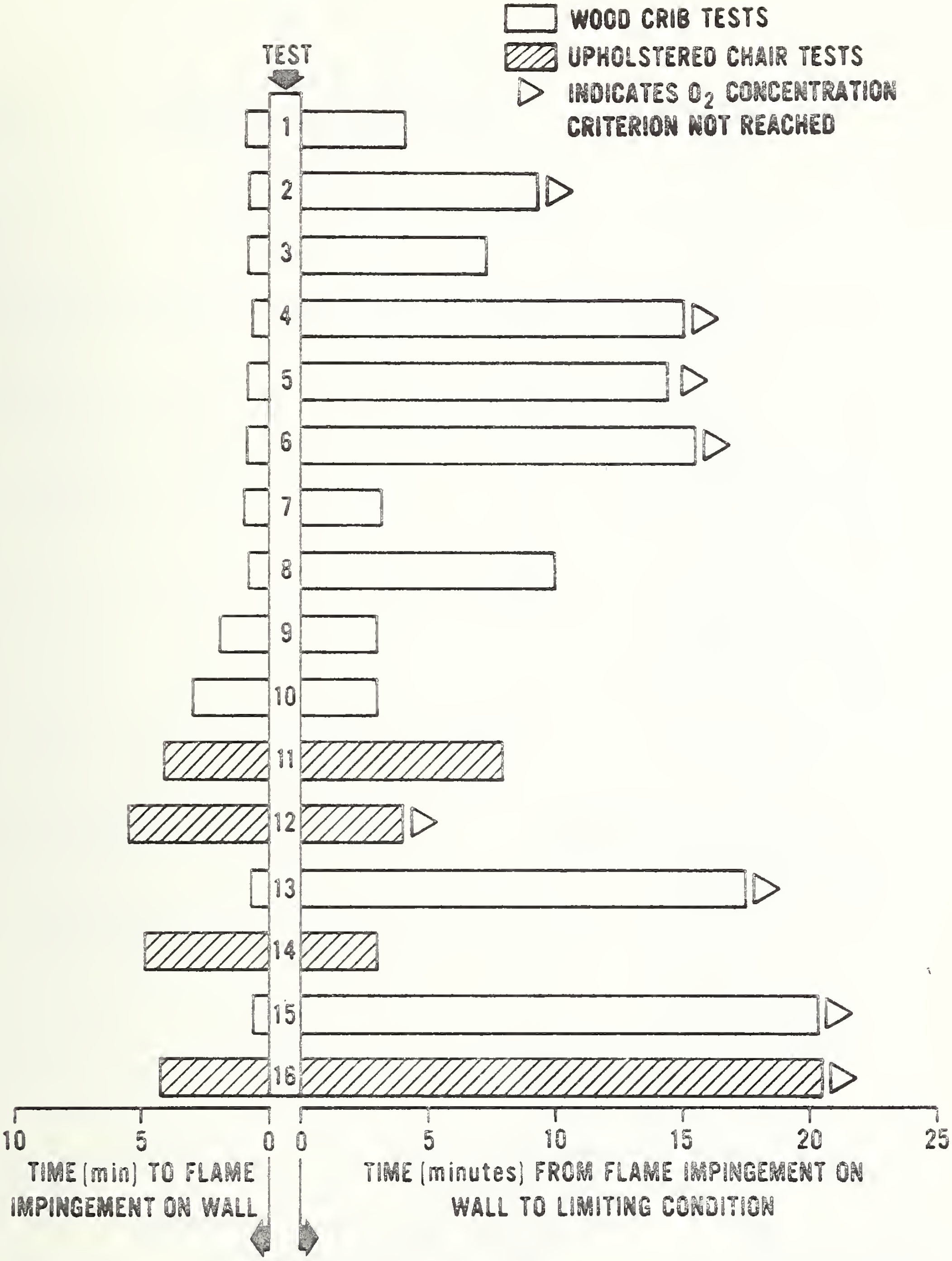


Figure 14. Illustrates Time From Intermittent Flame Impingement on the Wall Surface to 14% (vol) O_2 Concentration, 1.5 m Above the Floor Beyond the Back Exit Door Near the Entrance to Bedroom #1.

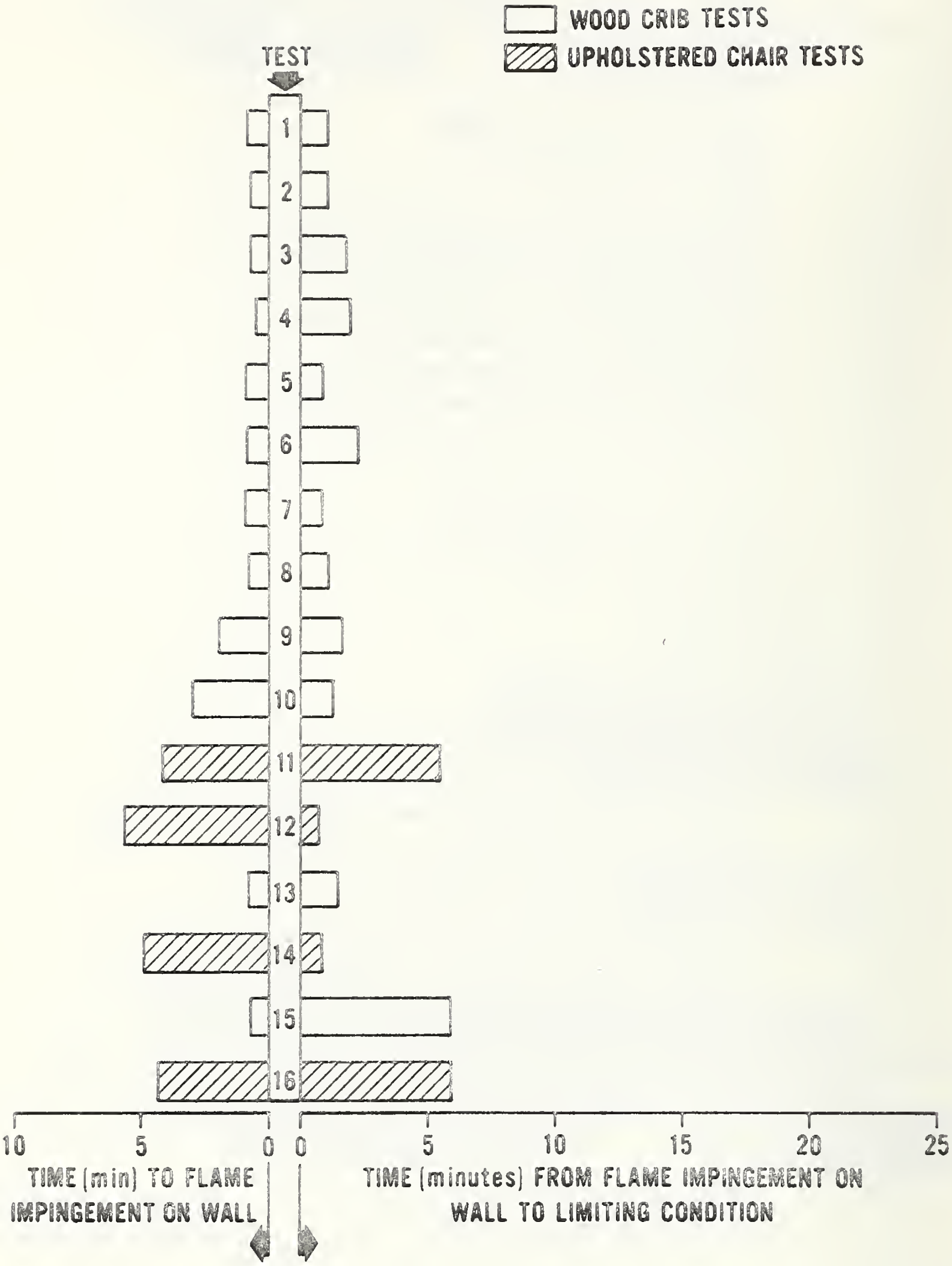
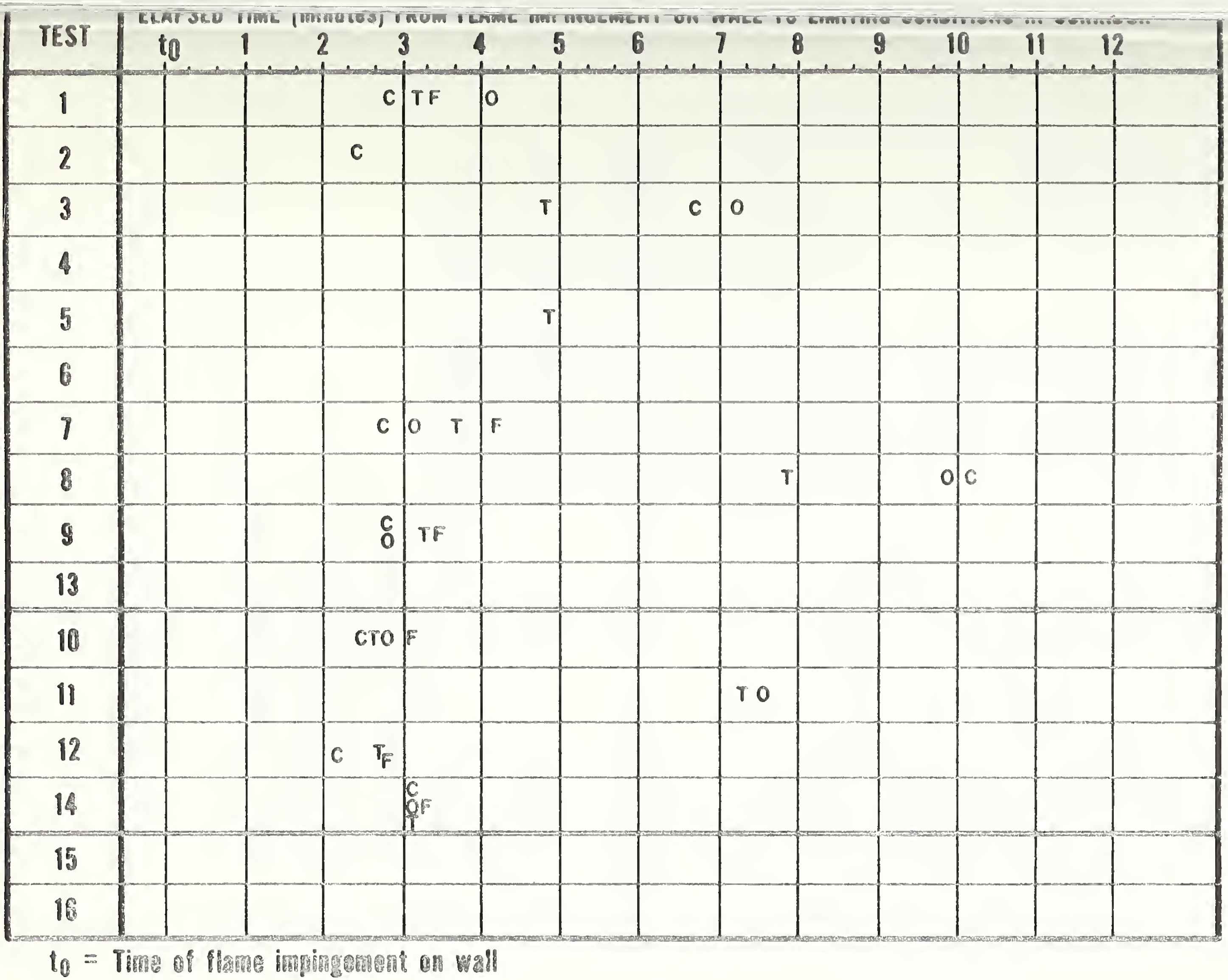


Figure 15. Illustrates Time From Intermittent Flame Impingement on the Wall Surface to 0.26 OD/m Smoke Density, 1.2m Above the Floor Beyond Back Exit Door Near Entrance to Bedroom #1.



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

Figure 16. Illustration of the Elapsed Time From Flame Impingement on the Wall to Limiting Conditions of Temperature, CO, O_2, and the attainment of Flashover for Sixteen Full-Scale Mobile Home Fire Tests.

		CEILING MATERIALS			
	ID CODE	16	4	6	5
WALL MATERIALS ID CODE	FSC	0	11	60	73
16	0	15 $\boxed{16}$			
14	23			13	
1	24		6 $\boxed{11}$		
10	41		4		8
11	56		5		7 4:21
9	160		3		
12	171			$\boxed{14}$ 3:14	$\boxed{12}$ 2:50
13	172				9 3:40 $\boxed{10}$ 2:18
5	182		2		1 3:25

ID - NBS MATERIAL IDENTIFICATION CODE

FSC - FLAME SPREAD CLASSIFICATION (ASTM E-84)

○ WOOD CRIB IGNITION SOURCE

□ UPHOLSTERED CHAIR IGNITION SOURCE

Figure 17. Flashover Data Matrix for Full-Scale Mobile Home Living Room Fire Tests with 6.4 kg Wood Cribs and Upholstered Chairs.

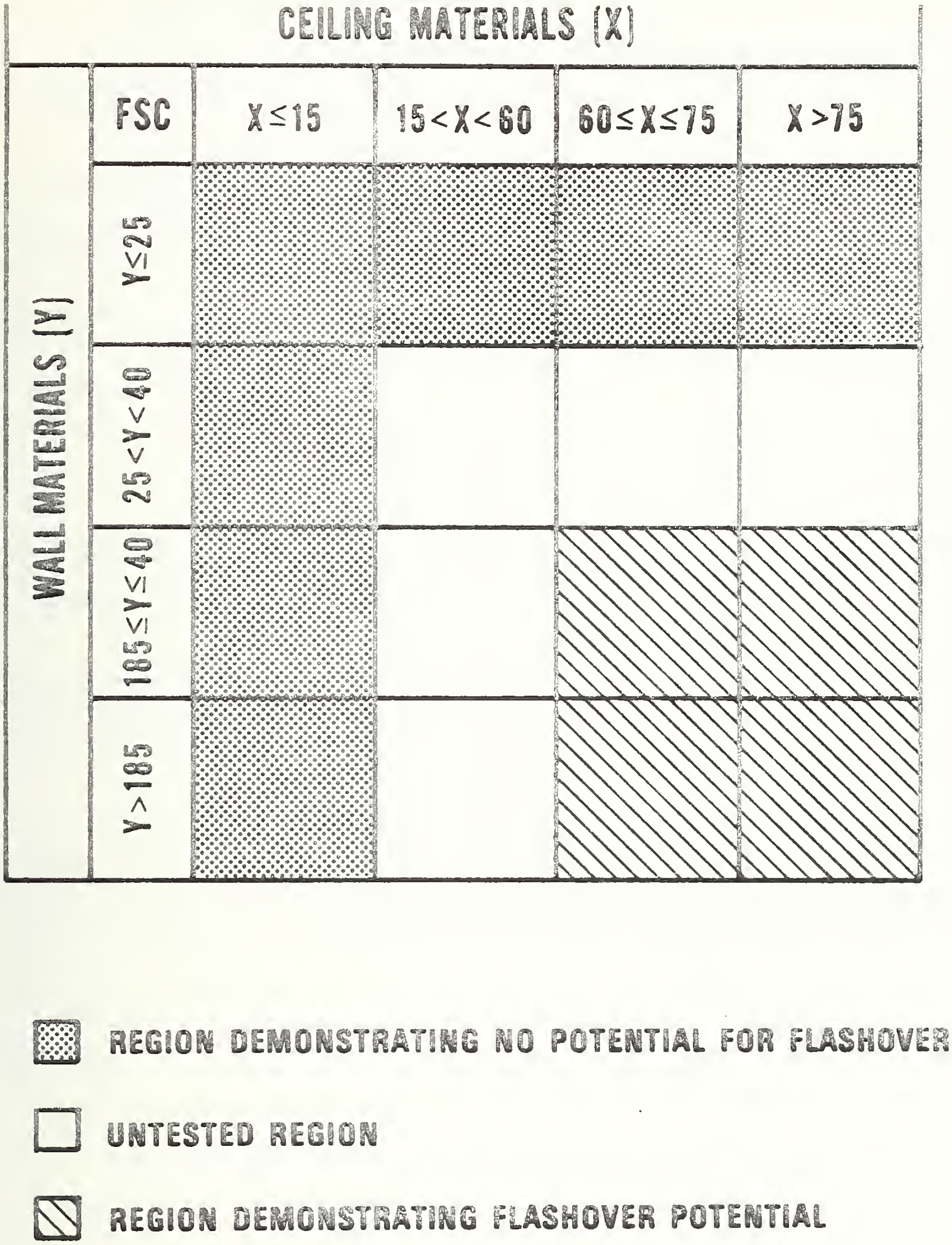


Figure 18. Material Hazard Matrix (Based on ASTM E-84 FSC)

FURNITURE ITEM	WT (kg)	DESCRIPTION
1. Coffee Table	2.7	Constructed of wood and wood products, with a high pressure laminated plastic top surface
2. Two end tables	9.1	Similar construction to coffee table
3. Sofa	37.6	Urethane foam padded on wood frame construction, rayon fabric covering
4. Occasional chair	11.3	Urethane foam padded on wood frame construction, polyester fabric covering
5. Ignition source	16.0	Cotton and urethane foam padded on wood frame construction, rayon fabric covering
6. Waste container	0.2	Molded polyethylene
7. Kitchen table	15.9	Table top constructed of wood products and finished with a high pressure laminated plastic top surface; legs were metal
8. Four kitchen chairs	17.2 *	Metal frames; back and seat constructed of wood products, cotton and urethane padding, and covered with a vinyl material
9. 3 sets of curtains	2.4	Sheer polyester fabric

* Total weight of four chairs

Errata Sheet

for: NBSIR 78-1530

entitled: "Mobile Home Living Room Fire Studies: The Role of Interior Finish"

by: Edward K. Budnick

dated: September 1978

Please make the following correction:

Page 70. This is Table 1 and should be labeled:

Table 1. Furniture Items Used in Tests with Moderate Fuel Loading.

NBS ID Code		...te (W/cm^2) ...nate Average ...alorimeter Exposure 6 W/cm^2	Exposure 8 W/cm^2
W-1	1	5	7
W-5	1	17	17
W-9	1	16	17
W-10	1	12	14
W-11	1	14	16
W-12	1	20	21
W-13	1	17	17
W-14	1	5	7
C-4	1	4	4
C-5	1	9	11
C-6	1	12	12

*Flame by AS

Table 3. Description of Interior Finish Materials Used in Each of the Sixteen Full-Scale Tests

Test No.	Wall Material		Ceiling Material		Ignition Source
	Description	NBS I.D. Code	Description	NBS I.D. Code	
1	4 mm (5/32 in) thick prefinished Lauan plywood	W-5	13 mm (1/2 in) thick prefinished low density wood fiberboard	C-5	6.4 kg wood crib
2	4 mm (5/32 in) thick prefinished Lauan plywood	W-5	8 mm (5/16 in) thick prefinished textured surface gypsum board	C-4	6.4 kg wood crib
3	6 mm (1/4 in) thick prefinished Lauan plywood	W-9	8 mm (5/16 in) thick prefinished textured surface gypsum board	C-4	6.4 kg wood crib
4	4 mm (5/32 in) thick Lauan plywood-fire retardant treated with clear intumescent	W-10	8 mm (5/16 in) thick prefinished textured surface gypsum board	C-4	6.4 kg wood crib
5	4 mm (5/32 in) thick Lauan plywood treated by application of fire retardant vinyl film	W-11	8 mm (5/16 in) thick prefinished textured surface gypsum board	C-4	6.4 kg wood crib
6	8 mm (5/16 in) thick prefinished gypsum board	W-1	8 mm (5/16 in) thick prefinished textured surface gypsum board	C-4	6.4 kg wood crib
7	4 mm (5/32 in) thick Lauan plywood-treated by application of fire retardant vinyl film	W-11	13 mm (1/2 in) thick prefinished low density wood fiberboard	C-5	6.4 kg wood crib
8	4 mm (5/32 in) thick Lauan plywood fire retardant treated with clear intumescent	W-10	13 mm (1/2 in) thick prefinished low density wood fiberboard	C-5	6.4 kg wood crib
9	4 mm (5/32 in) thick prefinished Lauan plywood	W-13	13 mm (1/2 in) thick prefinished low density wood fiberboard	C-5	6.4 kg wood crib
10	4 mm (5/32 in) thick prefinished Lauan plywood	W-13	13 mm (1/2 in) thick prefinished low density wood fiberboard	C-5	16 kg chair
11	8 mm (5/16 in) thick prefinished gypsum board	W-1	8 mm (5/16 in) thick prefinished textured surface gypsum board	C-4	16 kg chair
12	4 mm (5/32 in) thick prefinished Lauan plywood	W-12	13 mm (1/2 in) thick prefinished low density wood fiberboard	C-5	16 kg chair
13	8 mm (5/16 in) thick prefinished gypsum board	W-14	13 mm (1/2 in) thick prefinished low density wood fiberboard	C-6	6.4 kg wood crib
14	4 mm (5/32 in) thick prefinished Lauan plywood	W-12	13 mm (1/2 in) thick prefinished low density wood fiberboard	C-6	16 kg chair
15	13 mm (1/2 in) calcium silicate over 13 mm (1/2 in) thick unfinished gypsum board	W-16	13 mm (1/2 in) thick calcium silicate over 13 mm (1/2 in) thick unfinished gypsum board	W-16	6.4 kg wood crib
16	13 mm (1/2 in) thick calcium silicate over 13 mm (1/2 in) thick unfinished gypsum board	W-16	13 mm (1/2 in) thick calcium silicate over 13 mm (1/2 in) thick unfinished gypsum board	W-16	16 kg chair

Table 4. Test Conditions for Full-Scale Mobile Home Fire Tests (Living Room Series)

Test No.	Interior Conditions			Exterior Conditions			Ignition Source		Walls	Ceiling
	Temperature		Humidity	Temperature		Humidity	Type	Moisture Content	Moisture Content	Moisture Content
	(°C)	(°F)	(%)	(°C)	(°F)	(%)		(%)	(%)	(%)
1	18	64	39	9	49	42	Wood Crib	8.5	6.5	5.0
2	17	62	18	3	38	39	Wood Crib	7.5	5.5	7.5
3	18	64	24	10	50	52	Wood Crib	7.0	5.0	5.0
4	21	70	45	13	55	77	Wood Crib	7.5	9.5	8.0
5	22	72	34	18	64	25	Wood Crib	7.3	8.0	6.5
6	20	68	22	17	62	21	Wood Crib	8.0	6.5	6.5
7	20	68	24	12	54	32	Wood Crib	6.5	5.0	5.0
8	22	72	30	23	73	34	Wood Crib	8.0	9.5	<5.0
9	21	70	29	12	53	32	Wood Crib	8.5	7.0	<5.0
10	22	72	40	21	70	44	Upholstered Chair	*	8.0	7.5
11	30	86	41	33	91	31	Upholstered Chair	*	10.0	10.0
12	29	84	45	29	84	68	Upholstered Chair	*	8.75	<5.0
13	22	72	42	26	78	56	Wood Crib	9.0	9.5	8.0
14	24	75	42	22	72	57	Upholstered Chair	*	8.0	6.8
15	18	64	45	14	57	42	Wood Crib	7.0	8.5	7.5
16	20	68	42	23	73	52	Upholstered Chair	*	9.5	10.0

* Designates that data could not be reliably measured

Table 5. Mobile Home Living Room Test Series: Instrumentation Location

TC 1	TC - Living room, north wall	211 cm above floor
TC 2	TC - Living room, north wall	188 cm above floor
TC 3	TC - Living room, north wall	132 cm above floor
TC 4	TC - Living room, northwest corner	211 cm above floor
TC 5	TC - Living room, northwest corner	188 cm above floor
TC 6	TC - Living room, northwest corner	132 cm above floor
TC 7	TC - Living room, west wall	211 cm above floor
TC 8	TC - Living room, west wall	188 cm above floor
TC 9	TC - Living room, west wall	132 cm above floor
TC 10	TC - Living room, east wall	211 cm above floor
TC 11	TC - Living room, east wall	188 cm above floor
TC 12	TC - Living room, east wall	132 cm above floor
TC 13	TC - Living room, center	211 cm above floor
TC 14	TC - Living room, center	188 cm above floor
TC 15	TC - Living room, center	132 cm above floor
TC 16	TC - Living room, center	91 cm above floor
TC 17	TC - Living room, center	46 cm above floor
TC 18	TC - Living room, center	2.5 cm above floor
TC 19	TC - Living room, south wall	211 cm above floor
TC 20	TC - Living room, south wall	188 cm above floor
TC 21	TC - Living room, south wall	132 cm above floor
TC 22	TC - Living room, south wall	91 cm above floor
TC 23	TC - Corridor, north	211 cm above floor
TC 24	TC - Corridor, north	188 cm above floor
TC 25	TC - Corridor, north	132 cm above floor
TC 26	TC - Corridor, north	91 cm above floor
TC 27	TC - Corridor, north	46 cm above floor
TC 28	TC - Corridor, north	2.5 cm above floor
TC 29	TC - Corridor, center	211 cm above floor
TC 30	TC - Corridor, center	188 cm above floor
TC 31	TC - Corridor, center	132 cm above floor
TC 32	TC - Corridor, center	91 cm above floor
TC 33	TC - Corridor, center	46 cm above floor
TC 34	TC - Corridor, center	2.5 cm above floor
TC 35	TC - Corridor, south	211 cm above floor
TC 36	TC - Corridor, south	188 cm above floor
TC 37	TC - Corridor, south	132 cm above floor
TC 38	TC - Corridor, south	91 cm above floor
TC 39	TC - Corridor, south	46 cm above floor
TC 40	TC - Corridor, south	2.5 cm above floor
TC 41	TC - Bedroom 3, center	211 cm above floor
TC 42	TC - Bedroom 3, center	188 cm above floor
TC 43	TC - Bedroom 3, center	132 cm above floor
TC 44	TC - Bedroom 3, center	91 cm above floor
TC 45	TC - Bedroom 1, center	211 cm above floor
TC 46	TC - Bedroom 1, center	188 cm above floor
TC 47	TC - Bedroom 1, center	132 cm above floor
RAD 1	Incident heat flux transducer - Living room, center, floor level	
RAD 2	Incident heat flux transducer - Corridor, north, floor level	
RAD 3	Incident heat flux transducer - Corridor, south, floor level	
RAD 18	Incident heat flux transducer - North wall, 20cm from corner, .9 m above floor	
RAD 19	Incident heat flux transducer - North wall, 20cm from corner, 1.8 m above floor	
RAD 20	Incident heat flux transducer - Living room, center, ceiling level	
HSM 4	Horizontal smoke meter - corridor, north, .6 m above floor	
HSM 5	Horizontal smoke meter - corridor, north, 1.2 m above floor	
HSM 6	Horizontal smoke meter - corridor, north, 1.8 m above floor	
VSM 7	Vertical smoke meter - corridor, north, upper, .46 m	
HSM 8	Horizontal smoke meter - corridor, south, .6 m above floor	
HSM 9	Horizontal smoke meter - corridor, south, 1.2 m above floor	
HSM 10	Horizontal smoke meter - corridor, south, 1.8 m above floor	
VSM 11	Vertical smoke meter - corridor, south, .46 m	
CO 13	CO - Center of living room at 1.5 m above floor	
CO2 14	CO2 - Center of living room at 1.5 m above floor	
O2 15	O2 - Center of living room at 1.5 m above floor	
CO 16	CO - South corridor at 1.5 m above floor	
O2 17	O2 - South corridor at 1.5 m above floor	
L CELL	Load cell	

Table 6. Selected Results of Full-Scale Mobile Home Fire Tests (Living Room Series)

Test No.	Time to Ignition of Wall (Min:Sec)	Time to Flashover (Min:Sec)	Temperature: At TC 13, Maximum Temperature (°C)	Temperature: At TC 13, Elapsed Time (Min:Sec)	Temperature: Avg. Upper Room Temp. 25 mm Below Ceiling, Maximum Temperature (°C)	Temperature: Avg. Upper Room Temp. 25 mm Below Ceiling, Elapsed Time (Min:Sec)	Temperature: Avg. Upper Room Temp. 250 mm Below Ceiling, Maximum Temperature (°C)	Temperature: Avg. Upper Room Temp. 250 mm Below Ceiling, Elapsed Time (Min:Sec)	Incident Heat Flux, Floor Level in Center of Living Room: At Maximum Temperature At TC 13 (W/cm^2)	Incident Heat Flux, Floor Level in Center of Living Room: Maximum Level (W/cm^2)	Incident Heat Flux, Floor Level in Center of Living Room: Elapsed Time (Min:Sec)	Final Data Record (Min:Sec)	Final Visual Test Observation (Min:Sec)	Activation of Suppression System (Min:Sec)
1	1:15	4:20	743	5:10	634	4:25	600	5:10	1.27	3.18	4:10	6:30	5:15	5:10
2	1:09	NR **	429	3:30	426	3:30	381	3:50	0.43	0.60	2:20	10:00	10:15	10:12
3	1:00	NR	520	4:00	450	6:20	360	5:50	0.54	0.54	4:00	12:20	12:30	NA***
4	4:50	NR	311	8:30	349	8:30	217	8:40	0.18	0.18	8:30	15:30	15:26	NA
5	2:25	NR	438	5:00	422	5:40	313	5:20	0.29	0.38	3:50	15:20	15:30	NA
6	1:17	NR	176	11:30	150	12:40	105	12:40	0.05	0.07	15:50	16:20	15:50	NA
7	2:33	5:15	698	5:20	614	5:20	617	5:20	0.25	0.34	4:50	5:50	5:30	5:40
8	2:50	NR	673	7:40	518	7:40	402	8:50	0.50	0.59	8:10	15:40	15:35	NA
9	3:00	5:30	751	5:40	632	7:00	569	6:50	1.90	1.90	5:40	7:50	7:08	7:10
10	3:58	5:18	771	5:40	737	5:40	748	5:40	1.30	2.50	5:30	6:00	5:40	5:40
11	4:55	NR	444	11:20	448	11:20	296	11:30	0.50	0.50	11:20	18:30	18:20	NA
12	6:23	8:20	748	8:10	656	8:30	688	8:30	2.14	3.60	8:20	9:20	9:05	9:05
13	0:57 *	NR	316	14:20	326	15:00	187	14:50	0.27	0.27	14:20	18:40	18:40	NA
14	5:50	8:04	736	8:10	659	9:30	579	8:10	2.18	4.64	8:00	10:20	10:20	10:20
15	-	NR	148	13:00	142	14:20	116	14:20	0.07	0.08	15:10	20:20	20:00	NA
16	-	NR	236	15:30	215	15:30	167	15:30	0.15	0.15	15:30	20:30	20:00	NA

* Paper surface burned off north and west walls at 4:47 (Min:Sec)

** NR = Not reached

*** NA designates suppression system not activated

Table 7. Selected Levels of Carbon Monoxide, Carbon Dioxide, and Oxygen Measured in Living Room 1.5 m Above Floor

	Concentration of CO in Center of Living Room				Concentration of CO_2 in Center of Living Room			Concentration of O_2 in Center of Living Room			
	Time to Reach 1%	At Max. Temp. Level at TC 13	Maximum Concentration	Elapsed Time	At Max. Temp. Level at TC 13	Maximum Concentration	Elapsed Time	Time to Reach 14%	At Max. Temp. Level at TC 13	Minimum Concentration	Elapsed Time
	(Min:Sec)	(%)	(%)	(Min:Sec)	(%)	(%)	(Min:Sec)	(Min:Sec)	(%)	(%)	(Min:Sec)
1	3:50	2.8	8.0	4:50	15.0	17.4	4:40	4:10	11.4	7.8	4:50
2	NR*	<0.4	<0.4	5:00	2.0	3.8	5:10	NR	18.6	17.7	5:10
3	NR	0.2	0.7	6:10	2.1	6.9	6:10	NR	17.9	14.5	6:20
4	NR	<0.1	<0.1	15.30	1.3	3.8	12:40	NR	20.1	19.0	12:30
5	NR	<0.6	<0.6	7:20	2.0	5.2	11:30	NR	18.9	14.8	11:30
6	NR	0.1	<0.1	11:40	1.8	1.8	11:40	NR	18.8	18.8	11:40
7	3:50	2.4	6.9	5:30	9.9	11.0	5:30	4:10	8.7	4.6	5:40
8	13:20	-	1.0	13:30	1.7	6.0	12:40	12:50	19.0	14.0	12:40
9	5:40	1.4	6.6	6:10	9.7	17.1	6:00	5:40	11.7	2.6	6:10
10	5:30	3.0	3.0	5:40	10.1	10.1	5:40	5:30	9.0	9.0	5:40
11	NR	0.1	0.2	18:00	0.1	4.9	15:10	NR	16.8	14.9	15:10
12	7:55	2.9	5.5	8:50	10.1	15.7	8:50	7:55	10.3	3.8	8:50
13	NR	0.1	0.2	17:40	2.2	3.0	17:50	NR	18.4	17.4	17:50
14	7:50	3.0	5.4	8:30	12.1	12.1	8.20	8:00	11.6	8.8	8:30
15	NR	0.1	<0.1	11:40	1.8	1.9	13:10	NR	20.5	20.4	16:50
16	NR	0.1	0.1	17:20	0.1	3.1	16:50	NR	19.8	19.5	16:30

*NR = Not reached

Table 8. Selected Levels of Temperature, Optical Density, Carbon Monoxide, and Oxygen at Various Locations in the Mobile Home

Test No	Elapsed Time To Reach 100°C at Selected Thermocouple Locations (Min:Sec)						Time to Reach 0.26 OD/M Smoke Density in the Corridor (Min:Sec)		Concentrations of CO at South End of Corridor			Time Rated CO Accumulation at South End of Corridor			Concentrations of O_2 at South End of Corridor		
	TC 15	TC 25	TC 31	TC 37	TC 43	TC 47	HSM 5	HSM 9	1.0% (Min:Sec)	Maximum Concentration (%)	Maximum Concentration (Min:Sec)	41,800 ppm 1.036_{min} (Min:Sec)	Maximum Accumulation (PPM) $^{1.036}$(Min)	Maximum Accumulation (Min:Sec)	14% (Min:Sec)	Minimum Concentration (%)	Minimum Concentration (Min:Sec)
1	3:20	3:40	4:00	4:10	NR	4:20	1:50	2:00	3:50	2.0	5:10	5:10	98,360	6:30	5:00	12.5	5:10
2	2:20	4:10	NR	NR	NR	NR	2:20	1:50	3:10	1.1	3:10	8:30	48,860	10:00	NR	15.9	9:40
3	3:30	4:50	5:20	5:30	NR	6:20	2:50	2:40	NR	0.9	4:30	7:30	88,950	12:20	8:00	13.6	8:40
4	8:00	NR	NR	NR	NR	NR	2:40	2:00	NR	0.3	8:40	NR	23,540	15:30	NR	17.0	9:00
5	4:00	5:30	6:50	6:00	NR	11:00	1:50	1:50	NR	0.8	8:10	6:10	128,200	15:20	NR	15.4	4:50
6	NR*	NR	NR	NR	NR	NR	3:50	3:10	NR	0.1	15:20	NR	10,630	16:20	NR	18.4	14:50
7	3:20	4:10	4:30	4:40	NR	5:00	2:00	1:50	4:10	1.4	5:00	4:50	101,300	5:50	4:00	2.3	5:40
8	5:50	7:30	8:00	8:00	NR	8:30	2:10	1:50	12:30	1.1	13:10	11:00	109,000	15:40	10:40	12.9	13:10
9	4:00	5:10	5:10	5:10	NR	5:30	3:40	3:30	4:40	4.3	6:30	6:00	149,100	7:50	4:40	5.9	7:00
10	4:50	5:10	5:20	5:40	NR	5:40	4:20	4:20	5:30	2.2	5:40	NR	23,010	6:00	5:40	13.8	5:40
11	10:20	10:50	11:30	11:30	NR	12:10	9:50	9:40	NR	0.3	18:20	NR	16,720	18:30	11:50	13.4	12:00
12	7:30	7:55	8:10	8:15	NR	8:35	6:20	6:15	8:50	1.3	9:00	NR	20,350	9:20	NR	17.1	8:50
13	13:30	NR	NR	NR	NR	NR	2:40	2:10	NR	0.2	17:40	NR	3,417	18:40	NR	20.3	18:10
14	7:15	7:30	7:45	7:50	NR	8:10	5:45	5:40	7:55	3.6	8:50	8:50	118,800	10:20	7:50	4.6	10:00
15	NR	NR	NR	NR	NR	NR	2:40	5:50	NR	-	-	NR	4,606	20:20	NR	-	-
16	14:05	15:00	NR	NR	NR	NR	8:10	10:10	NR	<0.1	17:20	NR	9,504	20:30	NR	18.4	16:30

*NR = Not reached

Table 9. Measured Concentrations of CO, CO_2 and O_2 in Tests 15 and 16

Table 9 (a). Concentrations of CO, CO_2 and O_2 - Test 15

	Percent Concentration				
	Center of Living Room			Entrance to Bedroom #1	
	CO	CO_2	O_2*	CO	O_2*
Initial Concentration	0.00	0.2	21.0	0.00	21.0
Peak Concentration	<0.05	1.9	20.4	0.26	18.6

*Minimum Concentration

Table 9 (b). Concentrations of CO, CO_2 and O_2 - Test 16

	Percent Concentration				
	Center of Living Room			Entrance to Bedroom #1	
	CO	CO_2	O_2*	CO	O_2*
Initial Concentration	0.00	0.1	21.0	0.00	21.0
Peak Concentration	0.07	3.1	19.5	0.06	18.4

*Minimum Concentration

Table 10. Grouping of Tests Based on Peak Levels of Temperature, Carbon Monoxide, Carbon Dioxide and Oxygen Measured in the Living Room.

<table>
<tr><th></th><th>TEST NO.</th><th>MAX. UPPER ROOM TEMP.</th><th>MAX. CO CONCENTRATION</th><th>MAX. CO_2 CONCENTRATION</th><th>MIN. O_2 CONCENTRATION</th></tr>
<tr><td rowspan="7">GROUP 1</td><td>10</td><td rowspan="7">$T \geq 673°C$</td><td rowspan="8">$CO \geq 1.0\%$</td><td rowspan="9">$CO_2 \geq 6.0\%$</td><td rowspan="9">$O_2 \leq 14.0\%$</td></tr>
<tr><td>9</td></tr>
<tr><td>12</td></tr>
<tr><td>14</td></tr>
<tr><td>1</td></tr>
<tr><td>7</td></tr>
<tr><td>8</td></tr>
<tr><td rowspan="6">GROUP 2</td><td>5</td><td rowspan="6">$520 \geq T \geq 311°C$</td></tr>
<tr><td>3</td><td rowspan="4">$0.2 \leq CO \leq 0.7\%$</td></tr>
<tr><td>11</td><td rowspan="4">$3.7 \leq CO_2 \leq 5.2\%$</td><td rowspan="3">$14.9 \leq O_2 \leq 17.7\%$</td></tr>
<tr><td>2</td></tr>
<tr><td>13</td></tr>
<tr><td>4</td><td rowspan="4">$CO \leq 0.1\%$</td><td rowspan="4">$O_2 \geq 19.0\%$</td></tr>
<tr><td rowspan="3">GROUP 3</td><td>16</td><td rowspan="3">$T \leq 236°C$</td><td rowspan="3">$CO_2 \leq 3.0\%$</td></tr>
<tr><td>6</td></tr>
<tr><td>15</td></tr>
</table>

Table 11. Elapsed Time from Initial Flame Impingement on the Wall Surface to Limiting Conditions of Temperature, Carbon Monoxide and Oxygen, and 0.26 OD/m Optical Density in the Corridor Beyond the Back Exit Door

Test	Elapsed Time to Flame Impingement on Wall	Time (Min:Sec) From Flame Impingement on Wall To:							
		0.26 OD/m At HSM 5	0.26 OD/m At HSM 9	100°C At TC 37	1% CO At CO 16	41,800 (ppm) 1.036 (min)	14% At O_2 17	Flashover	To End of Test
1	0:55	0:55	1:05	3:15	2:55	4:05	4:05	3:25	5:15
2	0:40	1:40	1:10	NR *	2:30	7:50	NR	NR	8:51
3	0:42	2:08	1:58	4:48	NR	6:48	7:18	NR	11:20
4	0:32	2:08	1:28	NR	NR	NR	NR	NR	10:30
5	0:56	0:54	0:54	4:59	3:14	5:14	NR	NR	12:55
6	0:50	3:00	2:20	NR	NR	NR	NR	NR	15:03
7	0:54	1:06	0:56	3:46	2:56	3:56	3:06	4:21	2:17
8	0:48	1:22	1:02	7:56	10:46	10:12	9:56	NR	12:50
9	1:50	1:50	1:40	3:20	2:50	4:10	2:50	3:40	4:50
10	3:00	1:20	1:20	2:40	2:30	NR	2:50	2:18	3:02
11	4:10	5:40	5:30	7:20	NR	NR	7:40	NR	13:35
12	5:30	0:50	0:45	2:45	~2:20	NR	NR	2:50	2:57
13	0:43	1:57	1:27	NR	NR	NR	NR	NR	17:43
14	4:50	0:55	0:50	3:00	3:05	4:00	3:00	3:14	4:30
15	0:47	1:53	5:03	NR	NR	NR	NR	NR	20:20
16	4:10	4:00	6:00	NR	NR	NR	NR	NR	20:30

NR = Not reached

APPENDIX A. CHRONOLOGICAL TABULATION OF TEST OBSERVATIONS

Appendix A. Chronological Tabulation of Test Observations

MHL1V #1

Interior Finish Materials

Walls: W-5
Ceiling: C-5

Date: 3/8/76
Time: 11:00 AM

Ignition Source

6.4 kg cross piled wood crib

TIME(Min:Sec)	OBSERVATION/EVENT
0:00	Ignition of heptane
0:22	Intermittent flame height 1.2 m (4 ft.) above floor
0:30	Fire localized to center of crib
0:33	Single station ionization smoke detector alarmed
0:45	Flame height increased to approximately 1.5 m (5 ft.) above floor
0:50	Increase in crib involvement
0:55	Intermittent impingement of flame on wall and ceiling, some charring of panel in corner, ignition of corner molding
1:15	Ignition of north wall
1:30	Fire localized to corner
1:40	Flame height receded to < 1.2 m (4 ft.) above floor, panel on north wall continued to burn
1:53	No further burning of heptane ignitor
2:00	Burn rate of crib appears to be steady, resulting, in flame height approximately .9 m (3 ft.) above floor
2:15	Burn rate increasing from crib & north wall
2:40	Flames from burning plywood intermittently impinging on ceiling
2:53	Constant flame impingement at ceiling, lateral flame spread down north and west walls at ceiling
2:58	Gas phase burning at ceiling; failure of curtains on north wall
3:02	Ignition of west wall
3:10	Gas phase burning across entire ceiling
3:30	Failure of curtains on west wall; significant smoke obscuration
3:35	Failure of curtains on east wall above observation port
3:45	Failure of windows in north wall-flames extended outside unit
4:00	Extent of gas phase burning increased-burning gases .6-.9 m (2 ft.-3 ft.) down from ceiling
4:15	East wall burning from floor to ceiling
4:20	Flashover
4:47	Gas phase burning continued in north east corner
5:10	Sprinkler system activated
5:15	Termination of Test observations

Post Test Observations

1. Ceiling charred on exposed surface throughout living-dining area.
2. North and west walls burned through from ceiling to floor in vicinity of crib.
3. Failure of exterior metal skin on north wall adjacent to crib.
4. Entire east wall burned through at ceiling, total wall involved.
5. West wall involved down to corridor entrance-approximately 7.6 m (25 ft.).
6. No extensive burn through of ceiling tile (surface burning).
7. Extensive fire spread above ceiling-indication that fire penetrated north wall and burned up into ceiling vent.
8. Floor material burned throughout living room.

Interior Finish Materials

Walls: W-5
Ceiling: C-4

Date: 3/17/76
Time: 11:00 AM

Ignition Source

6.4 kg cross piled wood crib

TIME(Min:Sec)	OBSERVATION/EVENT
0:00	Ignition of heptane
0:31	Single station smoke detector alarmed
0:40	Flame impingement on wall
0:50	Intermittent flame height approximately 1.8 m (6ft.) above floor
1:09	Ignition of wall
1:15	Intermittent flame impingement at ceiling
1:25	Fire from crib receding
1:35	Slight lateral flame spread at ceiling
1:40	Ignition of curtains on north and west walls
1:50	Flame spread across ceiling to east wall
1:55	Gas phase burning one foot down from ceiling across entire ceiling
2:00	Curtain failed on east wall; curtains already down on north and west walls
2:20	Smoke level stratified .3-.6 m (1-2 ft.) down from ceiling
2:25	Textured surface on ceiling beginning to discolor
2:40	Plywood walls burning .3 m (1 ft.) down from ceiling along north and west walls
3:00	Burn through of panels in corner behind wood crib
3:01	Window on east wall cracked
3:35	Smoke has accumulated along floor and ceiling, leaving an area relatively clear between the two layers
3:55	Smoke emitted from vent above north wall
4:15	Visibility nearly negligible; smoke from floor to ceiling
4:35	Gasoline powered generator malfunctioned; resulted in loss of lighting
6:50	Burn through of exterior metal skin on west wall adjacent to wood crib
	Extended period with zero visibility
10:12	Actuation of sprinkler system
10:15	Termination of test observations

Post Test Observations

1. Burn through of west and north walls at ceiling level.
2. Surface burning in north-east corner.
3. Fire primarily localized to north-west corner.
4. Burn through of exterior skin on north and west walls.
5. Firestopping effective in limiting flame penetration into vent space adjacent to north wall.
6. Fire burned into stud cavity on west wall and up through top plate into ceiling space.
7. No contribution to fire in ceiling space from ceiling material; ignition of resins and paper face on glass fiber insulation.
8. No damage to flooring.
9. No damage in corridor.

Interior Finish Materials

Walls: W-9
Ceiling: C-4

Date: 3/23/76
Time: 11:00 AM

Ignition Source

6.4 kg. cross piled wood crib

TIME (Min:Sec)	OBSERVATION/EVENT
0:00	Ignition of heptane
0:15	Flame height approximately 1.2 m (4 ft.) above floor
0:18	Fire localized to center of crib
0:25	Flame height increased to approximately 1.8 m (6 ft.) above floor
0:30	Intermittent flame impingement at ceiling
0:33	Single station ionization detector alarmed
0:42	North and west walls charred behind crib; flame impingement on wall
0:57	Noticeable heat build-up at observation window
1:00	Ignition of north wall - lateral flame spread at ceiling level on north and west walls
1:10	Fire receded, flame height less than 1.2m (4 ft.) above floor, no further burning of heptane
1:23	Sustained burning of north and west walls
1:42	Contribution from walls increasing
2:20	Intermittent flame impingement at ceiling
2:30	Burn rate of crib increased
2:35	Lateral flame spread at ceiling 1.2 m (4 ft.) along north and west walls
2:45	Failure of curtains on north and west walls
2:55	Noticeable increase in heat at observation window
3:02	Gas phase burning across ceiling
3:15	Burning gases .3 m (1 ft.) down from ceiling - east wall involved
3:50	Burnthrough of north and west walls in corner
3:58	Window on east wall failed
4:45	Significant accumulation of smoke
4:50	Windows cracked on north wall
5:32	Fire penetrated east windows
	Period where observation difficult due to excessive smoke and failure of lighting
11:55	Crib burning at constant rate
12:20	Sprinkler system actuated
12:30	Termination of test observations

Post Test Observations

1. Burn through of north and west walls in corner and along ceiling of north, west and east walls.
2. West wall charred down to entrance to corridor.
3. Fire penetrated into ceiling cavity; excessive heat above ceiling in corridor.
4. Firestopping installed in north wall did not fail.
5. No burning of floor material or sofa.

Interior Finish Materials

Walls: W-10
Ceiling: C-4

Date: 3/30/76
Time: 11:00 AM

Ignition Source

6.4 kg. cross piled wood crib

TIME (Min:Sec)	OBSERVATION/EVENT
0:00	Ignition of heptane
0:27	Intermittent flame height approximately 1.2 m (4 ft.) above floor
0:32	Flame impingement of wall; surface adjacent to crib beginning to intumesce
0:34	Single station ionization detector alarmed
0:45	Intermittent flame height 1.8 m (6 ft.) above floor
0:51	Walls in north-west corner charring and intumescing
1:04	Intermittent flame impingement at ceiling
1:27	Fire from crib receded
1:34	Fire localized to center of crib; no further contribution from heptane
1:45	Flame height steady at approximately 1.2 m (4 ft.) above floor
3:05	Burn rate of wood crib increasing - flame height lengthening to 1.2-1.5 m (4-5 ft.) above floor
3:45	No visible indication of failure of intumescent surface on walls
4:30	Pin-hole failure of surface of north wall adjacent to crib
4:50	Sustained burning of north wall in corner behind crib
5:07	Intermittent flame height approximately 1.8 m (6 ft.) above floor
5:25	Intermittent flame impingement at ceiling
5:35	Ignition of molding at ceiling - lateral flame spread at ceiling approximately .6 m (2 ft.) along north and west walls
5:57	Burn through of north wall
6:00	Lateral fire spread 1.2 m (4 ft.) along north and west walls at ceiling
6:05	Slight smoke accumulation at ceiling
6:19	Intumescing action extending along walls at ceiling level
6:25	Textured surface on ceiling blistering, cracking
6:45	Failure of curtains on north and west walls
6:55	Gas phase burning across ceiling
7:00	Intensity of fire increasing
7:30	North wall completely open, burning in stud cavity
7:55	Major part of fire still localized to north-west corner; flame spread approximately 1.8 m (6 ft.) across north wall at ceiling
8:07	Cracking of windows on east wall
8:57	Poor visibility, can only see burning crib
9:24	Noticeable increase in heat at observation window
10:20	Burn rate of crib stabilized
11:55	No failure of windows
12:54	High volume of smoke (yellow) being released out vent above north wall
14:20	Temperature monitored above crib beginning to decrease
15:00	Flames appear to have penetrated ceiling membrane directly above crib

15:26	Termination of test observations

Post Test Observations

1. Extent of fire limited primarily to northwest corner, some burn through of papers exposed to crib.
2. Fire extended up through stud cavity in walls and into ceiling space.
3. Top plate burned through in corner.
4. No apparent failure of firestopping.
5. Wall surfaces intumesced along the ceiling throughout the burn room.

MHLlV #5

Interior Finish Materials

Walls: W-11B
Ceiling: C-4

Date: 4/7/76
Time: 1:30 PM

Ignition Source

6.4 kg. cross piled wood crib

TIME (Min:Sec)	OBSERVATION/EVENT
0:00	Ignition of heptane
0:22	Intermittent flame height 1.2 m (4 ft.) above floor
0:30	Intermittent flame height 1.5 m (5 ft.) above floor
0:36	Single station smoke detector alarmed
0:41	Intermittent height of 1.8 m (6 ft.) above floor
0:48	Intermittent flame impingement at ceiling
0:56	Flame impingement on wall; discoloration and charring of wall in northwest corner
1:12	Sustained flame impingement at ceiling
1:22	Heptane ignitor exhausted, flame height receding, back corner of crib involved
1:32	Flame height less than 1.2 m (4 ft.) above floor
1:48	Charring of wall confined to northwest corner behind crib
2:07	Flame height approximately 1.2 m (4 ft.) above floor, burn rate of crib appears stabilized
2:25	Ignition of north wall
2:40	Flame height lengthening due to contribution from wall; dense black smoke accumulating at ceiling
2:45	Ignition of west wall
2:55	Lateral flame spread along walls at ceiling
3:05	Curtains fell from north and west walls
3:25	Dense smoke/distinct odor not noticed in other tests
3:27	Fire continued to northwest corner
3:40	Burn through of west wall, burning extended into stud cavity
3:55	Gas phase burning at ceiling
4:05	Cracking of windows on west wall
4:10	Gases burning .3 m (1 ft.) below ceiling
4:28	Increase in burn rate in corner
4:37	Gas phase burning over entire ceiling
4:38	Poor visibility due to smoke
4:55	Excessive smoke, can no longer see burning crib

5:20	Zero visibility
7:15	Fire above ceiling at north end of mobile home
	No test observations during this period due to excessive smoke build-up
11:15	Apparent burning behind walls in stud cavity; temperatures monitored above crib stabilizing
15:23	Actuation of sprinkler system
15:30	Termination of test observations

Post Test Observations

1. Fire localized to northwest corner.
2. Burn through of north and west walls along ceiling.
3. Some random blistering of vinyl surface on walls.
4. Some fire penetration of ceiling due to failure of west wall along ceiling; firestopping in north wall performed adequately.
5. Failure of wall was due first to direct flame impingement, resulting in "pin-hole" failures in the wall surface and shortly thereafter sustained burning.

MHLIV #6

Interior Finish Materials

Walls: W-1 | Date: 4/14/76
Ceiling: C-4 | Time: 2:00 PM

Ignition Source

6.4 Kg. cross piled wood crib

TIME (Min:Sec)	OBSERVATION/EVENT
0:00	Ignition of heptane
0:08	Intermittent flame height .9 m (3 ft.) above floor
0:15	Intermittent flame height 1.2 m (4 ft.) above floor
0:28	Height of flame approaching 1.8 m (6 ft.) above floor
0:36	Single station ionization detector alarmed
0:40	Intermittent flame height 1.8 m (6 ft.) above floor
0:50	Flame impingement on wall and ceiling
1:10	Flame height from crib receding; molding burning in corner
1:17	Ignition of wall surface (paper)
1:34	No further burning of heptane, flame height approximately 1.2 m (4 ft.) above floor
1:50	Paper on north wall adjacent to crib still burning
2:17	Slight smoke generation - grey in color
3:30	Flame height from crib stabilized at approximately 1.4 m (4-1/2 ft.) above floor
3:38	No burning of wall or ceiling materials
4:00	Curtains remain as installed
5:15	Crib fire still constant at approximately 1.2 m (4 ft.)
5:35	Visibility clear, traces of ash from crib and paper surface of wall materials throughout burn room
7:17	Slight increase in smoke, no measureable effect on visibility

8:55	Burn rate of crib decreasing - center of crib beginning to collapse
9:20	Smoke well mixed throughout volume of burn room - visibility into corridor still clear
10:40	Smoke emitted at joint between two wall panels on west wall adjacent to crib - poor joint resulted in burning in stud cavity.
11:40	Flame height from crib still stable at approximately 1.2-1.5 m (4-5 ft.) above floor
12:05	Smoke density increasing - difficulty in seeing corridor
13:10	Slight increase in heat at observation window
14:00	Flame from crib has reduced to approximately .9 m (3 ft.) above floor; broad flame base covering most of the top surface of crib
14:58	Numbers on wall at 1.8 m (6 ft.) level adjacent to crib not visible
15:12	Flame height from crib reduced to approximately .8 m (2-1/2 ft.)
15:55	Termination of test observations

Post Test Observations

1. Fire spread localized to wall panels directly exposed to crib on north and west walls; failure of joint 152-203 mm (6-8 inches) from corner on west wall resulted in burning of studs and paper backing on glass fiber
2. No burning above ceiling; no apparent failure of ceiling membrane.

MHLlV #7

Interior Finish Materials

Walls: W-11A Date: 4/27/76
Ceiling: C-5 Time: 1:45 PM

Ignition Source

6.4 kg cross piled wood crib

TIME (Min:Sec)	OBSERVATION/EVENT
0:00	Ignition of heptane
0:23	Intermittent flame height 1 m (3 1/2 ft.) above floor
0:27	Flame height lengthened to approximately 1.5 (5 ft.) above floor
0:33	Single station detector alarmed
0:38	Fire localized to crib - no flame impingement on walls
0:54	Intermittent flame height 1.8 m (6 ft.) above floor, flame impingement on walls resulting in charring and blistering of walls in northwest corner
1:30	Grey smoke being released
1:48	No further burning of heptane - flame height receded to 1.2 m (4 ft.) above floor
2:25	Slight accumulation of smoke - well mixed in upper part of room
2:33	Ignition of north wall - characterized by pin hole

	failure of vinyl surface and the immediate release of dense black smoke
2:35	Sustained burning of north and west walls
2:45	Dense smoke accumulation at ceiling; can no longer read 1.8 m (6 ft.) marker on west wall adjacent to crib
2:55	Sustained flame impingement at ceiling, ignition of ceiling
3:00	Flame spread across ceiling to east wall; curtains on north and west walls down
3:18	Black smoke layer .3 - .6 m (1-2 ft.) down from ceiling, gases burning in smoke layer
3:30	Unable to read any wall markers in northwest corner
3:45	Gas phase burning across entire ceiling
4:15	Smoke layers provide no visibility at floor and ceiling; some visibility at 1.5 m (5 ft.) above floor
4:33	No visibility
5:10	Windows breaking in north and west walls
5:15	Flashover*
5:40	Actuation of sprinkler system
5:40	Termination of test observations

Post Test Observations

1. Failure of all windows in living room.
2. Walls charged throughout living room.
3. Flame propagation extensive above ceiling.
4. Floor cover near crib burned.

* Flashover occurred between 5:10 and 5:20.

MHLlV #8

Interior Finish Materials

Walls: W-10 — Date: 5/5/76
Ceiling: C-5 — Time: 1:30 PM

Ignition Source

6.4 kg. cross piled wood crib

TIME(Min:Sec)	OBSERVATION/EVENT
0:00	Ignition of heptane
0:16	Intermittent flame height 1.2 m (4 ft.) above floor
0:30	Clock malfunctioned
0:33	Single station detector alarmed
0:37	Intermittent flame height 1.5 m (5 ft.) above floor
0:44	Intumescing on north wall adjacent to crib
0:48	Flame impingement on wall;
0:55	Intermittent flame impingement at ceiling
1:15	Constant flame impingement at ceiling
1:16	Slight lateral flame spread along north and west walls and ceiling
1:30	No indication that walls are burning - molding ignited at ceiling
1:47	Flame height receded to approximately 1.4 m (4-1/2 ft.), no burning heptane

2:10	Pin-hole failure in surface of north wall directly exposed to flame from crib
2:23	Fire from crib stabilized at 1.2 m (4 ft.) above floor
2:50	Ignition of north wall up to 1.2 m (4 ft.) marked on northwest corner
3:01	Failure of intumescent on north and west walls; sustained burning
3:15	Smoke (grey color) accumulating in upper third of room, no appreciable affect on visibility
3:30	Flame height extended to approximately 1.8 m (6 ft.) in corner
3:40	Intermittent flame impingement at ceiling
4:00	Constant flame impingement at ceiling
4:20	Lateral flame spread at ceiling, gas phase burning; ignition of ceiling
4:38	Burn through of north and west walls behind crib
5:05	Lateral flame spread 1.8-2.4 m (6 to 8 ft.) along north and west walls at ceiling
5:25	Build-up of fire intensity in corner
5:50	Curtains fell on north and west walls; smoke accumulation from floor to ceiling
6:03	Combustible gases burning near ceiling surface
6:25	Fire still confined to northwest corner; increase in heat at observation window
7:15	Significant reduction in visibility
7:30	Fire still confined to northwest corner
7:46	Window in north wall cracked
7:53	Increased involvement of gas burning
8:10	Intensity of fire in corner increasing; visibility low
10:00	Low visibility
13:15	Increased heat at observation window
15:35	Actuation of sprinkler system, termination of test observations

MHL1V #9

Interior Finish Materials

Walls: W-13
Ceiling: C-5

Date: 5/12/76
Time: 1:45 PM

Ignition Source

6.4 kg cross piled wood crib

TIME (Min:Sec)	OBSERVATION/EVENT
0:00	Ignition of heptane
0:33	Intermittent flame height 1.2 m (4 ft.) above floor; detector alarm
0:41	Trace smoke generation from burning heptane
0:49	Intermittent flame height 1.8 m (6 ft.) above floor
1:00	No noticeable flame impingement on walls
1:13	Flame height receded to approximately 1.5 m (5 ft.) above floor
1:21	Fire localized in center of crib, slight char on north wall directly above crib
1:42	No further contribution from heptane
1:46	Flame height receded to approximately 1.2 m (4 ft.) above floor
1:50	Flame impingement on wall, charring of north and west walls

2:00	Flame height has receded to just under .9 m (3 ft.) above the floor
2:40	Flame height increasing - center of fire plume elongated to 1.2 m (4 ft.) above floor
3:00	Ignition of north wall - flame height immediately lengthened to 6 ft.
3:15	Intermittent flame impingement at ceiling
3:22	Ignition of west wall - lateral flame spread along north and west walls at ceiling level
3:33	Noticeable increase in fire intensity
3:41	Ignition of molding
3:47	Flames have spread across ceiling surface
4:00	Flames have involved 3/4 of the ceiling surface - primarily gas phase
4:08	North wall fully involved along ceiling
4:28	Burn through of west wall behind crib
4:45	Gas phase burning .3 m (1 ft.) down from ceiling
4:50	Fire spread on east wall
4:55	Dense smoke (black) resulting primarily from ignition of ceiling
5:10	Excessive heat buildup at observation window
5:17	Gas phase burning down to 1.5 m (5 ft.) above floor
5:27	Increase in smoke obscuration
5:28	Ignition of sofa
5:30	Flashover
5:58	Fire extended out windows in north wall
6:45	Gas phase burning from floor to ceiling
7:08	Actuation of sprinkler system
7:08	Termination of test observations

MHLIV #10

Interior Finish Materials

Walls: W-13
Ceiling: C-5

Date: 5/25/76
Time: 1:30 PM

Ignition Source

16 kg. upholstered chair

TIME(Min:Sec)	OBSERVATION/EVENT
0:00	Ignition of newsprint
0:05	Ignition of left arm of chair
0:17	Flame height approximately .8 m (2-1/2 ft.) above floor
0:19	Grey colored smoke being released from chair
0:27	Flame height lengthened to 1.2 m (4 ft.) above floor
0:33	Flames beginning to propagate towards back of chair
0:48	Single station detector alarmed
1:04	Flame height reduced from waste can; burn-through of exterior chair upholstery on left arm
1:15	Flame height receded to approximately .8 m (2-1/2 ft.); low intensity
2:10	Approximately 50% of waste container has burned or melted
2:18	Flame has propagated around to front of chair impinging on cushion

2:35	Flame height 1 m (3-1/2 ft.) above floor - increase in area of chair involved
3:00	Flame impingement on wall
3:35	Noticeable accumulation of black smoke
3:45	Cushion becoming involved
3:58	Ignition of north wall - flame height immediately increased to 1.8 m (6 ft.) above floor; intensity of fire increased, intermittent impingement at ceiling
4:12	Constant flame impingement at ceiling
4:22	Lateral flame spread along north and west walls at ceiling, primarily gas phase burning
4:35	Curtains down on north and west walls
4:39	Ignition of west wall at ceiling - approximately 2/3 of surface area of the chair involved
4:45	Flames have spread across ceiling to east wall
5:00	Gas phase burning across entire ceiling, rapid increase in fire intensity in corner
5:08	Gas phase burning approximately .3 m (1 ft.) down from ceiling
5:14	Ignition of floor material
5:18	Flashover
5:40	Actuation of sprinkler system
5:40	Termination of test observations

Post Test Observations

1. Observation windows distorted (appeared to be drawn in towards fire) windows broke on east, north and west walls.
2. Surface of ceiling damaged throughout living room (approximately 144 ft^2) burn through of ceiling above chair.
3. North wall burned through from floor to ceiling adjacent to waste container.
4. Burn-through of east, north and west walls along ceiling.
5. Ignition of floor occurred prior to flashover - 75% damage to floor.
6. Limited burn through of wall and ceiling materials due to rapid growth of fire from low intensity to flashover.
7. Chair developed slower than 6.4 kg crib, providing more preheat time.

MHL1V #11

Interior Finish Materials

Walls: W-1
Ceiling: C-4

Date: 6/11/76
Time: 2:12 PM

Ignition Source

16 kg. upholstered chair

TIME (Min:Sec)	OBSERVATION/EVENT
0:00	Activation of electric match - newsprint has not visibly ignited
0:25	Termination
0:00	Ignition of newsprint
0:20	Flame height approximately .9 m (3 ft.) above floor
0:25	Ignition of fabric on left arm of chair adjacent to waste container

0:39	Detector alarmed
1:05	Burn-through of fabric on chair
1:40	Flames have spread across top of left arm of chair
2:00	Fabric has opened on left arm - ignition of cotton ticking
2:05	Large particulate matter from burning newsprint
2:30	Slight flame spread towards back of chair - no impingement on wall
2:50	50% of waste container destroyed; slight accumulation of grey smoke at ceiling
2:55	Continued grey smoke from burning cotton in chair
3:30	Fire localized to waste container and part of left arm of chair
4:00	Flame height lengthening - .9 m (3 ft.) above floor
4:10	Flame impingement on wall
4:40	Flame height 1 m (3.5 ft.) above floor
4:55	Ignition of paper surface on north wall
4:58	Flame height 1.2 m (4 ft.) above floor
5:15	Intermittent flame height 1.5 m (5 ft.) above floor
5:27	Evidence of flame spread to underside of chair
5:45	North wall charred in corner; no attachment
6:00	Intermittent flame height 1.5 (5 ft.) above floor
6:10	Flame impingement on cushion
6:30	Flame height constant at 1.2 m (4 ft.) above floor
7:45	Some flame propagation on cushion, burn through of left arm - direct flame impingement on cushion
8:00	Back of chair involved
8:50	Cushion involved - black smoke indicated involvement of polyurethane foam
9:25	Flame height 1.5 m (5 ft.) above floor - direct impingement on north wall
9:35	Burn rate of chair increased
9:40	Accumulation of black smoke at ceiling - both arms of chair involved
10:00	Flame height 1.8 m (6 ft.) above floor - increased fire intensity in corner
10:20	Drapes falling on north and west walls; flames intermittently impinging on ceiling
10:35	Initial lateral fire spread along ceiling
10:00	Flame height 1.8 m (6 ft.) above floor - increased fire intensity in corner
10:20	Drapes falling on north and west walls; flames intermittently impinging on ceiling
10:35	Initial lateral fire spread along ceiling
10:53	Lateral flame spread .9-1.2 m (3-4 ft.) along north and west walls at ceiling
10:58	Sustained burning of right arm of chair
11:20	Lateral flame spread 1.8-2.4 m (6-8 ft.) along north and west walls at ceiling
11:30	Visible crack in north wall
11:45	Excessive accumulation of black smoke
12:15	Visibility reduced significantly
12:30	Fire still localized to corner - direct flame impingement on north wall
13:00	Visibility negligible at floor - intense flame exposure on north wall
13:25	Smoke from ceiling to floor
14:15	Fire still localized in northwest corner, excessive heat at observation window
16:00	Flames localized to right arm of chair, partial collapse of structure of chair
	No sustained burning of carpet
17:00	Flame height receded to less than 1.2 m (4 ft.)
18:20	Termination of test observations

Post Test Observations

1. Fire localized to northwest corner.
2. Paper ignited on first panels on north and west walls; paper surface burned off ceiling directly above fire.
3. No involvement of furnishings or newspaper flashover indicators in burn room.
4. Floor cover charred in immediate area of ignition.

MHLlV #12

Interior Finish Materials

Walls: W-12
Ceiling: C-5

Date: 7/28/76
Time: 11:00 AM

Ignition Source

16 kg. upholstered chair

TIME (Min:Sec)	OBSERVATION/EVENT
0:00	Ignition
0:30	Slight charring on left arm of chair
0:54	Flame height approximately .9 m (3 ft.) above floor
0:55	Ignition of curtain
0:58	Curtain melting away
1:00	Flame height approximately .3 m (1 ft.) above left arm of chair
1:05	Burn-through of fabric on left arm of chair
1:15	Smoke detector alarmed
1:30	Flame height approximately .9 m (3 ft.) above floor
1:45	Chair charred on left side
1:55	Flame height approximately .6 m (2 ft.) above floor
2:45	Waste container melted down approximately 25%
2:50	Slight amount of grey smoke being given off by chair
3:40	Some charring on wall from waste container
3:50	Some grey smoke being emitted from wall
4:05	Approximately 0.1 m^2 (1 sq. ft.) of char on wall from waste can
4:30	Sustained burning of left arm of chair
4:40	Increase of charring on north wall
4:45	Waste can 90% melted
4:48	Fire spreading underneath chair
4:50	Waste can completely melted - open burning (on floor) of newsprint
5:05	Flame impingement on chair cushion
5:25	Fire still primarily confined to newsprint and left arm of chair
5:30	Flame impingement on wall
5:48	Flame height increasing to above left arm of chair
6:15	Char area on wall increasing - smoke being emitted from this area
6:20	Flame height approximately .9 m (3 ft.) above floor
6:23	Ignition of wall
6:25	Flame height approximately 1.2 m (4 ft.) above floor
6:30	Flame height approximately 1.8 m (6 ft.) above floor
6:31	Intermittent impingement on ceiling
6:50	Burn through of wall into stud cavity
6:56	Fire still localized on left side of chair
7:00	Complete involvement of first panel on north wall

7:02	Smoke being emitted out exterior of north wall
7:12	Lateral flame propagation approximately 1.2-1.5 m (4-5 ft). along north and west walls
7:24	Lateral flame propagation approximately 1.8 m (6 ft.) across north wall
7:30	Gas phase burning approximately .5 m (1 1/2 ft.) below ceiling
7:35	Lateral propagation 2.4-3 m (8-10 ft.) across west wall
7:38	Burning of back of chair
7:50	Smoldering of newsprint (flashover indicator) on coffee table
7:58	Full involvement (including cushion) of chair in corner
8:07	Smoke being emitted out living room door
8:08	Windows in north and west walls crack
8:14	Ignition of newsprint (flashover indicator) on end table
8:16	Ignition of flashover indicator on coffee table
8:20	Ignition of sofa
8:20	Flashover
8:22	Windows in east wall crack
8:26	Gas phase burning approximately .9 m (3 ft.) below ceiling
8:29	Involvement of furnishings
9:05	Sprinkler system activated - termination of test observations
9:10	Sprinkler system shut down
9:25	Sprinkler system reactivated
9:30	Sprinkler system shut down

Post Test Observations

1. Burn through of north wall from floor to ceiling in area of left arm of chair.
2. Burning of studs and insulation in area of left arm of chair.
3. Charring of all 4 walls at ceiling level.
4. West wall charred from ceiling to .6 m (2 ft.) mark beginning at northwest corner and extending to north edge of sofa. Char area decreases starting at north edge of sofa but extends into corridor.
5. Peeling of surface plies of lauan wall vertically from ceiling down .8 m (2 1/2 ft.), horizontally from northwest corner to south end of sofa.
6. Surface of ceiling damaged throughout entire burn room and down approximately 1.5 m (5 ft.) into corridor.
7. Newsprint flashover indicators on north end table and coffee table both ignited.
8. Damage to all furnishings in burn room.
9. Damage to carpet throughout entire burn room. Carpet shrunk away from walls in some locations.
10. Cracking of windows in north, west and east walls.

Interior Finish Materials

Walls:	W-14	Date:	8/18/76
Ceiling:	C-6	Time:	11:00 AM

Ignition Source

6.4 kg. cross piled wood crib

TIME (Min:Sec)	OBSERVATION/EVENT
0:00	Ignition
0:11	Center of crib involved
0:27	Flame height at 1.2 m (4 ft.)
0:31	Smoke Detector alarmed
0:39	Flame height at 1.5 m (5 ft.)
0:43	Impingement of flame on north wall
0:53	Intermittent flame impingement at ceiling
0:57	Charring of north wall in corner, ignition of paper surface
1:03	Flame impingement at ceiling
1:06	Slight discoloration of ceiling
1:08	Charring of north and west walls
1:14	Ignition of molding at ceiling
1:16	Some gas phase burning at ceiling
1:24	Some charring at ceiling, .6-.9 m (2-3 ft.) from corner
1:31	Flame height at 1.2 m (4 ft.)
1:38	Batten strip is burning at ceiling
1:45	Heptane has burned out
1:47	Flame height from crib approximately 1 m (3 1/2 ft.) above floor
2:01	Part of the burning batten strip fell to floor
3:03	Flame height approximately 1.4 m (4 1/2 ft.)
3:22	Burning of paper on north wall
3:50	Flame still localized in corner
4:00	Still some glowing on ceiling batten strip; however, no indication of further involvement
4:20	Some burning in ceiling cavity above ceiling material
4:47	Paper has burned off the wall in northwest corner
5:00	Flame height approximately 1.4 m (4 1/2 ft.)
5:25	Continued burning in ceiling cavity of back side of ceiling material
5:45	Living room is saturated with grey colored smoke, however west wall is still clearly visible
6:20	Flame height approximately 1.4 m (4 1/2 ft.), localized to northwest corner
6:25	Continued burning in ceiling cavity of back side of ceiling material
6:52	Smoke being emitted out vent in ceiling
7:30	Brief flaming on exposed side of ceiling
7:45	Flame height from ignition source approximately 1.2 m (4 ft.) above floor
8:47	Brief flaming on exposed side of ceiling
9:00	Flame height stabilized at 1.2 m (4 ft.); is no longer contributing to the spread of the fire
9:25	Second ceiling panel from corner beginning to crack and break up
9:30	Burning of gases at ceiling level
10:00	Visibility decreasing - 1.8 m (6 ft.) mark on west wall no longer visible
10:23	Burning of batten strip at ceiling level

10:35	Flaming of ceiling material now exposed
10:54	Nothing is visible in the living room except the crib and the burning in the ceiling
11:30	Grey smoke being emitted from vent on roof of the mobile home
13:00	Noticeable increase in radiation at observation window (at floor level)
13:05	Flames moving at ceiling level toward east wall
13:10	Entire first ceiling panel is open - burning on exposed and unexposed sides
13:20	Flames at ceiling are .6-.9 m (2-3 ft.) from east wall
13:50	Free burning above ceiling visible through opening in ceiling at north wall
15:40	Smoke being emitted from roof vent at south end of mobile home
16:10	Fire still freely burning in ceiling cavity
16:20	No indication of any window failures
16:30	Fire burning in the roof vent space in the eave of the north wall
17:35	Continued free burning in ceiling cavity at north end of mobile home
18:40	Termination of test observations

Post Test Observations

1. Damage to walls localized to northwest corner. There was no burn-through.
2. Burn-through of ceiling at north end of mobile home.
3. Burning of unexposed side of ceiling material at north end of mobile home.
4. Discoloration of exposed side of ceiling material throughout most of living room.
5. Extensive damage to studding and insulation in ceiling cavity at north end of mobile home.
6. No damage to sofa or other furnishings.

MHLlV #14

Interior Finish Materials

Walls: W-12
Ceiling: C-6

Date: 8/31/76
Time: 12:00 noon

Ignition Source

16 kg. upholstered chair

TIME (Min:Sec)	OBSERVATION/EVENT
0:00	Ignition
0:14	Burning of curtains near waste can
0:19	Ignition of chair on left side
0:22	Flame height approximately .6 m (2 ft.)
0:32	Smoke being emitted from arm of chair
1:45	Smoldering along left side of chair - no additional flame propagation
2:30	Flame height approximately .9 m (3 ft.)

2:40	Increased burning of waste can
3:15	Flame height approximately .6-.9 m (2 1/2-3 1/2 ft.) above floor, left side of chair becoming slightly more involved
3:25	Charring of wall approximately .3 m (1 ft.) above floor opposite waste can
4:00	Flame height approximately 1.2 m (4 ft.)
4:05	Waste can collapsed
4:06	Entire left side of chair involved
4:20	Flame height approximately 1.2 m (4 ft.); flame impingement on wall
4:27	Char area on wall increasing in size
5:20	Plies are beginning to separate in plywood
5:25	Char area approximately .2 m^2 (2 sq. ft.)
5:37	Flame height 1.2 m (4 ft.) - contribution is still primarily from the chair
5:50	Ignition of wall at the .6 m (2 ft.) mark
6:20	Flame height approximately 1.4 m (4 1/2 ft.)
6:25	Flame height approximately 1.5 m (5 ft.)
6:35	Smoke accumulating in upper part of room - 1.8 m (6 ft.) marker no longer visible
6:42	Flame impingement at ceiling
6:55	Flame front moving away from corner at ceiling level
7:10	Flame spread 1.2-1.8 m (4-6 ft.) from corner in both directions at ceiling
7:12	Gas phase burning .6 m (2 ft.) down from ceiling
7:20	Chair cushion involved
7:22	Flames completely across north wall
7:25	Flame spread to 3 m (10 ft.) mark on west wall
7:29	Gas phase burning throughout burn room
7:35	Top surface of chair fully involved
7:36	Newsprint ignited on end table
7:44	Newsprint ignited on coffee table
7:50	Ignition of sofa
8:04	Flashover
9:10	Flames out north end of mobile home
9:15	Burning in the ceiling cavity throughout north end of mobile home
9:30	Smoke being emitted from south end of mobile home
10:20	Activation of sprinkler system; termination of test observations

Post Test Observations

1. Second hand of clock malfunctioned during test - clock may not be accurate in photographs.
2. Involvement of wall materials throughout the burn room.
3. Charring of carpeting throughout the burn room.
4. Charring and burning of both corridor walls down approximately as far as the door of bedroom No. 1 (master bedroom).
5. Damage to ceiling throughout the living room; involvement of all furnishings in the living room; distortion of the observation windows.

Interior Finish Materials

Walls: W-16
Ceiling: W-16

Date: 10/21/76
Time: 3:45 PM

Ignition Source

6.4 kg. cross piled wood crib

TIME (Min:Sec)	OBSERVATION/EVENT
0:00	Ignition
0:15	Flame height approximately 1.2 m (4 ft.) above floor
0:29	Smoke detector activated
0:30	Flame height approximately 1.2 m - 1.4 m (4-4 1/2 ft.) above floor
0:40	Flame height approximately 1.5 m (5 ft.) above floor
0:47	Intermittent flame impingement on wall
0:55	Flame height approximately 1.8 m (6 ft.) above floor
1:00	Flame height approximately 1.8 m (6 ft.) above floor
1:15	Flame impingement on ceiling
1:30	Flame impingement on ceiling
1:35	Flames receeding from ceiling
1:45	Flame height 1.2-1.4 m (4-4 1/2 ft.) above floor
1:48	Heptane burned out - crib continued to burn
2:00	Flame height .9-1.2 m (3 1/2-4 ft.) above floor
2:17	Flame height 1.2 m (4 ft.) above floor
2:30	Flame height 1.2 m (4 ft.) above floor
3:00	Flame height 1.2 m (4 ft.) above floor
3:00-8:00	No appreciable change in conditions or size of fire
8:00	Flame height 1.2 m (4 ft.) above floor, no significant change in visibility
8:30	Flame height .9-1.2 m (3 1/2-4 ft.) above floor
9:00	Flame height 1.2 m (4 ft.) above floor
9:00-13:00	No appreciable change
13:00	Flame height 1.2 m (4 ft.) above floor
13:30	Flame height 1.2 m (4 ft.) above floor
13:50	Crib beginning to collapse in center
14:00	Flame height 1.2 m (4 ft.) above floor
14:30	Flame height 1 m (3 1/2 ft.) above floor
15:00	Flame height 1 m (3 1/2 ft.) above floor
15:30	Flame height 1 m (3 1/2 ft.) above floor
15:40	Flame height 1 m (3 1/2 ft.) above floor, flame more yellow, not as intense
16:45	Flame height 1 m (3 1/2 ft.) above floor
17:20	Flame height .9 m (3 ft.) above floor
17:35	Flame height .9 m (3 ft.) above floor
17:55	Flame height .9 m (3 ft.) above floor
19:05	Flame height 152-203 mm (6-8 in.) above top of crib (approximately .6 m (2 ft.) above floor)
19:25	Crib has collapsed throughout the center
20:00	Termination of test observations

Interior Finish Materials

Walls: W-16
Ceiling: W-16

Date: 9/28/76
Time: 2:30 PM

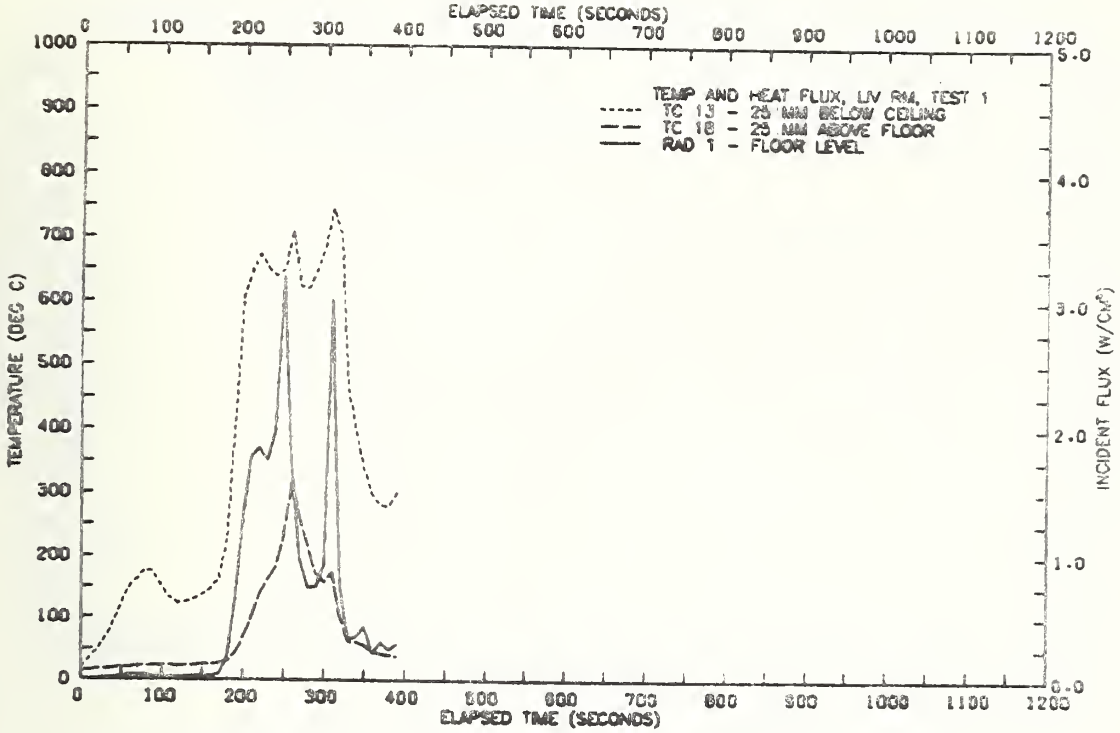
Ignition Source

16 kg. upholstered chair

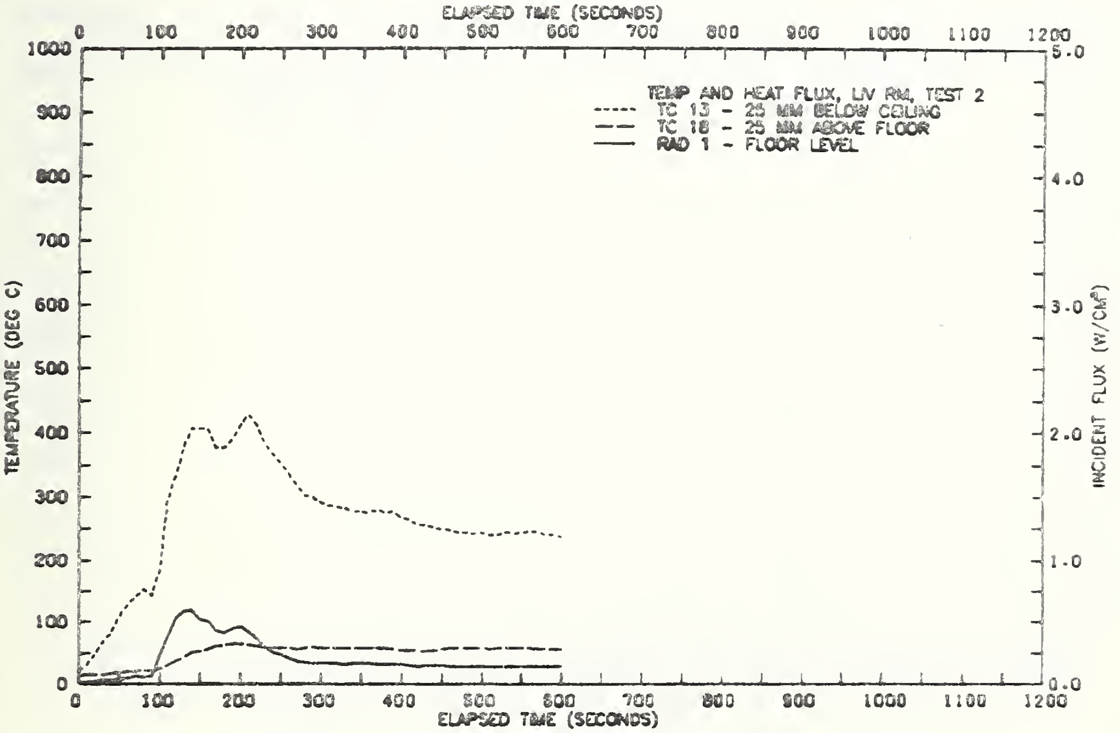
TIME (Min:Sec)	OBSERVATION/EVENT
0:00	Ignition of newsprint
0:20	Flame impingement on left arm of chair
0:43	Smoke detector alarmed
0:53	Waste can (polyethylene) melting
1:00	Flame height .9 m (3 ft.) above floor
1:15	Slight flame propagation along left arm of chair
1:35	Waste container 50% melted
1:45	Flame height approximately 152 mm (6 inches) on left arm of chair
2:10	Slight involvement of polyurethane foam
2:15	Increased involvement of left arm of chair; flame size increased to 229 mm (9 in.) along arm
2:35	Waste container totally destroyed
2:45	Flame height approximately .9 m (3 ft.) above floor (.3 m high on chair arm)
2:55	Initial burn through of left arm of chair, some exposure of chair cushion to intermittent flame
3:35	Significant amount of left side of chair involved
4:10	Flames have propagated around towards front of chair, flame impingement on wall
4:45	Flame height .3 m (1 ft.) above arm of chair
5:25	Flames propagating towards back of chair
5:35	Flame height approximately 1 m (3.5 ft.) above floor
6:10	Flame attachment to seat cushion -102 mm - (4 in.) flame height
7:00	Increased exposure of seat cushion from burning along left arm
8:00	Some accumulation of smoke particulate - no noticeable reduction in visibility
8:30	Increase in smoke generation
8:45	Flames propagating along front of chair
9:30	Flames have propagated under seat cushion; flame height approximately .9 m (3 ft.) above floor
10:00	Dilution of grey colored smoke throughout room
11:00	Approximately 1/2 of surface of seat cushion (left side) involved; flame height 1 m (3.5 ft.) above floor and noticeable increase in fire intensity
11:45	Marker at 1.8 m (6 ft.) location on north and west walls in the corner no longer visible
12:05	Seat cushion is 3/4 involved - flame height increased to 1.7-1.8 m (5.5-6 ft.)
13:00	Visibility poor; flame envelop appears to be intermittently impinging on ceiling
13:30	Ignition of right arm of chair; flames at ceiling
14:10	Marker at 1.5 m (5 ft.) level not visible
14:30	Marker at 1.2 m (4 ft.) level not visible
15:00	Total involvement of back of chair; seat cushion nearly consumed
15:25	Noticeable increase in temperature at observation window

15:40	Maximum intensity of chair fire appears to have been reached
16:45	Involvement of chair primarily on right side
17:30	Marker at .9 m (3 foot) level no longer visible
18:30	Noticeable decay in fire intensity
20:00	Termination of test observations

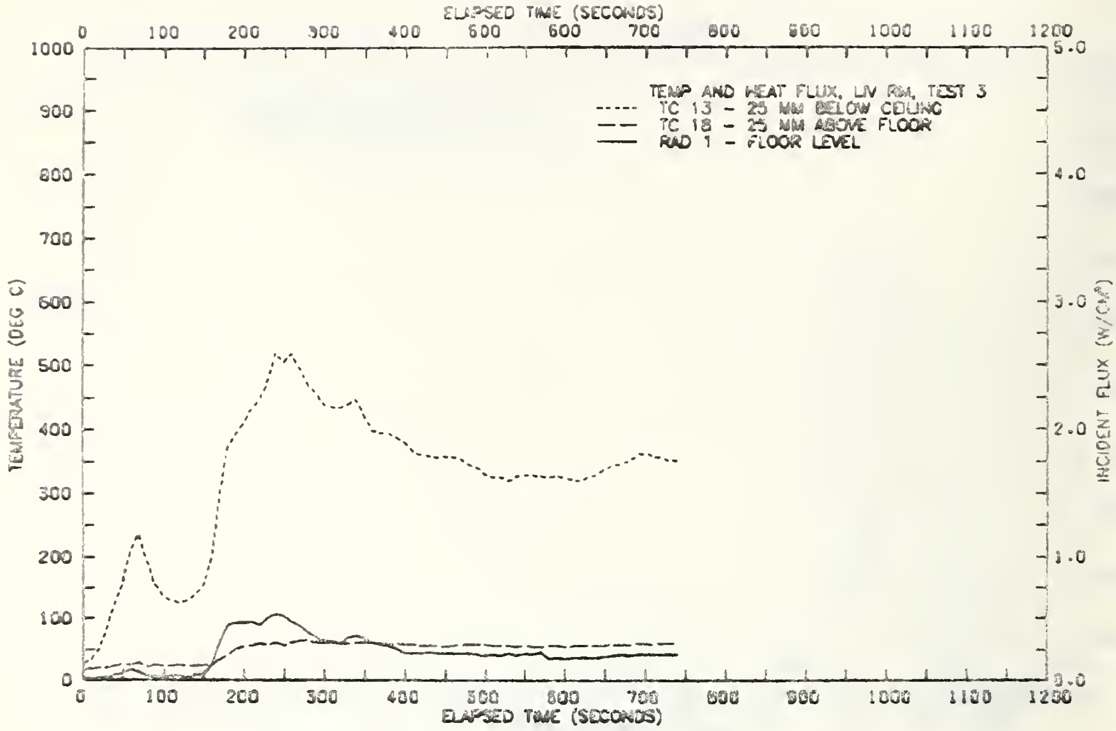
APPENDIX B. PLOTTED TEST DATA ILLUSTRATING KEY CHANGES IN VARIOUS MEASURED CONDITIONS



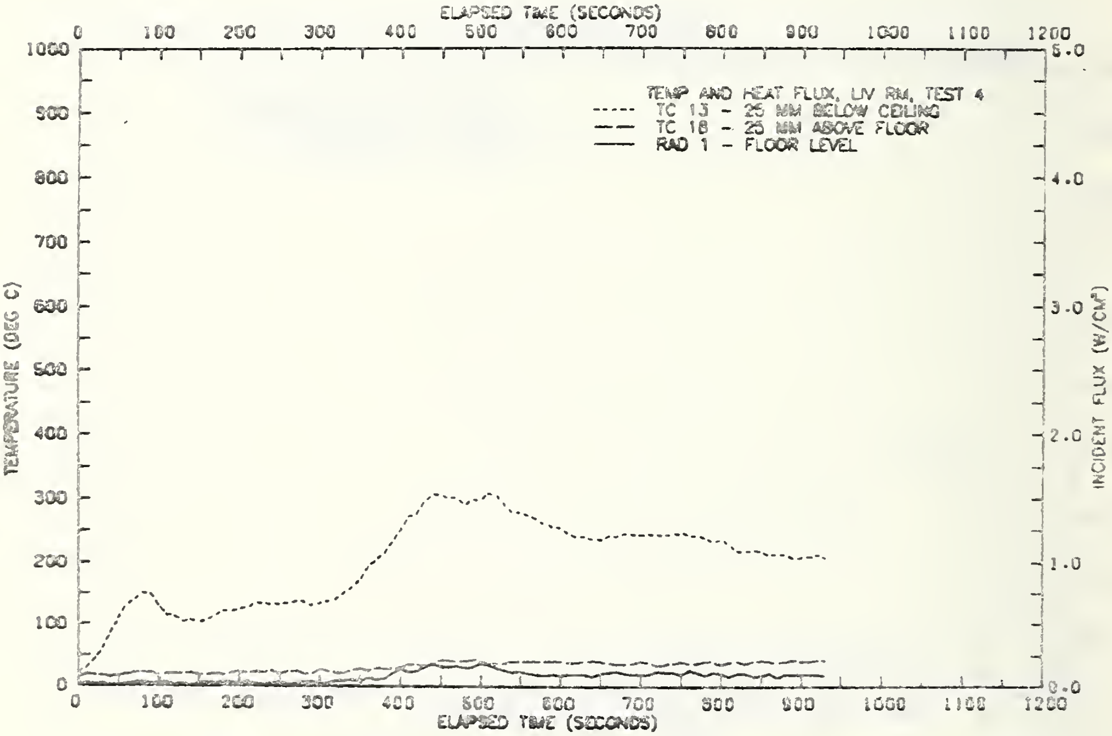
B1. Gas Temperature and Incident Heat Flux Measured in Center of Living Room



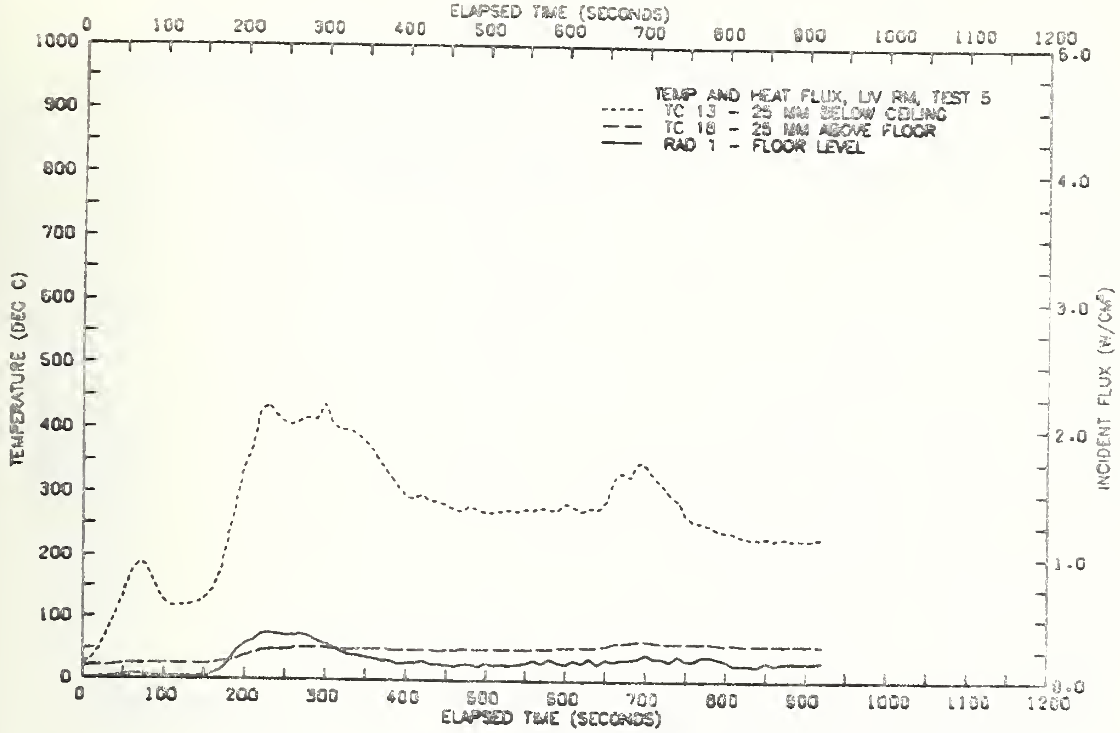
B2. Gas Temperature and Incident Heat Flux Measured in Center of Living Room



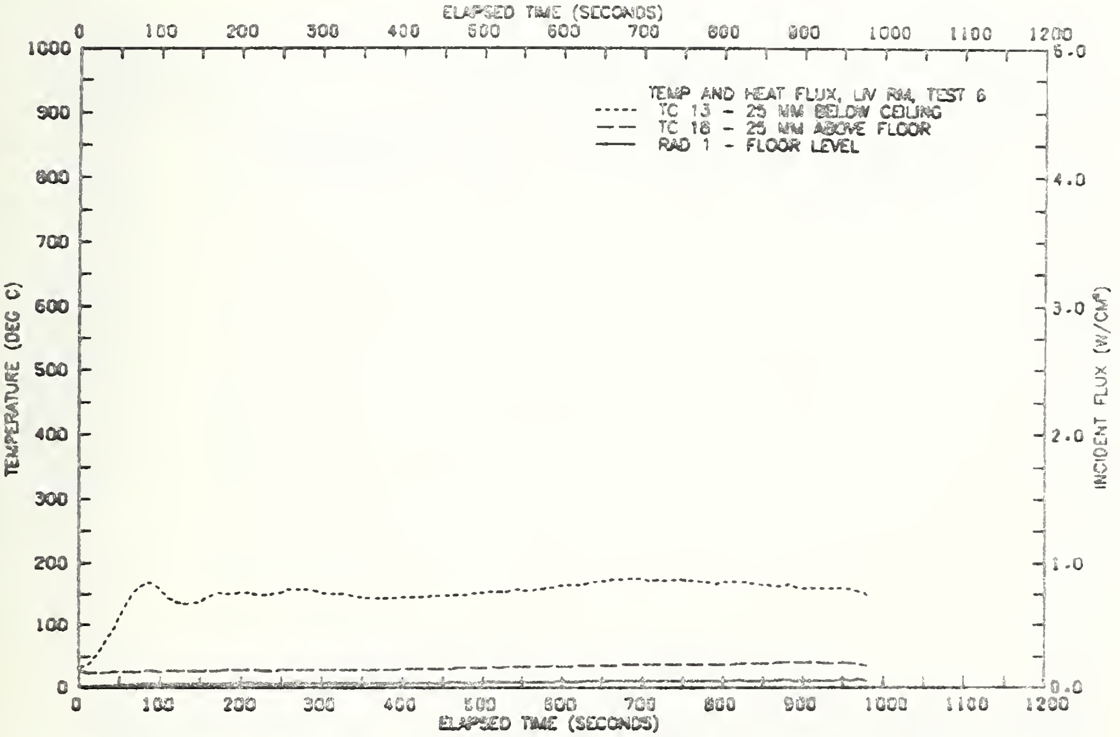
B3. Gas Temperature and Incident Heat Flux Measured in Center of Living Room



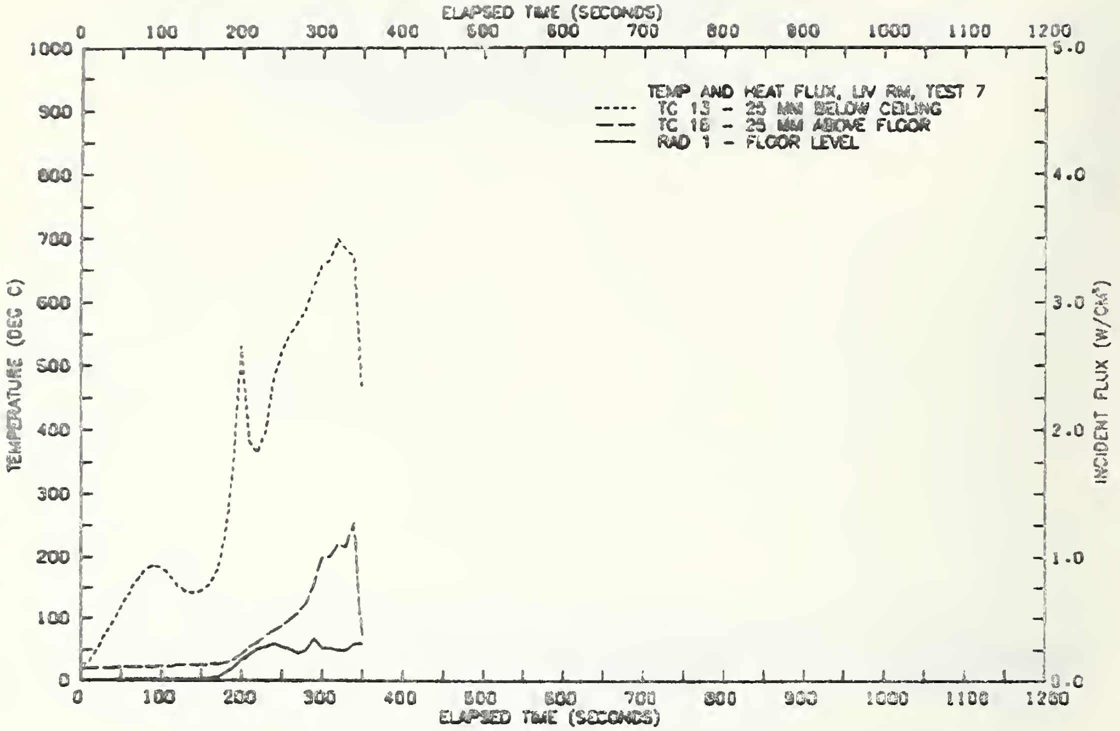
B4. Gas Temperature and Incident Heat Flux Measured in Center of Living Room



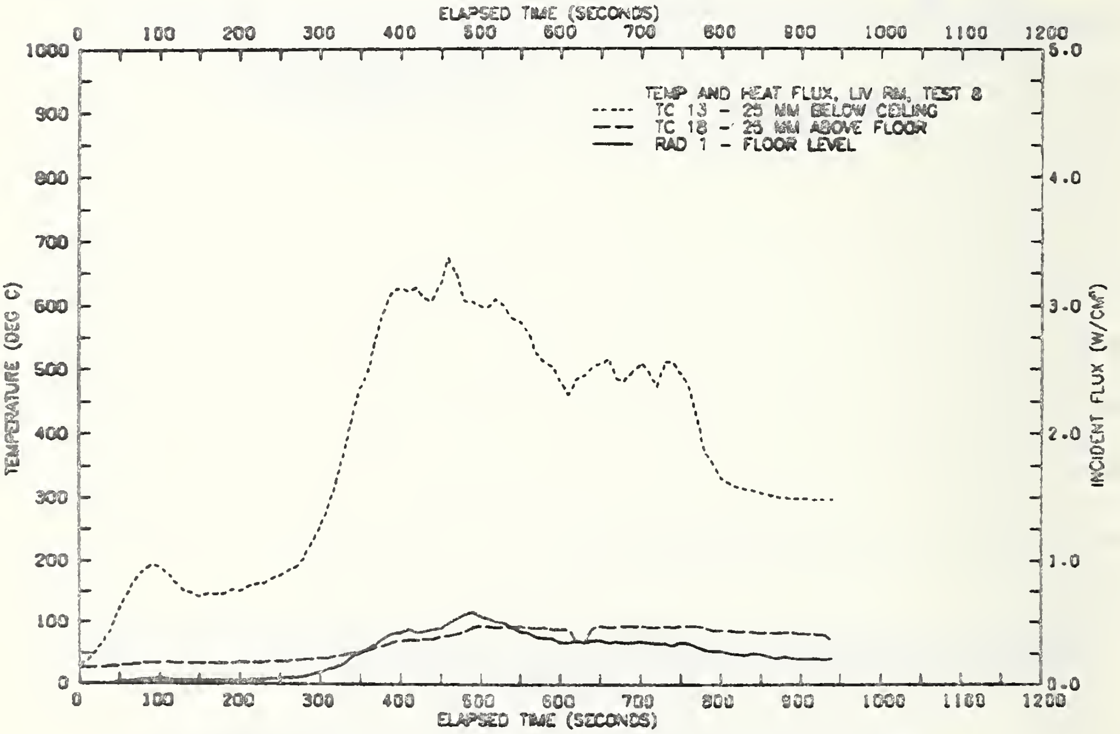
B5. Gas Temperature and Incident Heat Flux Measured in Center of Living Room



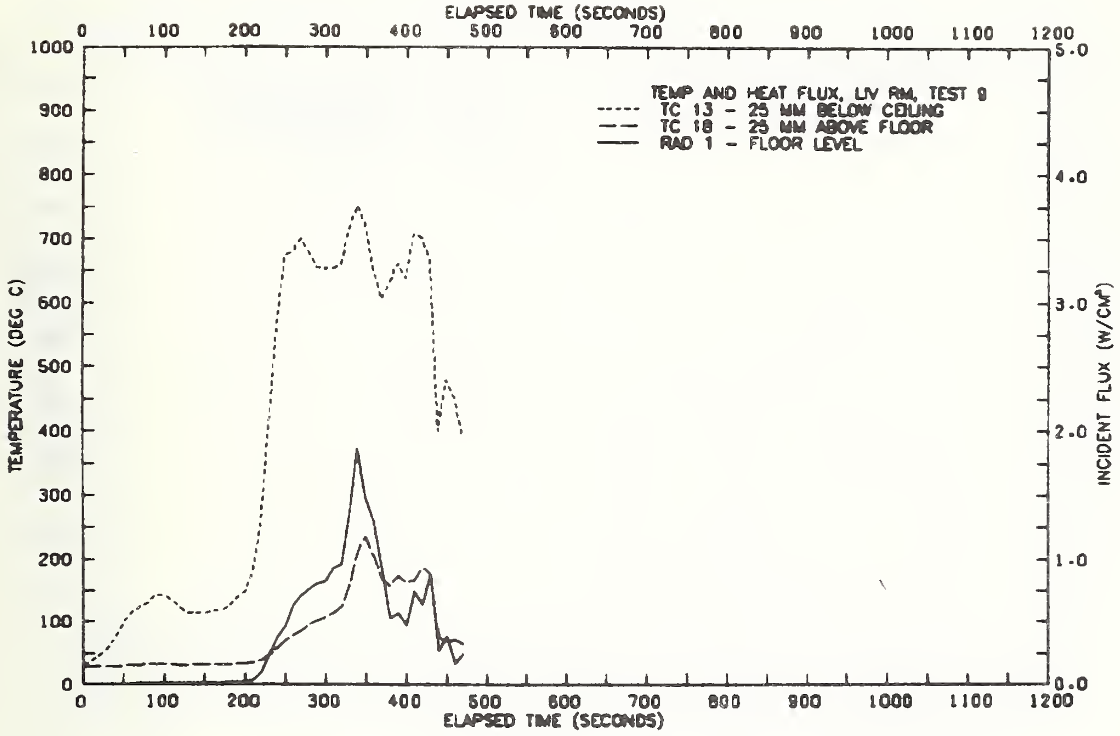
B6. Gas Temperature and Incident Heat Flux Measured in Center of Living Room



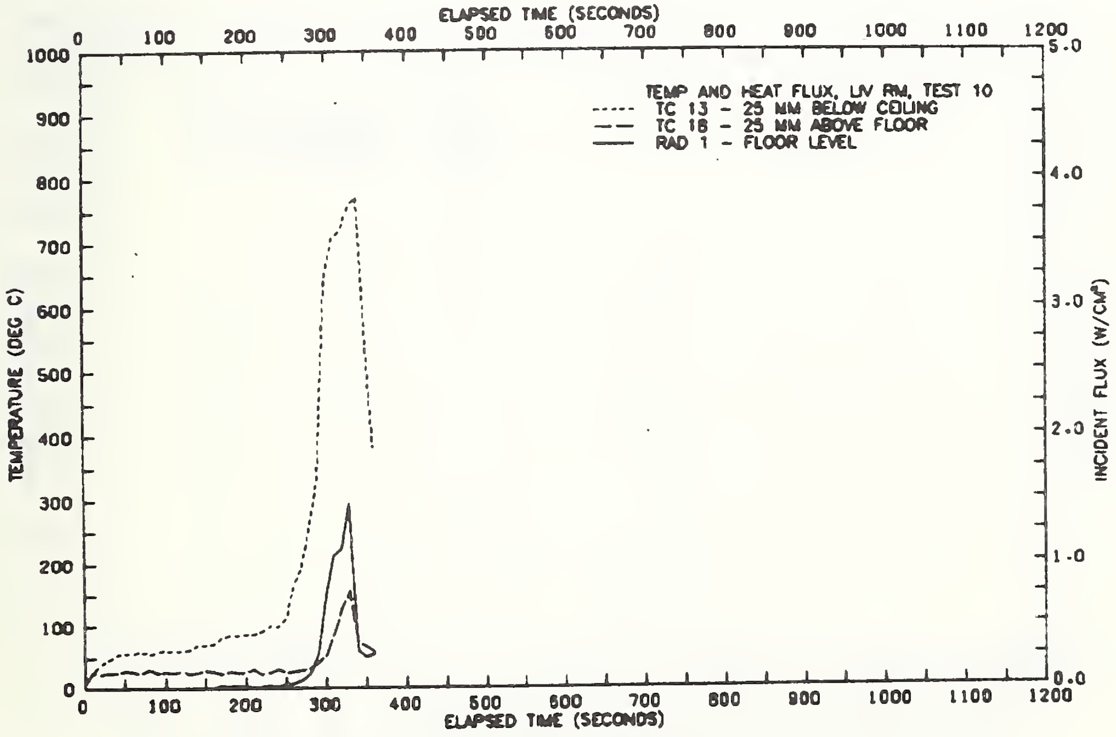
B7. Gas Temperature and Incident Heat Flux Measured in Center of Living Room



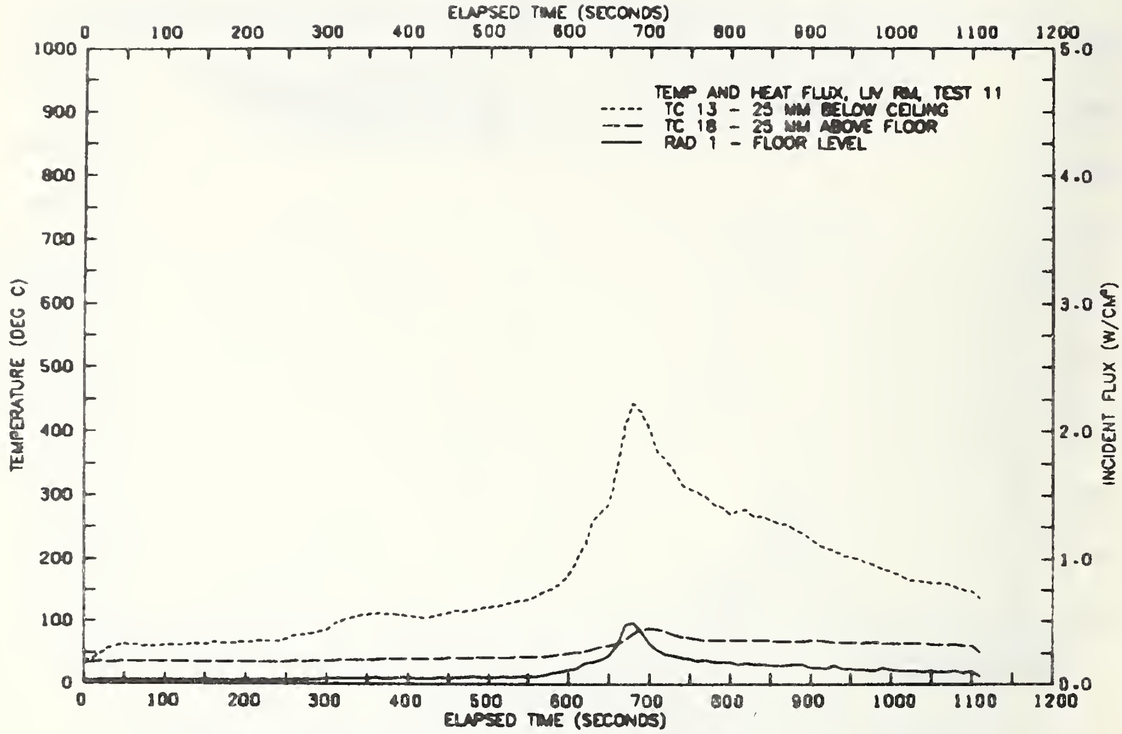
B8. Gas Temperature and Incident Heat Flux Measured in Center of Living Room



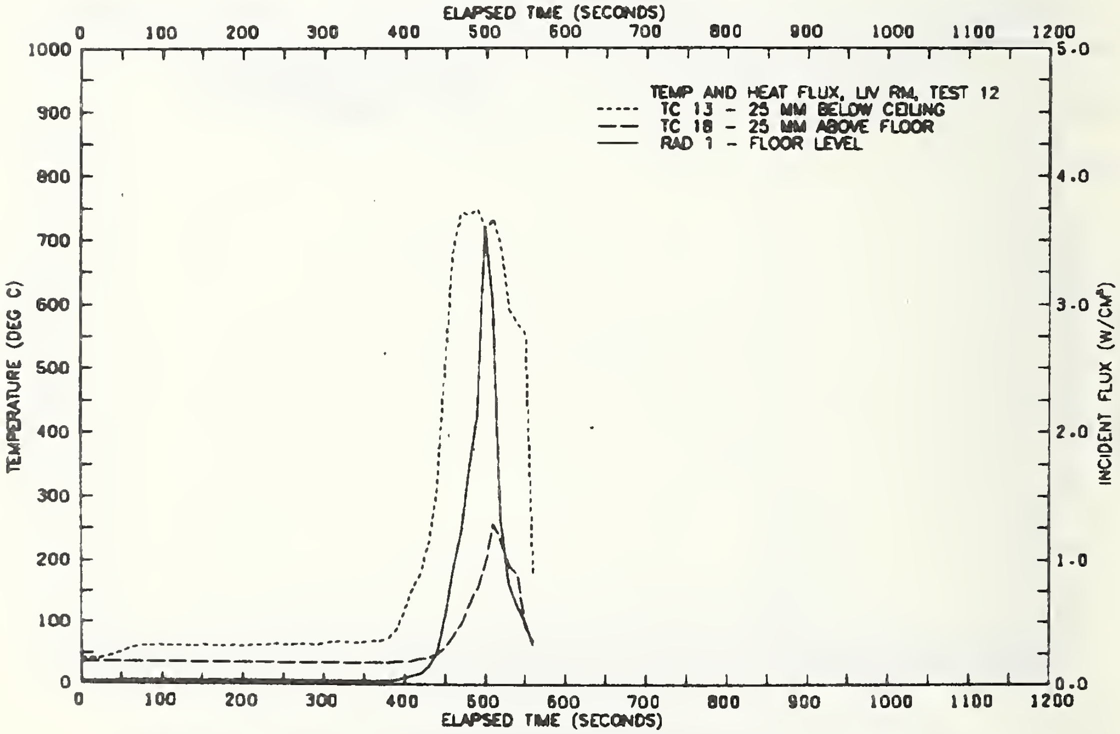
B9. Gas Temperature and Incident Heat Flux Measured in Center of Living Room



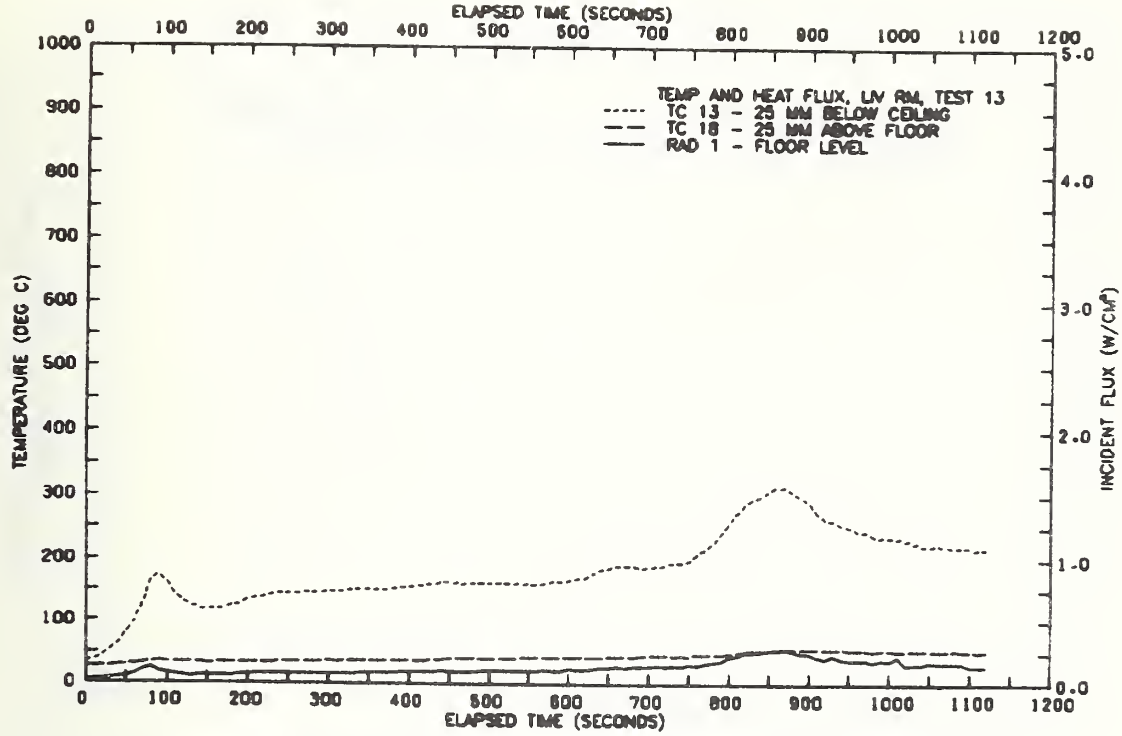
B10. Gas Temperature and Incident Heat Flux Measured in Center of Living Room



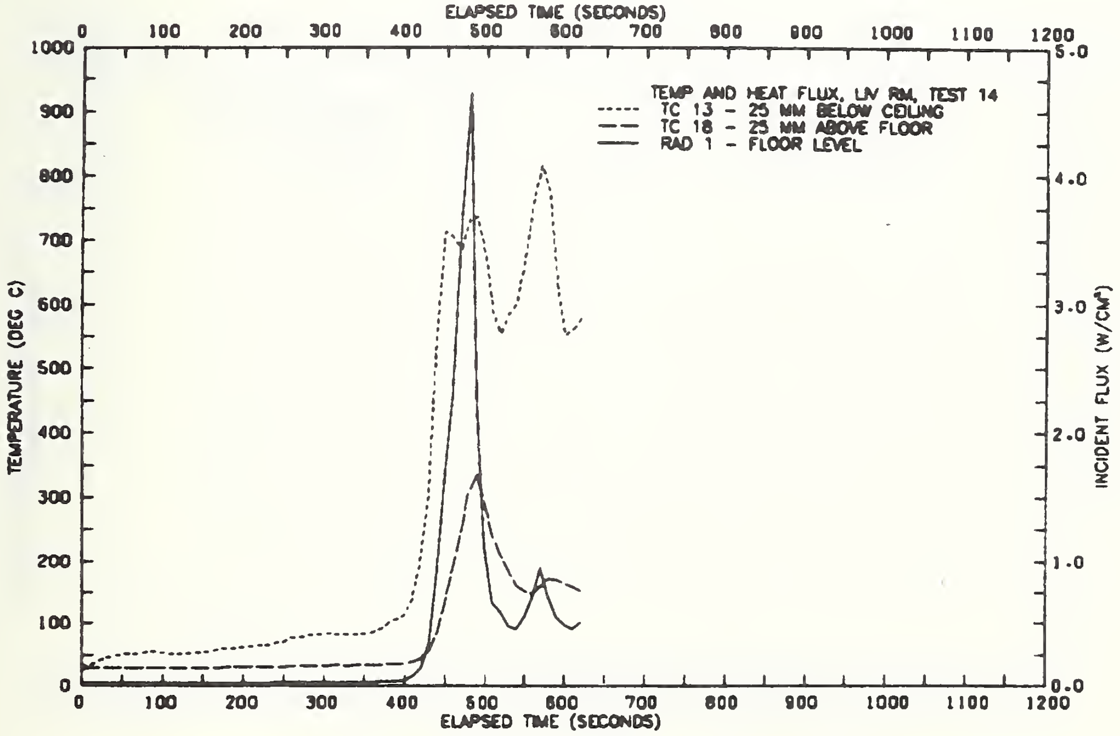
B11. Gas Temperature and Incident Heat Flux Measured in Center of Living Room



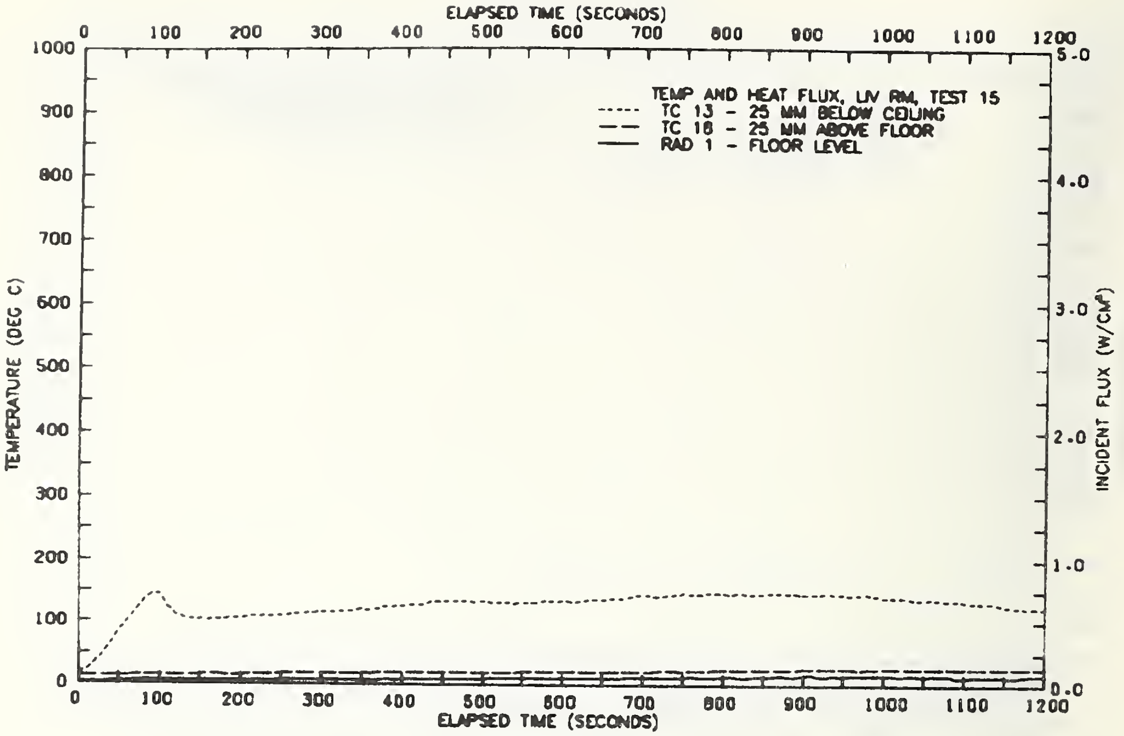
B12. Gas Temperature and Incident Heat Flux Measured in Center of Living Room



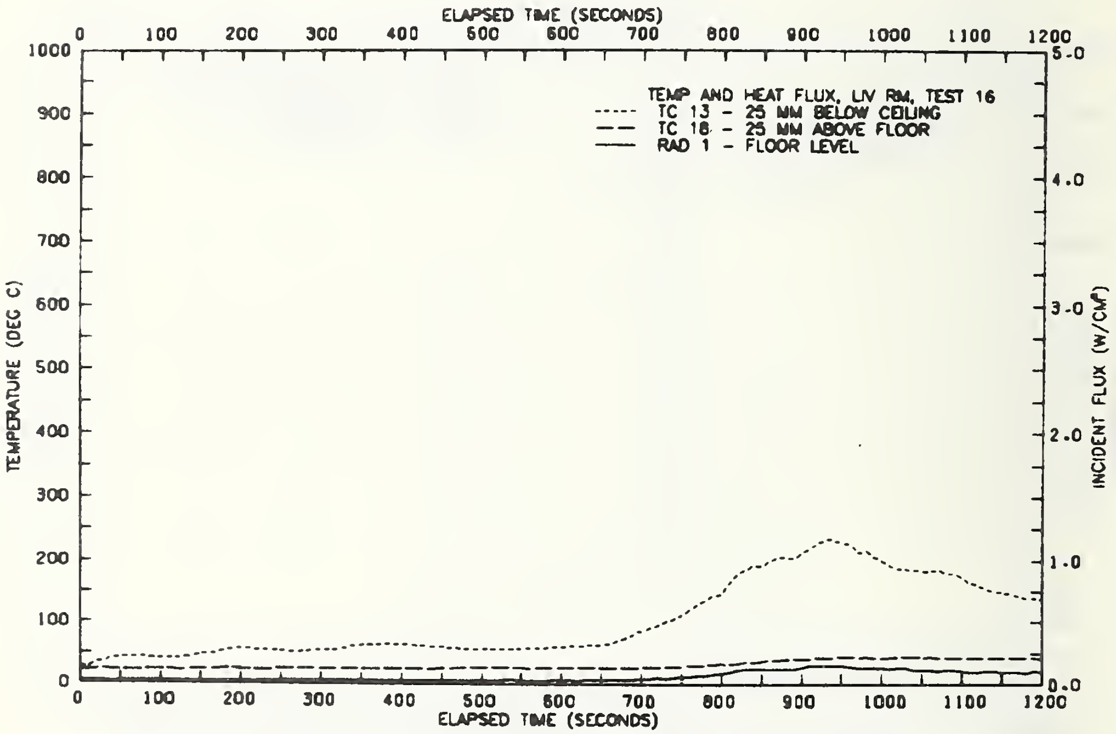
B13. Gas Temperature and Incident Heat Flux Measured in Center of Living Room



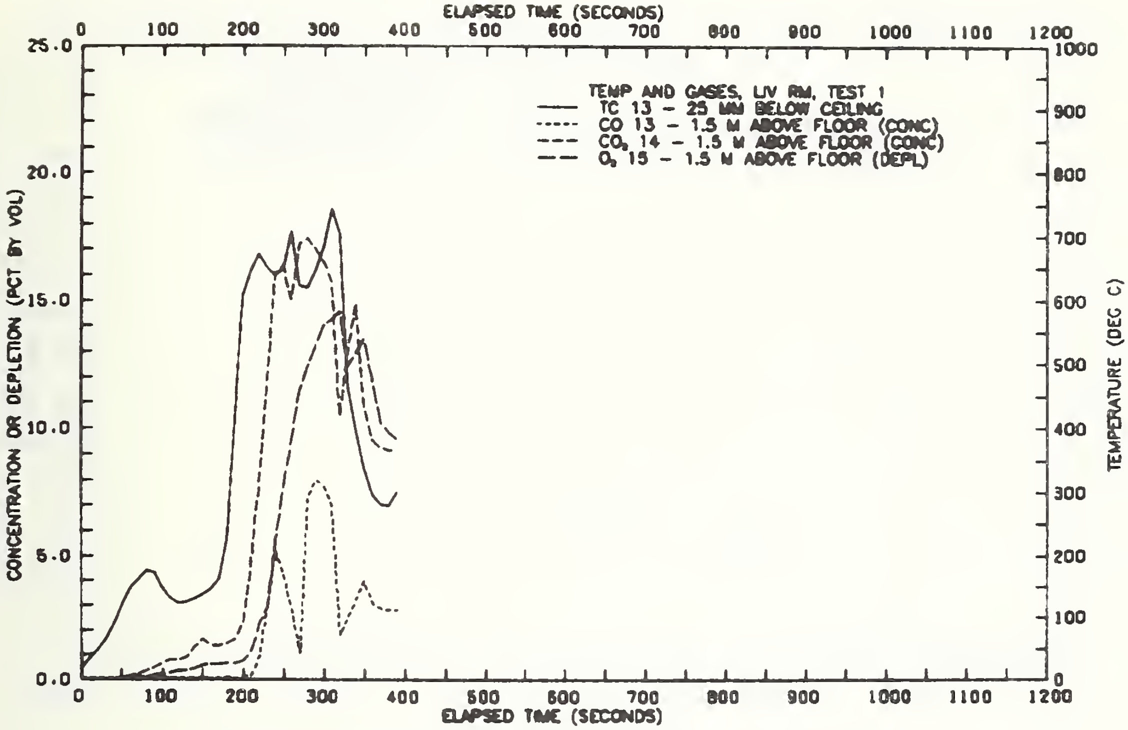
B14. Gas Temperature and Incident Heat Flux Measured in Center of Living Room



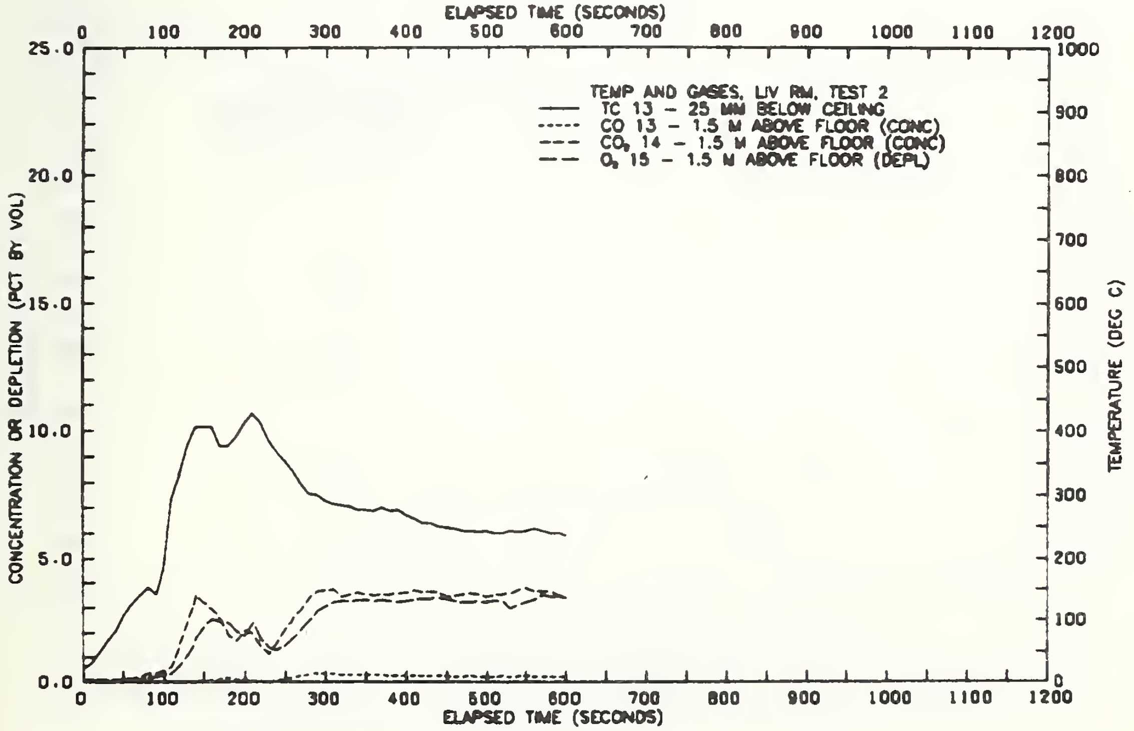
B15. Gas Temperature and Incident Heat Flux Measured in Center of Living Room



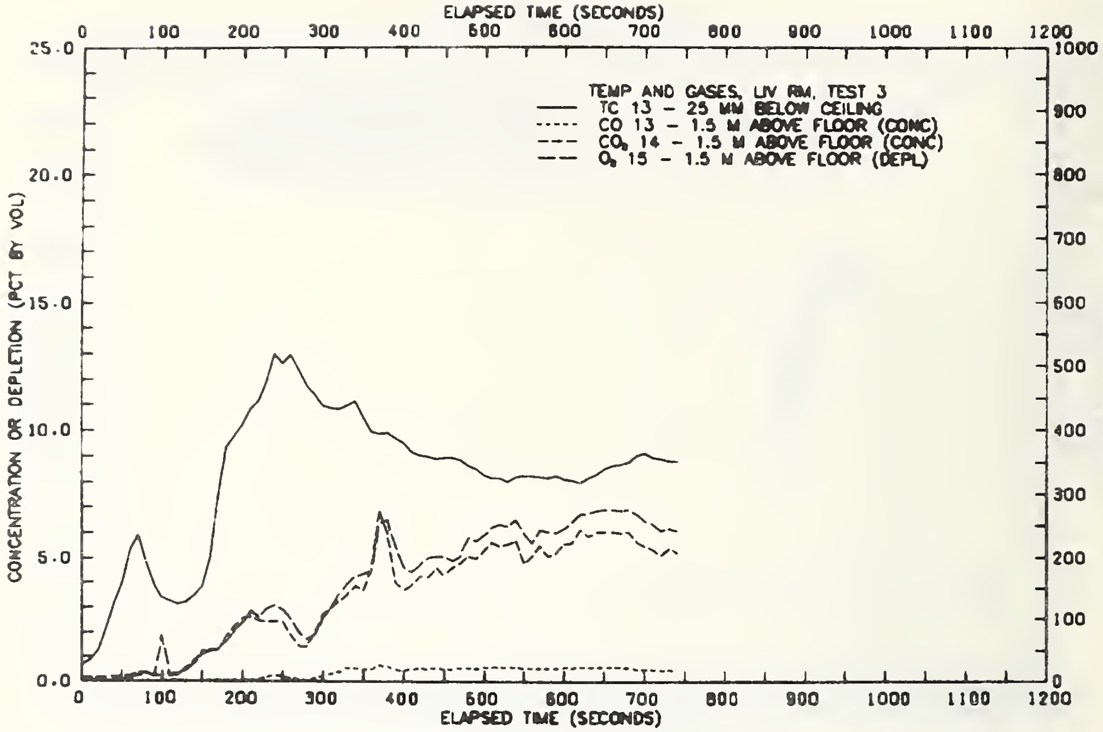
B16. Gas Temperature and Incident Heat Flux Measured in Center of Living Room



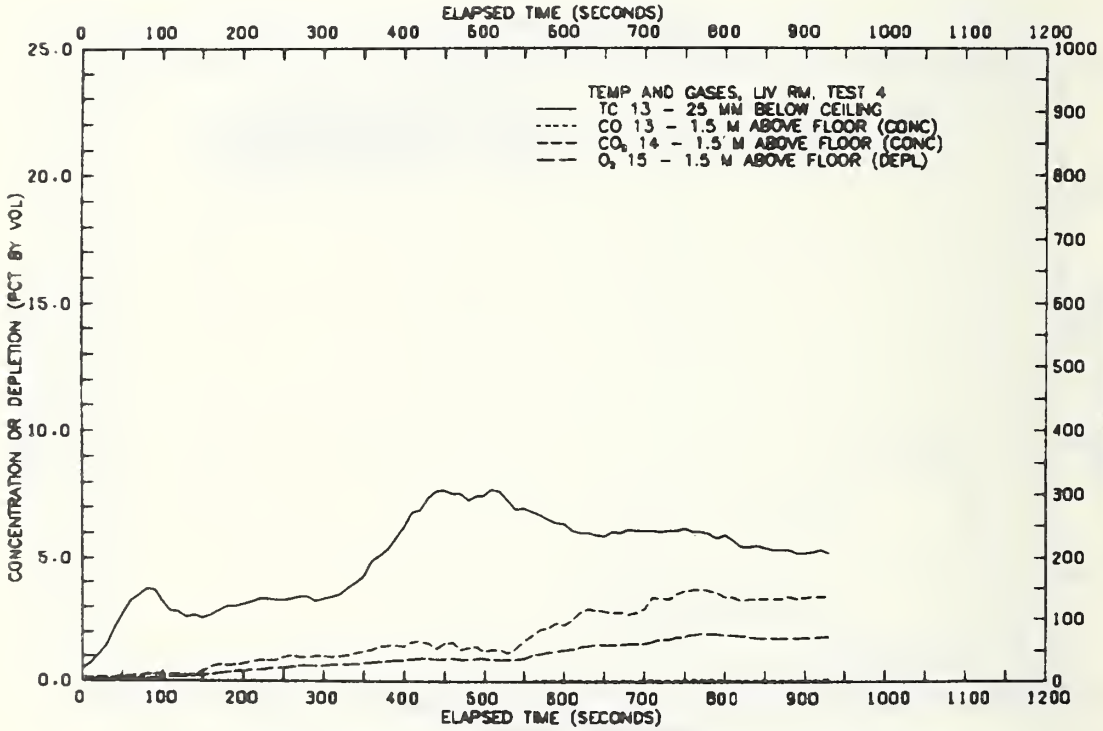
B17. Gas Temperature, CO and CO_2 (% Concentration), and O_2 (% Depletion) Measured in Center of Living Room



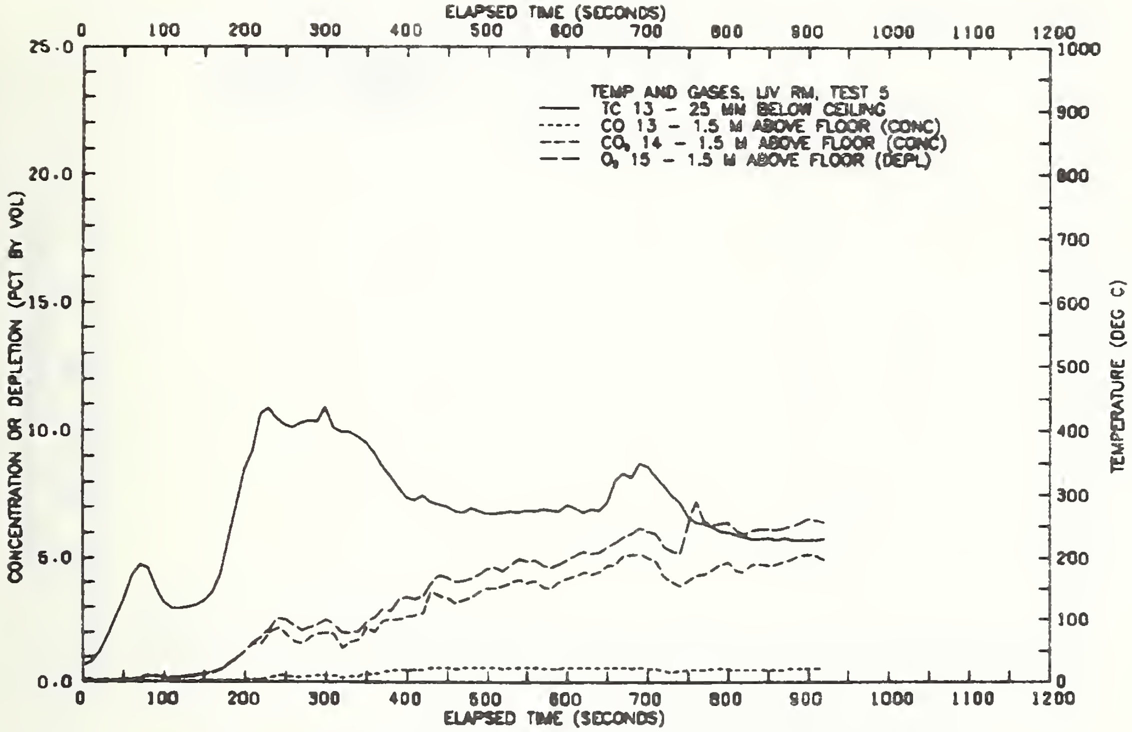
B18. Gas Temperature, CO and CO_2 (% Concentration), and O_2 (% Depletion) Measured in Center of Living Room



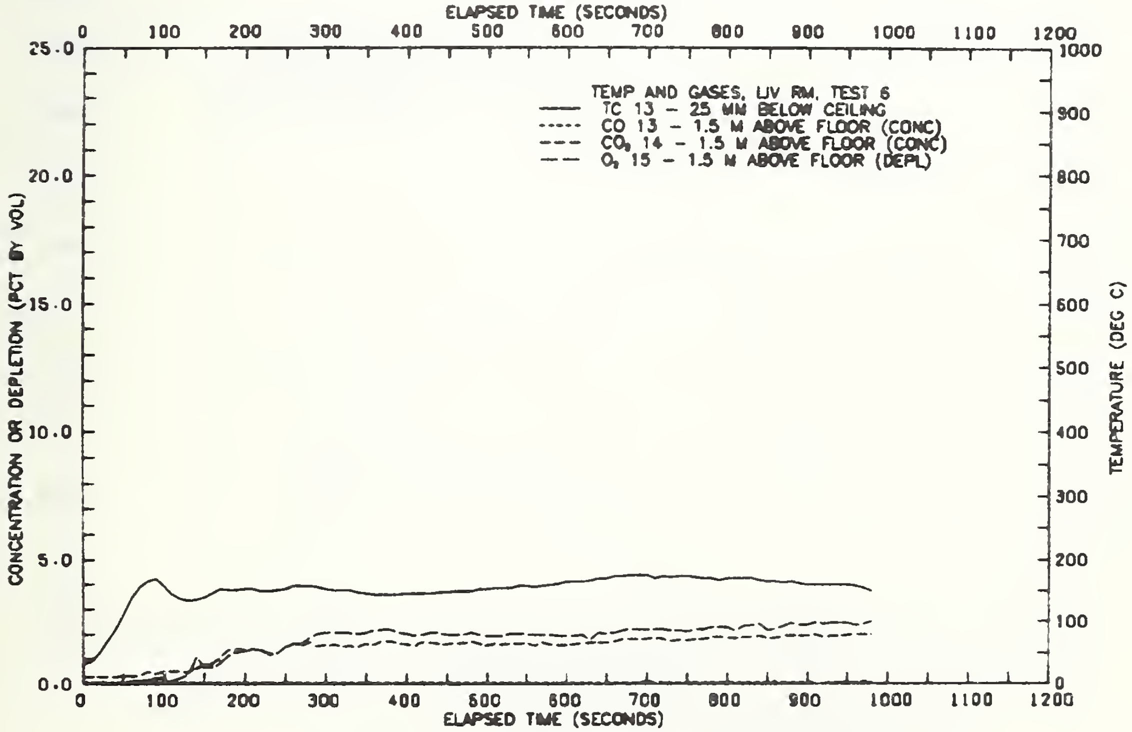
B19. Gas Temperature, CO and CO_2 (% Concentration), and O_2 (% Depletion) Measured in Center of Living Room



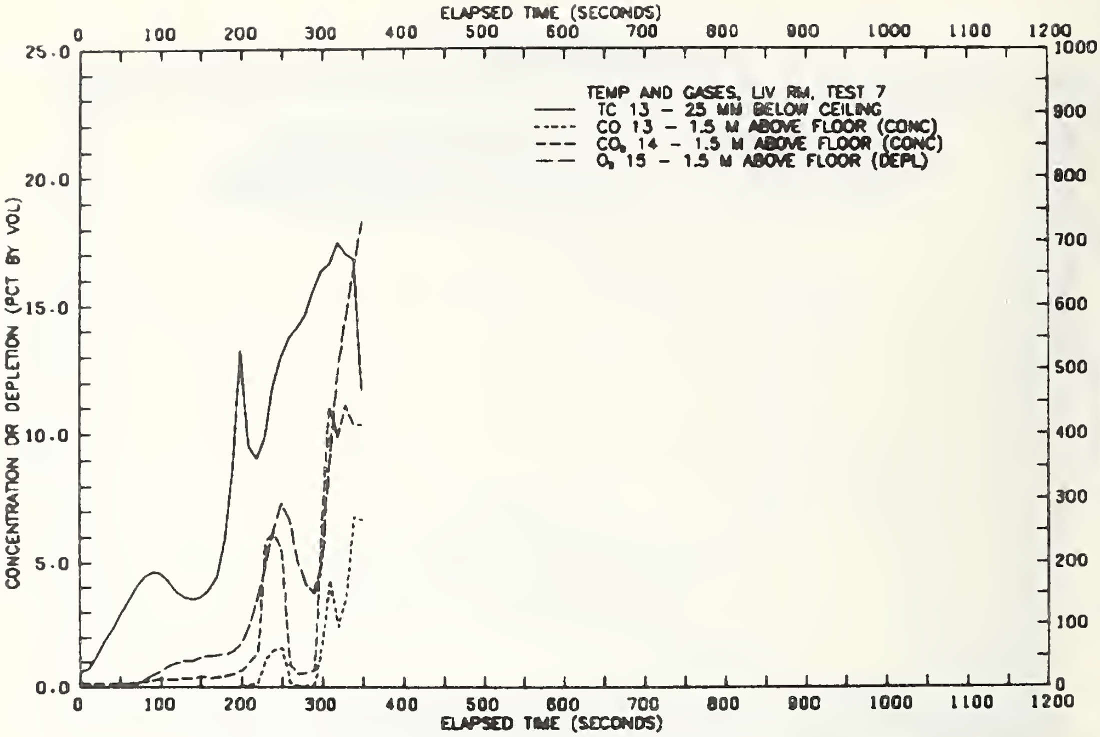
B20. Gas Temperature, CO and CO_2 (% Concentration), and O_2 (% Depletion) Measured in Center of Living Room



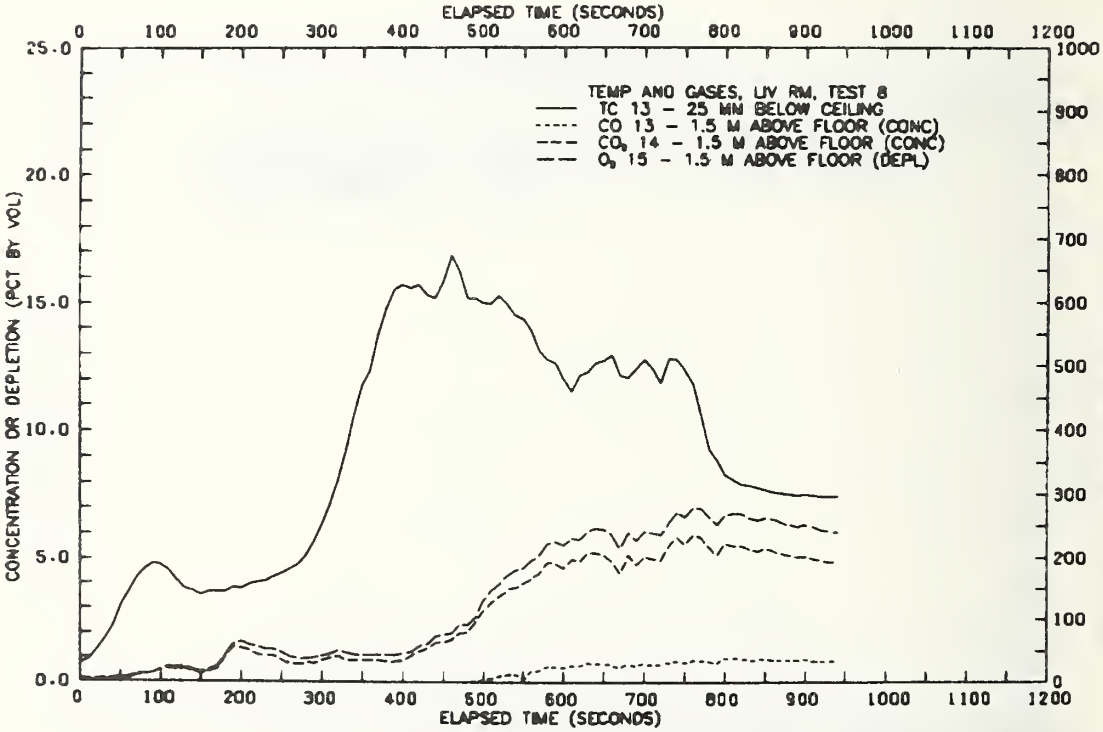
B21. Gas Temperature, CO and CO_2 (% Concentration), and O_2 (% Depletion) Measured in Center of Living Room



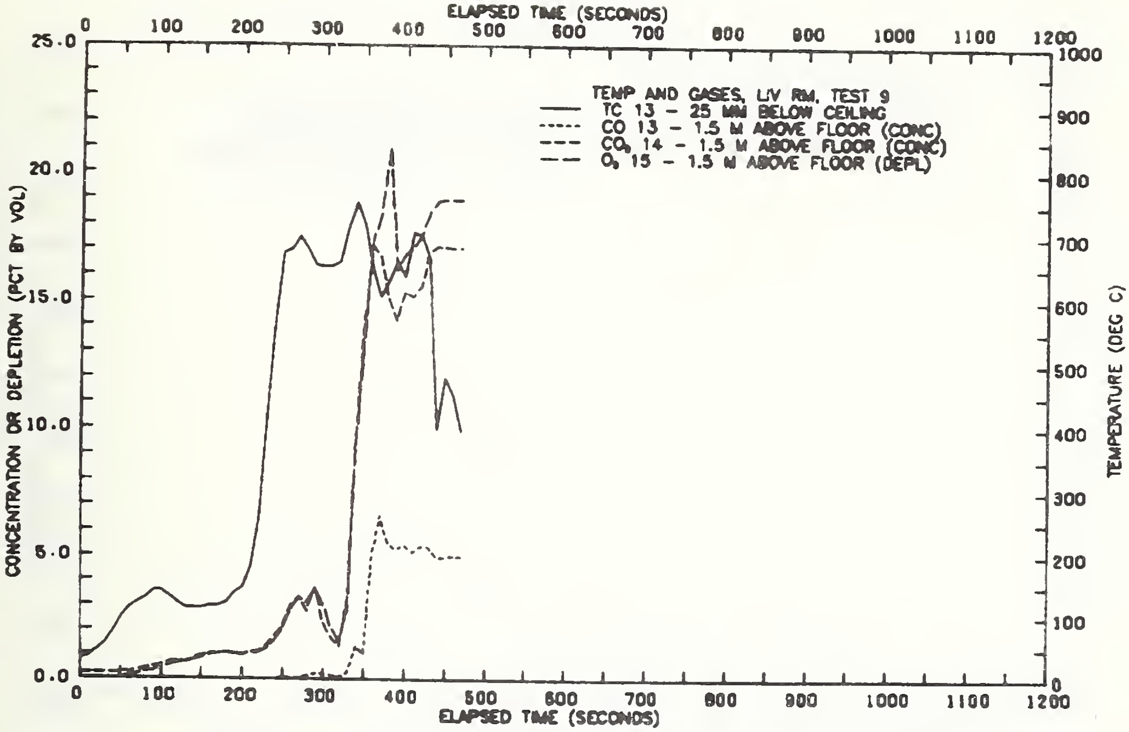
B22. Gas Temperature, CO and CO_2 (% Concentration), and O_2 (% Depletion) Measured in Center of Living Room



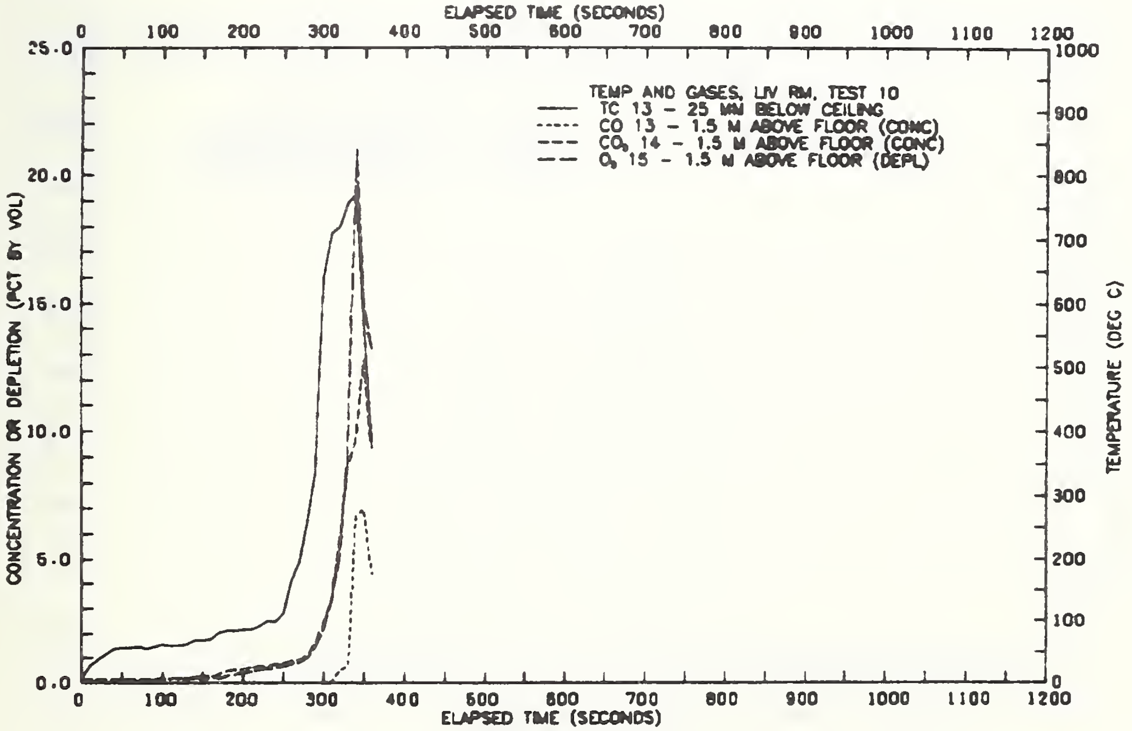
B23. Gas Temperature, CO and CO_2 (% Concentration), and O_2 (% Depletion) Measured in Center of Living Room



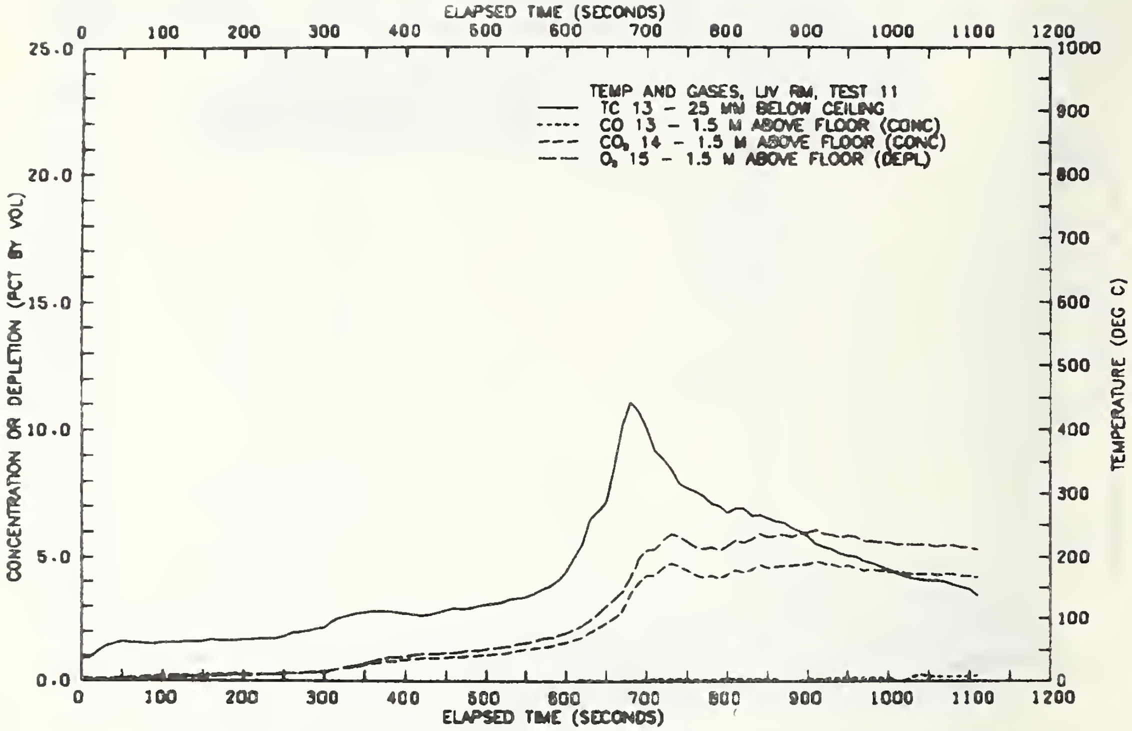
B24. Gas Temperature, CO and CO_2 (% Concentration), and O_2 (% Depletion) Measured in Center of Living Room



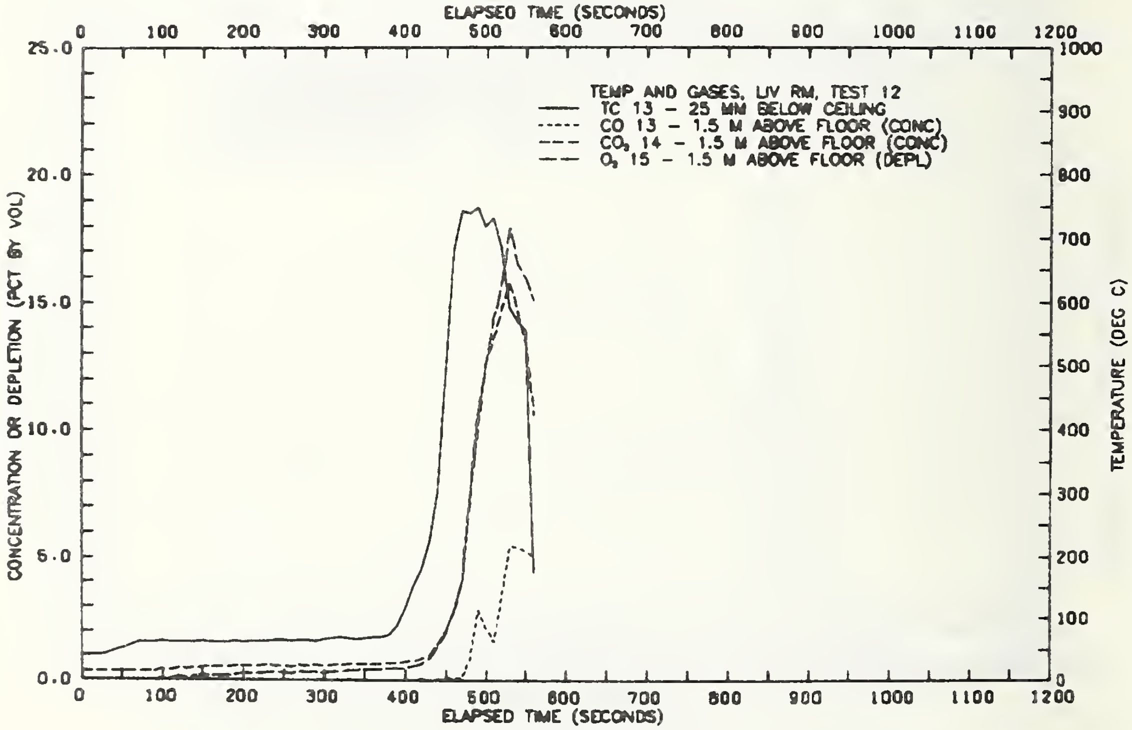
B25. Gas Temperature, CO and CO_2 (% Concentration), and O_2 (% Depletion) Measured in Center of Living Room



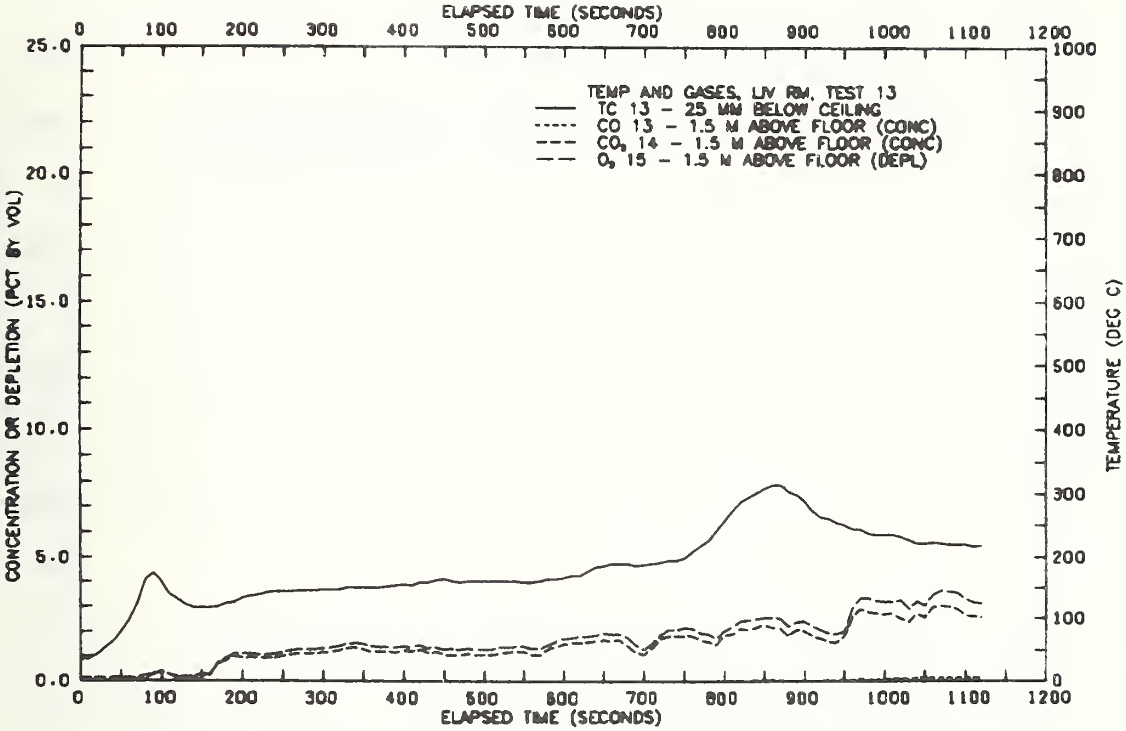
B26. Gas Temperature, CO and CO_2 (% Concentration), and O_2 (% Depletion) Measured in Center of Living Room



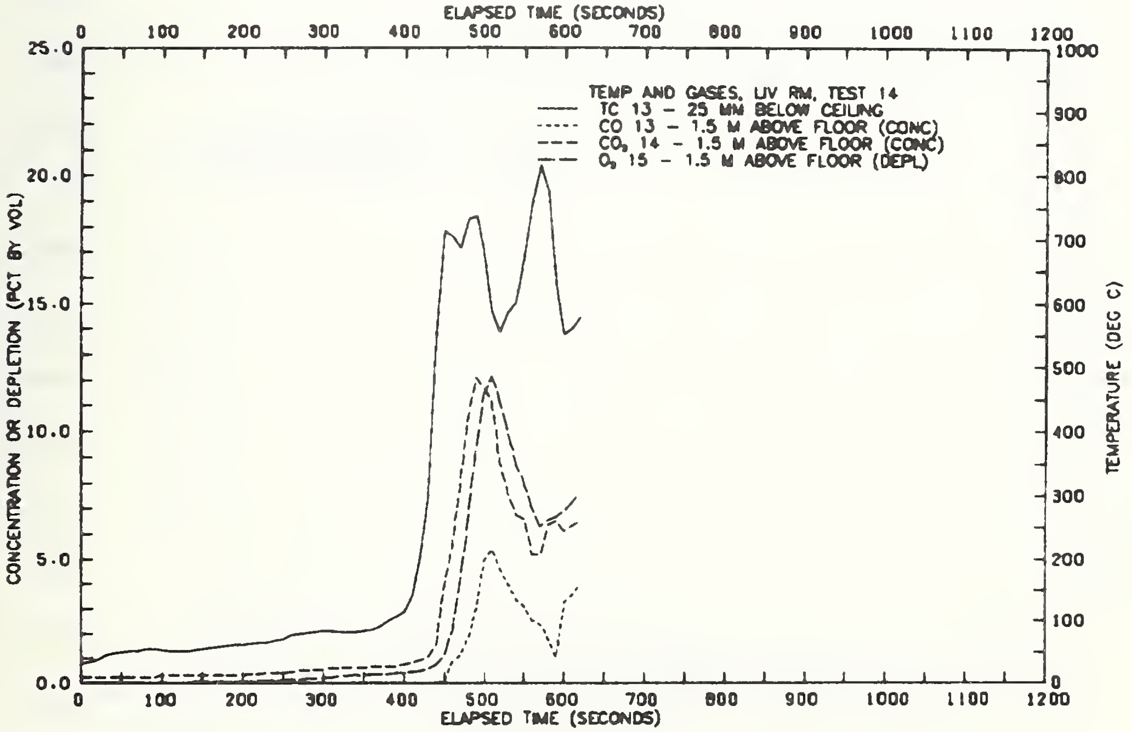
B27. Gas Temperature, CO and CO_2 (% Concentration), and O_2 (% Depletion) Measured in Center of Living Room



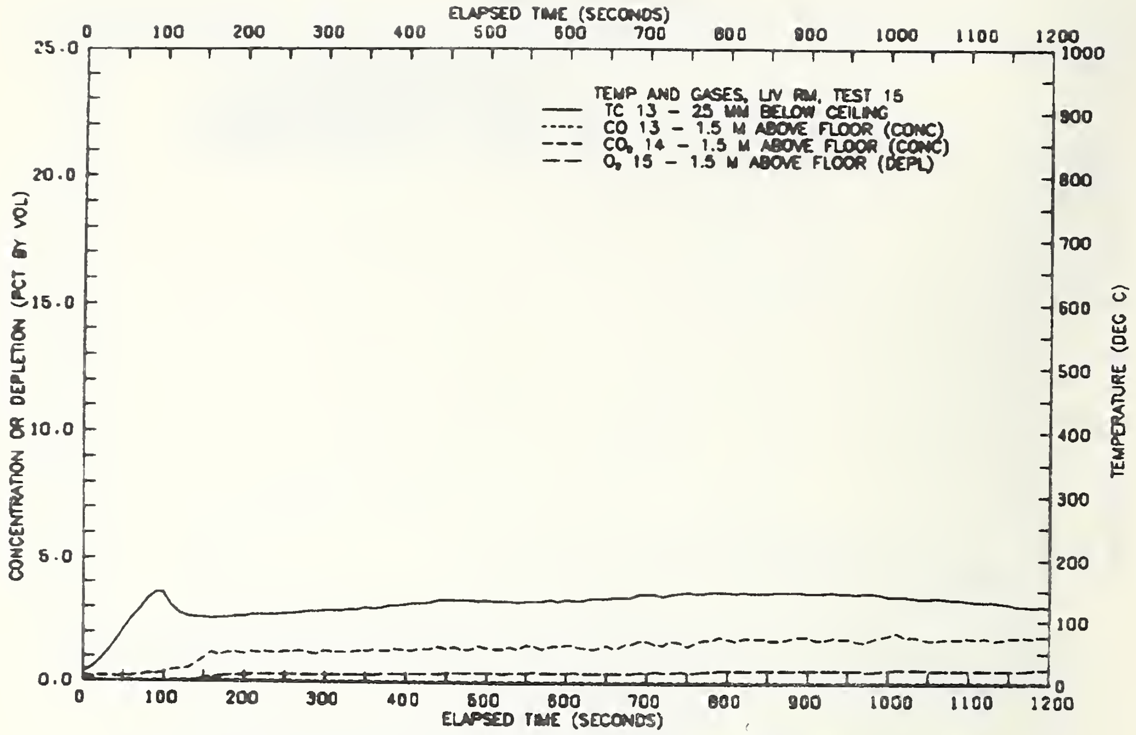
B28. Gas Temperature, CO and CO_2 (% Concentration), and O_2 (% Depletion) Measured in Center of Living Room



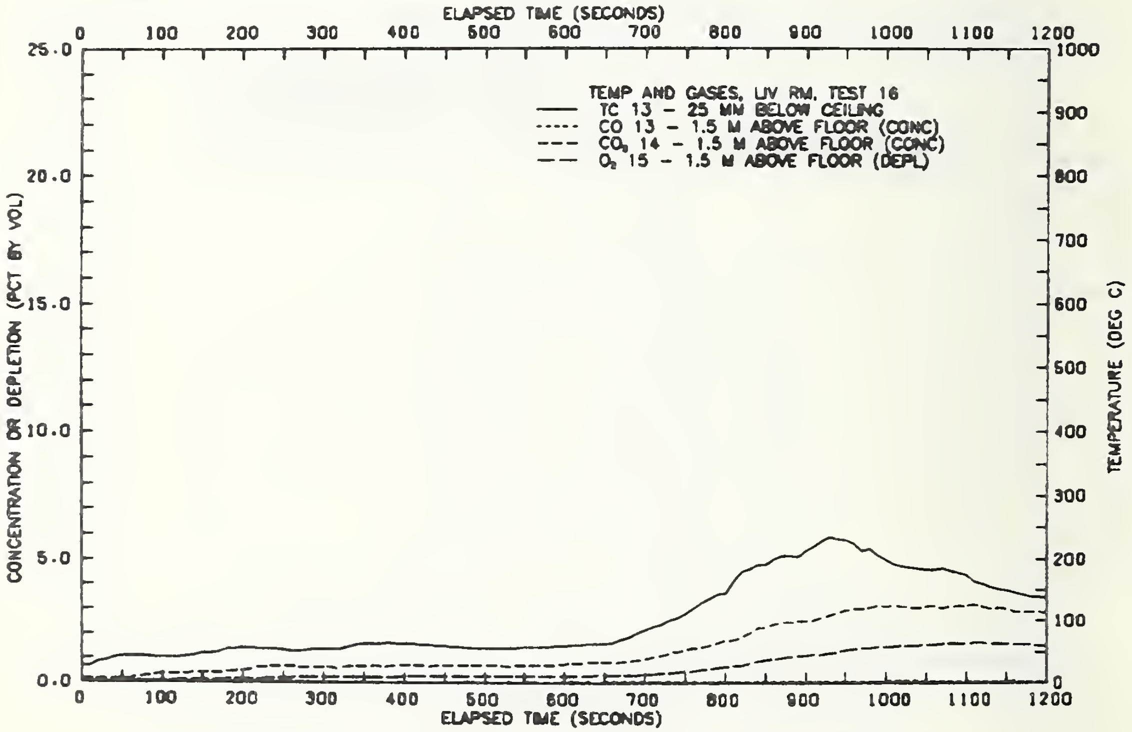
B29. Gas Temperature, CO and CO_2 (% Concentration), and O_2 (% Depletion) Measured in Center of Living Room



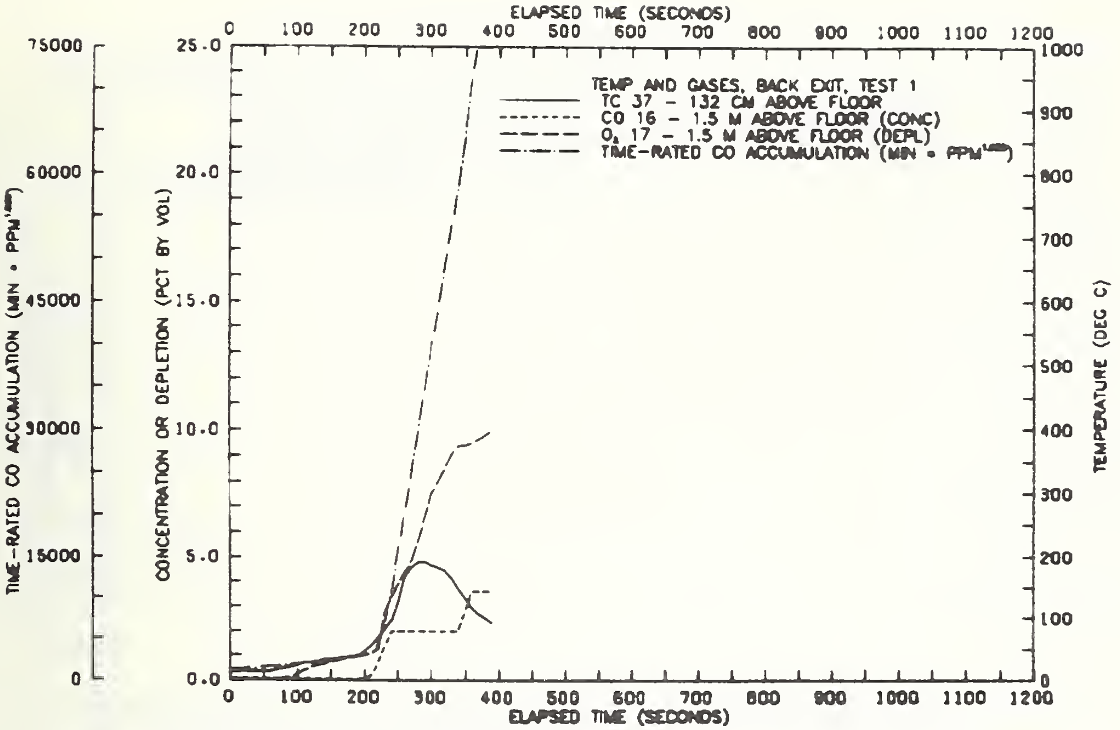
B30. Gas Temperature, CO and CO_2 (% Concentration), and O_2 (% Depletion) Measured in Center of Living Room



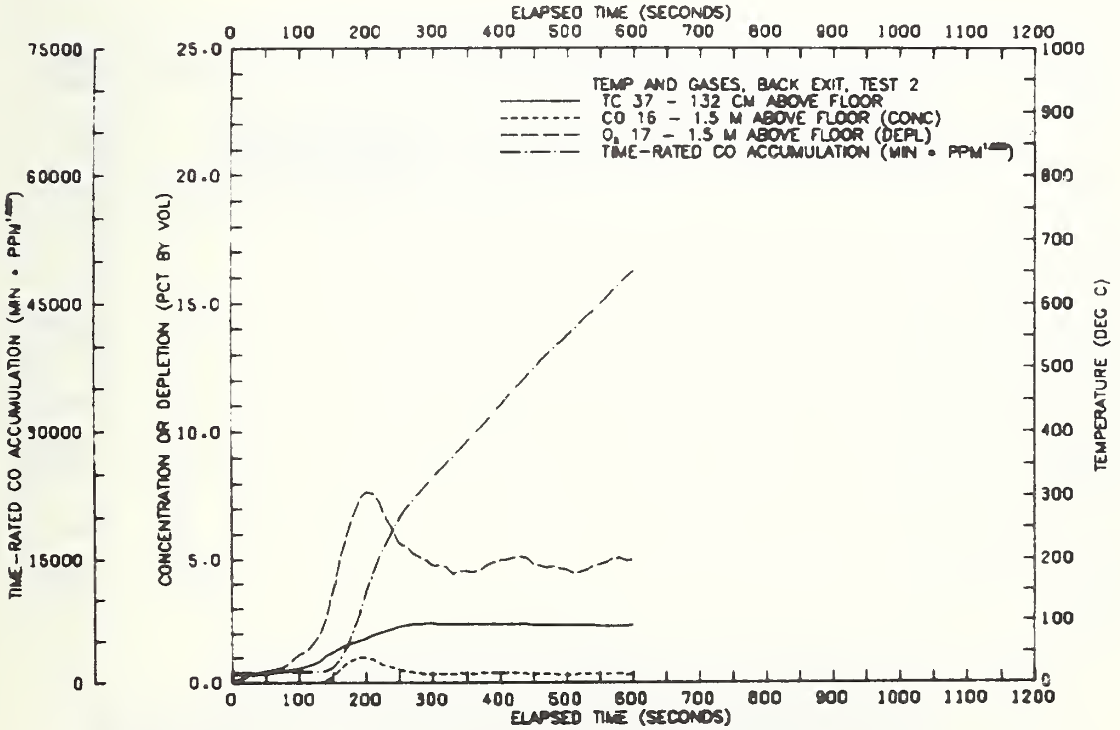
B31. Gas Temperature, CO and CO_2 (% Concentration), and O_2 (% Depletion) Measured in Center of Living Room



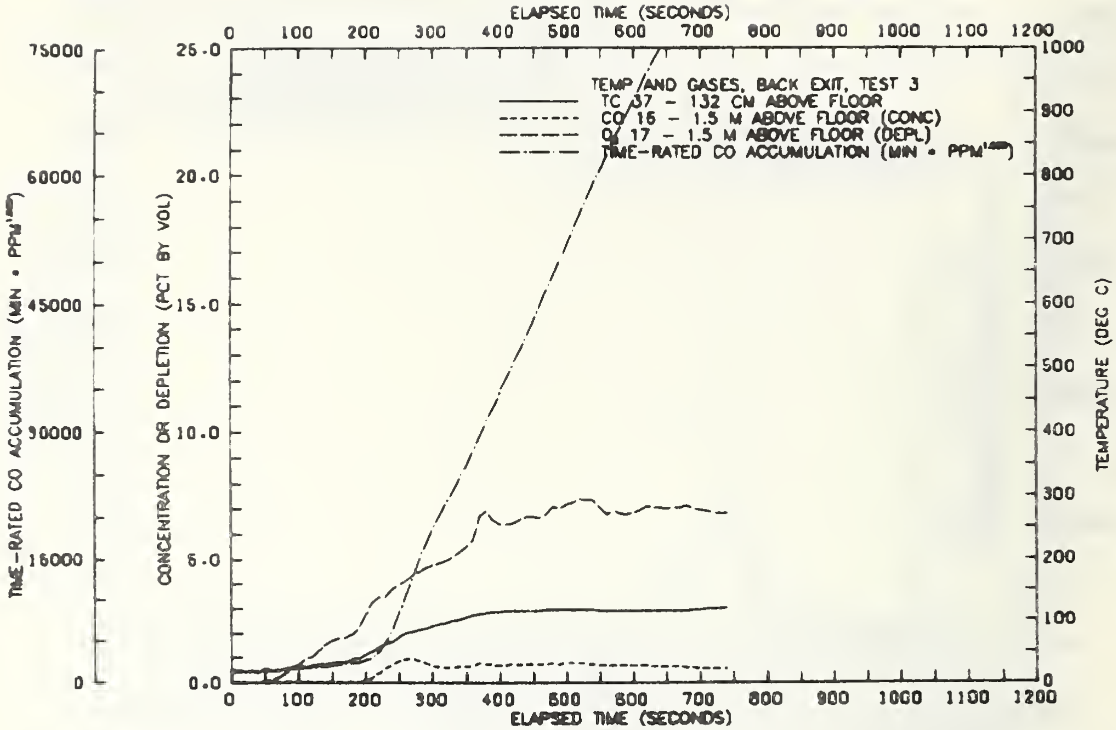
B32. Gas Temperature, CO and CO_2 (% Concentration), and O_2 (% Depletion) Measured in Center of Living Room



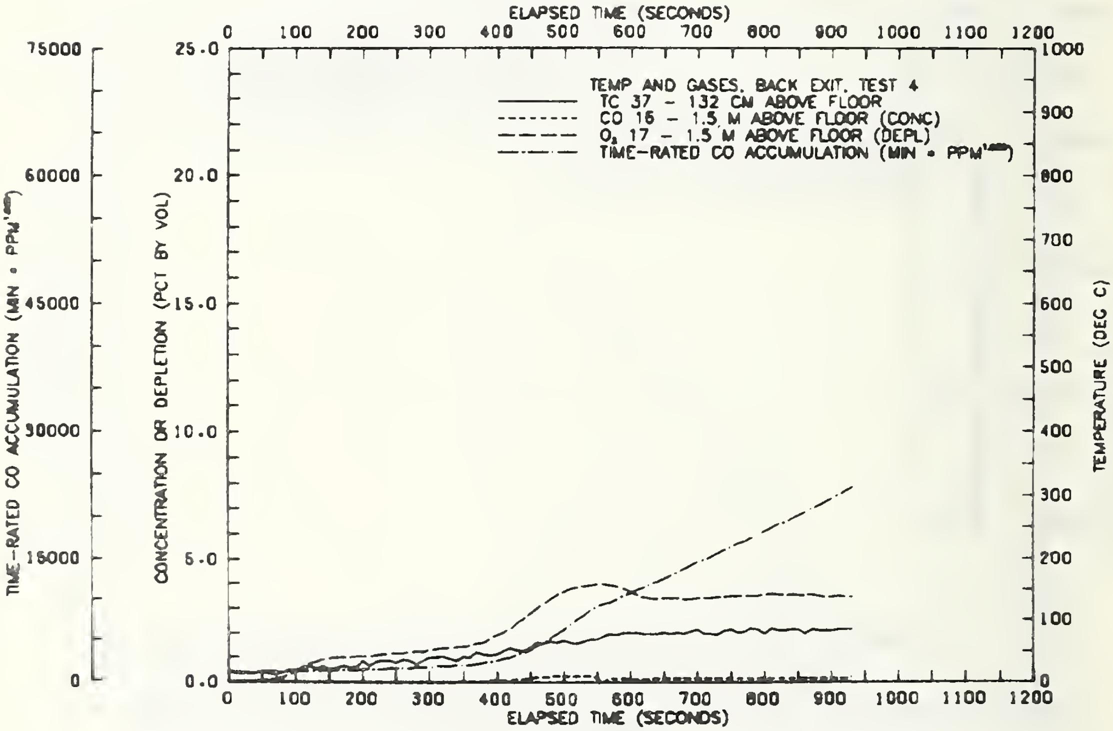
B33. CO (% Concentration), Time-Rated CO Accumulation (ppm$^{1.036}$ min), and O_2 Depletion Measured Just Beyond the Back Exit Door.



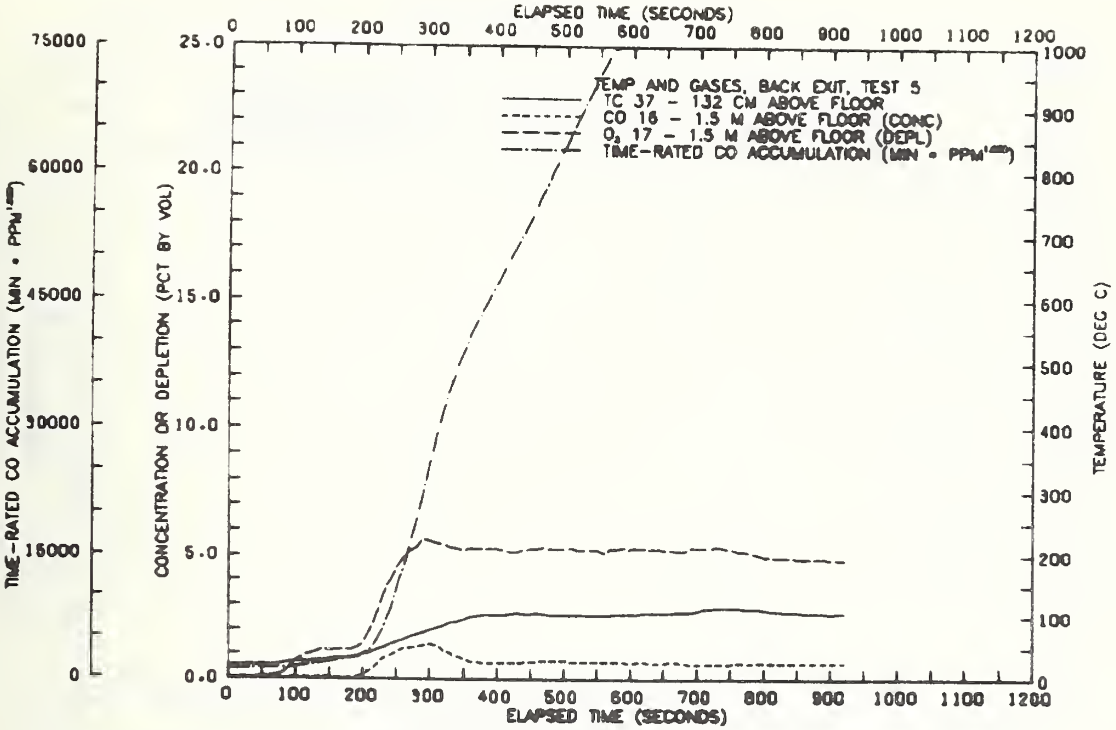
B34. CO (% Concentration), Time-Rated CO Accumulation (ppm$^{1.036}$ min), and O_2 Depletion Measured Just Beyond the Back Exit Door.



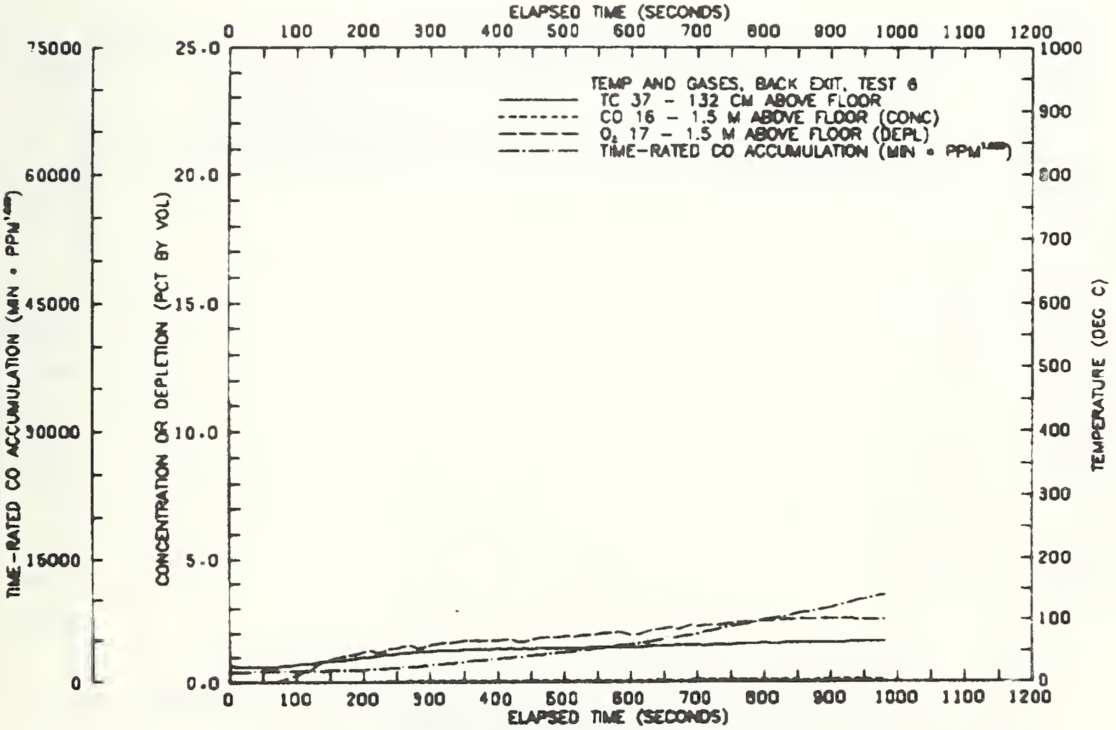
B35. CO (% Concentration), Time-Rated CO Accumulation (ppm$^{1.036}$ min), and O_2 Depletion Measured Just Beyond the Back Exit Door.



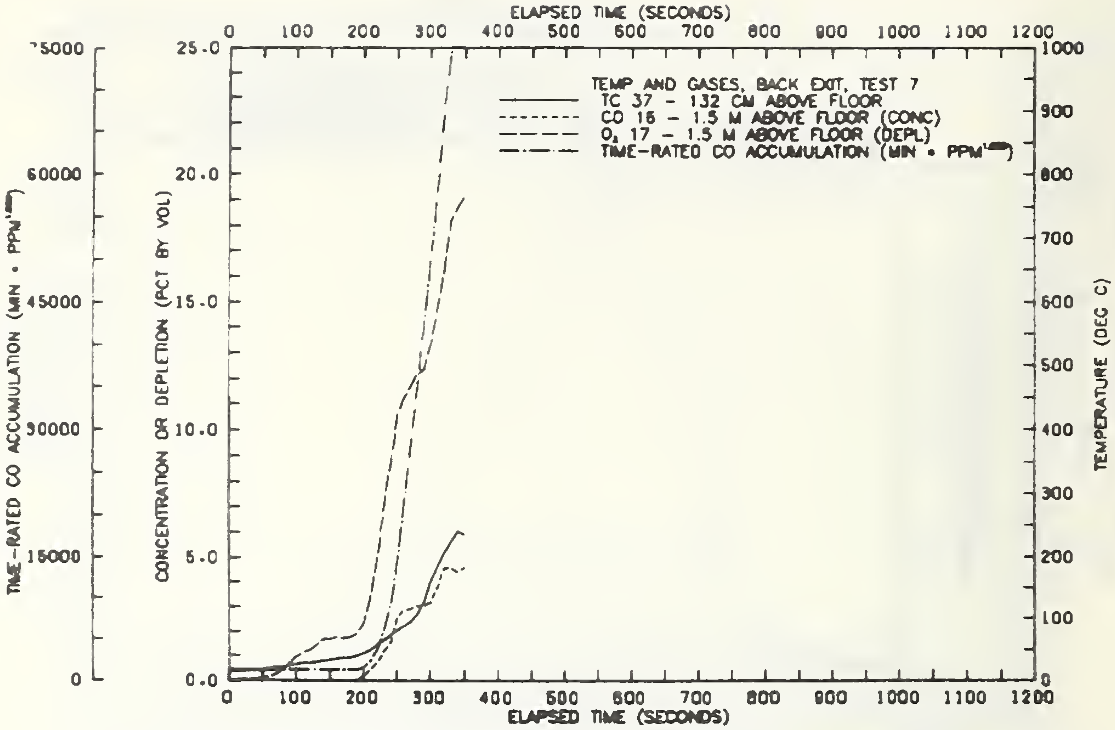
B36. CO (% Concentration), Time-Rated CO Accumulation (ppm$^{1.036}$ min), and O_2 Depletion Measured Just Beyond the Back Exit Door.



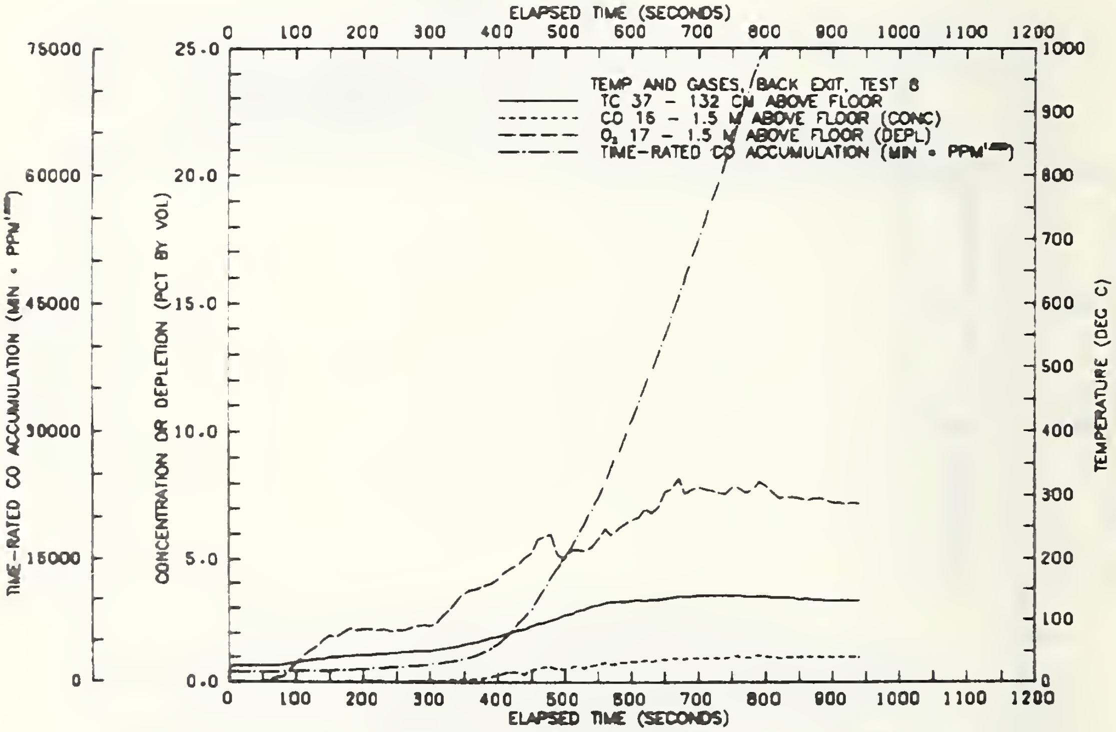
B37. CO (% Concentration), Time-Rated CO Accumulation ($ppm^{1.036}$ min), and O_2 Depletion Measured Just Beyond the Back Exit Door.



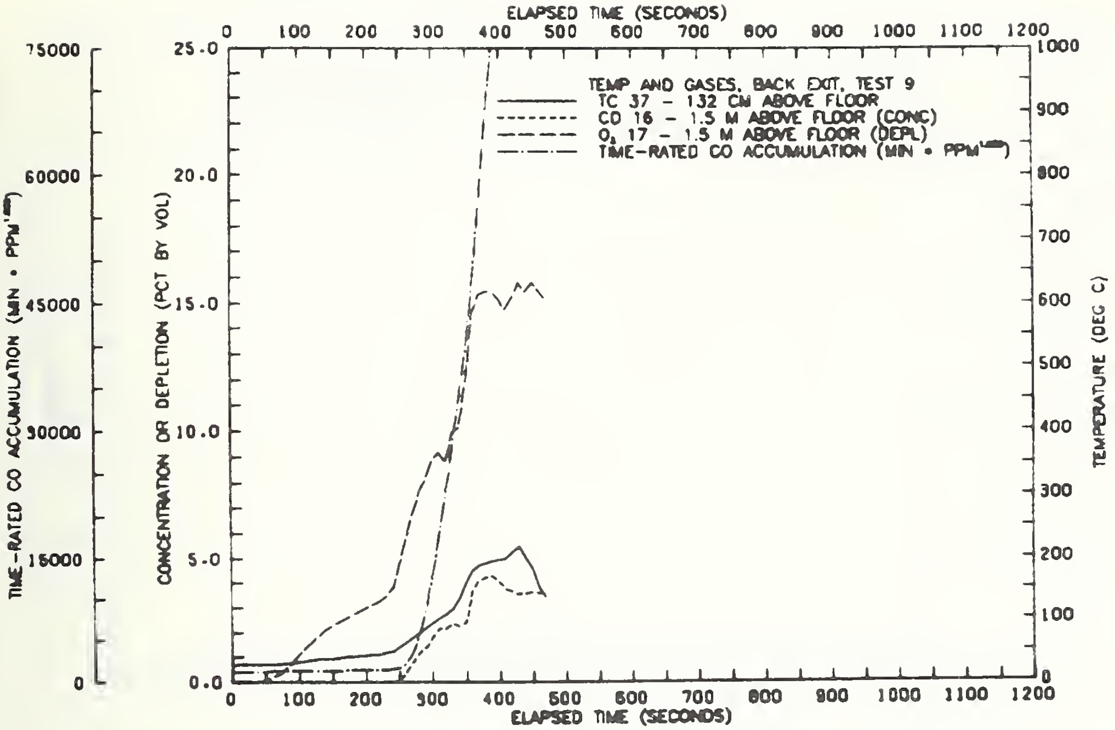
B38. CO (% Concentration), Time-Rated CO Accumulation ($ppm^{1.036}$ min), and O_2 Depletion Measured Just Beyond the Back Exit Door.



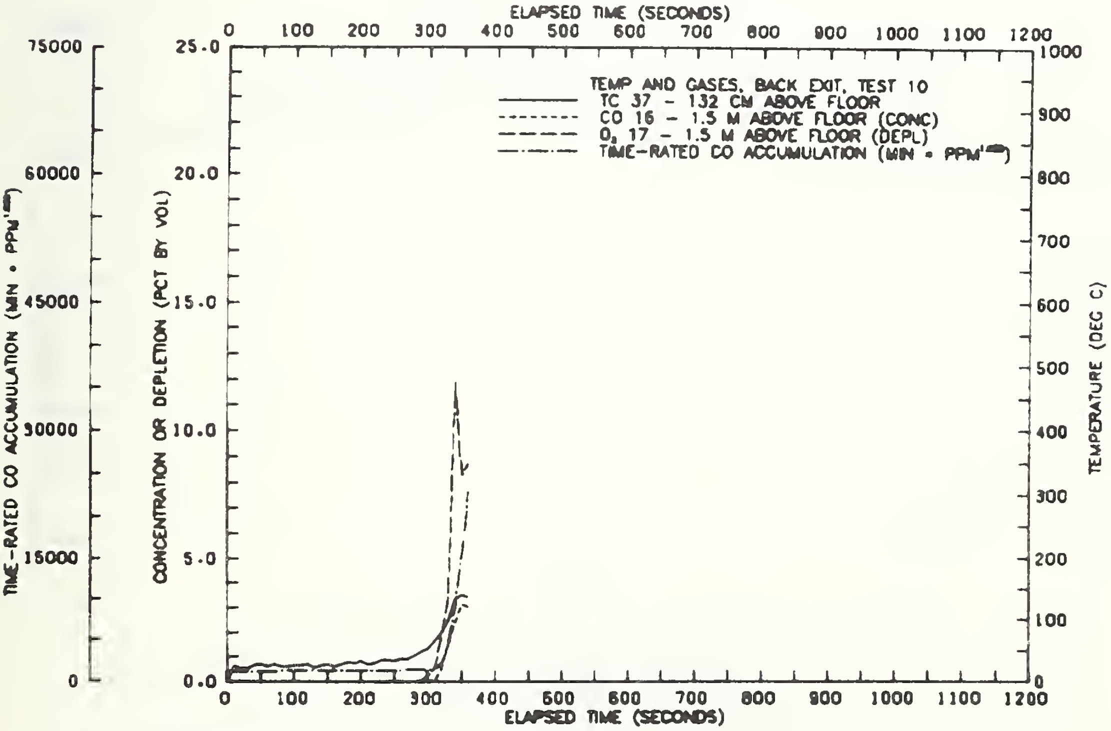
B39. CO (% Concentration), Time-Rated CO Accumulation ($ppm^{1.036}$ min), and O_2 Depletion Measured Just Beyond the Back Exit Door.



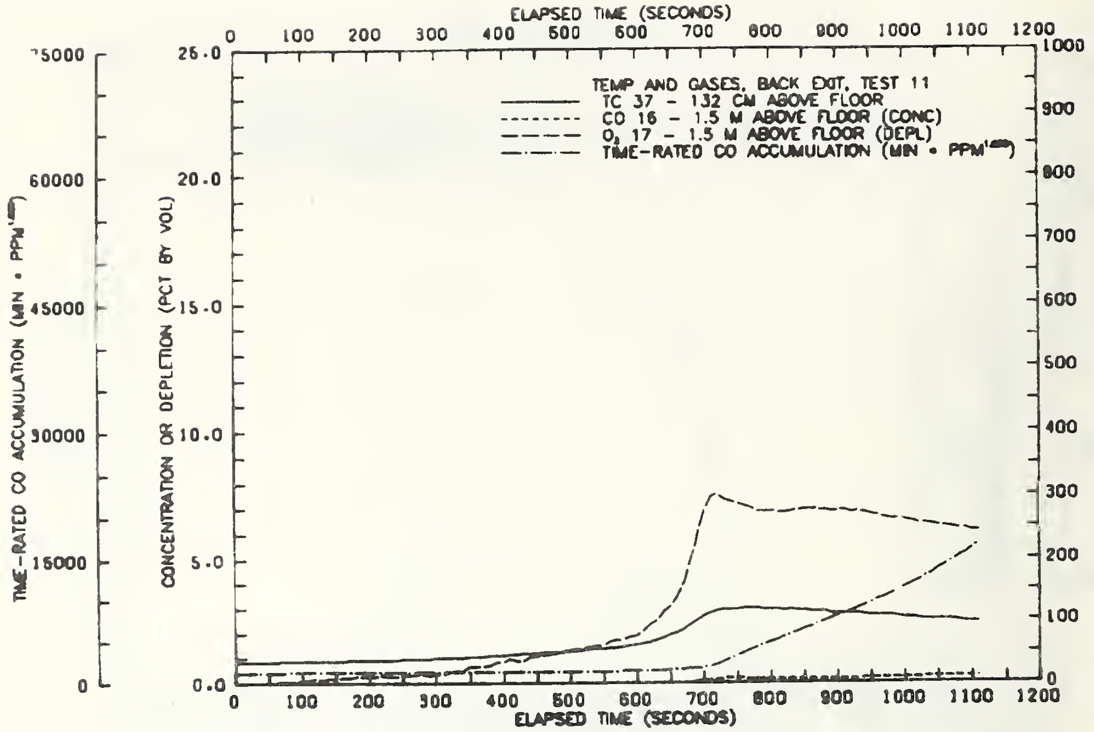
B40. CO (% Concentration), Time-Rated CO Accumulation ($ppm^{1.036}$ min), and O_2 Depletion Measured Just Beyond the Back Exit Door.



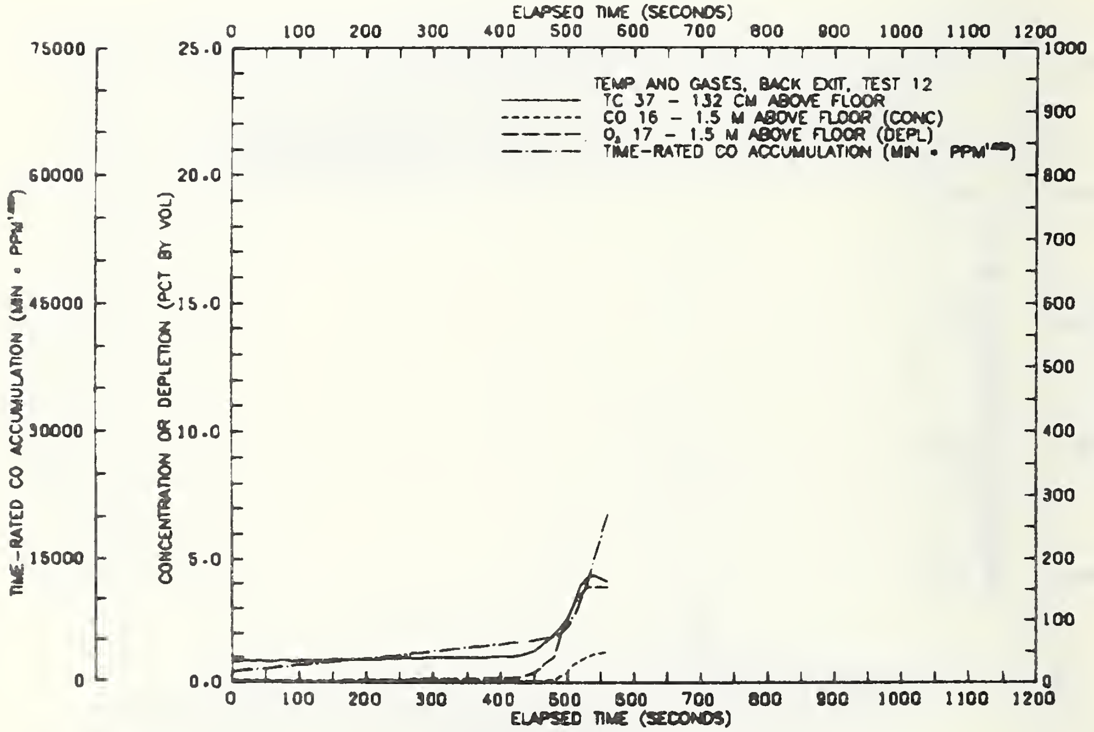
B41. CO (% Concentration), Time-Rated CO Accumulation (ppm$^{1.036}$ min), and O_2 Depletion Measured Just Beyond the Back Exit Door.



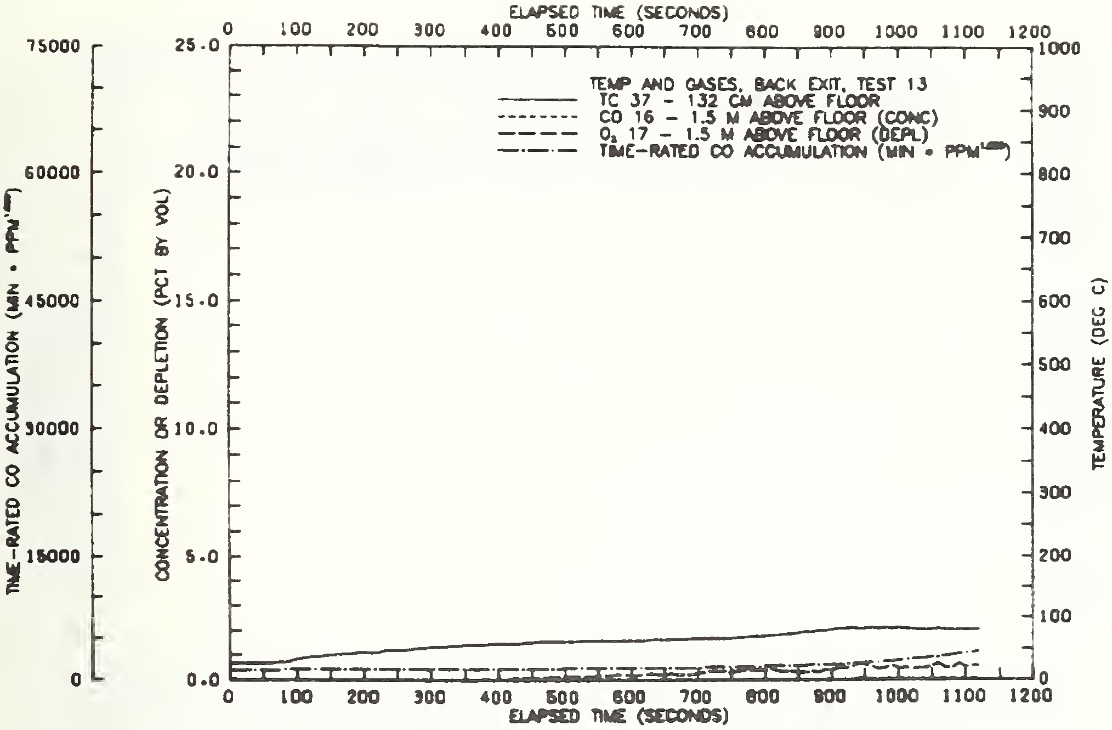
B42. CO (% Concentration), Time-Rated CO Accumulation (ppm$^{1.036}$ min), and O_2 Depletion Measured Just Beyond the Back Exit Door.



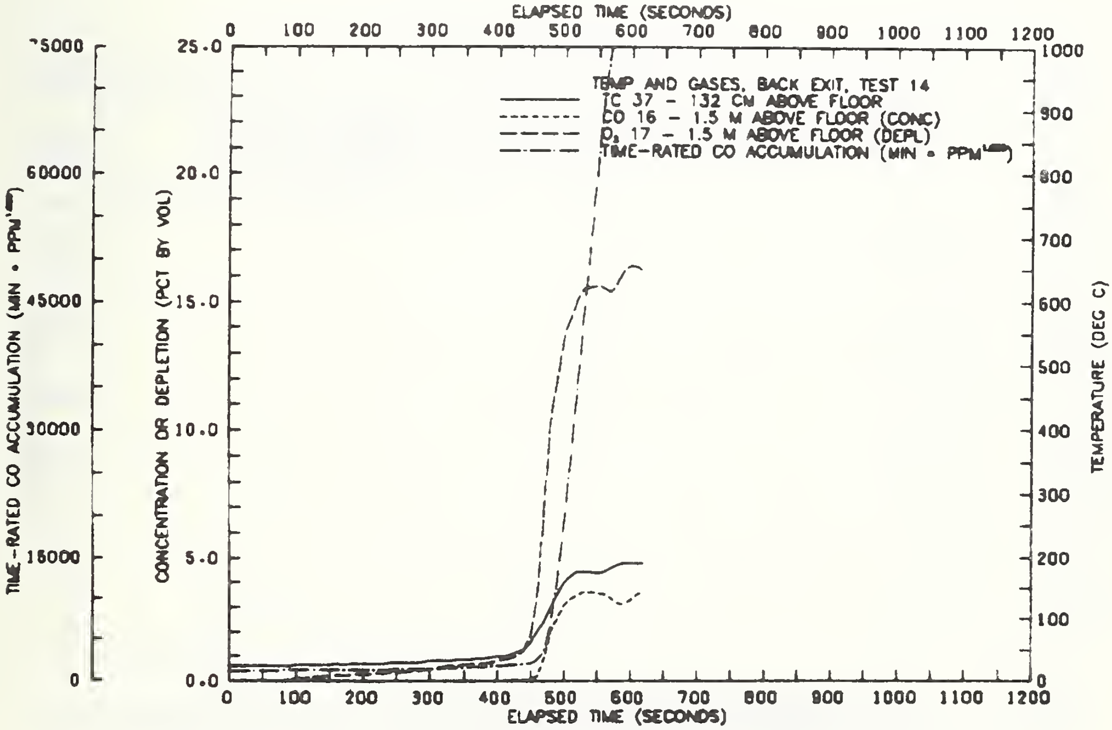
B43. CO (% Concentration), Time-Rated CO Accumulation (ppm$^{1.036}$ min), and O_2 Depletion Measured Just Beyond the Back Exit Door.



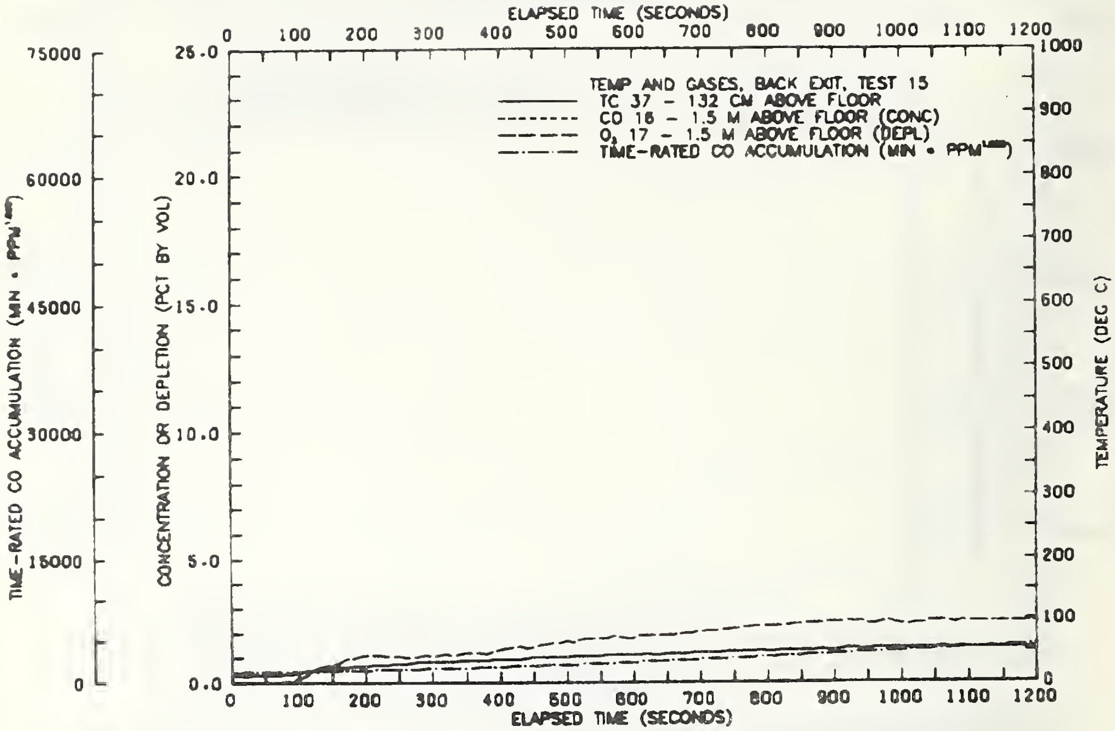
B44. CO (% Concentration), Time-Rated CO Accumulation (ppm$^{1.036}$ min), and O_2 Depletion Measured Just Beyond the Back Exit Door.



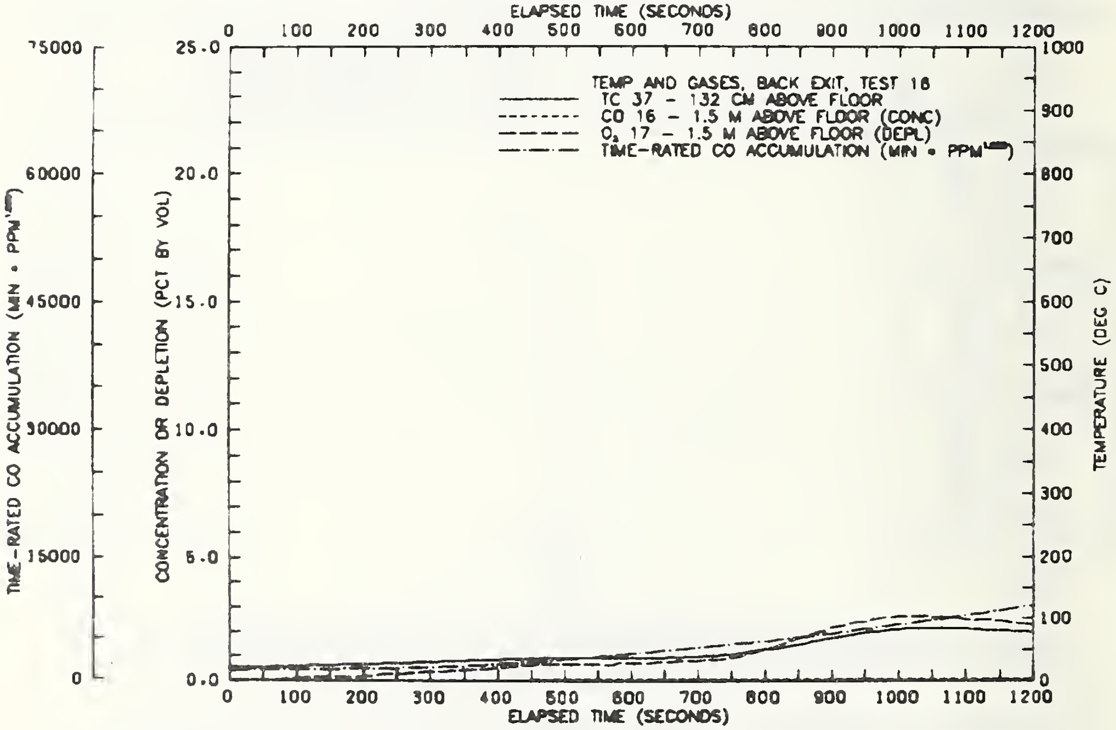
B45. CO (% Concentration), Time-Rated CO Accumulation ($ppm^{1.036}$ min), and O_2 Depletion Measured Just Beyond the Back Exit Door.



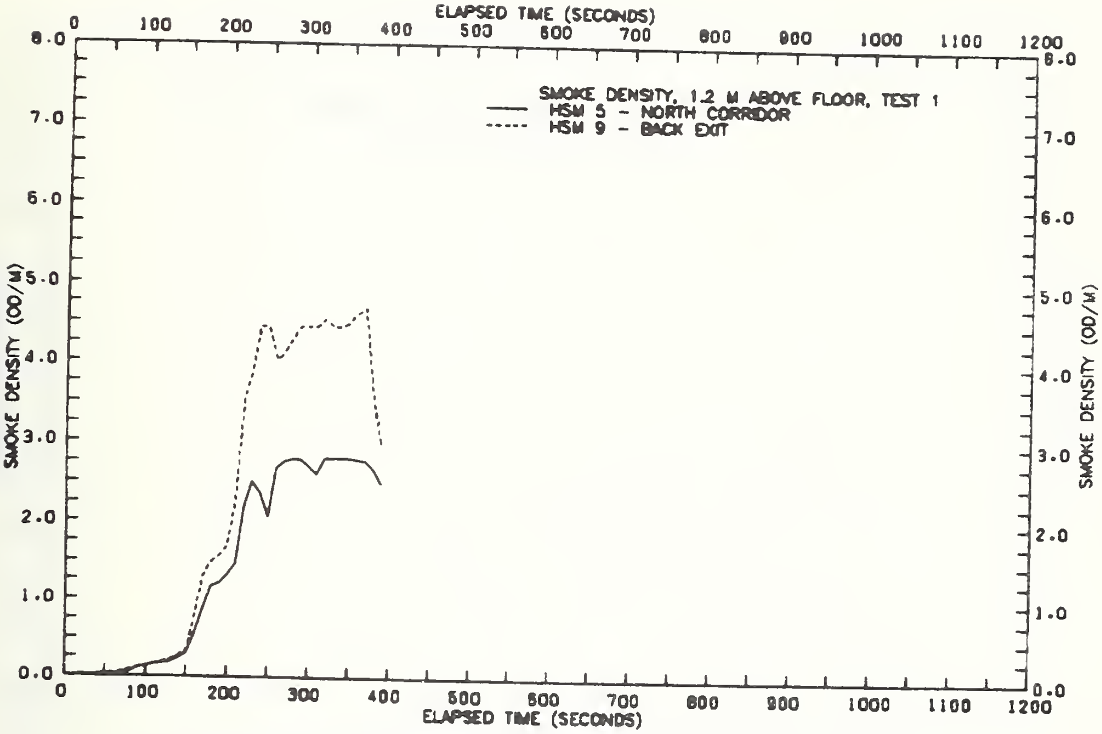
B46. CO (% Concentration), Time-Rated CO Accumulation ($ppm^{1.036}$ min), and O_2 Depletion Measured Just Beyond the Back Exit Door.



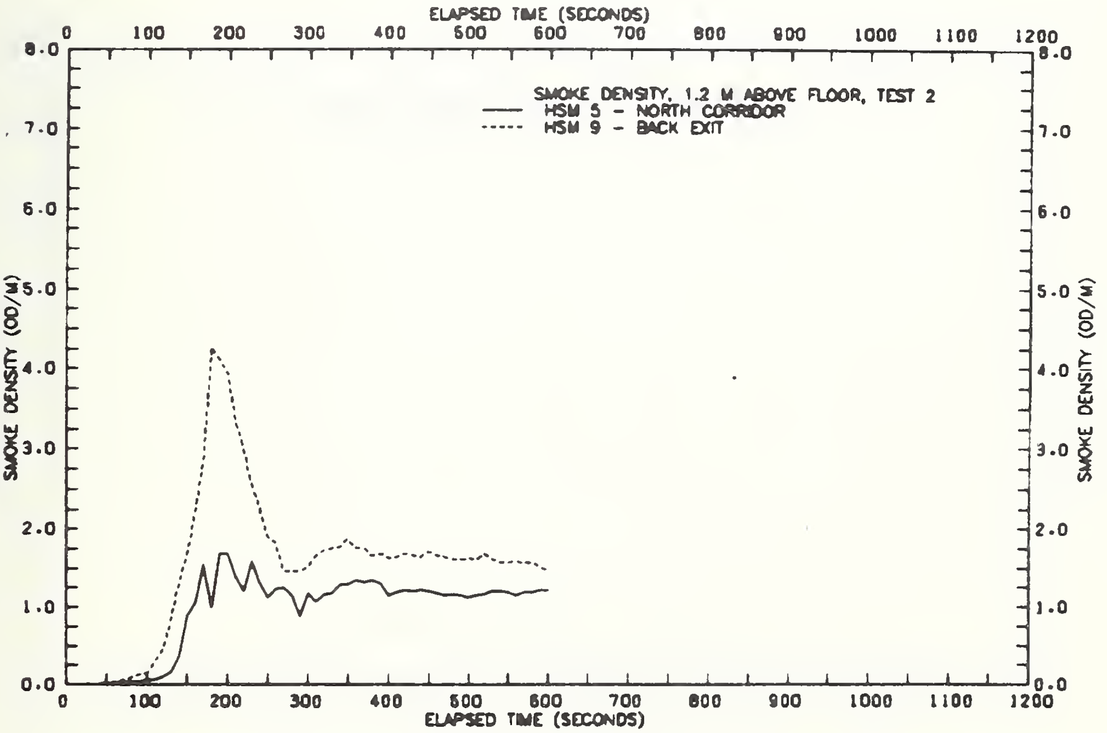
B47. CO (% Concentration), Time-Rated CO Accumulation (ppm$^{1.036}$ min), and O_2 Depletion Measured Just Beyond the Back Exit Door.



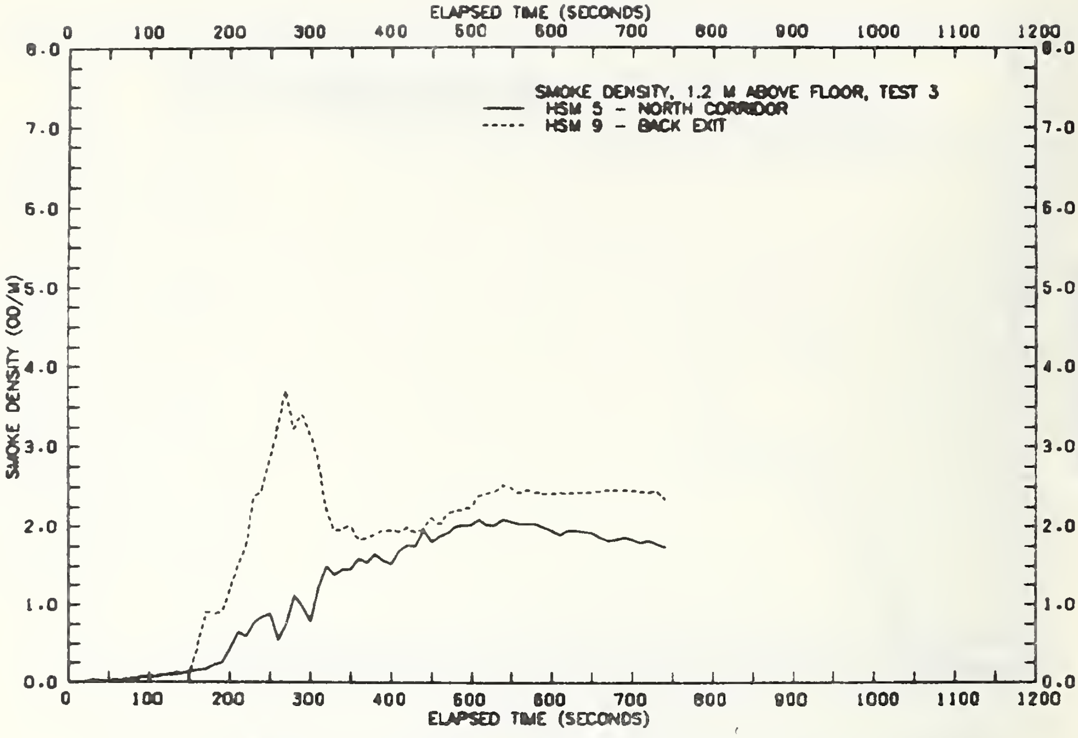
B48. CO (% Concentration), Time-Rated CO Accumulation (ppm$^{1.036}$ min), and O_2 Depletion Measured Just Beyond the Back Exit Door.



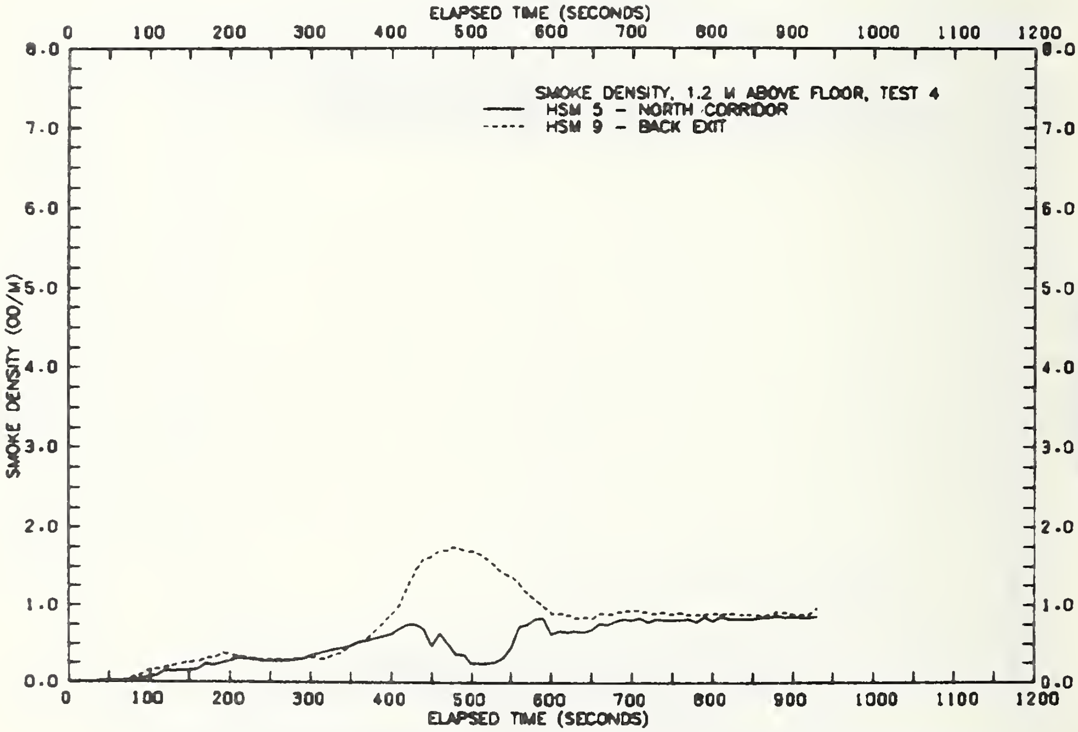
B49. Smoke Density (OD/m) Measured at the Entrance to Corridor from Living Room and Just Beyond Back Exit door



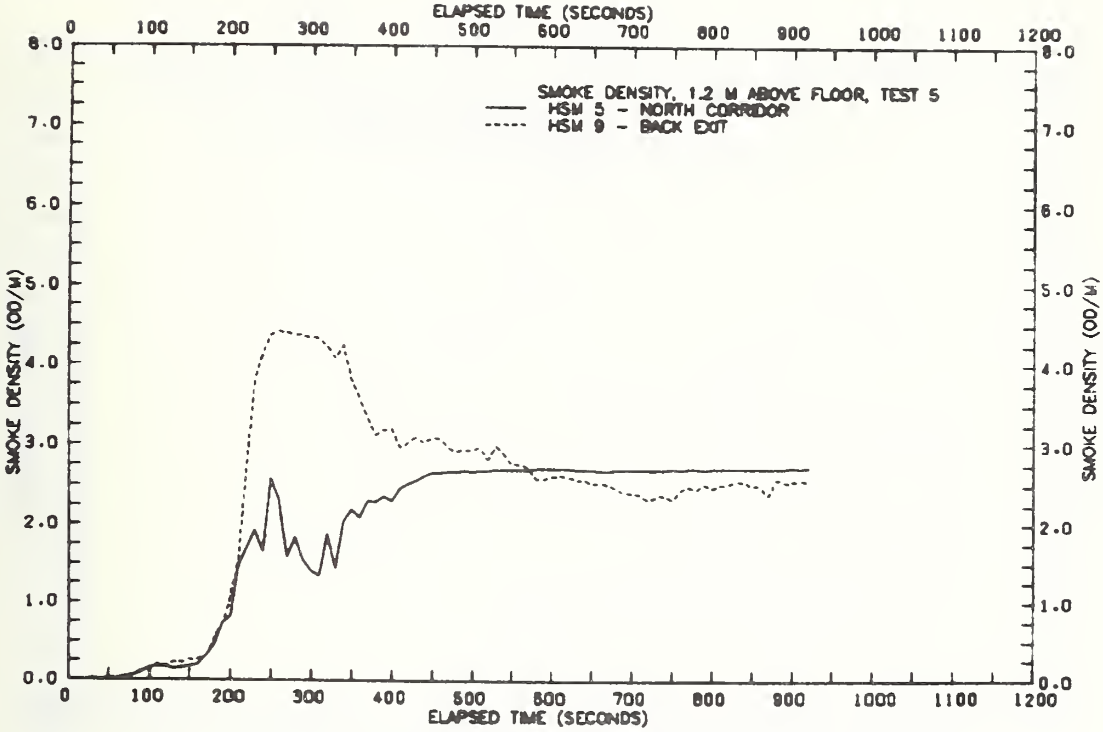
B50. Smoke Density (OD/m) Measured at the Entrance to Corridor from Living Room and Just Beyond Back Exit Door



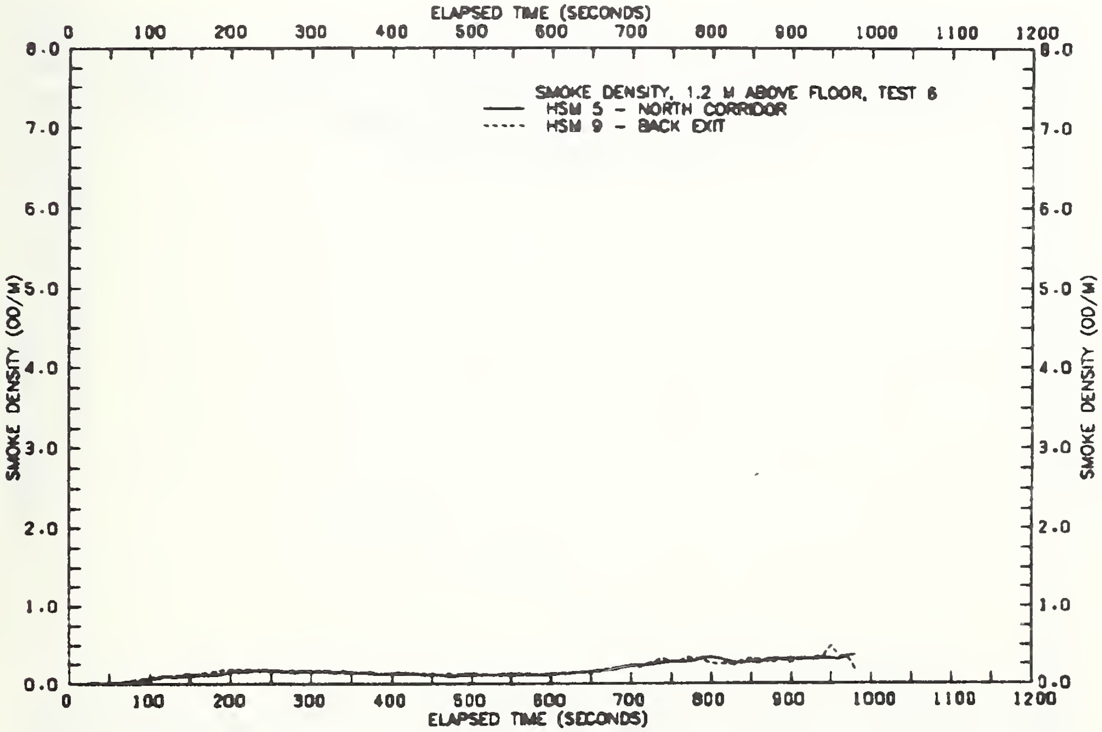
B51. Smoke Density (OD/m) Measured at the Entrance to Corridor from Living Room and Just Beyond Back Exit Door



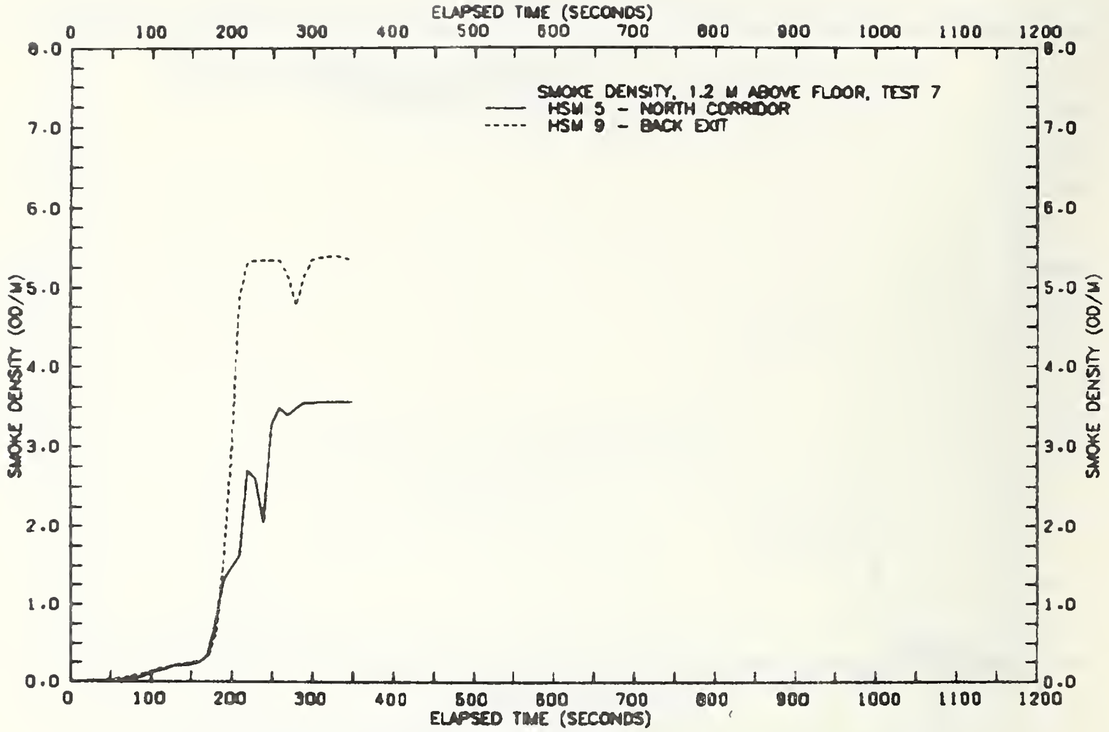
B52. Smoke Density (OD/m) Measured at the Entrance to Corridor from Living Room and Just Beyond Back Exit Door



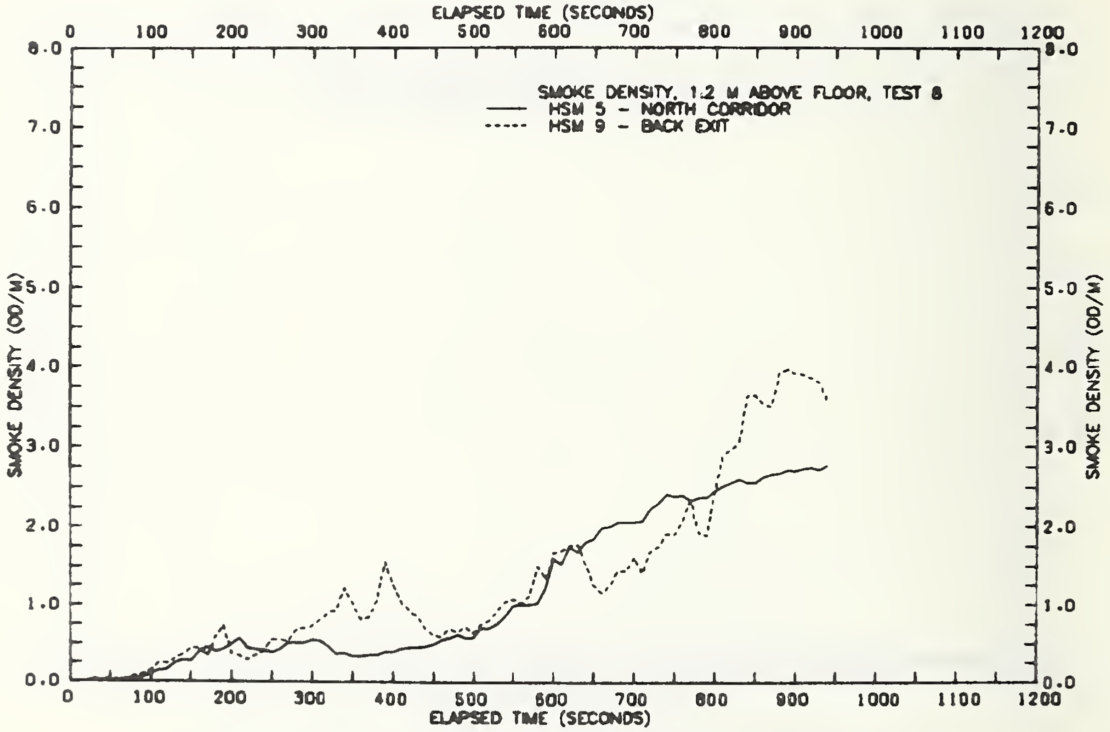
B53. Smoke Density (OD/m) Measured at the Entrance to Corridor from Living Room and Just Beyond Back Exit Door



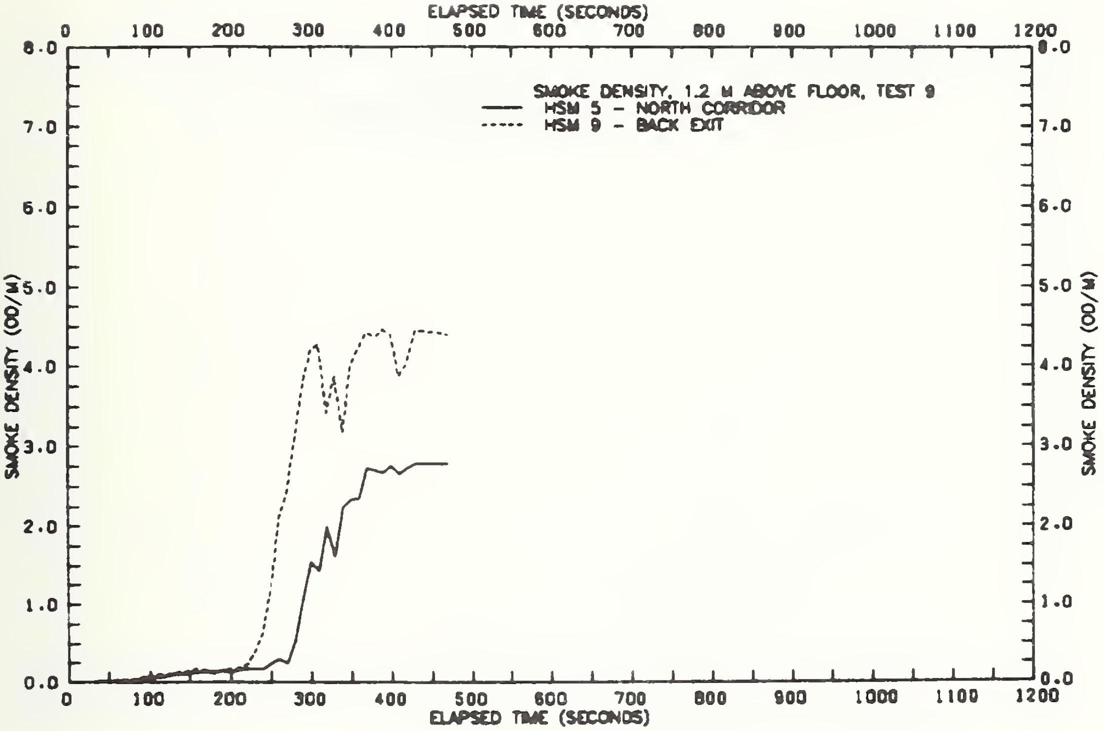
B54. Smoke Density (OD/m) Measured at the Entrance to Corridor from Living Room and Just Beyond Back Exit Door



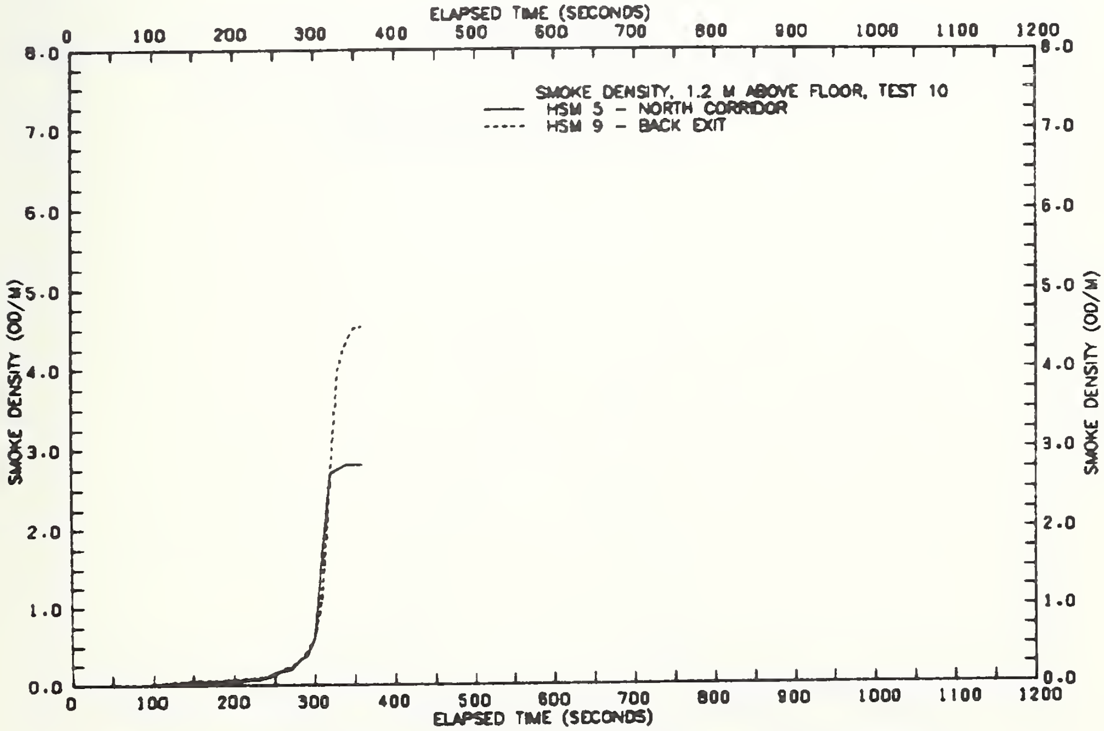
B55. Smoke Density (OD/m) Measured at the Entrance to Corridor from Living Room and Just Beyond Back Exit Door



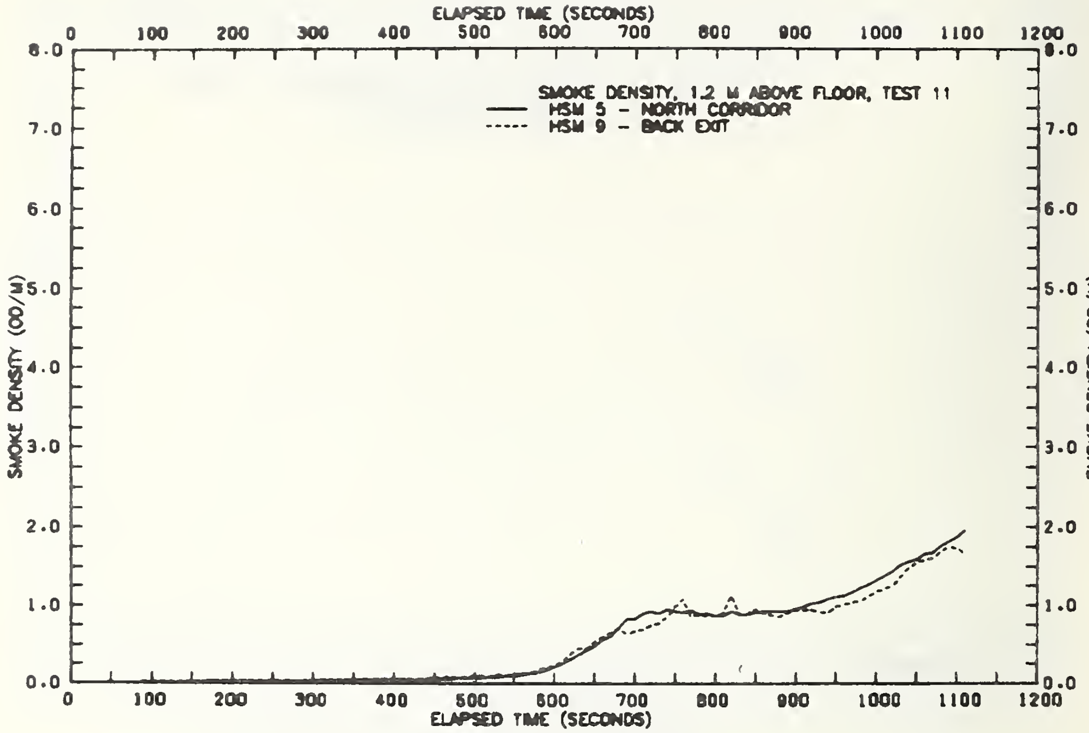
B56. Smoke Density (OD/m) Measured at the Entrance to Corridor from Living Room and Just Beyond Back Exit Door



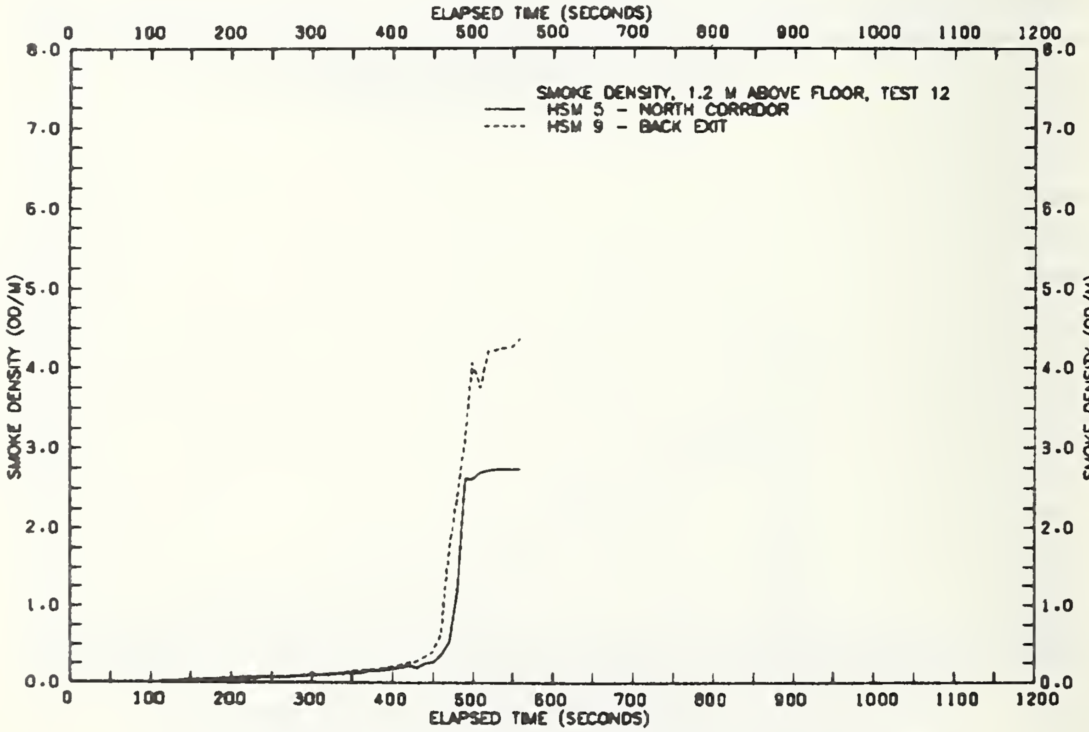
B57. Smoke Density (OD/m) Measured at the Entrance to Corridor from Living Room and Just Beyond Back Exit Door



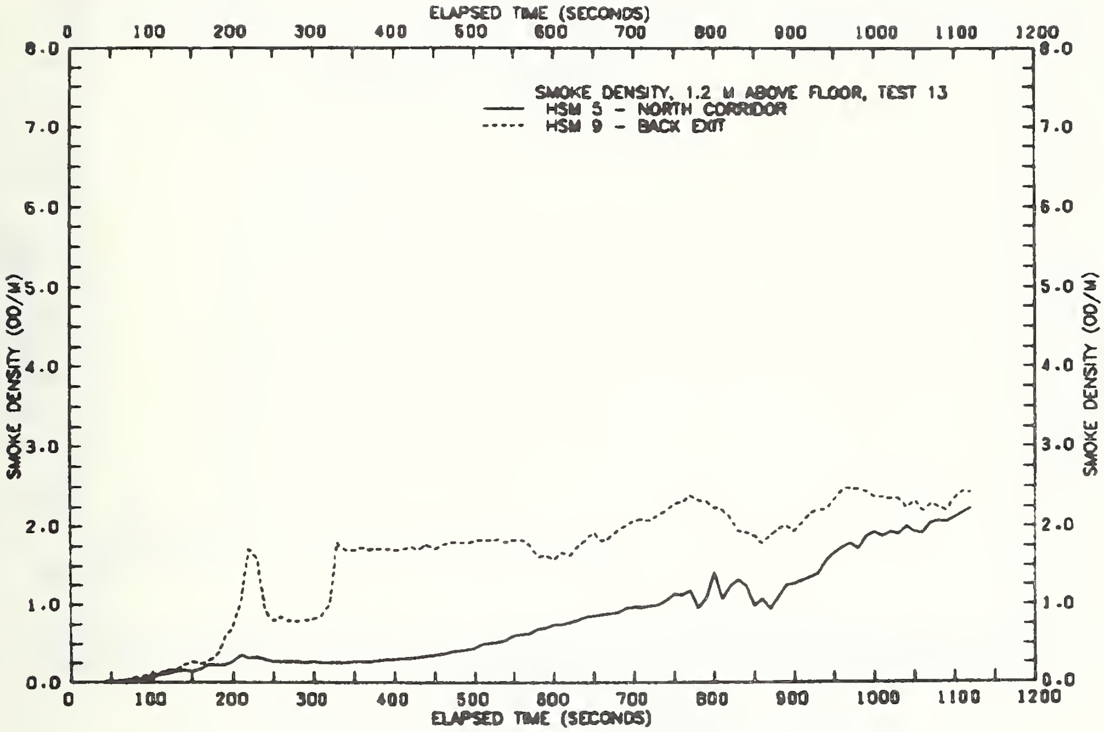
B58. Smoke Density (OD/m) Measured at the Entrance to Corridor from Living Room and Just Beyond Back Exit Door



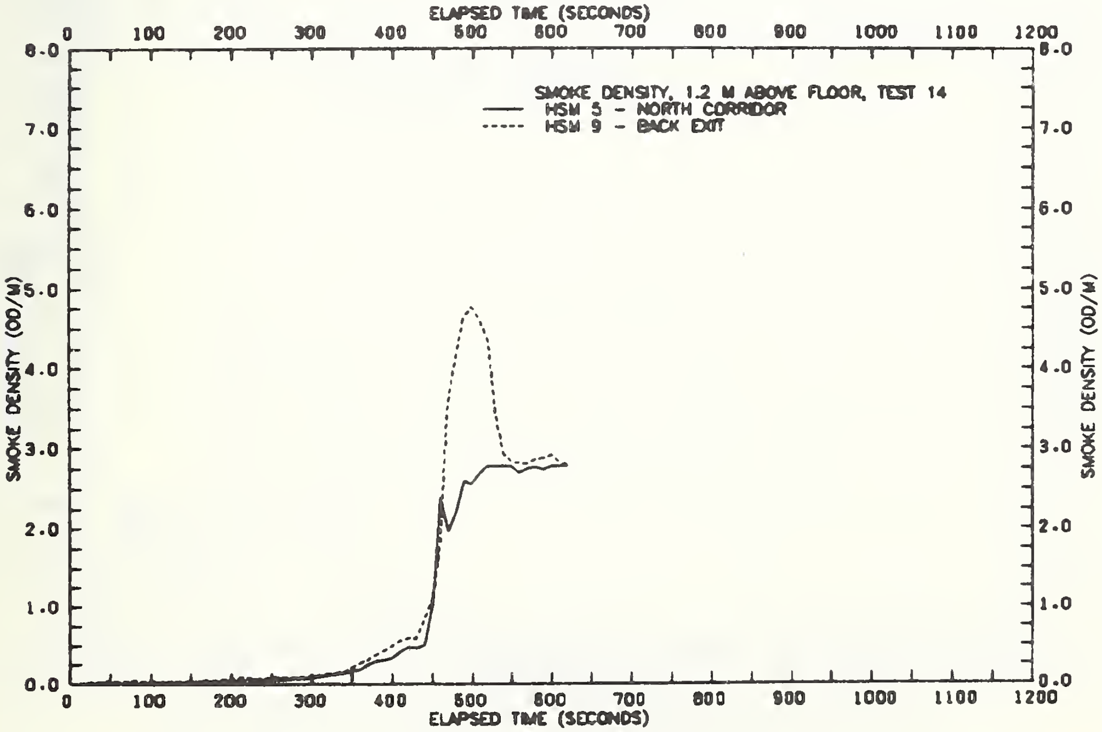
B59. Smoke Density (OD/m) Measured at the Entrance to Corridor from Living Room and Just Beyond Back Exit Door



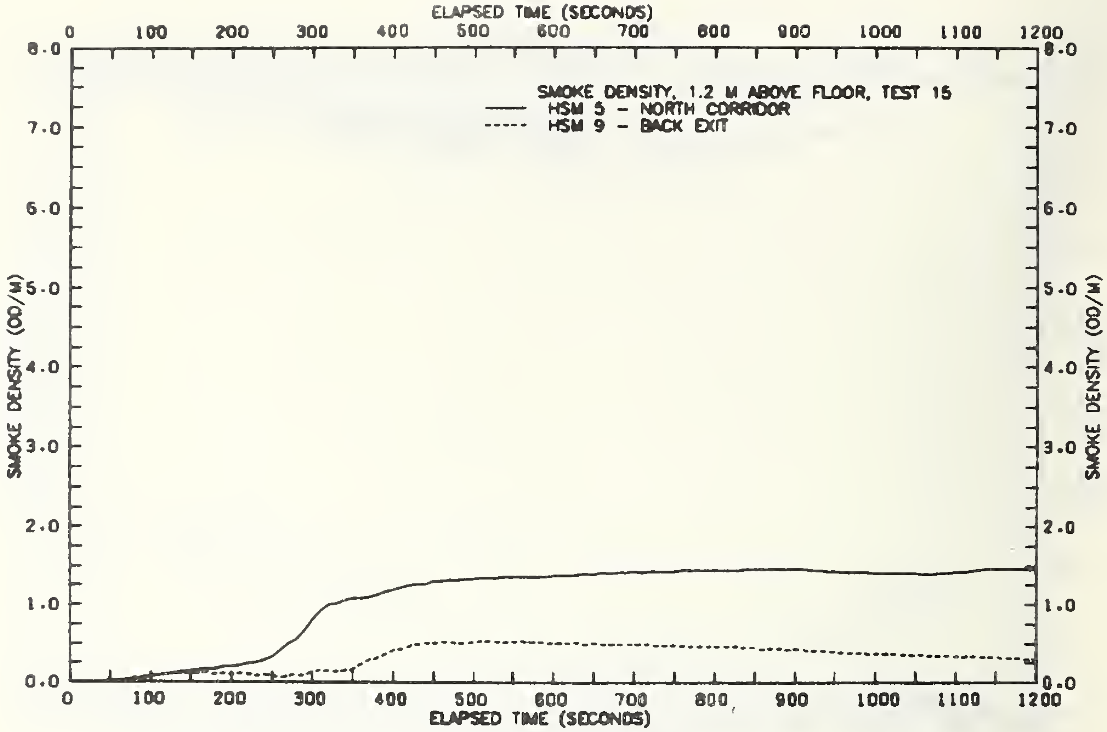
B60. Smoke Density (OD/m) Measured at the Entrance to Corridor from Living Room and Just Beyond Back Exit Door



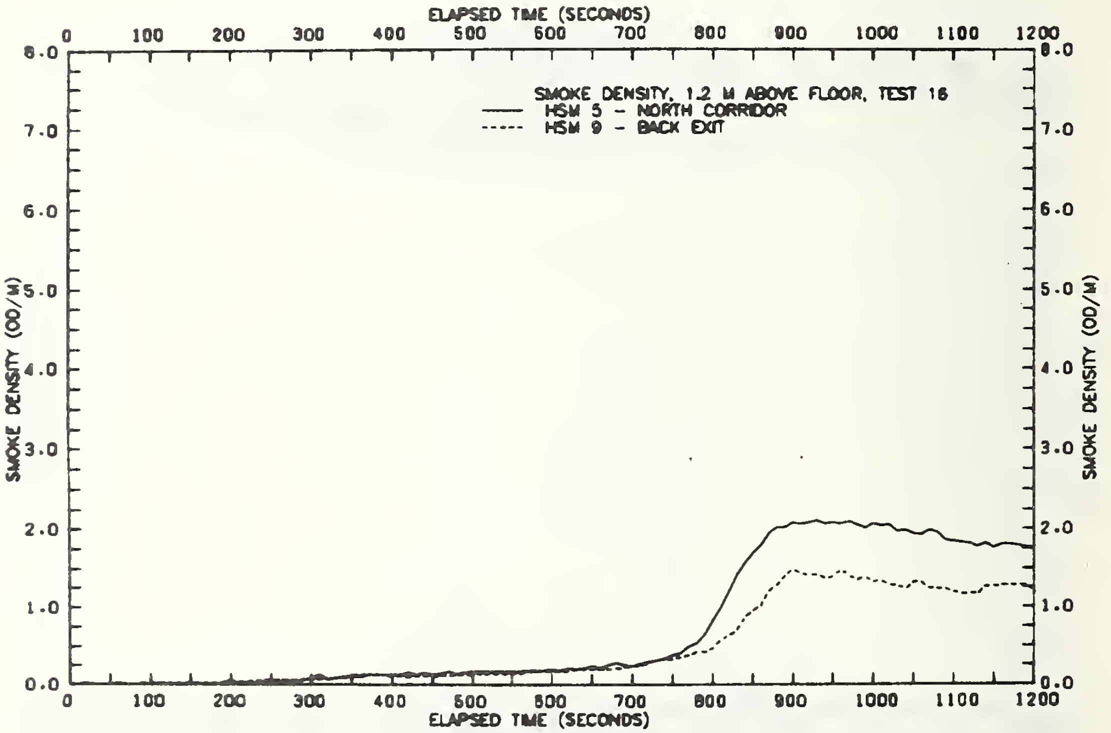
B61. Smoke Density (OD/m) Measured at the Entrance to Corridor from Living Room and Just Beyond Back Exit Door



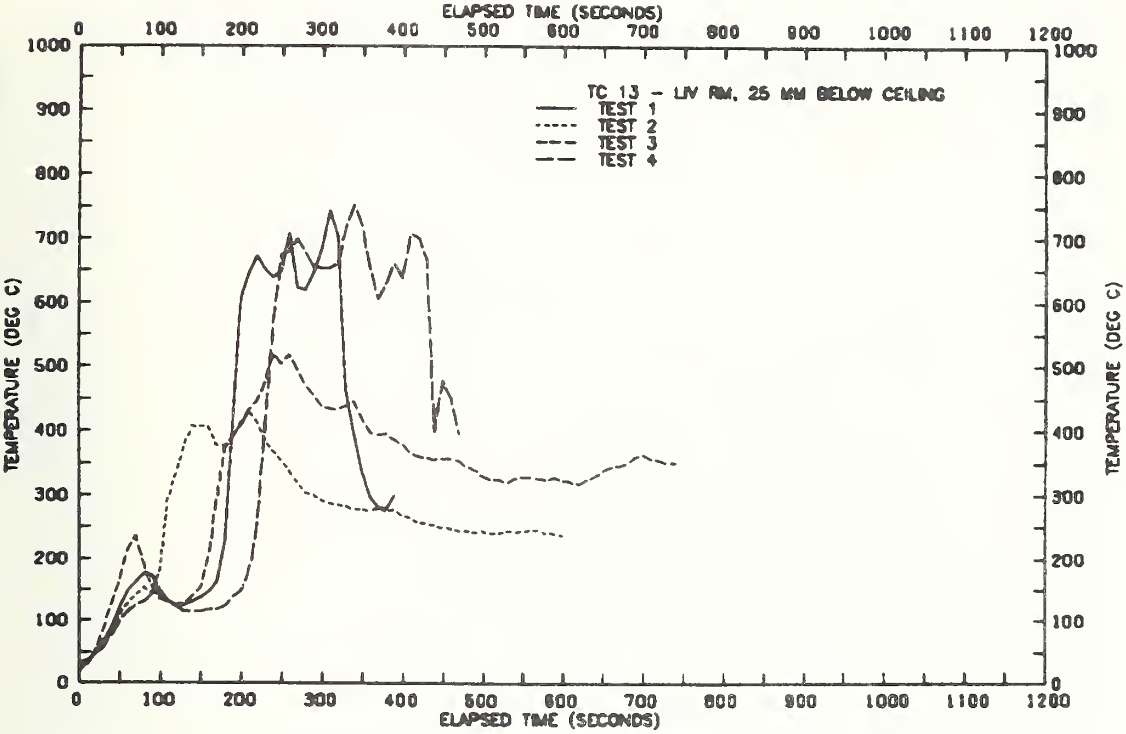
B62. Smoke Density (OD/m) Measured at the Entrance to Corridor from Living Room and Just Beyond Back Exit Door



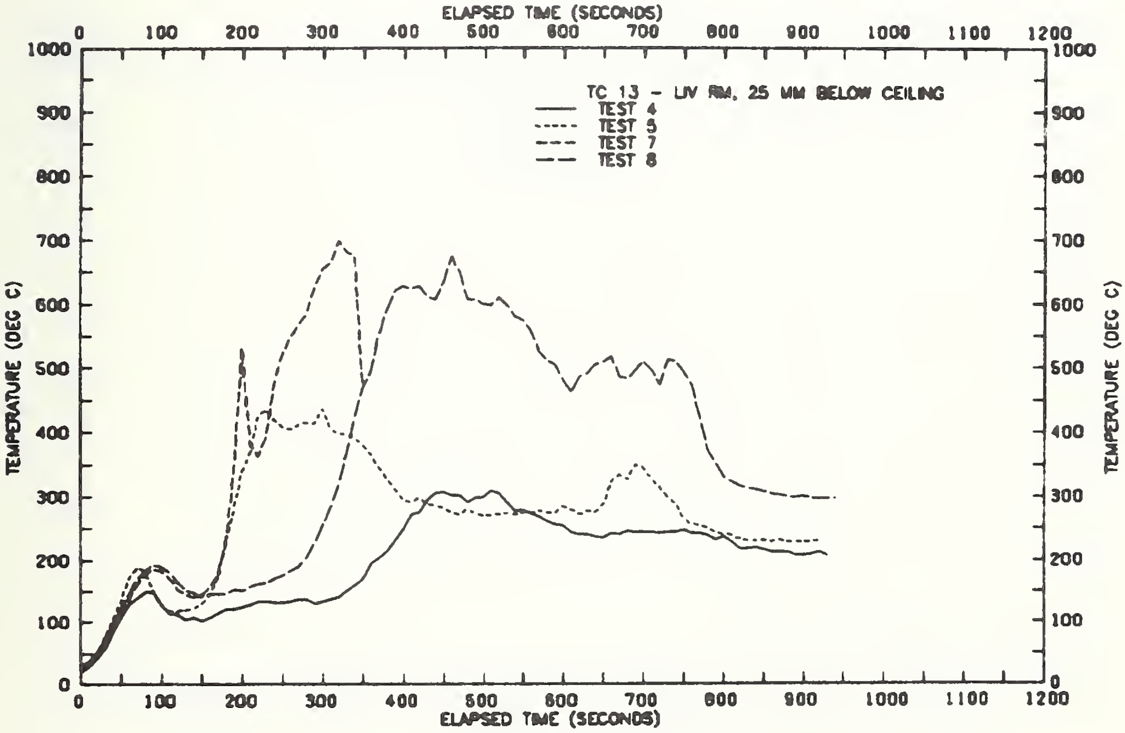
B63. Smoke Density (OD/m) Measured at the Entrance to Corridor from Living Room and Just Beyond Back Exit Door



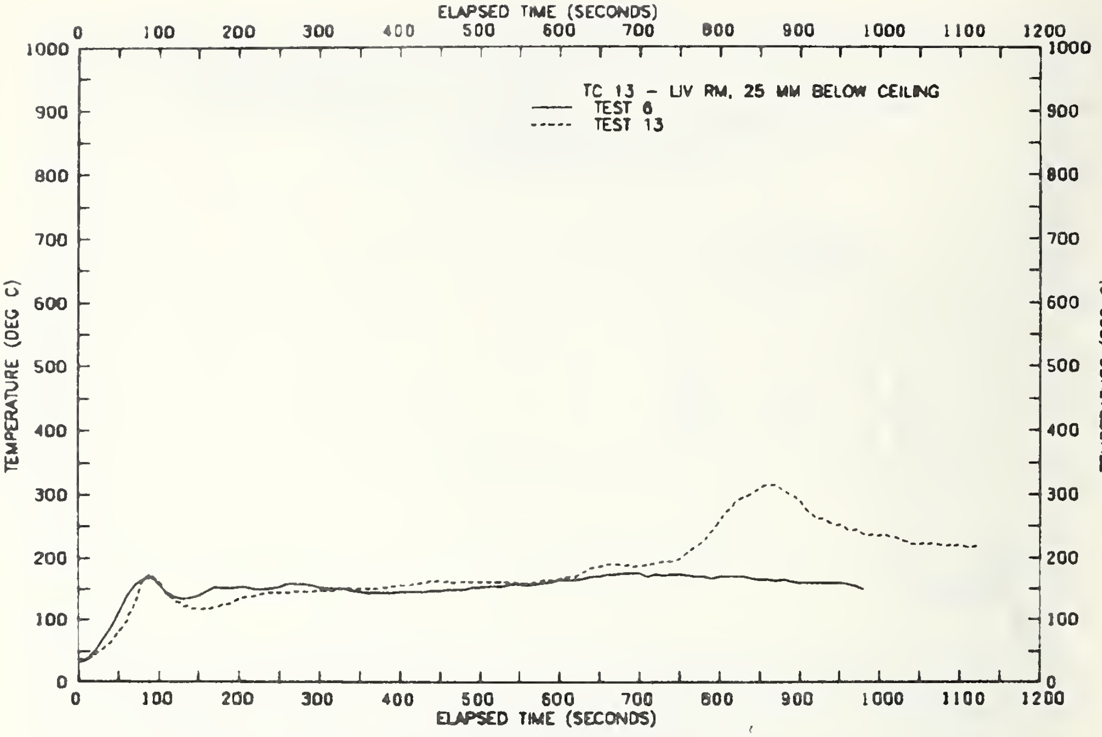
B64. Smoke Density (OD/m) Measured at the Entrance to Corridor from Living Room and Just Beyond Back Exit Door



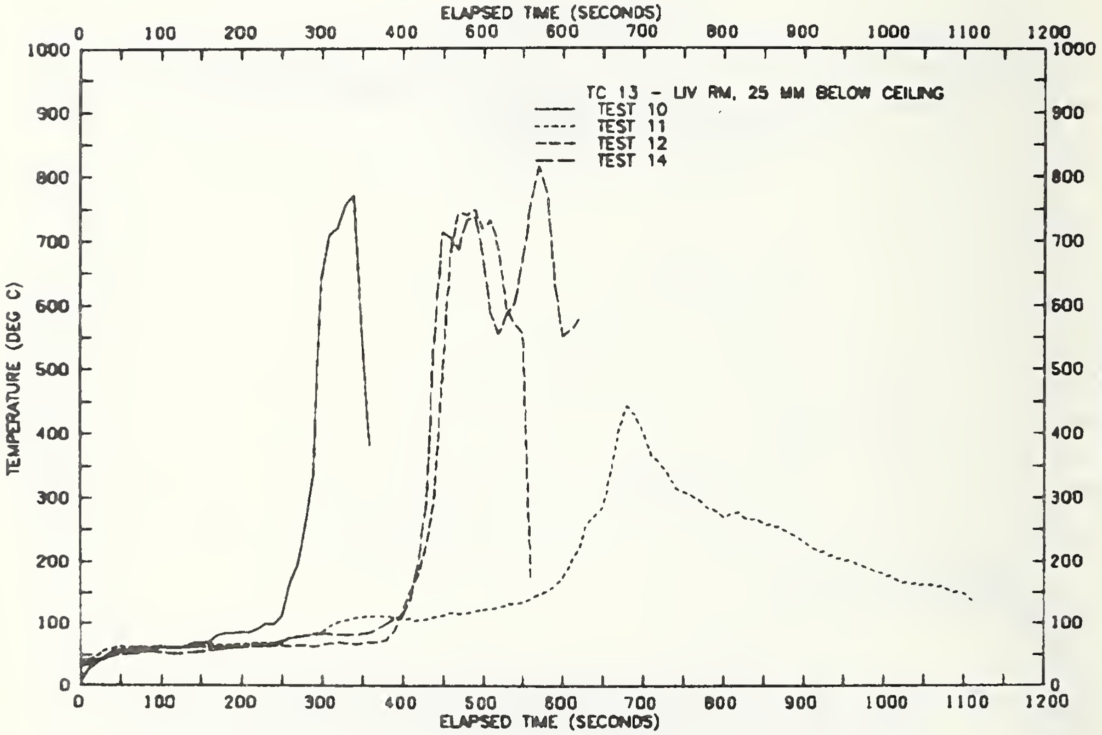
B65. Comparison of Gas Temperature Measured Near the Ceiling in the Center of the Living Room for Selected Tests



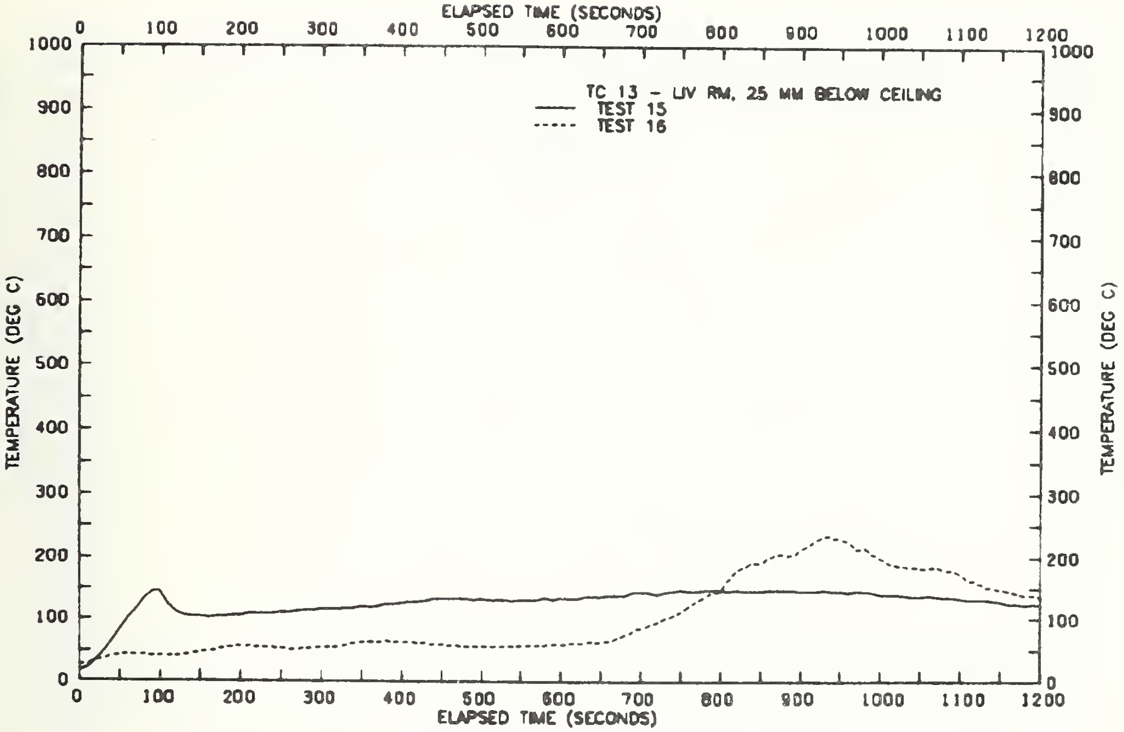
B66. Comparison of Gas Temperature Measured Near the Ceiling in the Center of the Living Room for Selected Tests



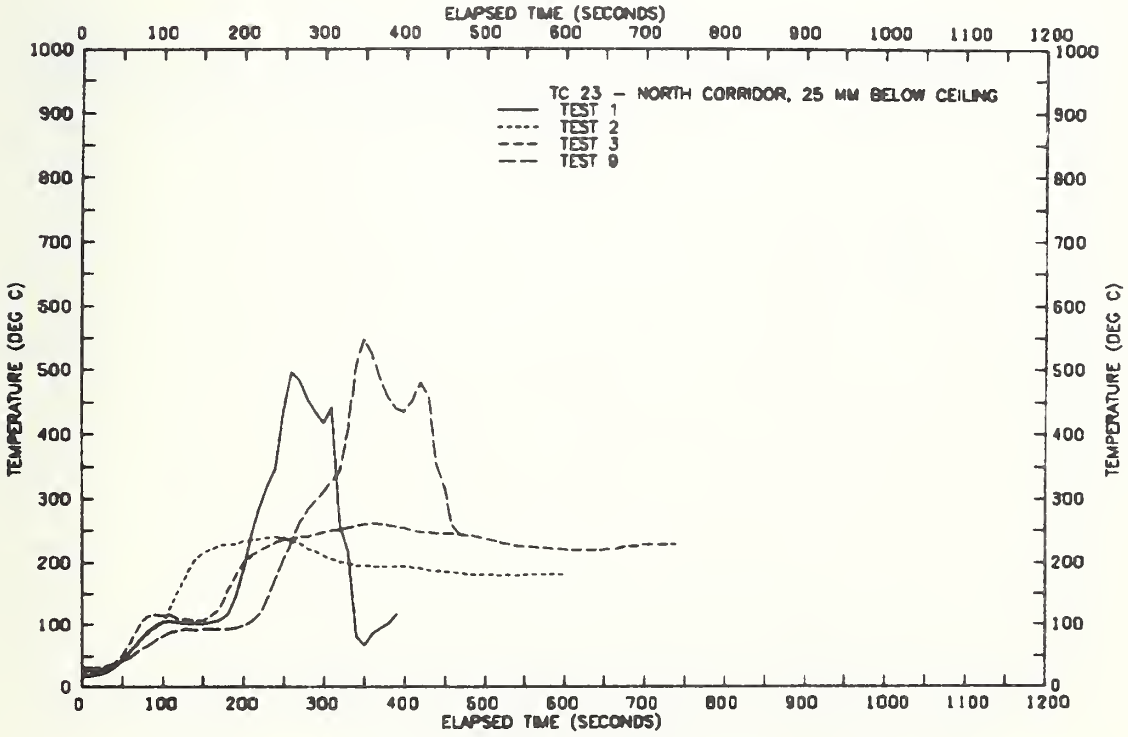
B67. Comparison of Gas Temperature Measured Near the Ceiling in the Center of the Living Room for Selected Tests



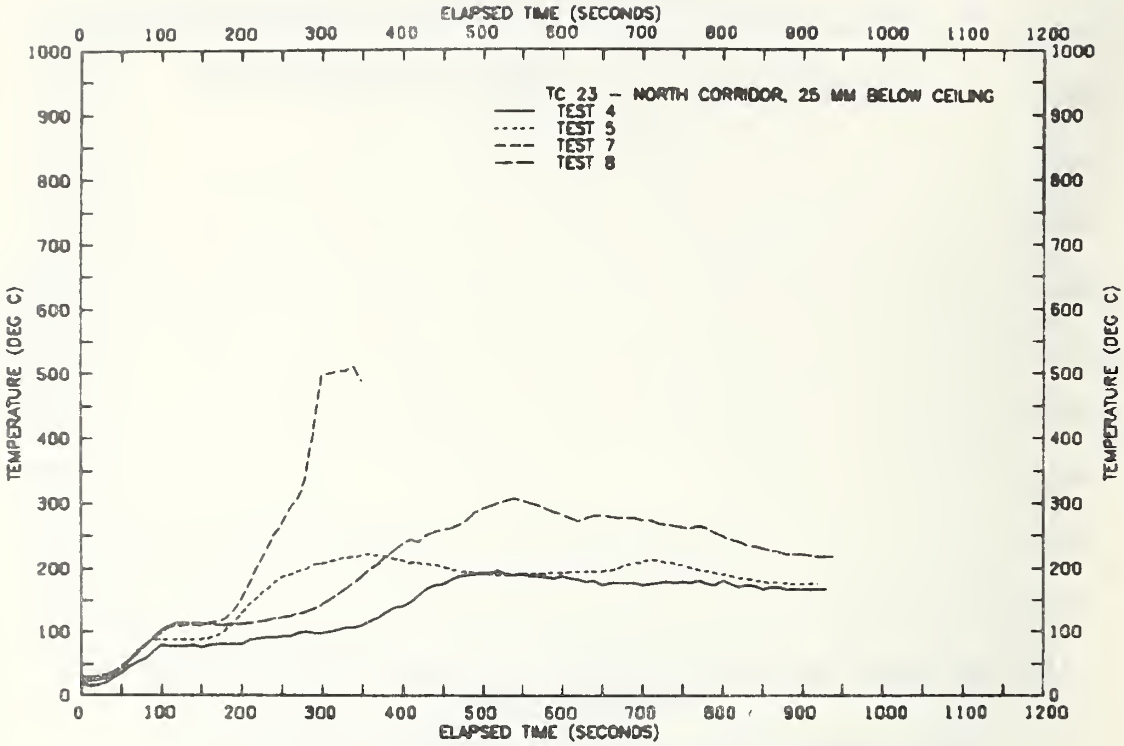
B68. Comparison of Gas Temperature Measured Near the Ceiling in the Center of the Living Room for Selected Tests



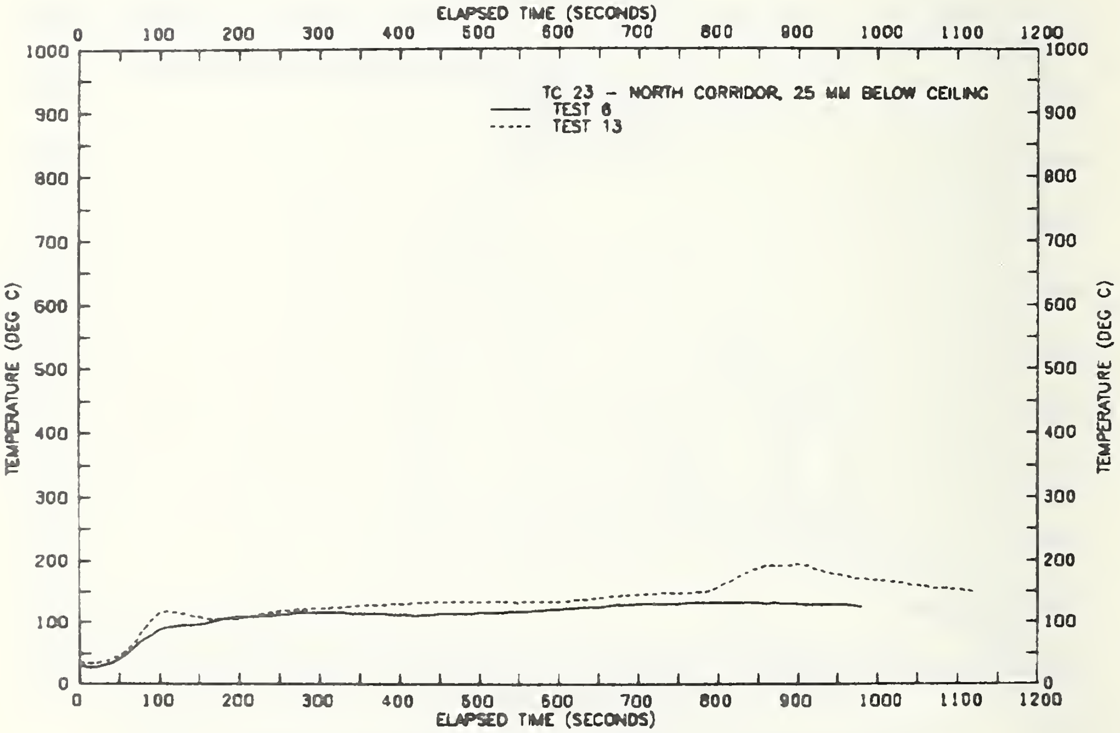
B69. Comparison of Gas Temperature Measured Near the Ceiling in the Center of the Living Room for Selected Tests



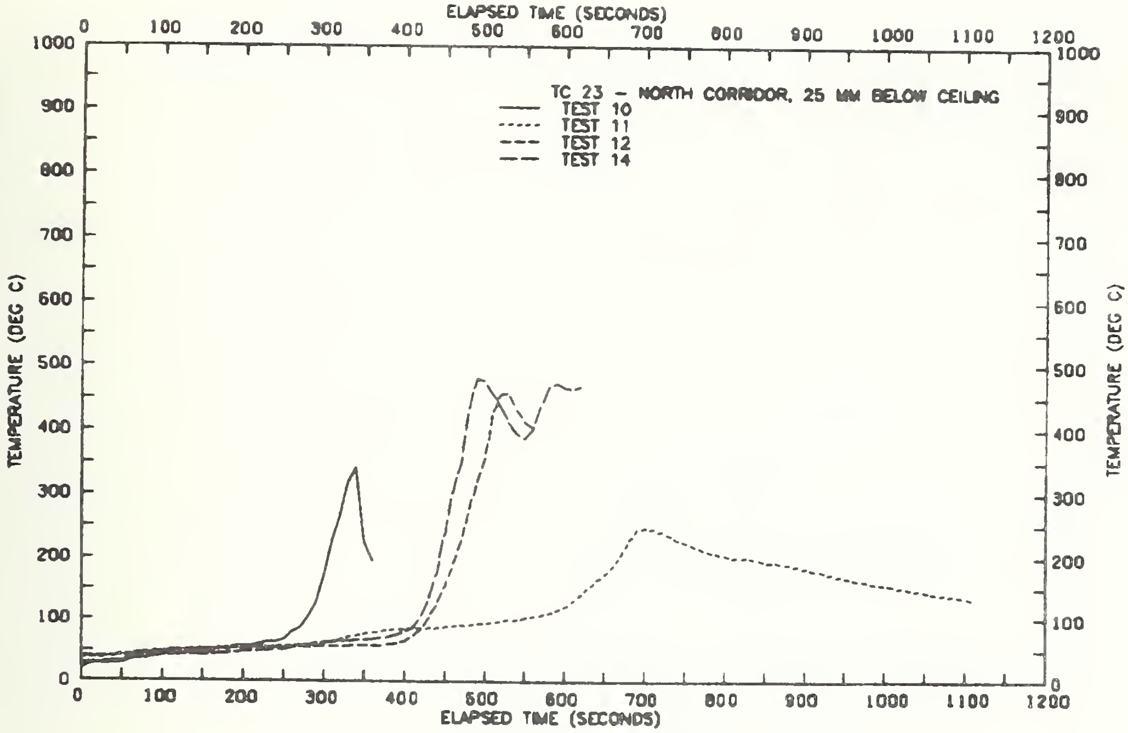
B70. Comparison of Gas Temperatures Near Ceiling at Entrance to Corridor from Living Room for Selected Tests



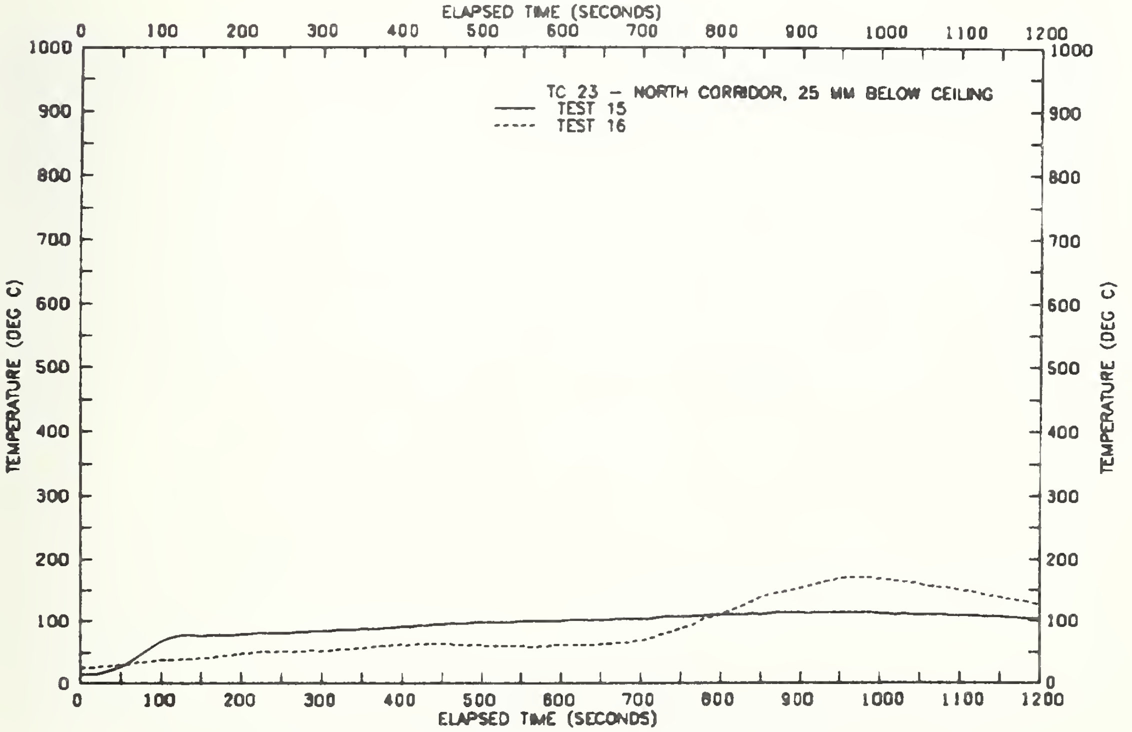
B71. Comparison of Gas Temperatures Near Ceiling at Entrance to Corridor from Living Room for Selected Tests



B72. Comparison of Gas Temperatures Near Ceiling at Entrance to Corridor from Living Room for Selected Tests



B73. Comparison of Gas Temperatures Near Ceiling at Entrance to Corridor from Living Room for Selected Tests



B74. Comparison of Gas Temperatures Near Ceiling at Entrance to Corridor from Living Room for Selected Tests

APPENDIX C. PHOTOGRAPHIC SEQUENCES OF FIRE BUILDUP FOR SELECTED TESTS

Photographs 1 through 7 illustrate fire build-up and resulting damage in Test #1 with 4 mm thick prefinished lauan plywood walls and 13 mm thick cellulosic fiber ceiling.

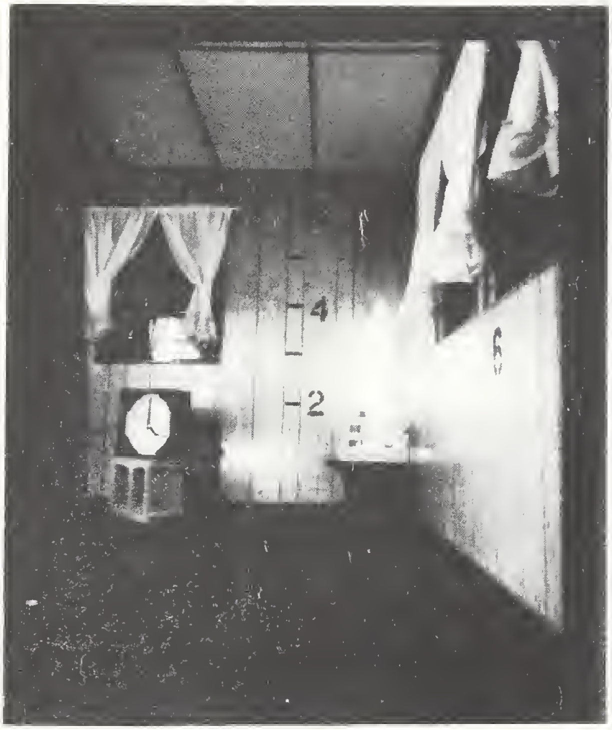


Photo 1. Flame localized in center of wood crib (37 sec. elapsed).

Photo 2. Ignition of wall material (1:44 min. elapsed).

Photo 3. Extension of flame towards ceiling (2:45 min. elapsed).

Photo 4. Advanced flame propagation across ceiling (3:19 min. elapsed).

Photo 5. Initial phase of room flashover (3:27 min. elapsed).

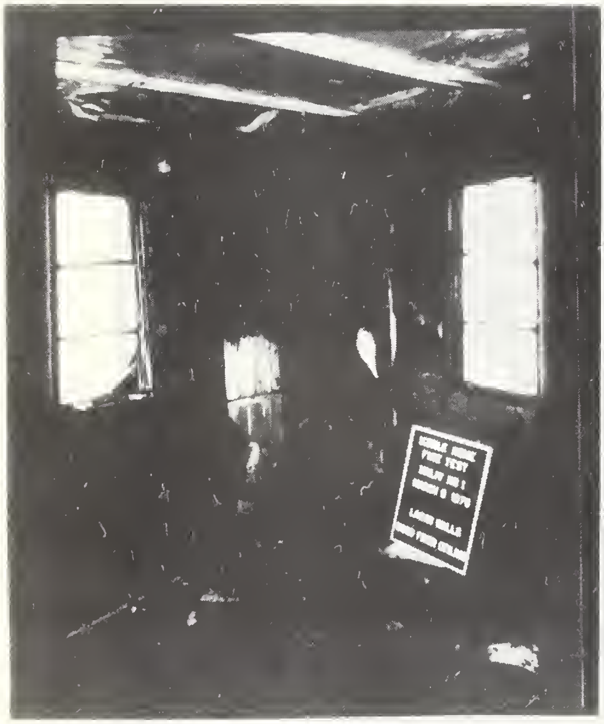


Photo 6. Damage in corner; illustrates burn-through to exterior and damage to structural members and insulation.

Photo 7. Illustrates extent of damage in living room including sofa which ignited during flashover.

Photographs 8 through 14 illustrate fire build-up and damage occurring in Test #2 with 4 mm thick prefinished lauan walls and 8 mm thick prefinished gypsum board ceiling.

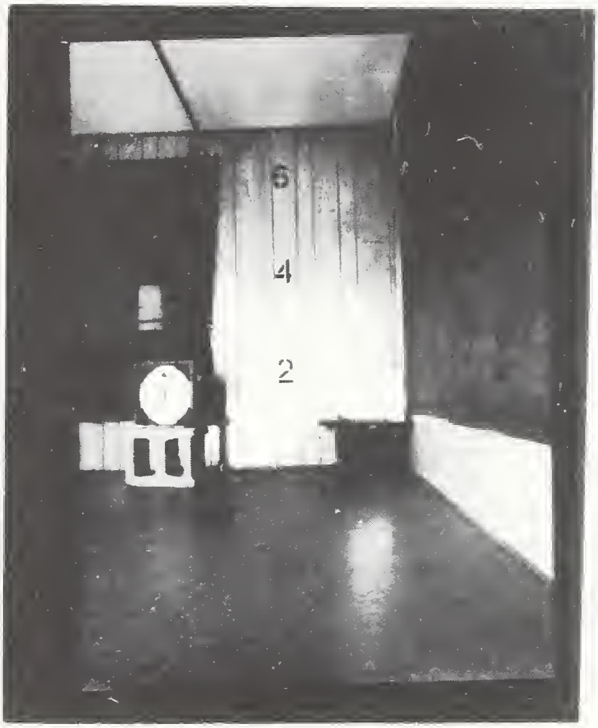


Photo 8. Initial burning of wood crib (10 sec. elapsed).

Photo 9. Involvement of wall material and extension of flame towards ceiling (50 sec. elapsed).

Photo 10. Flame impingement at ceiling (1:30 min. elapsed).

Photo 11. Increased involvement of walls and lateral propagation of flames along the ceiling. (2:38 min. elapsed)

Photo 12. Burning of upper walls along ceiling (3:31 min. elapsed).

Photo 13. Illustrates damage in corner including burn-through of walls and charring of structural members.

Photo 14. Illustrates damage in living room. Ceiling has been removed to observe the extent of damage.

Photographs 15 through 21 illustrate fire build-up and damage occurring in Test #4 with 4 mm thick fire retardant treated walls and 8 mm thick prefinished gypsum board ceiling.

Photo 15. Initial burning of wood crib (13 sec. elapsed).

Photo 16. Fire localized to burning wood crib. Charred area in corner indicates intumescing of surface treatment (3:35 min. elapsed).

Photo 17. Burning of molding in corner; flame extension to ceiling. (4:01 min. elapsed)

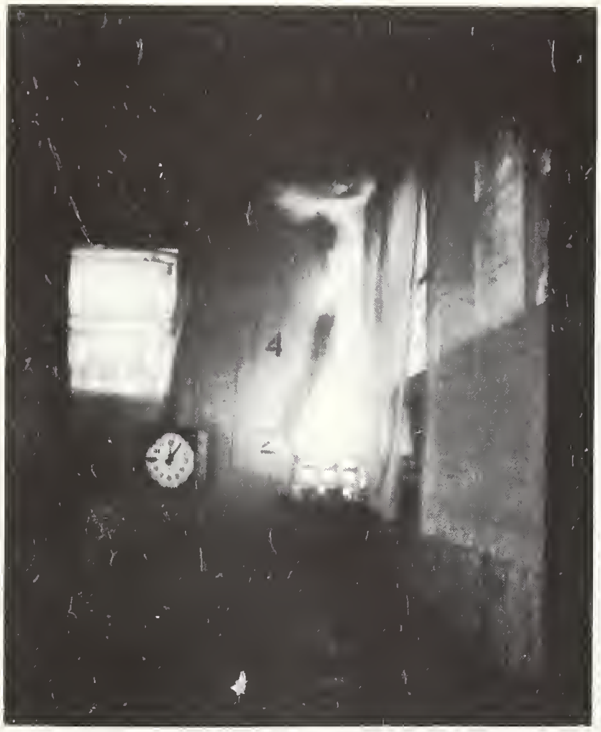


Photo 18. Wall is involved; flames have extended slightly along ceiling (5:53 min. elapsed).

Photo 19. Crib fire has reduced in intensity; wall material continues to burn and flames have extended laterally along ceiling (8:35 min. elapsed).

Photo 20. Illustrates damage in corner including burn-through of walls and extensive charring along ceiling. Minor damage observed above ceiling.

Photo 21. Illustrates damage to corner in living room and charring of upper walls along ceiling.

Photographs 22 through 28 illustrate fire build-up and damage occurring in Test #6 with 8 mm thick gypsum board walls and ceiling.

Photo 22. Initial burning of wood crib (5 sec. elapsed).

Photo 23. Burning of the paper surface on the wall. Flame has reached maximum size (4:18 min. elapsed).

Photo 24. Continued burning of wood crib; no contribution from interior finish (4:18 min. elapsed).

Photo 25. Wood crib continuing to burn at nearly a constant burn rate (6:39 min. elapsed).

Photo 26. Reduction in intensity of burning crib; noticeable smoke accumulation (15 min. elapsed).

Photo 27. Illustration of damage in corner. Charring of insulation and structural member due to penetration of wall material along a vertical joint.

Photo 28. Illustrates limitation of damage to corner in living room.

Photograph 29 through 35 illustrate fire build-up and damage occurring in Test #10 with 4 mm thick prefinished lauan plywood walls and 13 mm thick cellulosic fiber ceiling.

Photo 29. Initial fire localized to waste container and left arm of chair (50 sec. elapsed).

Photo 30. Waste container nearly destroyed. Increased involvement of chair (8:55 min. elapsed).

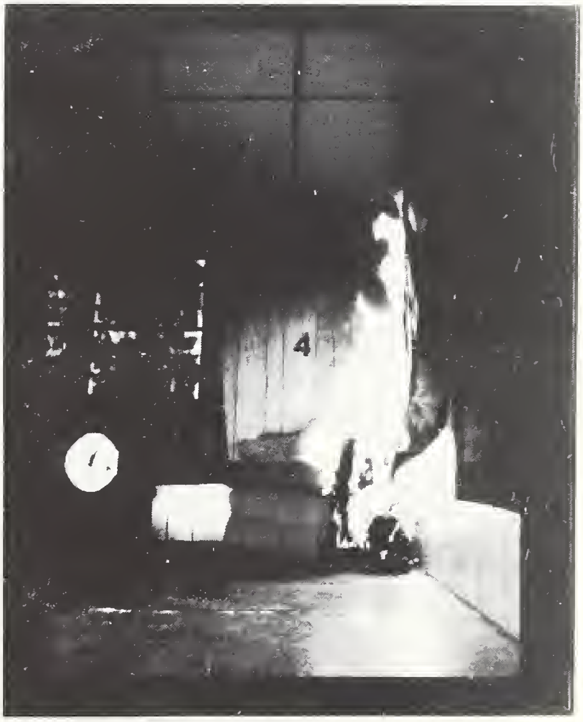


Photo 31. Wall material involved. Flame extension to ceiling (4:05 min. elapsed).

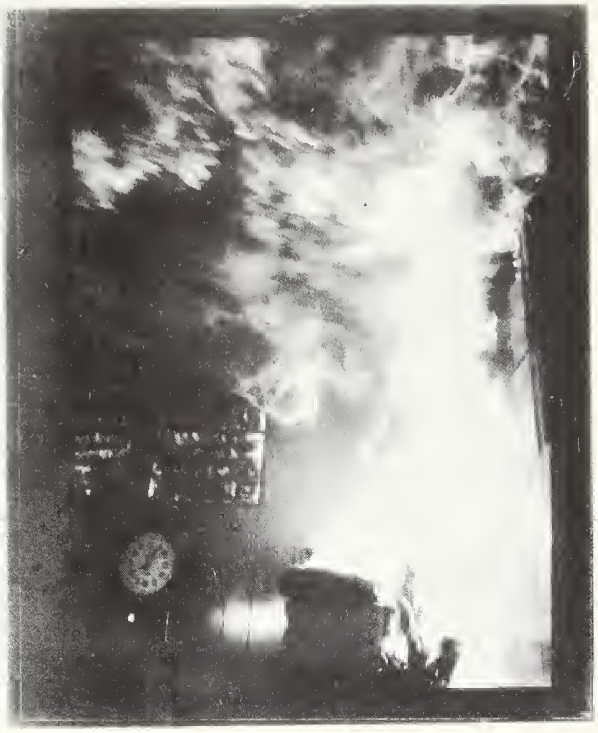


Photo 32. Extensive propagation along upper walls and across ceiling (4:55 min. elapsed).

Photo 33. Initial stage of flashover. Radiant ignition of floor covering (5:11 min. elapsed).

Photo 34. Illustration of damage in corner. Burn-through of wall in corner; charring damage to ceiling material.

Photo 35. Illustrates damage to interior finish and sofa in living room.

Photographs 36 through 42 illustrate fire build-up and damage occurring in Test #11 with 8 mm thick prefinished gypsum walls and ceiling.

Photo 36. Initial fire localized to waste container and left arm of chair (53 sec. elapsed).

Photo 37. Waste container melting; increased involvement of arm of chair; burning of curtain and wall surface (4:58 min. elapsed).

Photo 38. Increased intensity of chair fire; flames approaching ceiling. (9:55 min. elapsed)

Photo 39. Chair fire has reached maximum intensity; flame impingement on ceiling. (11:42 min. elapsed)

Photo 40. Reduced intensity of chair fire; no involvement of interior finish; noticeable smoke accumulation (13:30 min. elapsed).

Photo 41. Illustrates damage in corner.

Photo 42. Illustrates damage to interior finish-confined to corner; no involvement of other combustibles.

APPENDIX D. RANGES AND LIMITS OF ERROR FOR INSTRUMENTATION

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Instrument	Range	Limits of Error
Thermocouples	0 to 277°C 277 to 1260°C	±2.2°C ±0.75% of reading
Heat Flux Transducers RAD 1 RAD 2 RAD 3 RAD 18 RAD 19 RAD 20	 0 to 5.7 W/cm^2 0 to 5.7 W/cm^2 0 to 5.7 W/cm^2 0 to 23 W/cm^2 0 to 23 W/cm^2 0 to 23 W/cm^2	10% of reading
Gas Analysers CO 13 CO 16 CO_2 14 O_2 15 O_2 17	 0-10% 0-2% 0-20% 0-20.9% 0-20.9%	 ±2% of range ±5% of range ±2% of range ±1% of reading ±1% of reading
Smoke Meters HSM 4,5,6,8,9,10 VSM 7,11	 0-10 mV 0-15 mV	 ±4% of reading ±10% of reading
Load Cell	-225 to +225 kg	±0.1% of reading

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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 sixteen full-scale fire tests was conducted in the living room of a typically constructed single-wide mobile home. These tests were designed (1) to 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) to determine the relationship between the surface flame spread properties of the interior finish materials as determined by the ASTM E-84 Tunnel Test and the behavior of the materials as installed under actual full-scale conditions.

The test procedure was based on a fire scenario in which the interior wall finish was exposed to an incidental fire from a standardized 6.4 kg (14 lb) wood crib or a 16 kg (35 lb) upholstered chair positioned in a corner in the living room.

Performance of the various combinations of wall and ceiling materials was evaluated based on (1) the rate of fire buildup and extent of living room involvement, and (2) changes in the environment in the corridor and bedroom areas which may adversely affect the life safety of the occupants. Measurements utilized in the evaluation of changes in the environment due to fire growth and spread included gas temperatures, irradiance, concentrations of carbon monoxide, carbon dioxide and oxygen, and smoke densities. Under this set of conditions it was found that the fire properties of the interior finish materials directly affected the rate of fire growth and spread, the severity of the fire, and the resulting effects on life safety.

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)*

Key Words: ASTM E-84 Tunnel Test; carbon dioxide; carbon monoxide; fire growth; fire tests; flame spread; flashover; interior finishes; life safety; mobile homes; radiant heat flux; room fires.

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