NBSIR 79-1720

Mobile Home Fire Studies: Summary and Recommendations

Edward K. Budnick
David P. Klein

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

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Prepared for:
Division of Energy, Building Technology and Standards
Office of Policy Development and Research
U.S. Department of Housing and Urban Development
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U.S. DEPARTMENT OF COMMERCE, Juanita M. Kreps, *Secretary*

Jordan J. Baruch, *Assistant Secretary for Science and Technology*

NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

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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 per incident were three to five times greater than for conventional residences.

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 suggested as one of the most important contributors to fire spread in mobile homes. No organized research studies had 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 rating for interior finish materials of 200 or less, based on the ASTM E-84 Tunnel Test Method. In addition, results from initial segments of the Mobile Home Fire Safety Project (NBS) 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. Results from a total of five segments of the project have been published, addressing fire growth and spread in the kitchen, corridor, living, and sleeping areas of a mobile home, and the characterization of the ignition sources used in these segments. This report provides a summary of the most important findings from these previously reported segments of the project. In addition, it includes the results and analysis of a segment of work not previously published. That final segment of work encompassed eight 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 fires from burning upholstered chairs and sofas.

The full-scale fire testing conducted for each of the segments of the project, including the segment being reported herein, was conducted in typical single-wide mobile homes constructed in accordance with the NFPA 501B Standard for Mobile Homes in effect in 1972 (reference figure A1, Appendix A). These units had comparable structural, material and spatial characteristics to mobile homes currently being constructed to comply with the present Federal standard. Analyses of the tests were directed at evaluating the extent of the potential hazard to life and/or property damage occurring in each of the tests.

The criteria used to evaluate the hazard to life were selected based on available reference literature on human tenability, and included high temperature, excessive carbon monoxide, and oxygen deficiency. The criterion used to evaluate the extent of property damage was the attainment of flashover in the room of fire origin. Flashover is defined for this work as a fire phenomenon in which thermal radiation from the upper walls and ceiling and from the hot gases and smoke layer in the upper part of the room is sufficient to cause ignition amd rapid complete fire involvement of all combustible materials in the room.

This report describes the rationale upon which the overall experimental approach was based, and provides a series of recommendations, some in the form of design options, for possible changes to the standard. These recommendations are presented in the form of specific material and design requirements for the kitchen range area and in the form of a series of design options concerning ASTM E-84 flame spread requirements for interior finish in general. The design options provide for increasing levels of fire safety and are based on an overall analysis of the work performed at NBS, with consideration given to applicable work conducted by other organizations. A limited impact assessment is included to provide a relative measure of the potential impact of each of three design options for flame spread requirements for interior wall and ceiling materials. The impact is based on the likely effect on fire severity, and does not include an economic analysis.

MOBILE HOME FIRE STUDIES: SUMMARY AND RECOMMENDATIONS[1]

Edward K. Budnick and David P. Klein

Abstract

Since 1974, a major research project has been ongoing at the National Bureau of Standards to investigate various aspects of fire growth and spread in typical single-wide mobile homes. The objective of this project is to provide recommendations for possible changes to the Federal Mobile Home Construction and Safety Standard promulgated in June, 1976 by the Department of Housing and Urban Development. These changes are intended to provide an improved level of fire safety in mobile home construction.

This report provides a summary of the important findings from previously reported parts of the project which involved the conduct of full-scale fire tests in the kitchen, corridor, living room and bedroom areas of typical mobile homes. Also included in this summary are the findings from a previously unreported series of full-scale living room tests, which are discussed in some detail in Appendix A.

This report describes the rationale upon which the overall experimental approach was based, and provides a series of recommendations, some in the form of design options, for possible changes to the standard. A limited impact assessment is included to provide a relative measure of the potential impact of each of three design options for flame spread requirements for interior wall and ceiling materials. This assessment is based on the likely effect of each option on fire severity, and does not include an economic analysis.

Key Words: ASTM E-84 Tunnel Test; construction standard; fire growth; fire tests; flame spread; flashover; impact assessment; interior finish; kitchen fires; life safety; mobile homes; room fires.

[1]Principal support for this project was provided by the Division of Energy, Building Technology and Standards, Office of Policy Development and Research, U.S. Department of Housing and Urban Development, Washington, D.C. 20410.

1. INTRODUCTION

1.1. Background

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 per incident were three to five times greater than for conventional residences [1-9][2].

Examination of fire loss statistics indicates that most residential fires are initially localized and small in size [1]; that is, they do not spread beyond the room of fire origin and by themselves do not pose a serious problem. However, 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 suggested as one of the most important contributors to fire spread in mobile homes.

No organized research studies have been performed to evaluate these characteristics. 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 which was initiated in 1974. The purpose of this ongoing project was to provide experimental data on the potential growth and spread of fire in mobile homes.

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

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 rating for interior finish materials of 200 or less based on the ASTM E-84 Tunnel Test Method. In addition, results from initial segments of the Mobile Home Fire Safety Project [10] 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. A total of ninety full-scale fire tests have been conducted in typically constructed 3.7 x 18.3 m (12 x 60 ft)[3] single-wide mobile homes (reference figure A1 in Appendix A). These mobile homes were constructed in accordance with the NFPA 501B Standard for Mobile Homes in effect in 1972, and from a fire safety standpoint had comparable structural, material and spatial characteristics to mobile homes presently constructed in accordance with the current Federal standard. Analyses of these tests were directed at evaluating the extent of potential hazard to life and property damage under the experimental set-ups selected.

The criteria used to evaluate the hazard to life were selected based on available reference literature on human tenability, and included high temperature, excessive carbon monoxide, and oxygen deficiency. The criterion used to evaluate the extent of property damage was the attainment of flashover in the room of fire origin. Flashover is defined for this work as a fire phenomenon in which the radiation from the upper walls and ceiling and from the hot gases and smoke layer in the upper part of the room is sufficient to cause ignition and rapid complete fire involvement of all combustible materials in the room.

Five interim technical reports have been published, addressing fire growth and spread in the kitchen, corridor, living, and sleeping areas of a mobile home, as well as the characterization of the ignition

[3] Values given in engineering units are actual; metric equivalent units may be approximate.

sources used in these segments. These reports contain extensive detail regarding the full-scale experimental approaches, the rationale for selection of evaluation criteria, and the results. Reference may be made to these reports for details not included in this summary report. The five interim reports are:

(1) NBSIR 75-788, Evaluation of the Fire Hazard in a Mobile Home Resulting from an Ignition on the Kitchen Range, Edward K. Budnick and David P. Klein [10].

(2) NBSIR 76-1021, Fire Spread Along A Mobile Home Corridor, Edward K. Budnick [11].

(3) NBSIR 78-1522, Characteristics of Incidental Fires in the Living Room of a Mobile Home, David P. Klein [12].

(4) NBSIR 78-1530, Mobile Home Living Room Fire Studies: The Role of Interior Finish, Edward K. Budnick [13].

(5) NBSIR 78-1531, Mobile Home Bedroom Fire Studies: The Role of Interior Finish, Edward K. Budnick, David P. Klein and Robert J. O'Laughlin [14].

This report provides a summary of the important findings from these previously reported segments of the project. In addition, it includes the results and analysis of a segment of work not previously published. This final segment of work encompassed eight 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 fires from upholstered chairs and sofas. The work is similar to, and was designed to complement, the series of sixteen tests conducted in the living room area, the results of which have been previously reported [13].

This report describes the rationale on which the overall experimental approach was based, and provides a series of recommendations, some in the form of design options, for possible changes to the standard. These recommendations are presented in the form of specific material and design requirements for the kitchen area and in the form of a series of design options concerning ASTM E-84 flame spread requirements for interior finish in general. The design options provide for increasing levels of fire safety and are based on an

overall analysis of the work performed at NBS, with consideration given to applicable work conducted by other organizations. A limited impact assessment is included to provide a relative measure of the potential impact of each of three design options for flame spread requirements for interior wall and ceiling materials. The impact is based on the likely effect on fire severity, and does not include an economic analysis.

1.2. Project Objective

Mobile homes are currently constructed in compliance with the Federal Mobile Home Construction and Safety Standard [15], which was developed and promulgated by HUD in accordance with Title VI of the Housing and Community Development Act of 1974 [16]. The long range objective of this project is to provide recommendations for possible changes to the standard with respect to material and design requirements that would provide an improved level of fire safety in mobile home construction. Recommendations previously published [10], dealing with the kitchen area included both material and design considerations. The remaining recommendations included in this report involve additional material requirements, relating specifically to flame spread ratings of interior finish.

1.3. Approach

The general approach to this project can be described in terms of four discrete but related steps. The first step was to define the problem--that is, to isolate the aspects of particular significance in mobile home fires which are within the rule-making jurisdiction of HUD. This was accomplished by defining probable scenarios for fire growth and spread based on a compilation of available mobile home fire incidence data.

The second step was to design an experimental approach for several series of full-scale fire tests in a typically constructed mobile home in order to examine the characteristics of fire growth and spread for the major scenarios. This step included the selection of evaluation criteria for analysis of the test data.

The third step involved the actual conduct of the particular series of full-scale tests to examine the effect of changing key design parameters on fire development for each of the scenarios. This step included the collection and analysis of experimental test data from 90 fire tests in a fully-instrumented mobile home. While these tests were performed under a set of environmental and end-use conditions likely to be encountered in mobile home use, it was not possible to investigate all conditions and variables. For example, the effects of a wide range of interior and exterior ambient temperature and humidity, of natural or forced ventilation, and of different levels of thermal insulation were not examined. In addition, while many interior finish materials having a wide range of flame spread values were tested, it was not possible to test every material which might be used in a mobile home, nor was it possible to examine all combinations of wall and ceiling flame spread values presented by the representative interior finish materials used.

The last step was an analysis of the experimental results of the various segments of the project, an examination of the relative impact of possible changes to the standard, and the preparation of recommendations to increase the level of fire safety in mobile homes.

2. SCENARIO DEFINITION

A fire scenario can be defined as a postulated sequence of events starting with ignition and including the subsequent chain of events leading to a fire loss or injury [17]. The scenario plays a significant role in the experimental design and in the interpretation of the data collected during testing. Therefore, it has a distinct bearing on the qualifications or limitations of the results. For example, the significance of the contribution to fire growth of particular wall and ceiling materials in a room may depend to a large degree on the location and configuration of the furnishings and other movable contents which may be the initial source of the fire and/or serve as a critical link in fire spread. The size or location of the initial burning item (the exposure fire) could be selected so that the influence of the interior finish materials would be insignificant. That is, the exposure fire may be very small or may be located such that the interior finish is not exposed during initial fire buildup, or it may be very large, thus masking the contribution of the interior finish. Considerable attention was given to the development of plausible fire scenarios upon which the experimental work was based in order to avoid such extremes.

If a fire cannot be prevented, a chain of events occurs (referred to by some fire researchers as stages or "states" of fire growth). This chain includes:

1. Ignition
2. Incipient burning (single item)
3. Spread to surrounding combustibles
4. Total room involvement (flashover)
5. Spread beyond room (post-flashover)

A survey of available mobile home fire incidence data [1-9, 18] provided information which could be related to the concept of "stages" for fire buildup (see table 1). Key elements in the data which were identified were:

1. Area (location) of fire origin
2. Primary source of ignition
3. Primary means of fire spread beyond initial item

As shown in table 1, the data indicated that the three most common areas of fire origin were:

1. Bedroom/living room
2. Kitchen
3. Heating equipment area

It was further indicated that the most common sources of ignition were:

1. Fuel fired equipment
2. Electrical
3. Smoking

And finally, the most common means of spread were:

1. Structural or interior finish
2. Power transfer equipment

Based on these findings, scenarios for fire incidents were developed. A rank ordering of the scenarios in terms of probable occurrences resulted in the three major scenarios illustrated in table 2.

Experimental plans were developed to conduct full-scale tests to provide data on the first two scenarios. Interim reports NBSIR 76-1021, NBSIR 78-1522, NBSIR 78-1530 and NBSIR 78-1531 all provide experimental results and analysis of selected measurements of fire growth and spread from incidental[4] fires in the bedroom, living room and corridor areas of a 3.7 x 18.3 m (12 x 60 ft) single-wide, three bedroom mobile home. Interim report NBSIR 75-788 specifically addresses the results of experimental testing to examine the impact of incidental fires occurring on the kitchen range. The exposure fires used in the kitchen tests consisted of cooking oil on a kitchen range. The exposure fires used in the other tests included wastebaskets, standardized wood cribs, upholstered chairs, and a mattress.

The third scenario, involving ignitions in heating equipment, was not selected for study. Section 280.203(3) of the Federal Mobile Home Construction and Safety Standard included requirements to increase the fire resistance of the enclosures where the hot water heaters and heating units were located. It was anticipated that these requirements would have a significant impact on the potential spread of these types of fires beyond the compartment. Therefore, this scenario was assigned a low priority, and no experiments were planned.

3. EXPERIMENTAL TEST PLANS

Details of the experimental procedures, the facilities, and rationale for selection of evaluation criteria are included in the interim reports.

4. KEY EXPERIMENTAL FINDINGS

The following are conclusions, drawn from the various experimental segments of the project, which are pertinent in considering recommendations to improve the fire safety in mobile home construction.

[4] For this work an incidental fire is defined to be one which by itself does not cause flashover in the room in which it is burning. Flashover is defined to be a fire phenomenon in which the radiation from the upper walls and ceiling and from the hot gases and smoke layer in the upper part of the room is sufficient to cause ignition and rapid complete fire involvement of all combustible materials in the room. The term is synonymous with the phrase "total room involvement" [19].

4.1. NBSIR 75-788, Evaluation of the Fire Hazard in a Mobile Home Resulting from an Ignition on the Kitchen Range

1. A pan of cooking oil which burned freely for as little as 40 seconds on a range in a mobile home kitchen represented a potential of fire spread and involvement of the cabinets and back wall in the kitchen area.

2. For the range of vertical clearances studied, 57 to 79 cm (22.5 to 31 in), the height to the bottom surface of the cabinet directly above the range had a slight effect on the time it took to reach sustained burning of the cabinet. Without a metal range hood, sustained burning of the Class C cabinet underside occurred within three minutes after ignition in the majority of tests with a cooking oil fire. Class C refers to a flame spread classification (FSC) within the range 76-200 according to ASTM E-84 [20].

3. Installation of a metal range hood of a design described in the test report provided significantly improved resistance to sustained burning of the underside of the cabinet directly above the range, significantly reduced the rate of temperature rise and maximum temperatures at the ceiling above the range, and increased the time to ignition of the vertical surfaces of the cabinet assembly, including doors and trim.

4. Installation of minimum 6 mm (0.25 in) inorganic board between the underside of the cabinet and the metal range hood provided a significant reduction in temperatures transmitted to the cabinet underside. However, due to direct exposure on other surfaces, this did not prevent ignition of the cabinet in all cases.

5. The partition behind the kitchen range represented a critical area for lateral flame spread and for fire penetration into the adjacent room due to a cooking oil fire on a rear burner. The presence of a range hood tended to increase this potential for the typical ASTM E-84 Class C partition material.

6. With a range hood installed, the differences in performance of the three types of cabinet door materials were less pronounced than with a range hood not installed. However, in all of the

tests with polystyrene cabinet doors, there was a structural collapse of the door.

7. Cabinets adjacent to the cabinet directly above the kitchen range could be ignited from a cooking oil fire, but not as readily as the cabinet directly above.

4.2. NBSIR 76-1021, Fire Spread Along a Mobile Home Corridor

1. The tests showed that an incidental fire entering the corridor in a mobile home, rather than venting itself by burning up through the roof or out the windows located along the corridor or burning through partitions into adjacent areas, initially progressed directly down the length of the corridor, significantly limiting egress.

2. For fires starting in the corridor, the extent of fire spread and the time to reach thresholds for limiting physiological conditions, based on the various criteria provided, were significantly influenced by the surface flame spread characteristics of the wall and ceiling finish materials in the corridor.

3. Combustible corridor wall and ceiling linings with ASTM E-84 flame spread classifications in the vicinity of 200, produced untenable temperature conditions in the corridor in less than four minutes after ignition of a wood crib in the corridor.

4.3. NBSIR 78-1522, Characteristics of Incidental Fires in the Living Room of a Mobile Home

1. Under the experimental conditions of this test series, including non-combustible walls and ceiling and no additional furnishings, an incidental fire resulting from the burning of a wood crib weighing up to 13.6 kg (30 lb) or a medium size upholstered chair by itself did not result in conditions conducive to full room involvement (flashover).

4.4. NBSIR 78-1530, Mobile Home Living Room Fire Studies: The Role of Interior Finish

1. Fire spread beyond the initial burning item occurred as a result of involvement of the wall and ceiling interior finish materials near the burning item. The rate of fire growth and spread, the severity of the fire, and the resulting attainment of limiting conditions selected for life safety depended on the thermo-physical and fire properties of the wall and ceiling finish materials.

2. Flashover, observed to have occurred as a result of radiative heat transfer from the hot smoke layer and the surfaces in the upper part of the room to the combustibles in the lower part of the room, occurred in those tests in which the upper room temperature exceeded 600°C. Lateral heat transfer and flame propagation from the initial burning item were not of sufficient intensity prior to the attainment of flashover to involve other combustibles except those in close proximity to it.

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

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

4.5. NBSIR 78-1531, Mobile Home Bedroom Fire Studies: The Role of Interior Finish

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

2. Given a fire in bedding with a mattress susceptible to rapid flaming combustion (e.g., a polyurethane mattress) in the corner of the master bedroom of a single-wide mobile home, flashover is likely to occur regardless of the FSC of the interior finish materials. However, it should be noted that bedding fires involving mattresses constructed of other materials such as cotton batting or neoprene may not pose as serious a hazard as the polyurethane mattress used in this series.

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

4.6. Supplemental Mobile Home Living Room Fire Studies: The Role of Interior Finish (See Appendix A)

1. The test results provided the basis for extending the material hazard matrix developed in NBSIR 78-1530 to a higher intensity exposure fire. This supported the earlier finding that the use of the ASTM E-84 flame spread rating (FSC) provided an indication of the potential contribution of interior finish materials when exposed to an incidental fire under the conditions established in this test series.

2. The range of FSC for combinations of wall and ceiling materials demonstrating no flashover was reduced significantly when the exposure fire was increased from one of low intensity to one of moderate intensity.

5. DESIGN STRATEGIES FOR LIMITING FIRE GROWTH AND SPREAD

Fire safety can be accomplished either through preventing the ignition or by managing the impact of the fire. It is not realistic to expect that design requirements for construction can effectively prevent all hostile ignitions. Flaming ignitions are common in normal

activities (e.g., cooking on a gas range or striking a match for a cigarette) and any one of them could, under the proper circumstances, become a hostile ignition. In addition, electrical appliances which are malfunctioning or are improperly used could produce a spark or produce the heat to cause a hostile ignition.

Given the condition that a fire has occurred, it becomes necessary to manage the fire impact. Referring back to the "chain" of events in the typical fire growth process,

(1) Ignition
(2) Incipient burning (single item)
(3) Spread to surrounding combustibles (including walls and ceiling)
(4) Total room involvement (flashover)
(5) Spread beyond room (post-flashover)

it is necessary to identify where regulations could be imposed that would make use of available engineering techniques to effectively control the fire growth process. Furthermore, it is necessary to define the criteria that can be used to measure the successful application of these techniques.

Intervention strategies involving control of the construction and interior finish materials were developed to limit the impact of a fire (1) resulting from an ignition on the kitchen range, and (2) from an item of burning furniture or other incidental fire. These strategies were based on an analysis of the test results which indicated that flashover was a critical stage in mobile home fire growth. The strategies were designed to prevent a fire from reaching step 4 of the "chain". Other strategies were not developed here.

5.1. Controlling Incidental Fires on the Kitchen Range

The effectiveness of several design features in preventing the spread of an accidental fire occurring on the kitchen range to the surrounding combustibles was examined. Design requirements were derived which, if implemented, would reduce the likelihood of rapid fire spread to the combustible overhead cabinets, the back wall, and other combustibles within close proximity to the kitchen range. The recommended design requirements are:

1. A steel range hood of minimum no. 26 U.S. Standard Gage thickness should be installed above the kitchen range with a minimum vertical clearance from the range top to the hood of 61 cm (24 in). The range hood should be designed such that a minimum 13 cm (5 in) eyebrow is extended beyond the front vertical surface of the overhead cabinets to prevent direct impingement of flames on the vertical cabinet surfaces such as the doors. In cases where the hood and overhead cabinet are recessed so that the bottoms of the adjacent cabinets to the hood are lower than the hood, the exposed sides of these adjacent cabinets should be protected by an extension of the hood design. In all cases, a sheet of minimum 6 mm (0.25 in) thick inorganic board (or equivalent) should be provided between the hood and the surfaces of the overhead and adjacent cabinets. The underside of the adjacent overhead cabinets within a horizontal distance of at least 46 cm (18 in) from the range should be constructed of materials having a maximum flame spread classification not greater than 50 when tested in accordance with the Standard Test Method for Surface Burning Characteristics of Building Materials, ASTM E-84 [20], and a rating of limited combustibility as defined in NFPA No. 220, Types of Building Construction, 1975 edition [21].

2. The material comprising the exposed partition behind the range should be limited to a flame spread classification of not greater than 50 (under ASTM E-84) and a rating of limited combustibility (under NFPA 220, 1975 ed.) to prevent fire penetration into adjoining areas. It should be attached by mechanical means and extend at least 46 cm (18 in) beyond the edge of the range.

5.2. Controlling Incidental Room Fires

5.2.1. Development of Material Hazard Matrices

A room fire may initially involve the ignition of a small piece of furniture, a waste container filled with combustibles, or a small appliance; or it may involve the ignition of an upholstered chair, a sofa, or a bed. Other parameters to be considered are the size of the room in which the fire occurs, the ventilation, and the interior finish.

Tests were conducted in the living room, bedroom and corridor areas to provide data on a range of enclosure sizes. In addition, a range of incidental exposure fires was selected to provide data on the growth and spread of low and moderate intensity fires[5], which would typically be expected to occur in a residence. Various combinations of wall and ceiling materials were tested covering a wide range of FSC. As a result of the variations in these parameters the examination of the incidental room fire scenario for mobile homes required the conduct of over sixty full-scale fire tests.

The role of fire growth and spread and the maximum fire size are strongly affected by the intensity of the exposure fire, the size of the room, and the interior finish of the wall and ceiling materials. It was found that the attainment of flashover in the room of fire origin was of paramount significance not only in terms of the extent of property damage but also in terms of attainment of limiting conditions selected for occupant tenability. It was also found that the use of limited flame spread interior finish materials on the walls and ceiling could provide successful design options to prevent the attainment of flashover from a low or moderate intensity incidental fire.

In order to illustrate the effect of various combinations of wall and ceiling materials with different FSC values on fire growth to flashover for a particular size room and particular intensity incidental fire, material hazard matrices (flashover matrices) were developed. Such matrices were used in NBSIR 78-1530 and NBSIR 78-1531, and are used with the supplemental living room test results in Appendix A. The matrices illustrate, based on the results of the full-scale tests, the range of FSC combinations for wall and ceiling materials which would not be expected to result in room flashover from exposure to an incidental fire. They also illustrate the range of combinations in which flashover would be expected to occur, as well as an intermediate range in which flashover is uncertain due to the absence of test data for some combinations of FSC. All flame spread values, referred to as FSC, are based on the results of the ASTM E-84-77a Tunnel Test (see table 1 of Appendix A in this report, table 2 of NBSIR 78-1530, and table 1 of NBSIR 78-1531).

[5]For purposes of this study, a low intensity fire is a fire resulting from the ignition of a small piece of furniture, a waste container or a small appliance. A moderate intensity fire is one resulting from the ignition of a larger item such as an upholstered chair or sofa. Both the low and moderate intensity fires are considered to be "incidental" as defined in footnote 4.

Three matrices were constructed. The one in figure 1 illustrates the range of wall and ceiling materials, as a function of the FSC, for which flashover would or would not be expected when exposed to a low intensity incidental fire in the corner of a mobile home living room. The two matrices in figure 2 provide similar illustrations for flashover in the living room and the bedroom, depending on the FSC of the interior finish materials, but from exposure to a moderate intensity incidental fire in the corner.

These matrices represent the probable occurrence of flashover based on the full-scale mobile home tests conducted at NBS and the results of ASTM E-84 tests conducted at a single testing laboratory. For these reasons the borders separating the "no flashover", "untested", and "flashover" regions, while shown as well defined boundaries, should not be assumed to be that precise. This is due to inherent variations in ASTM E-84 results among laboratories, due to batch to batch variations of the same generic material, and due to the effects of different fire properties such as ignitability, heat release rate, potential heat, etc., for the different generic materials with the same FSC. In addition, more information could become available about other combinations of wall and ceiling materials currently falling in the "untested" region if such materials are used in future full-scale fire tests.

Where appropriate, data from one test series are extrapolated from one matrix to another. For example, in figure 1 the region where flashover was not observed for the low intensity fires has been increased slightly based on the results of the upholstered chair series. The more severe chair fire did not result in flashover in test MHLIV 24 which tested a wall material having higher FSC than wall materials in similar tests in the series with the low intensity fire exposure. It is assumed that for similar materials, if the larger exposure fire did not result in flashover, then it is unlikely that flashover would occur for a smaller exposure fire.

Similarly, the region defined as that where flashover was observed for the moderate intensity exposure fire in the bedroom (fig. 2) has been extended to include those material combinations which demonstrated flashover for the moderate intensity exposure fire in the living room. This extrapolation was based on the understanding that if flashover occurred in the living room with a given size exposure fire, then it is likely that flashover will occur in the bedroom, which is significantly smaller, for a similar exposure fire.

In figure 2, the material hazard matrix covering moderate intensity incidental fires in the living room shows a common region of intersection between the regions of high and low flashover probability. The tests which define that uncertain region (MHLIV 23 and 24) both used intumescent treated lauan plywood walls (FSC of 36 and 45, respectively). In addition, both tests used ceiling materials with an FSC of 25. However, in test MHLIV 23, where flashover was observed, the ceiling was a fire-retardant treated finished wood fiberboard while in test MHLIV 24, where flashover was not observed, the ceiling consisted of taped, spackled, and painted gypsum board.

This result serves to highlight a limitation in the use of FSC alone in determining the hazard of a material. It is important to recognize that FSC alone is not a complete measure of the contribution of a material to fire growth and spread. Consideration of other properties such as ignitability, heat release rate, thermal conductivity, density, potential heat, and specific heat would provide a more accurate prediction of the contribution, particularly for materials having widely divergent thermophysical properties while at the same time having similar FSC values. The two ceiling materials tested in MHLIV 23 and 24 provide a case in point. While the FSC was similar for both materials, the integrated heat release rate for a five minute period, based on laboratory tests conducted in the NBS Rate of Heat Release Calorimeter Model II at an exposure of 6 W/cm^2, was quite different for the two materials. The fire retardant treated wood fiberboard had an integrated heat release rate of 1324 J/cm^2; the value for the gypsum board was 394 J/cm^2. (Further discussion of this is included in section 5 of Appendix A.)

In addition to the extrapolations mentioned above, the region where "flashover was not observed" for the moderate intensity exposure fire in the bedroom has been expanded to include ceiling materials having FSC values up to 25. The gypsum board ceiling material tested in the bedroom series had a measured FSC of 15. However, a gypsum board ceiling material with similar material and fire properties tested in the living room series had an incrementally higher FSC of 25. The results of the two test series indicate that there was no significant difference in performance under full-scale conditions for the two similar ceiling materials having FSC values of 15 and 25 respectively when tested with a wall material having an FSC value of 25 or less. Therefore, the region in the matrix was extended for ceilings up to FSC of 25, in lieu of the more restrictive limit of 15.

However, limitations on the use of FSC, as described above, and the absence of comparative full-scale test data discourage a direct extension of the non-flashover region in the low intensity material hazard matrix (fig. 1) to include ceiling materials having FSC values up to 25. While such an extrapolation of the full-scale results was performed for the moderate intensity exposure fire in the bedroom, some comparative full-scale test data were available, and the corresponding FSC values for the wall materials in the non-flashover region did not exceed 25. In the case of the low intensity exposure fires in the living room, wall materials having much higher FSC values (from 45 up to 182) are involved. The results of tests MHLIV 23 and 24 provide at least an indication that the use of some ceiling materials having FSC values of 25, in conjunction with a wall material having an FSC value as low as 36, can result in flashover. As discussed in section 5 of Appendix A, material properties other than surface flame spread are likely responsible for this. Therefore, in the absence of applicable full-scale test data, an extension of the non-flashover region of the matrix in figure 1 from ceiling materials with FSC values up to 15 to ceiling materials with FSC values up to 25 (when combined with wall materials ranging in FSC from 45 to 182) cannot be made without introducing additional requirements for the ceiling materials. That is, it may be permissible to allow a ceiling material with an FSC value up to 25, provided that other key properties of the material such as potential heat, ignitability, and heat release rate do not vary appreciably from those of the material actually tested in the living room with the low intensity incidental fire exposure.

5.2.2. Review of Similar Work

Discussions of the significance of previous experimental research on related aspects of fire growth and spread are included in the interim reports, and will not be repeated. However, it was desirable to use the material hazard matrix to compare the results of other experimental work of similar scope.

The results of the following three projects were analyzed for this purpose:

1. Hardwood Plywood Manufacturers Association (HPMA)/Southwest Research Institute (SwRI), Fire Tests (1967-1968). [22,23]

2. Hardwood Plywood Manufacturers Association/Underwriters Laboratories, Inc. (UL), Fire Tests (1977). [24]

3. Hardwood Plywood Manufacturers Association/Underwriters Laboratories, Inc., Fire Tests (1978). [25]

The first project involved the conduct of four full-scale fire tests to examine the relative performance of wall materials having different FSC when exposed to an upholstered chair fire. The tests were conducted in a rectangular shaped three-room home which generally resembled a mobile home in configuration.

The second project involved the conduct of two full-scale tests in identically designed mobile homes. The only parameter which was varied was the interior wall finish which was 4 mm thick lauan plywood in one test and 8 mm thick gypsum board in the other. The exposure fire was an upholstered chair, positioned in a corner in the living room.

In the third project an actual mobile home was not used, but the test facility was representative of mobile home construction. The spatial characteristics of the facility varied from those tested in the second project. That is, the spatial dimensions of the living room were reduced in scale. The bedrooms were eliminated and the corridor was reduced in length and left open at the end, providing different ventilation. The furniture was not scaled down although the rooms were, and the two tests were again performed by varying the wall finish and exposing the room to an upholstered chair fire.

The following key observations were made from the HPMA tests:

(1) Attainment of flashover resulted in exceeding the thresholds for limiting conditions for occupant safety of temperature, carbon monoxide and oxygen (thresholds adopted by NBS) at remote locations from the initial fire.

(2) In the one test in which flashover did not occur, thresholds for limiting conditions were not reached (SwRI #1).

These key observations, based on the results of these projects of SwRI and UL, are in agreement with the results of the studies conducted at NBS.

The material hazard matrix developed for the moderate intensity exposure fires was extended to include the eight tests from these projects. Figure 3 illustrates the resulting changes in the material hazard matrix for the moderate intensity exposure fires in the living room of the mobile home. In essence, the additional information from these eight tests provided some limited reduction in the size of the untested region, by expansion of the region where flashover was observed. The combinations of materials in the "no flashover" region remained the same.

The results of this analysis indicate that the material hazard matrix can be extended to provide a framework for evaluation of results from experiments conducted under similar conditions. However, it should not be assumed that the material hazard matrix is independent of geometric constraints. The actual effect on the validity of the matrix of changes in the experimental configuration cannot be ascertained from this limited exercise.

5.2.3. Design Options for Improved Fire Safety

The results of the full-scale testing clearly demonstrate the significance of flashover in terms of both property damage and occupant safety in mobile homes. While the absence of flashover does not assure occupant safety under all possible fire conditions, in the event that flashover occurs, conditions throughout the mobile home deteriorate rapidly. The material hazard matrices provide tools for identification, based on the limited number of full-scale tests conducted, of combinations of interior finish materials which did not result in flashover.

The individual matrices in figures 1 and 2 are based essentially on three different combinations of test conditions, reflecting variations in room size, the intensity of the exposure fire, and the measured FSC of the various interior finish materials tested. As a result of these variations, three design options are identified, each reducing the likelihood of flashover for a different set of conditions. This is accomplished by limiting the FSC of the wall and ceiling interior finish materials to those which fall in the region of the matrices which is identified, as a result of the full-scale tests, as not demonstrating flashover.

The design options are:

1. Any combination of wall and ceiling materials having FSC values which place them in the "flashover not observed" region of the material hazard matrix for low intensity exposure fires in the living room (fig. 1).

2. Any combination of wall and ceiling materials having FSC values which place them in the "flashover not observed" region of the material hazard matrix for a moderate intensity exposure fire in the living room (fig. 2).

3. Any combination of wall and ceiling materials having FSC values which place them in the "flashover not observed" region of the material hazard matrix for a moderate intensity exposure fire in the bedroom (fig. 2).

It is intended that design option 1 limit the likelihood of flashover from exposure of the interior finish materials to a low intensity incidental fire in the living room. Design option 2 would extend this limitation to include both low and moderate intensity exposure fires in the living room.

As would be expected, the FSC limitations are more restrictive for the moderate intensity exposure fires than for the low intensity exposure fires.

Design option 3 is intended to limit the likelihood of flashover for moderate intensity incidental fires in the bedroom. In addition, because the bedroom is smaller than the living room, implementation of this design option in the living room will also limit the likelihood of flashover from a moderate intensity fire in that area. While a material hazard matrix was not developed for the corridor area, the test results [11] indicate that design option 3 will limit flashover from a low or moderate intensity exposure fire starting in or near the corridor.

The full-scale tests on which the flashover matrices and the design options are based involved varying the interior finish materials only in the room of fire origin and not the entire mobile home. However, to provide the increased level of fire safety in areas where fires could begin other than the specific locations which have been

investigated with full-scale fire testing, the FSC requirements for each of the three design options are specified for the entire mobile home. In addition, because of the configuration of the "flashover not observed" regions in the matrices, separate flame spread limitations must be specified for the wall material and the ceiling material.

6. IMPACT ASSESSMENT

6.1. General

It was necessary to quantify the effect of each of the three design options for limiting the FSC of interior finish materials in order to provide an assessment of their relative effectiveness. Therefore, a limited analysis of data on actual fire incidents involving mobile homes was performed to assess the likely impact[6] of each of the three design options on the severity of these fires had the options been implemented before the incidents occurred.

6.2. Classification of Data

The statistical data base chosen for this analysis was the National Fire Incident Reporting System (NFIRS) data base which is collected and maintained by the U.S. Fire Administration (USFA). This data base covers several states across the country, offers a breakdown of each fire incident, and is computer based, permitting easy access. The states from which mobile home fire incidents were examined are listed in table 3.

NFIRS uses the coding system described in the National Fire Protection Association (NFPA) publication, Fire Incident Data Coding Guide [26], based on NFPA 901, Uniform Coding for Fire Protection [27]. This system of coding provides classification of many aspects of a fire incident, including a breakdown of the area of origin and the form of material ignited. The NFPA classifications and related code numbers for possible areas of origin are shown in table 4. For the purpose of examining mobile home fire incidents, these classifications were grouped together into nine general areas: Living Room

[6] Impact is defined here as the likelihood that the particular design option under consideration would have prevented or significantly reduced the potential for flashover for the fire incidents examined.

Area (living room, dining room, lounge and other larger volume rooms), Sleeping Area (also closets, storage and laundry rooms, and other smaller volume rooms), Kitchen Area, Hallway or Corridor Area, Heating Equipment Area, Structural Assembly, Chimney or Duct, Exterior, and Multiple Use or Unknown. Table 5 lists the NFPA 901 code numbers for area of origin classifications which comprise each of the nine general areas of a mobile home where a fire could originate. Since the NFPA area of origin classifications were designed for general use with any fire incident, many classifications are not directly applicable to mobile homes and were either never referenced in any of the mobile home fire incident data examined or were only referenced in a small number of incidents. These area of origin classifications were not included in the nine general areas and are designated in table 5 as being not applicable.

The NFPA classifications and related code numbers for the form of material ignited (i.e., exposure fire) are shown in table 6. These classifications have been separated into four groups of exposure fires, including low, moderate, high, and unknown. These groups are based on the intensity of the fires. A 6.4 kg (14 lb) wood crib of the type used as an exposure fire in the NBS fire tests conducted in the mobile home living room, bedroom, and corridor is considered to be of low intensity. A pan of 100% vegetable oil which is burning on the kitchen range, as was used as the exposure fire for tests conducted in the kitchen area, is also considered to be of low intensity. A 16 kg (35 lb) polyurethane and cotton upholstered chair of the type used as an exposure fire in tests conducted in the living room and bedroom is considered a moderate exposure fire. And a 100% polyurethane mattress with sheets and pillows, as was used as an exposure fire in a bedroom test, is considered to be a high intensity exposure fire. The low and moderate fires are not sufficiently intense to cause flashover by themselves (i.e., they are incidental fires). The high intensity fires are normally large enough to flash over a room without contributions from other combustible materials. The classification "unknown" covers all fires of unknown intensity or fires which otherwise did not fall into one of the groupings of low, moderate or high.

6.3. Sorting Of Data

The NFIRS data base was first sorted to separate and discard all incidents not involving mobile homes. A mobile home was defined as: Fixed Property Type = 411, Mobile Property Use = 17 (see line I of NFPA Form 902 F [26]). The remaining incidents were then sorted again by area of origin and examined.

Table 8 lists for each state and year, the total number of fire incidents involving mobile homes and the number of fire incidents with an unknown area of origin. This table is based on all reported fire incidents involving mobile homes. However, in order to relate the statistics to the experimental test results, only those fire incidents which resulted in fire spread beyond the room of fire origin and could have involved interior finish were considered. This was achieved by sorting the data again and retaining only those fires that spread beyond the initial room of fire origin (i.e., the NFPA Form 902 F entry for Extent of Flame Damage was 5, 6 or 7).

The data were already sorted by the intensity of the exposure fire. Generally, a low or moderate intensity incidental fire by itself will not cause flashover in a typical mobile home living room or bedroom, and therefore, will not cause a fire severe enough to spread beyond the room of origin [12,13,14]. It follows that a fire which begins as a low or moderate intensity fire but eventually spreads beyond the room of origin must have involved an additional source of fuel. The results of the experimental studies demonstrated that interior finish contributed to fire growth and spread and the attainment of flashover. Therefore, for purposes of this limited assessment, it was assumed that in those fire incidents in which flashover and subsequent fire spread beyond the room occurred, interior finish provided the additional source of fuel.

Table 9 shows an example summary, for Oregon 1977, of all reported fires which spread beyond the initial room of origin, classified by area of origin and intensity of exposure fire. Such a summary was made for each of the eight states having 1977 incident data. The year 1977 was chosen because the number of mobile homes in each individual state at the end of 1976 (i.e., the beginning of 1977) was readily available [28]. Oregon was used in table 9 simply as an example.

A number of the categories of incidents listed in table 9 were not included in the impact analysis. This resulted in a conservative estimate. First, the requirements in the Federal Mobile Home Construction and Safety Standards [15] concerning the ASTM E-84 flame spread rating for interior finish in the heating equipment compartment and the requirements for fire protection in the kitchen area around the range are currently such that any additional future impact in these areas would probably be marginal. Therefore, all fires which originated in these areas were eliminated from consideration. Second, although lower FSC interior finish materials could have an impact on fires originating in the structural assembly, chimney, duct, or outside of the mobile home, no experimental research was conducted to evaluate this possibility. Therefore, these fires were eliminated from consideration along with fires of unknown or multiple use areas of origin.

These exclusions leave only those fires originating in the living room area, sleeping area, or corridor. In those areas high intensity exposure fires were either not tested or were so severe that flashover was reached independent of any contribution from the interior finish material; although not all high intensity exposure fires would be expected to cause flashover they were eliminated from consideration in the impact analysis. The category of unknown exposure fires, which also includes those special cases which did not fall into the other categories, were also eliminated. Therefore, the only fires to be considered in the analysis were those of low or moderate intensity, occurring in the living room area, sleeping area, or corridor area.

6.4. Application of Data

The estimated impact of the design options, in terms of limiting the occurrence of flashover, for the example data for Oregon for 1977 (table 9), is as follows:

Design Option 1: If the interior finish of the mobile homes represented by the Oregon 1977 data had been restricted to combinations having flame spread values which fall in the "flashover not observed" region for the Living Room Low Intensity Fire Matrix (fig. 1), it is expected that 26 fires (all of the low intensity fires in the living room area) could have been impacted; e.g., limiting the occurrence of flashover. Although many low intensity fires in the sleeping area and corridor area would also have been impacted, these fires are not included in the estimate.

Design Option 2: If the interior finish in those mobile home fire incidents tabulated in table 9 had been restricted to combinations having flame spread values which fall in the "flashover not observed" region of the Living Room Moderate Intensity Fire Matrix (fig. 2), it is expected that 34 fires (all of the low and moderate intensity fires in the living room area) could have been impacted. Again, although many fires in the sleeping area and corridor area would also have been limited to a severity lower than that associated with flashover, no estimate of these fires is included.

Design Option 3: If the interior finish in those mobile home fire incidents (table 9) had been restricted to combinations having flame spread values which fall in the "flashover not observed" region of the Bedroom Moderate Intensity Fire Matrix (fig. 2), it is expected that 67 fires (all of the low and moderate intensity fires occurring in the living room area, sleeping area, and corridor area) could have been impacted.

Similar calculations for the other seven states with 1977 data resulted in the values shown in table 10. From these numbers an average value for the number of fires per thousand mobile homes which would have been impacted had these design options been present in mobile homes was determined as follows:

$$\left[\frac{\text{Impacted Fires}}{\text{Reported Fires}}\right] \times \left[\frac{\text{Reported Fires}}{\text{Thousand Mobile Homes}}\right] = \left[\frac{\text{Impacted Fires}}{\text{Thousand Mobile Homes}}\right]$$

For Design Option 1: $\frac{76}{2890} \times \frac{2890}{926.250} = 0.082$

For Design Option 2: $\frac{115}{2890} \times \frac{2890}{926.250} = 0.124$

For Design Option 3: $\frac{250}{2890} \times \frac{2890}{926.250} = 0.270$

If it is assumed that this sample of eight states is representative of national fire incidence, then an estimate of the number of mobile home fires which would have been impacted in the United States had the design option been present in all mobile homes may be obtained as follows:

$$\left[\frac{\text{Impacted Fires}}{\text{Thousand Mobile Homes}}\right] \times \left[\begin{array}{l}\text{Number (in thousands) of Mobile Homes}\\ \text{in United States}\end{array}\right] =$$

$$\left[\begin{array}{l}\text{Number of Impacted Mobile Home Fires}\\ \text{in United States}\end{array}\right]$$

For Design Option 1: 0.082 x 4,308.391 = 353
For Design Option 2: 0.124 x 4,308.391 = 534
For Design Option 3: 0.270 x 4,308.391 = 1,163

These numbers represent estimates of the relative effectiveness of each of the design options for a static population of mobile home fire incidents. The accuracy of the assessment is dependent on the accuracy of the data base. In order to assess the actual impact of each design option on mobile home fire safety based on their future implementation in the manufacturing of new mobile homes, a more comprehensive approach is necessary. This approach should include consideration of the rate of influx of new mobile homes with the selected option present into the mobile home population, and the effect of other design criteria which could impact fire frequency and severity in mobile homes.

7. RECOMMENDATIONS

Changes are recommended to the Federal Mobile Home Construction and Safety Standards as a means of controlling the likelihood and extent of fire spread in mobile homes. These changes are based on an extensive series of full-scale fire tests performed under a prescribed set of environmental and end-use conditions likely to be encountered in mobile home use. Details of the testing, of the supporting rationale, criteria and analysis, and of the limitations on its applicability are set out in the reports. The recommendations relate to protection in the kitchen range area, where cooking fires are likely, and to flame spread limitations for the wall and ceiling finish materials throughout the mobile home, since interior finish surfaces could serve as means of rapid flame spread.

Based on an analysis of the results of experimental testing previously referenced in this report, the following changes to the Federal Mobile Home Construction and Safety Standards are recommended. Because of the variability of FSC values, all FSC values have been rounded down to the nearest 5. Limitations on FSC values are based strictly on the results of the full-scale tests, and the logical extrapolations discussed in this report.

7.1. Kitchen Area Protection

Intent of Kitchen Area Protection

The intent of the following two recommendations is to reduce the likelihood of vertical or horizontal spread of a fire occurring on the cooking range beyond the immediate area of the range, by restricting the flammability of materials which are in close proximity to it.

Recommended Wording of Paragraph 280.204 (a):

A steel hood of minimum No. 26 U.S. Standard Gage shall be installed above the cooking range with a vertical clearance from the range top to the hood of at least 61 cm (24 in). The range hood shall be designed such that a minimum 13 cm (5 in) eyebrow (measured horizontally) extends beyond the front vertical surface of the overhead cabinets to prevent direct impingement of flames on the cabinets. In cases where the hood and overhead cabinet are recessed so that the bottoms of the cabinets adjacent to the hood are lower than the hood, the exposed sides of these adjacent cabinets shall be protected by an extension of the hood design. In all cases, a sheet of minimum 6 mm (0.25 in) thick inorganic board (or equivalent) shall be provided between the hood and the surfaces of the overhead and adjacent cabinets. The underside of the adjacent overhead cabinets shall be constructed, for a horizontal distance of at least 46 cm (18 in) beyond the edge of the range, of materials having a flame spread rating not exceeding 50 when tested in accordance with the Standard Test Method for Surface Burning Characteristics of Building Materials, ASTM E-84, and a rating of limited combustibility as defined in NFPA No. 220, Types of Building Construction, 1975 edition.

Recommended Wording of Paragraph 280.203 (a)(5):

The material comprising the exposed partition behind the cooking range shall be limited to a flame spread rating not exceeding 50 (by ASTM E-84) and a rating of limited combustibility (as defined in NFPA 220, 1975 ed.) to prevent fire penetration into adjoining areas. This material shall be attached by mechanical means and extend at least 46 cm (18 in) (measured horizontally) beyond the edge of the range.

7.2. Interior Finish Flame Spread Requirements

7.2.1. Design Option 1

[For protection against the attainment of flashover from a low intensity exposure fire in the Living Room Area]

Intent of recommendations of section 7.2.1.

The intent of the following two recommendations is to prevent a fire of low intensity in a relatively large volume enclosure such as a living room from reaching the point of flashover. This is accomplished by permitting only combinations of wall and ceiling interior finish materials which have been shown not to contribute appreciably to rapid fire growth and spread and the attainment of flashover under these conditions.

Recommended Wording of Paragraph 280.203 (a)(1):

The interior finish of all walls and partitions shall not have a flame spread rating exceeding 180 except as otherwise specified herein. The flame spread limitation shall not apply to: molding, trim, windows, doors or series of doors not exceeding 1.2 m (4 ft) in width, and permanently attached decorative items such as pictures or accent panels constituting not more than 10 percent of the aggregate wall surface in any room or space nor more than 3 square meters (32 square feet) in surface area whichever is less.

Recommended Wording of Paragraph 280.203 (a)(2):

Ceiling interior finish, excluding molding and trim 5 cm (2 in) or less in width, shall not have a flame spread rating exceeding 15, with two exceptions. Exception 1: Ceiling interior finish, excluding molding and trim 5 cm (2 in) or less in width, shall not have a flame spread rating exceeding 25 provided the interior finish of all walls and partitions does not have a flame spread rating exceeding 45. Exception 2: Ceiling interior finish, excluding molding and trim 5 cm (2 in) or less in width, shall not have a flame spread rating exceeding 60 provided the interior finish of all walls and partitions does not have a flame spread rating exceeding 25.

7.2.2. Design Option 2

[For protection against attainment of flashover from a low or moderate intensity exposure fire in the Living Room Area]

Intent of recommendations of section 7.2.2.

The intent of the following two recommendations is to prevent a fire of low or moderate intensity in a relatively large volume enclosure such as the living room from reaching the point of flashover by permitting only combinations of wall and ceiling interior finish materials which have been shown not to contribute appreciably to rapid fire growth and spread and the attainment of flashover under these conditions.

Recommended wording of Paragraph 280.203 (a)(1):

The interior finish of all walls and partitions shall not have a flame spread rating exceeding 45 except as otherwise specified herein. The flame spread limitation shall not apply to: molding, trim, windows, doors or series of doors not exceeding 1.2 m (4 ft) in width, and permanently attached decorative items such as pictures or accent panels constituting not more than 10 percent of the aggregate wall surface in any room or space nor more than 3 square meters (32 square ft) in surface area whichever is less.

Recommended Wording of Paragraph 280.203 (a)(2):

Ceiling interior finish, excluding molding and trim 5 cm (2 in) or less in width, shall not have a flame spread rating exceeding 25. Exception: Ceiling interior finish, excluding molding and trim 5 cm (2 in) or less in width, shall not have a flame spread rating exceeding 55 provided the interior finish of all walls and partitions does not have a flame spread rating exceeding 25.

7.2.3. Design Option 3

[For protection against attainment of flashover from a low or moderate intensity exposure fire in the Living Room Area, Sleeping Area or Corridor Area]

Intent of recommendations of section 7.2.3.

The intent of the following two recommendations is to prevent a fire of low or moderate intensity in either a small volume enclosure such as a corridor or bedroom, or a larger volume enclosure such as the living room from reaching the point of flashover. This is accomplished by permitting only combinations of wall and ceiling interior finish materials which have been shown not to contribute appreciably to rapid fire growth and spread and the attainment of flashover under these conditions.

Recommended Wording of Paragraph 280.203 (a)(1):

The interior finish of all walls and partitions shall not have a flame spread rating exceeding 25 except as otherwise specified herein. The flame spread limitation shall not apply to: molding, trim, windows, doors or series of doors not exceeding 1.2 m (4 ft) in width, and permanently attached decorative items such as pictures or accent panels constituting not more than 10 percent of the aggregate wall surface in any room or space nor more than 3 square meters (32 square ft) in surface area whichever is less.

Recommended Wording of Paragraph 280.203 (a)(2):

Ceiling interior finish, excluding molding and trim 5 cm (2 in) or less in width, shall not have a flame spread rating exceeding 25.

7.2.4. Discussion

Sections 7.2.1., 7.2.2., and 7.2.3. present three alternate design options for controlling the growth and spread of fires in mobile homes through the use of interior finish. These options represent different levels of safety and are based on the material hazard matrices shown in figures 1 and 2. The material hazard matrices are based on results of the ASTM E-84 Tunnel Test from a single

laboratory and therefore the borders separating the "no flashover," "untested," and "flashover" regions for the matrices may not be exact due to inherent variations in ASTM E-84 results among laboratories and from batch to batch of the same generic material. Certain combinations of flame spread values which now fall in the "untested" region of a matrix may, if tested in a full-scale fire test, exhibit no flashover. Therefore, it is recommended that HUD consider requests from mobile home manufacturers to test such interior finish materials and to provide complete data from full-scale tests which duplicate all the conditions and instrumentation of the NBS test series as an alternate basis for acceptability of a combination of wall and ceiling materials.

In addition, the use of the matrices should be restricted to "conventional materials." A "conventional material" is one whose history supports the applicability of flame spread values, as determined by the ASTM E-84 Tunnel Test, as a prediction of relative fire hazard. Materials with widely divergent properties such as low density foam plastics or other exposed insulation materials would require full-scale testing in order to determine performance.

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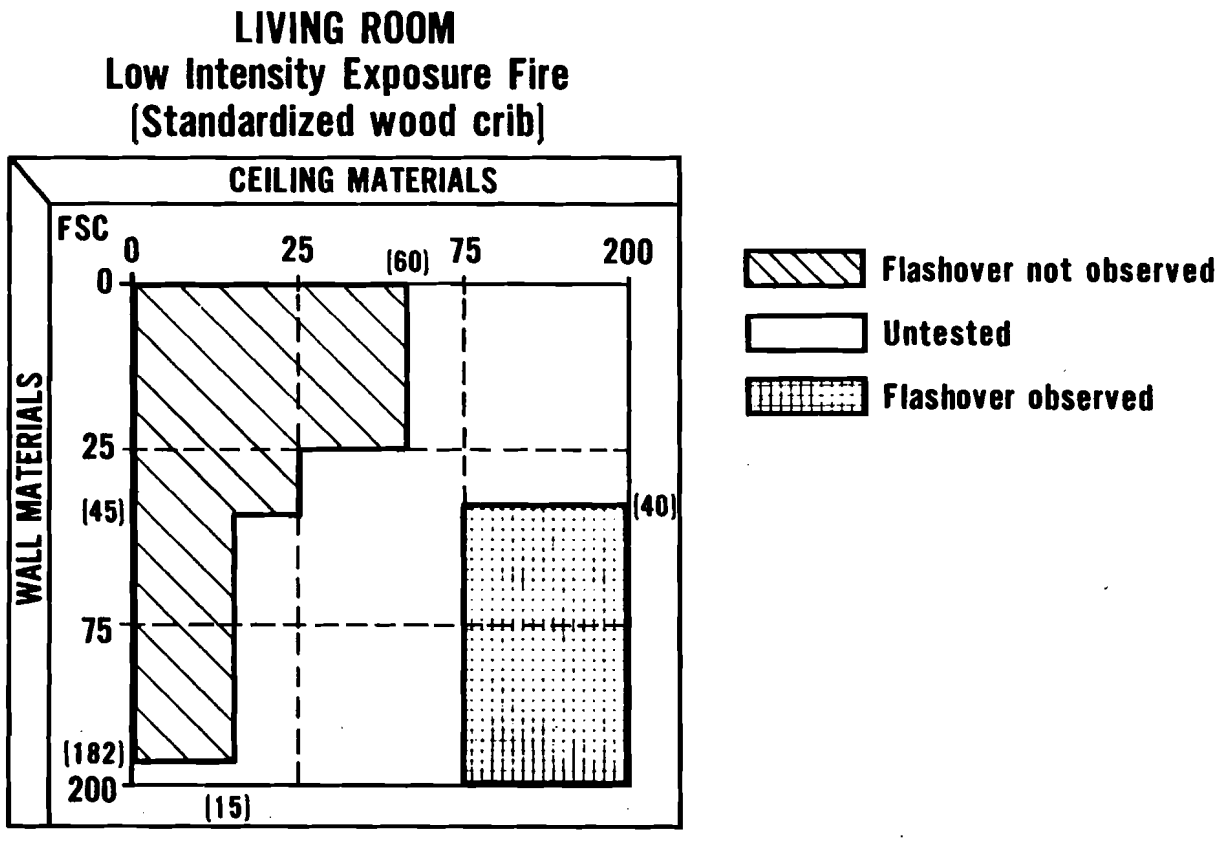

Figure 1. Material Hazard Matrix for Low Intensity Exposure Fire in Living Room (Based on ASTM E-84 FSC)

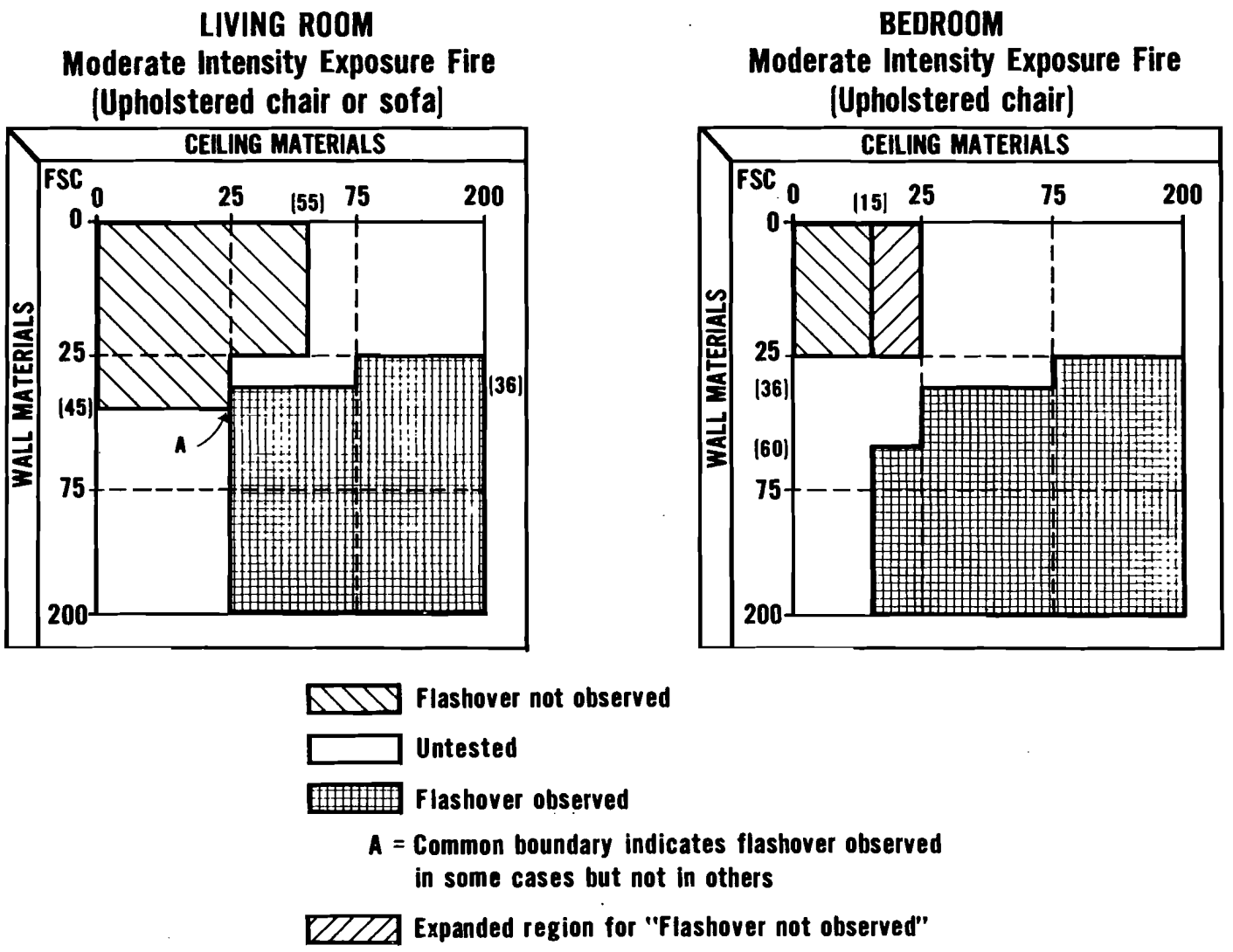

Figure 2. Material Hazard Matrices for Moderate Intensity Exposure Fires in the Living Room and Bedroom (Based on ASTM E-84 FSC)

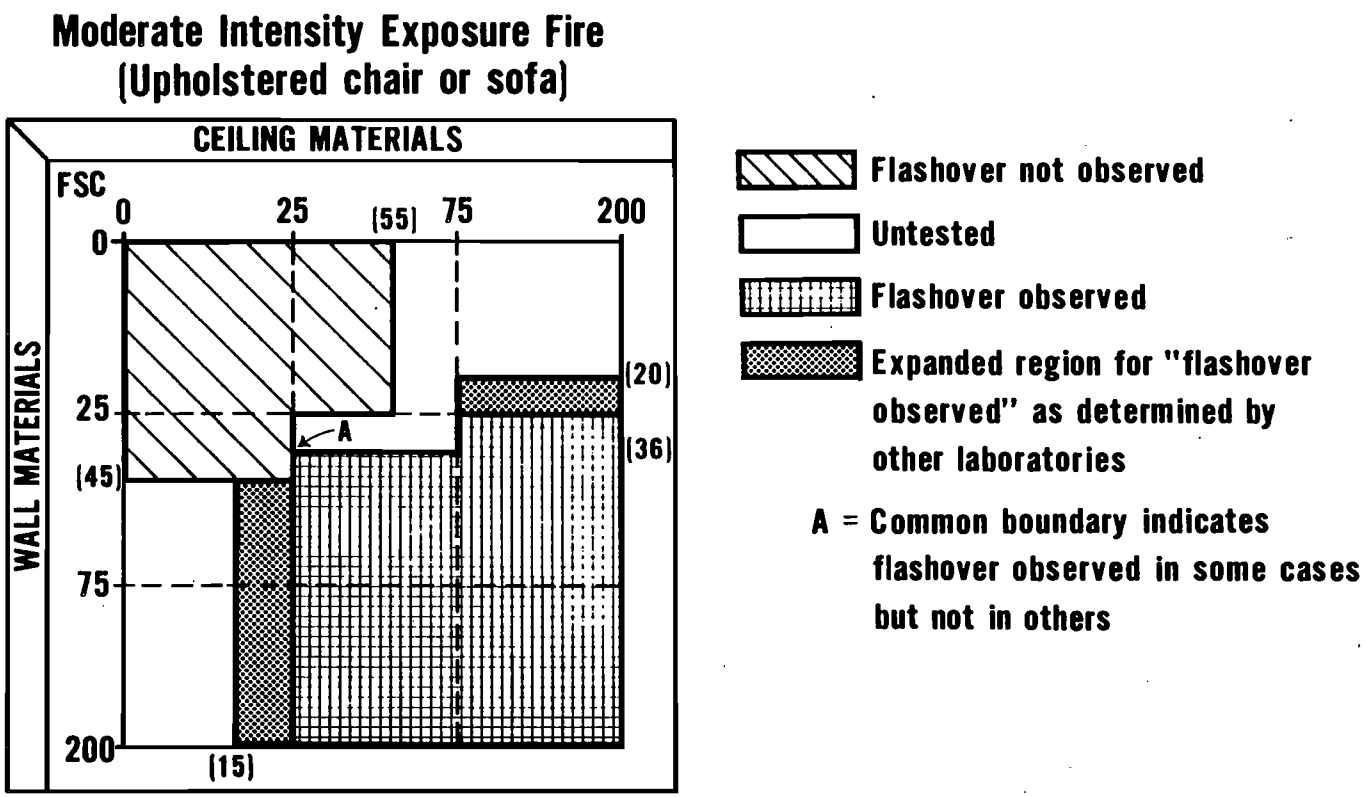

Figure 3. Expanded Material Hazard Matrix Based on SwRI and UL Test Results (Based on ASTM E-84 FSC)

Area of Origin	Source of Ignition	Primary Means of Fire Spread
Bedroom or Living Room (32.2)	Fuel Fired Equipment (27.8)	Structural/Interior Finish (40.9)
Kitchen (22.0)	Electrical Arc, Short (27.6)	Power Transfer Equipment (15.5)
Heating Equipment (18.0)	Smoking Material (12.5)	Gas, Liquid Escaping Container (13.0)
Structural Areas (9.6)	Hot Object (8.6)	Furniture (8.5)
Closet (2.8)	Misc. Open Flame (5.8)	Soft Goods, Wearing Apparel (6.7)
Dining Room (0.3)	Explosives (1.4)	Stock, Supplies (2.2)
Other (15.1)	Other (16.3)	Other (13.2)

Numbers represent percent of total.

Table 1. Accumulated Mobile Home Fire Incident Statistics [9-18]

Table 2. Probable Mobile Home Fire Scenarios

AREA OF ORIGIN	SOURCE OF IGNITION	PRIMARY MEANS OF FIRE SPREAD
BEDROOM, LIVING ROOM	SMOKING MATERIAL	STRUCTURAL/ INTERIOR FINISH
KITCHEN	FUEL FIRED EQUIPMENT	STRUCTURAL/ INTERIOR FINISH
HEATING EQUIPMENT	ELECTRICAL ARC, SHORT	POWER TRANSFER EQUIPMENT

Table 3. States and Years of NFIRS Data Examined for Analysis

Alaska	1977
California	1975
	1976
	1977
Maryland	1977
	1978 1/ 2/
Michigan	1978 1/
Minnesota	1977
Missouri	1976
	1977
	1978 1/
New York	1976 3/
	1977
	1978 1/
Ohio	1976
	1977
	1978 1/
Oregon	1977
Rhode Island	1978 1/ 2/
South Dakota	1978 1/ 2/

1/ First quarter only

2/ Not included in analysis due to small sample size

3/ Third and fourth quarters only

Table 4. NFPA Classifications for Area of Fire Origin (reproduced from reference [26])

AREA OF FIRE ORIGIN*

0. Means of Egress

01. Hallway, corridor, mall.
02. Exterior stairway.
    Included are fire escapes and exterior ramps.
03. Interior stairway.
    Included are interior ramps.
04. Escalator.
05. Lobby, entrance way.
09. Means of Egress not classified above.

1. Assembly, Sales Areas (groups of people)

11. Large assembly area with fixed seats (100 or more persons).
    Included are auditoriums, chapels, places of worship, theaters, arenas, and lecture halls.
12. Large open room without fixed seats (100 or more persons).
    Included are ballrooms, gymnasiums, roller rinks, bowling alley lanes, multi-use areas, and the like.
13. Small assembly area with or without fixed seats (less than 100 persons).
    Included are classrooms, meeting rooms, multipurpose rooms, and the like.
14. Lounge area.
    Included are living rooms, common rooms, TV rooms, dens, recreation rooms, family rooms, sitting rooms, music rooms, and the like.
15. Sales, showroom area.
    Included are shops.
    Excluded are display windows (56).
16. Library.
    Included are art galleries and exhibit spaces.
17. Swimming pool.
19. Assembly, Sales Areas not classified above.

2. Function Areas

21. Sleeping room for under 5 persons.
    Included are patient rooms, bedrooms, cells, lockups, and the like.
22. Sleeping area for 5 or more persons.
    Included are wards, dormitories, barracks, and the like.
23. Dining area, lunchroom, cafeteria.
    Included are dining rooms, mess rooms, canteens, and beverage service bars.
24. Kitchen, cooking area.
25. Lavatory, locker room, cloakroom.
    Included are checkrooms, rest rooms, bathrooms, powder rooms, washrooms, shower rooms, sauna baths, outhouses, and portable toilets.
26. Laundry room, area.
    Included are wash houses.
27. Office.
28. Personal service area.
    Included are health clubs, massage parlors, and barber and beauty treatment areas.

*See NFPA No. 901, Chapter E.

3. Function Areas (Continued)

31. Laboratory.
32. Printing or photographic room, area.
33. First aid, treatment room.
    Included are areas where minor surgery is performed.
34. Operating room.
    Included are recovery rooms and operating theaters.
35. Electronic equipment room, area.
    Included are control centers, radar rooms, electronic computer areas, data processing centers, telephone equipment rooms, telephone booths, and the like.
36. Performance, stage area.
    Included are backstage areas, dressing rooms, ice rinks, boxing rings, and basketball floors.
37. Projection room, area.
    Included are stage light and spotlight areas.
38. Process, manufacturing area.
    Included are workrooms.
39. Function Areas not classified above.

4. Storage Areas

41. Product storage room or area, storage tank, storage bin.
    Included are all areas where products are held awaiting process, shipment, use, or sale.
42. Closet.
43. Supply storage room or area.
    Included are tool rooms, maintenance supply rooms, dead storage rooms, and the like.
44. Records storage room, vault.
45. Shipping, receiving, loading area.
    Included are packing departments, mail rooms, and loading bays.
46. Trash or rubbish area, container.
    Included are wastepaper storage areas, industrial waste containers, compactors, garbage and trash chutes without incinerators.
    Excluded are incinerators (64).
47. Garage, carport, vehicle storage area.
49. Storage Areas not classified above.

5. Service Facilities

51. Elevator, dumb-waiter.
    Included are the shaft areas.
52. Utility shaft.
    Included are pipe, ventilation, and conduit shafts.
53. Light shaft.
54. Chute.
    Included are laundry chutes and mail chutes.
    Excluded are trash chutes (46).
55. Duct.
    Included are air conditioning, heating, cable, and exhaust ducts.
56. Display window.
57. Chimney
58. Conveyor.
59. Service Facilities not classified above.

6. Service, Equipment Areas

61. Machinery room, area.
    Included are elevator machinery rooms, engine rooms, pump rooms, head houses, refrigeration rooms, and the like.
62. Heating equipment room or area, water heater area.
63. Switchgear area, transformer vault.
64. Incinerator room, area.
    Included are all incinerator operations.
    Excluded are rubbish areas without incinerators (46).
65. Maintenance shop, area.
    Included are repair shops, welding shops, paint shops, workshops, and paint spraying areas.
66. Test cell.
67. Enclosure with pressurized air.
68. Enclosure with enriched oxygen atmosphere.
69. Service, Equipment Areas not classified above.

7. Structural Areas

71. Crawl space, substructure space.
72. Exterior balcony, open porch.
73. Ceiling and floor assembly, concealed floor/ceiling space.
74. Ceiling and roof assembly, concealed roof/ceiling space.
75. Wall assembly, concealed wall space.
76. Exterior wall surface.
77. Exterior roof surface.
78. Awning.
79. Structural Areas not classified above.

8. Transportation, Vehicle Areas

81. Passenger area of transportation equipment.
82. Trunk, load carrying area of transportation equipment.
83. Engine area, running gear, wheel area of transportation equipment.
84. Fuel tank, fuel line area of transportation equipment.
85. Operating, control area of transportation equipment.
    Included are the bridge of ships, cockpit of planes, cab of trucks, and the like.
86. Exterior exposed surface of transportation equipment.
89. Transportation, Vehicle Areas not classified above.

9. Other Area of Origin

91. On or near railroad right of way, embankment.
92. On or near highway, public way, street.
93. Court, terrace, patio.
94. Lawn, field, open area.
    Included are farmland, parks, and vacant lots.
95. Wildland area, woods.
97. Multiple location, use area
98. Area of Origin not applicable.
99. Other Area of Origin not classified above.
00. Area of Origin undetermined or not reported.

Table 5. Areas of Fire Origin for Mobile Home Analysis and Corresponding NFPA 901 Codes for Area of Fire Origin

Areas of Fire Origin for Mobile Home Analysis	NFPA 901 Codes for Area of Fire Origin (Line J on NFPA Form 902 F)
LIVING ROOM AREA	
Living room, lounge area	14
Dining area	23
Other larger volume rooms	[11-13]*
SLEEPING AREA AND OTHER LESSER VOLUME ROOMS	
Sleeping area for under 5 persons	21
Sleeping area for 5 or more persons	22
Bathroom	25
Laundry room	26
Closet, storage room	27, 42, 43, 49
Other storage or function area	[31, 32, 35, 39, 41, 46]
KITCHEN AREA	
Kitchen, cooking area	24
HALLWAY CORRIDOR	
Hallway, corridor	01
Interior stairway	[03]
Entrance way	05
Other egress area	[04], 09
HEATING EQUIPMENT AREA	
Heating equipment area, water heater area	62
Other service equipment area	[61, 63-65, 68, 69]
STRUCTURAL ASSEMBLY	
Ceiling/Floor assembly or concealed space	73
Ceiling/Roof assembly or concealed space	74
Wall assembly or concealed space	75
Other structural area	79
CHIMNEY, DUCT	
Duct	55
Chimney	57
Other shaft or service facility	52, 59
EXTERIOR	
Crawl space	71
Exterior wall surface	76
Exterior roof surface	77
Stairway, porch, awning, garage	02, 47, 72, 78, 93
Lawn, field, woods	17, 94, 95
Other exterior location	91, 92
MULTIPLE USE, UNKNOWN, OTHER	
Miscellaneous transportation related	[81-86, 89]
Multiple location or use area	97
Not applicable or not classified above	[98], 99
Undetermined or not reported	00

*Codes in brackets [ ] are not applicable.
Codes not listed were never referenced in the incident data.

Table 6. NFPA Classifications for Form of Material Ignited (reproduced from reference [26])

FORM OF MATERIAL IGNITED*

1. Structural Component, Finish

11. Exterior roof covering, surface, finish.
12. Exterior sidewall covering, surface, finish.
    Included are eaves.
13. Exterior trim, appurtenances.
    Included are doors, porches, and platforms.
14. Floor covering, surface.
    Included are tile, carpet, rug, flooring, and stairs.
15. Interior wall covering, surface items permanently affixed to wall and door surface.
    Included are cloth wall coverings.
    Excluded are curtains and draperies (36).
16. Ceiling covering, surface.
    Included are cloth permanently affixed to ceiling, and acoustical tile.
17. Structural member, framing.
18. Thermal, acoustical insulation within wall, partition, or floor/ceiling space.
19. Structural Component, Finish not classified above.
10. Structural Component, Finish; insufficient information available to classify further.

2. Furniture

Included is built-in furniture.

21. Upholstered sofa, chair, vehicle seats.
22. Nonupholstered chair, bench.
23. Cabinetry.
    Included are filing cabinets, pianos, dressers, chests of drawers, desks, tables, and bookcases.
    Excluded are TV set and organ housings, bottle warmers, and appliance housings (25).
24. Ironing board.
25. Appliance housing or casing.
29. Furniture not classified above.
20. Furniture; insufficient information available to classify further.

3. Soft Goods, Wearing Apparel

31. Mattress, pillow.
32. Bedding, blanket, sheet, comforter.
    Included are heating pads.
33. Linen, other than bedding.
    Included are towels and tablecloths.
34. Wearing apparel not on a person.
35. Wearing apparel on a person.
36. Curtain, blind, drapery, tapestry.
37. Goods not made up.
    Included are fabrics and yard goods.
38. Luggage.
39. Soft Goods, Wearing Apparel not classified above.
30. Soft Goods, Wearing Apparel; insufficient information available to classify further.

See NFPA No. 901, Chapter I.

4. Adornment, Recreational Material

41. Christmas tree.
42. Decoration for special event.
43. Book.
44. Magazine, newspaper, writing paper.
    Included are files.
45. Toy, game.
46. Awning, canopy.
47. Tarpaulin, tent.
49. Adornment, Recreational Material not classified above.
40. Adornment, Recreational Material; insufficient information available to classify further.

5. Supplies, Stock

51. Box, carton, bag.
52. Basket, barrel.
53. Pallet, skid (not in use).
54. Rope, cord, twine, yarn.
55. Packing, wrapping material.
56. Bale storage.
57. Bulk storage.
58. Cleaning supplies.
    Included are brooms, brushes, mops, and cleaning cloths.
59. Supplies, Stock not classified above.
50. Supplies, Stock; insufficient information available to classify further.

6. Power Transfer Equipment, Fuel

61. Electrical wire, cable insulation.
62. Transformer.
63. Conveyor belt, drive belt, V-belt.
64. Tire.
65. Fuel.
69. Power Transfer Equipment, Fuel not classified above.
60. Power Transfer Equipment, Fuel; insufficient information available to classify further.

7. General Form

71. Agricultural product.
72. Fence, pole.
73. Fertilizer.
74. Growing, living form.
    Included are forests, brush, and grass.
75. Rubbish, trash, waste.
76. Cooking materials.
77. Sign.

8. Special Form

81. Dust, fiber, lint.
82. Pyrotechnics, explosives.
83. Atomized, vaporized liquid.
84. Chips.
85. Palletized material, material stored on pallets.
86. Gas or liquid in or from pipe or container.
    Included are accelerants.
87. Rolled material.
    Included is rolled paper.
88. Adhesive.

9. Other Form of Material

97. Multiple form of material ignited.
    Use this subdivision only where there are multiple fires started at approximately the same time on the same property and more than one form of material was initially involved. If one major material was involved, use the appropriate classification. List each material in the report.
98. Form of Material not applicable.
99. Form of Material not classified above.
00. Form of Material undetermined or not reported.

Table 7. Intensity of Exposure Fire and Corresponding NFPA 901 Codes for Form of Material Ignited

Intensity of Exposure Fire	NFPA 901 Codes for Form of Material Ignited (Line L on NFPA Form 902 F)
1 Low Intensity Exposure Fire	10-19, 24, 25, 30, 33, 34, 36-40, 42-45, 49, 51, 52, 54, 55, 58, 60-63, 69, 71, 72, 76, 77, 81, 84, 88
2 Moderate Intensity Exposure Fire	20-22, 29, 41, 46, 47, 50, 53, 59, 64, 65, 73, 75, 83, 85-87
3 High Intensity Exposure Fire	23, 31, 32, 56, 57, 74, 82
4 Exposure fires which are of unknown intensity or are otherwise not classified above.	35, 97-99, 00

Table 8. Mobile Home Fires with Unknown Area of Origin

STATE AND YEAR	TOTAL FIRES	NUMBER OF FIRES WITH AREA OF ORIGIN UNDETERMINED OR NOT REPORTED	
		NUMBER	PERCENT OF TOTAL
Oregon 1977	316	12	3.80
California 1977	1,045	56	5.36
Michigan 1978	136	9	6.62
Ohio 1978	161	11	6.83
California 1976	1,162	82	7.06
Maryland 1977	65	5	7.69
Ohio 1976	526	41	7.79
Alaska 1977	125	10	8.00
California 1975	1,022	92	9.00
Ohio 1977	619	66	10.66
Missouri 1978	112	13	11.61
Missouri 1977	204	25	12.25
New York 1978	134	21	15.67
Minnesota 1977	184	32	17.39
Missouri 1976	158	28	17.72
New York 1976	199	60	30.15
New York 1977	332	106	31.93
	6500	669	
Maryland 1978	15 1/		
South Dakota 1978	12 1/		
Rhode Island 1978	2 1/		

1/ Not included in analysis due to small sample size

Table 9. Summary for Oregon 1977 of all Fires Which Spread Beyond the Initial Room of Origin

Area of Origin	Intensity of Exposure Fire				Total
	Low	Moderate	High	Unknown	
Living Room Area	26	8	0	8	42
Sleeping Area, Lesser Vol. Rooms	24	3	11	7	45
Kitchen Area	16	7	0	3	26
Hallway, Corridor	2	4	1	0	7
Heating Equip. Area	5	1	0	1	7
Structural Assembly	3	0	0	0	3
Chimney, Duct	0	0	0	0	0
Exterior	5	0	0	1	6
Multiple Use, Unknown	0	1	0	9	10
Not Applicable	0	0	0	1	1
Total	81	24	12	30	147

Table 10. Impact Summary for 1977 Data

STATE & YEAR	Number of fires that would have been impacted				
	Low Intensity in Living Room Area	Low & Moderate Intensity in Living Room Area	Low & Moderate Intensity in Living Room, Sleeping, Corridor Area	Number of NFIRS fires	Estimated Number of Mobile Homes in 1976*
OREGON 77	26	34	67	316	86,046
CALIFORNIA 77	8	12	16	1045	328,973
MARYLAND 77	2	4	5	65	30,085
ALASKA 77	2	5	16	125	16,280
OHIO 77	21	31	71	619	153,599
MISSOURI 77	6	13	30	204	103,324
MINNESOTA 77	6	10	25	184	71,686
NEW YORK 77	5	6	20	332	136,257
TOTALS	76	115	250	2,890	926,250

Estimated Number of Mobile Homes in U.S. in 1976 was 4,308,391*

*See reference [28]

APPENDIX A. SUPPLEMENTAL MOBILE HOME LIVING ROOM FIRE STUDIES: THE ROLE OF INTERIOR FINISH

1. INTRODUCTION

This appendix provides a summary of a series of eight full-scale mobile home fire tests conducted by the Center for Fire Research (CFR) at NBS over a period of six months, from April to September, 1978. These tests were conducted in the living room of a typical single-wide mobile home and were designed to provide experimental data to supplement a previous series of sixteen full-scale fire tests. The results of that test series were reported in an NBS technical report, NBSIR 78-1530, Mobile Home Living Room Fire Studies: The Role of Interior Finish [13][1]. As in the first series of tests, the experiments were conducted in the living room area of a 3.7 x 18.3 m (12 x 60 foot) 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, promulgated effective June 15, 1976 [15].

It should be noted that the same experimental approach was used in both series of tests. Rationale for the experimental approach as well as the basis for evaluation criteria were provided in the previous report. Therefore, NBSIR 78-1530 will be extensively referenced. As a result, this appendix will provide an evaluation of the experimental results in a framework similar to that utilized in NBSIR 78-1530, with detailed descriptions of the experimental approach, results, and analysis included only when not adequately covered in NBSIR 78-1530.

The primary purpose for this supplemental series of experimental tests was to provide data to expand the utility of the material hazard matrix developed in NBSIR 78-1530. In particular, additional interior finish materials were tested having flame spread classifications (FSC) in the intermediate ranges in accordance with the ASTM E-84-77a Tunnel Test to reduce the size of the untested region in the matrix. Further, for this series of eight tests, upholstered chairs were used as the exposure fires in order to supplement the data from the five upholstered chair tests conducted in the first series. This provided the basis for expanding the material hazard matrix for a moderate intensity exposure fire.

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[1] Numbers in brackets refer to the literature references at the end of the summary report.

1.1. Technical Objectives

The technical 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.

1.2. Approach

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 interior finish materials on the walls and ceiling, having different surface flame spread characteristics, were evaluated to determine if they significantly influenced the growth and spread of the fire, and the resulting severity. Formulation of this scenario was based on (1) statistical evidence that most fires occurring in residential occupancies are initially small in size [1]; and (2) in a significant number of mobile home fires combustible interior finish materials on the walls and ceiling provide the means for growth and spread of the fire beyond the initial burning item [1-9].

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

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 by incorporating the supplemental test results along with the results of the initial series into a matrix similar to that developed in NBSIR 78-1530.

2. EXPERIMENTAL PROGRAM

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. Figure A1 illustrates the spatial design of the mobile home and location of the exposure fire. Reference NBSIR 78-1530 for detailed descriptions of the mobile home, construction of the living room, and combustible furnishings. (For this test series, the living room was "sparsely" furnished as in tests #1 through #9 of the first experimental series).

2.1. Initial Burning Items

In six of the eight tests the exposure fire resulted from the ignition of a 16 kg (35 lb) upholstered chair positioned in the northwest corner of the living room. The chairs 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 25 ± 10% RH until the weight of the chair stabilized.

In two of the tests (MHLIV 18 and 19) a 35 kg (78 lb) sofa constructed of wood, polyurethane foam and cotton materials and also covered in a rayon fabric was used as the exposure fire. The sofas were also conditioned at 75 ± 5°F and 35 ± 10% RH until their weight stabilized.

2.2. Interior Finish Materials

Table A1 lists the interior finish materials used in each of the eight tests, their flame spread classification values (FSC) determined in accordance with the ASTM E-84-77a, Tunnel Test Method[2], and the type of exposure fire.

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[2]FSC calculated based on the area of the flame distance versus time curve, adopted by ASTM in April, 1976.

2.3. Full-Scale Test Criteria

Criteria for evaluating the test results were based on two related aspects of fire growth. First, the measurements of fire growth, and in particular the attainment of flashover in the room of fire origin were selected as the primary criterion for assessment of property damage. Generally, flashover was assumed and reported to have occurred when radiant ignition of the 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.

Limiting criteria were selected to evaluate the 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 was 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. However, for purposes of analysis there is sufficient information available to tentatively establish levels at which adverse effects begin to occur. Therefore, based on this information, the following thresholds for limiting conditions for life safety were adopted:

Temperature.....100°C (212°F)
Oxygen Concentration.....14% (by vol.)
Carbon Monoxide.....41,800 [$(ppm)^{1.036}$ x (min)] time-integrated CO; or
1.0% (10,000 ppm), short duration exposure level

In selecting these thresholds, no consideration has been given to either the synergistic effects or additive effects resulting when limiting conditions are reached for two or more of these measured conditions. Further, the thresholds suggested here are based on the levels of these elements which result in "incipient incapacitation" rather than death. Incipient incapacitation is defined as that point at which physiological and psychological effects are sufficient to impair thinking and influence physical efforts to escape. The criteria are based upon the assumption that these critical levels represent thresholds for human beings who are capable of normal physiological and psychological behavior. The thresholds should not be interpreted as precise boundaries but rather an approximation, based on the literature and the unique characteristics of the occupancy type being assessed, of the levels of conditions which would result in adverse effects. Reference NBSIR 78-1530 (pp 8-15) for detailed discussion of rationale.

2.4. Measurements

2.4.1. Ambient Measurements

The moisture content of the wall and ceiling finish materials was 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. Pertinent measurements are tabulated in table A2.

2.4.2. Test Measurements

Test measurements were carried out in similar locations to those in the test series reported in NBSIR 78-1530. Figure A2 illustrates the locations of measurements and table A3 lists each channel and the type of measurement taken.

3. PROCEDURE

The procedures for installation of the interior finish materials, and for conditioning of the interior environment of the mobile home were similar to those in the previous test series.

In the tests using the upholstered chair as the exposure fire, the chairs, having an approximate weight of 16 kg (35 lbs) were positioned on the load cell platform in the northwest corner of the living room 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 A3).

In the two tests using the sofa as the exposure fire, the sofa was positioned on a load cell platform along the west wall in the northwest corner. The sofa was approximately 10 cm (4 in) from the walls in both tests which was the minimum permitted distance from the walls without interference with the weighing platform. The sofas were ignited by placing 400 gms (0.9 lbs) of newsprint, folded once, on a stainless steel rack and igniting the newsprint. The rack was designed to expose both the seat and back cushion of the sofa to the burning newsprint (figure A4).

4. RESULTS

The fires developed in a similar sequence to those in the first series of tests, and varied in length depending on the development of the exposure fires and the extent of involvement of materials comprising the interior finish. The tests ranged from just under eight minutes in test MHLIV 21 to approximately 38 minutes in test MHLIV 19. The tests were terminated either when there was a significant reduction in the intensity of the fire or, when total room involvement occurred (flashover). The determination that a significant reduction in the intensity of the fire had occurred 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.

Key measurements selected based on the extensive analysis of the initial series of tests are tabulated in tables A4 and A5. In addition, plotted data based on the selected measurements are provided in Appendix AA (pp. AA1-16).

5. ANALYSIS AND DISCUSSION

The primary objective of this series of tests was to extend the scope of the flashover matrix developed in NBSIR 78-1530. Therefore the analysis specifically addresses this objective. The results were also examined to determine whether or not the contribution of different types of interior finish materials when exposed to similar ignitions appreciably affected 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. Changes in temperature, CO and O_2 at the back exit door which would serve as the primary means of egress in the event that a fire occurs in the living room at the other end of the mobile home were used in this determination.

As in the first series of tests, the results of these eight full-scale tests indicated that in a typical single-wide mobile home, the rate of fire growth and the maximum fire size directly affected whether or not limiting conditions were reached. Flashover occurred in four of the six upholstered chair tests (MHLIV 17, 20, 21, 23), and, as in the previous studies [13,14], was accompanied by upper room temperatures in excess of 600°C. Flashover was not observed in tests MHLIV 22 and 24 where the respective maximum upper room temperatures reached 556 and 536°C. For both tests the temperature development in the upper room was characterized by a short period of rapid increase up to the peak levels, followed by a decrease. The corresponding plot for incident flux at the floor level was similar in shape to the temperature plot, with peak levels of incident heat flux occurring during the same time period as maximum temperature (reference data plots in Appendix AA).

Although flashover was not observed in test MHLIV 22, the thresholds for limiting conditions of temperature, CO and O_2 were either reached or exceeded. It should be noted however that these thresholds were marginally exceeded, and after an extended period of time; on the order of 16 to 19 minutes when compared to those tests in which flashover occurred (reference table A5).

In test MHLIV 24 the thresholds for temperature and CO were exceeded. However, as in test MHLIV 22, the rate of change of these measured conditions was not as high as that which occurred in tests where flashover was observed. As illustrated by the data plots in Appendix AA the rates of change for the measured conditions were lower, and so were the peak values. While flashover was not observed, it would appear that the combinations of wall and ceiling materials used in these two tests resulted in fire conditions which may place these combinations very close to the boundary between flashover and no flashover in the material hazard matrix.

Flashover occurred prior to the attainment of thresholds for limiting conditions of temperature, carbon monoxide and oxygen in all four chair tests where flashover was observed. With the exception of test MHLIV 23 where the limiting threshold for O_2 was not reached, the limiting thresholds for temperature, CO and O_2 were exceeded for all four tests. And, for the

most part, as can be seen from the data tabulated in table A5, the thresholds for limiting conditions occurred within a very short period after flashover in these tests.

Flashover did not occur in either of the two sofa tests. In test MHLIV 18 the fire progressed along the sofa, eventually consuming most of the combustible materials. The flame envelope was somewhat larger in area than that of the chair fires, and was of sufficient height to impinge on the ceiling. However, there appeared to be no qualitative difference in the severity of the sofa fire in MHLIV 18 and the upholstered chair fires. The maximum upper room temperature was 453°C which was only 9°C higher than the maximum upper room temperature which occurred in test MHLIV 11 (NBSIR 78-1530) under similar experimental conditions with an upholstered chair. In addition, after reaching this peak of 453°C, temperatures in the upper room dropped off rapidly, and fluctuated between approximately 150° and 250°C for the duration of the test. This indicated that for this experimental configuration the peak intensity of the exposure fires from the sofa and the upholstered chairs were of similar magnitude, though the duration of burning was longer for the sofa due to the additional fuel.

The initial fire buildup in the sofa in test MHLIV 18 occurred more rapidly than in the chair fires due to the direct exposure of the polyurethane seat and back cushions on the sofa to the burning newsprint. This buildup of the exposure fire resulted in marginally exceeding the thresholds for limiting conditions of temperature and oxygen at the back exit door, again indicating a slightly more severe fire from the burning sofa. The oxygen concentration dropped to a minimum concentration of 13.6% at 4 min 10 sec into the test, but then increased to approximately 18% where it remained for the duration of the test. The temperature development was similar in that it exceeded the 100°C threshold, peaking at 119°C during the same time that the minimum O_2 concentration was reached, and then decreased to approximately a constant level of 100°C for the duration of the test. The peak O_2 depletion and temperature rise coincided with the rapid initial development of the sofa fire.

In test MHLIV 19, the intensity of the exposure fire from the sofa was significantly lower than that of the upholstered chair tests or the other sofa fire. The maximum upper room temperature was only slightly higher than in the tests conducted in the first series with the wood crib exposure fires. Fire spread along the surface of the sofa as well as the mass consumption rate was considerably slower than in test MHLIV 18, and during the period of most intense burning the height of the flame envelope was not sufficient to reach the ceiling.

Why the sofa fire in test MHLIV 19 did not develop into a more severe exposure fire than the wood cribs as would be expected could not be determined. However, the results of the test indicated considerable deviation from the remainder of the tests. Therefore, the results of test MHLIV 19 are included for information purposes but are not included in the discussion regarding the material hazard matrix. Test MHLIV 20 provided information on the exposure to an upholstered chair fire of the same interior finish materials as in test MHLIV 19. The results of this test provided an evaluation of the performance of this combination of interior finish materials to an exposure fire of realistic intensity from an upholstered chair.

5.1. Comparison of Full-Scale Results and ASTM E-84 FSC

Based on analysis of results a matrix was prepared to illustrate the likelihood for flashover from exposure of interior finish materials to an upholstered chair fire. The matrix was based on the results of the five upholstered chair fires conducted in the initial series of tests and seven of the tests in the supplemental series. As previously discussed, analysis indicated that in this test configuration the sofa fire (test MHLIV 18) was only slightly more severe than the upholstered chair fires and therefore was included in the analysis. The results of test MHLIV 19 were not included.

The material hazard matrix for the upholstered chair tests is provided in figure A5. For comparative purposes a modified form of the material hazard matrix developed for the low intensity fire exposures is also provided. The modification involved only a change in indexing of the FSC axes. In the original matrix the categories specifically identified those FSC values tested. In figure A5, this was modified to provide a basis for comparing performance of similar combinations of wall and ceiling materials to both exposure fires. In addition, the traditional ASTM E-84 classification ranges corresponding to Classes A (0-25), B (26-75) and C (76-200) were adopted to provide a more conventional interpretation. These matrices, while simplified for purposes of illustration, reflect the experimental results similar to the matrix presented in NBSIR 78-1530.

The results of MHLIV 23 and 24, when incorporated into the material hazard matrix, give rise to an interface between the flashover and non-flashover regions, at which the untested region is eliminated. This interface is itself an uncertain region. Flashover occurred in MHLIV 23 with a wall material having a measured FSC of 36, while it did not occur in MHLIV 24 with a wall material having a measured FSC of 45. Both ceiling materials

had an approximate FSC of 25, though the one in MHLIV 23 was a wood fiberboard having a higher potential heat than the material in MHLIV 24 which was gypsum board.

This result serves to highlight limitations in the use of FSC alone in determining the hazard of a material. First, while FSC has been demonstrated as a tool for providing some prediction of performance, material properties such as ignitability, potential heat, rate of heat release, and rate of flame spread, not adequately accounted for in FSC values, also influence fire growth and spread. While the values for most of these properties for the materials tested in this series have not been determined in time to be included in this report, heat release rates were determined for the two ceiling materials tested in MHLIV 23 and 24[3]. The integrated heat release rates over a five minute interval were 1324 J/cm^2 and 394 J/cm^2 for the fiberboard and the gypsum board respectively. Therefore, while the FSC of the two materials were similar, the higher heat release rate of the wood fiberboard material could account for the more severe fire which occurred in test MHLIV 23.

Furthermore, it should not be assumed that the boundaries drawn to distinguish among the "flashover", "no flashover" and "untested" regions in the matrix can be precisely defined. The method of determining the FSC does not provide sufficient accuracy or repeatibility to enable such an interpretation. The boundaries in the matrices are constructed based strictly on the reported FSC values of the materials tested. However, when considering the accuracy of the values, it is more appropriate to interpret the boundaries in terms of a range of FSC values (e.g., $\pm$ 5).

A conservative approach would suggest that test MHLIV 24 having walls with a FSC of 45 and ceiling with a FSC of 24 should be included in the non-flashover region of the matrix. This gives rise to an anomaly in the material hazard matrix based on the results of test MHLIV 23. This anomaly cannot be satisfactorily resolved in terms of FSC. And, the limited data regarding other fire properties of the ceiling materials, while providing an explanation for the anomaly, is not sufficient to permit adoption of an additional criterion, based on a test method other than the ASTM E-84. Such an approach would require additional analysis in order to establish the technical basis for adoption of the additional test method.

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[3]Values for heat release rates for materials C9 (gypsum board) and C10 (wood fiberboard) were determined from laboratory tests with NBS Rate of Heat Release Calorimeter, Model II. Tests were conducted at 6 w/cm^2 sample exposure.

It should be noted that the area of the region in the matrix (figure A5) where flashover was not observed for the low intensity fire has been increased slightly. This increase reflects extrapolation of the results of the upholstered chair fires. The more severe chair fire did not result in flashover in test MHLIV 24 which tested a wall material having higher FSC than wall materials in similar tests in the series with the low intensity fire exposure. It is assumed that for similar materials, if the larger exposure fire did not result in flashover, then it is unlikely that flashover would occur for a smaller exposure fire. Therefore, the area of the non-flashover region was extended to reflect this.

In comparing the two matrices, the impact of increasing the intensity of the exposure fire can be visualized. The area in the matrix where flashover was observed is somewhat larger for the upholstered chair fires. However, a more significant difference is found in the size of the region that includes those combinations of wall and ceiling materials which did not result in flashover. In the upholstered chair tests this region was significantly reduced.

6. SUMMARY

Eight full-scale fire tests were conducted in the living room of a typical single-wide mobile home. The experimental scenario established for this series of tests involved the exposure of a number of combinations of interior wall and ceiling finish materials to a moderate intensity fire from the burning of a 16 kg (35 lb) upholstered chair or a 35 kg (78 lb) upholstered sofa located in one corner of the room.

As in previous studies on mobile homes, [13,14] flashover was determined to be a critical point in fire growth, after which property damage is extensive and the thresholds for limiting conditions for life safety, including temperature, carbon monoxide and oxygen, are significantly exceeded.

The contribution from the interior finish was found to significantly affect the extent of fire growth and the subsequent attainment of limiting conditions for life safety.

The following are specific conclusions based on the results of these tests.

1. The extent of fire spread beyond the initial burning item varied depending on the extent of involvement of the wall and ceiling materials near the burning item.

2. Rapid fire growth and the attainment of flashover resulted in exceeding all of the selected limits established for occupant incipient incapacitation at the back exit door.

3. The test results provided the basis to extend the material hazard matrix developed in NBSIR 78-1530 to a higher intensity exposure fire. This supported the earlier finding that the use of the ASTM E-84 flame spread classification (FSC) provided an indication of the potential contribution of interior finish materials when exposed to an incidental fire under the conditions established in this test series.

4. The range of FSC for combinations of wall and ceiling materials which did not result in flashover was reduced significantly when the exposure fire was increased from one of low intensity to one of moderate intensity.

7. ACKNOWLEDGMENTS

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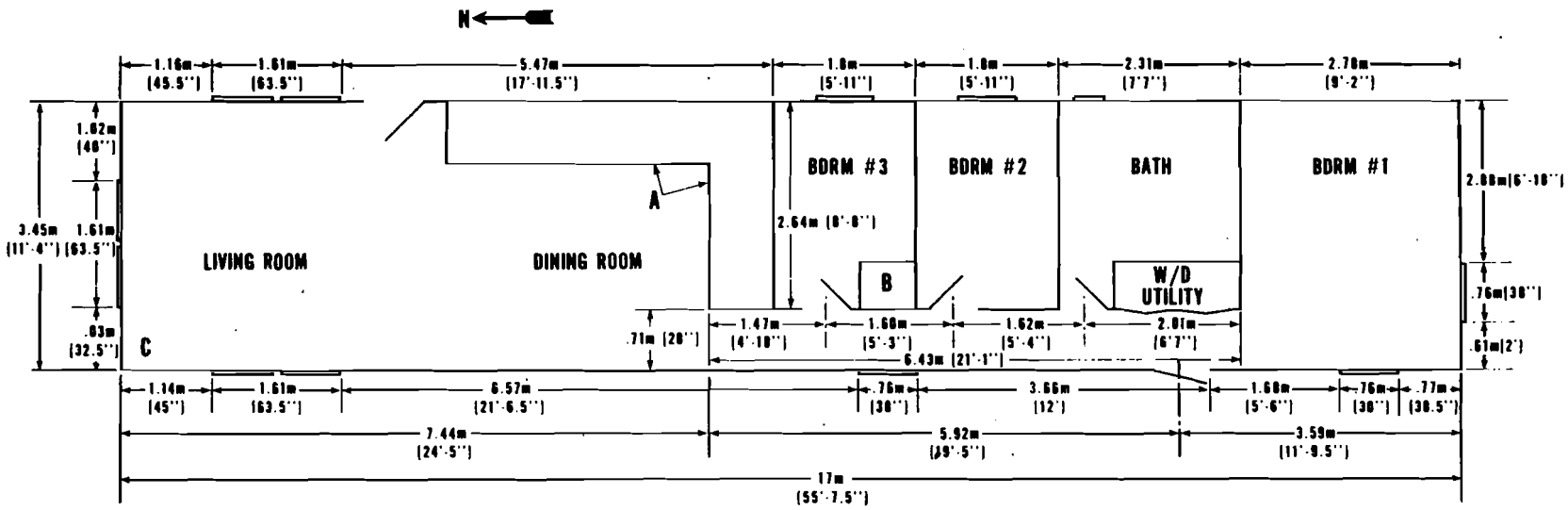
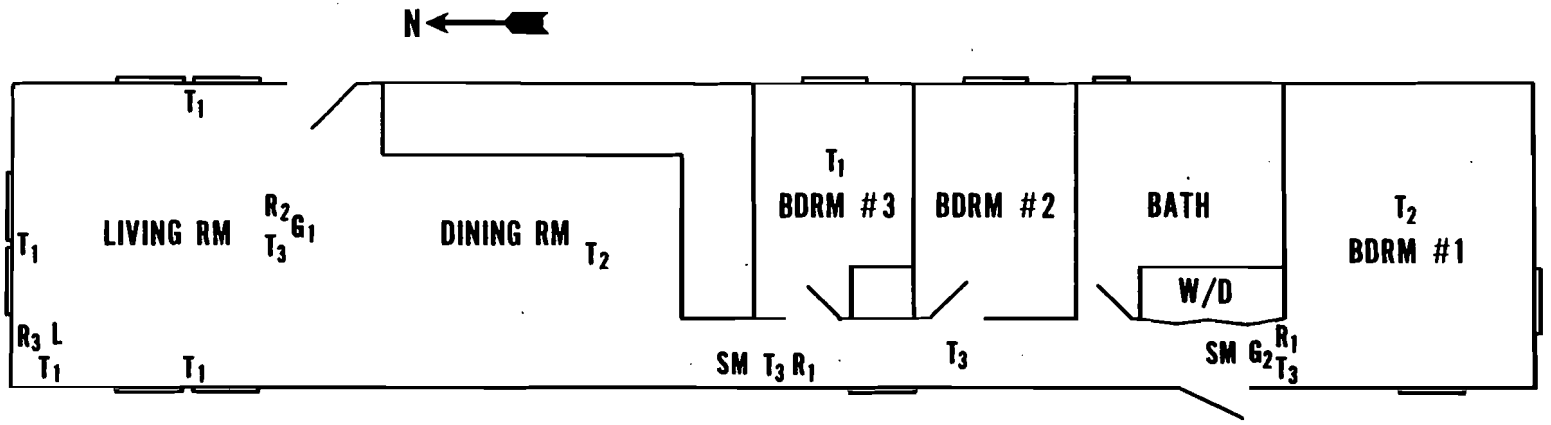


A = CEILING HIGH PARTITION CONSTRUCTED OF ASBESTOS-CEMENT BOARD
B = FURNACE ENCLOSURE
C = LOCATION OF INITIAL BURNING ITEM
W/D = WASHER/DRYER ENCLOSURE

Figure A1. Plan View of Mobile Home Test Unit



Temperature Measurements

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

Incident Heat Flux

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, horizontally centered with respect to burning item

Weight Loss of Initial Burning Item

L - high temperature strain gage load cell

Combustion Gas Measurements

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

Smoke Generation Measurements

SM - vertically aligned photometer located at ceiling; path length of light beam 0.46m
- horizontal path photometers 0.6, 1.2, and 1.8m above floor; light path 0.71m measured across corridor

Figure A2. Plan View of Mobile Home Test Unit Illustrating Location of Experimental Measurements

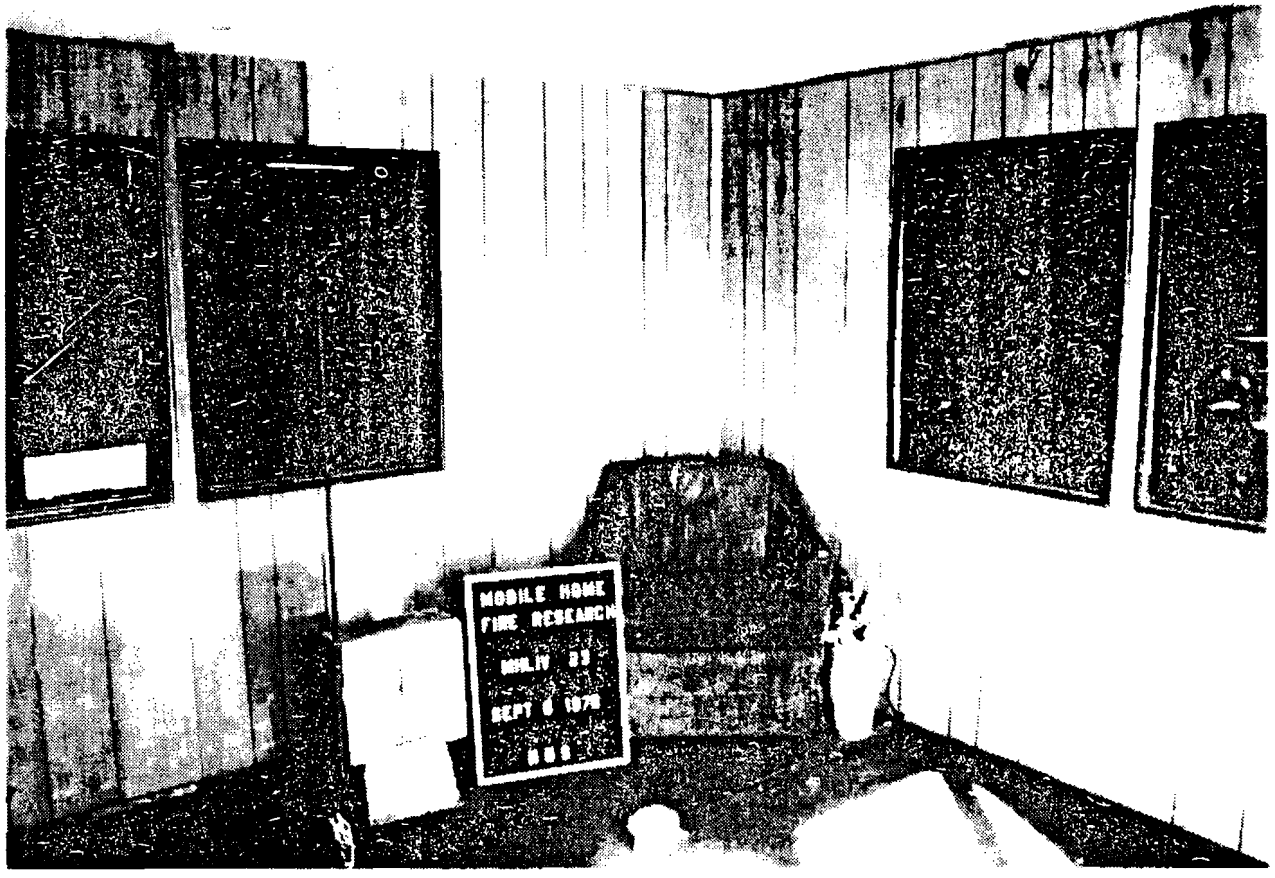


Figure A3. Typical Test Set-Up Illustrating Location and Positioning of the Upholstered Chair as Initial Burning Item

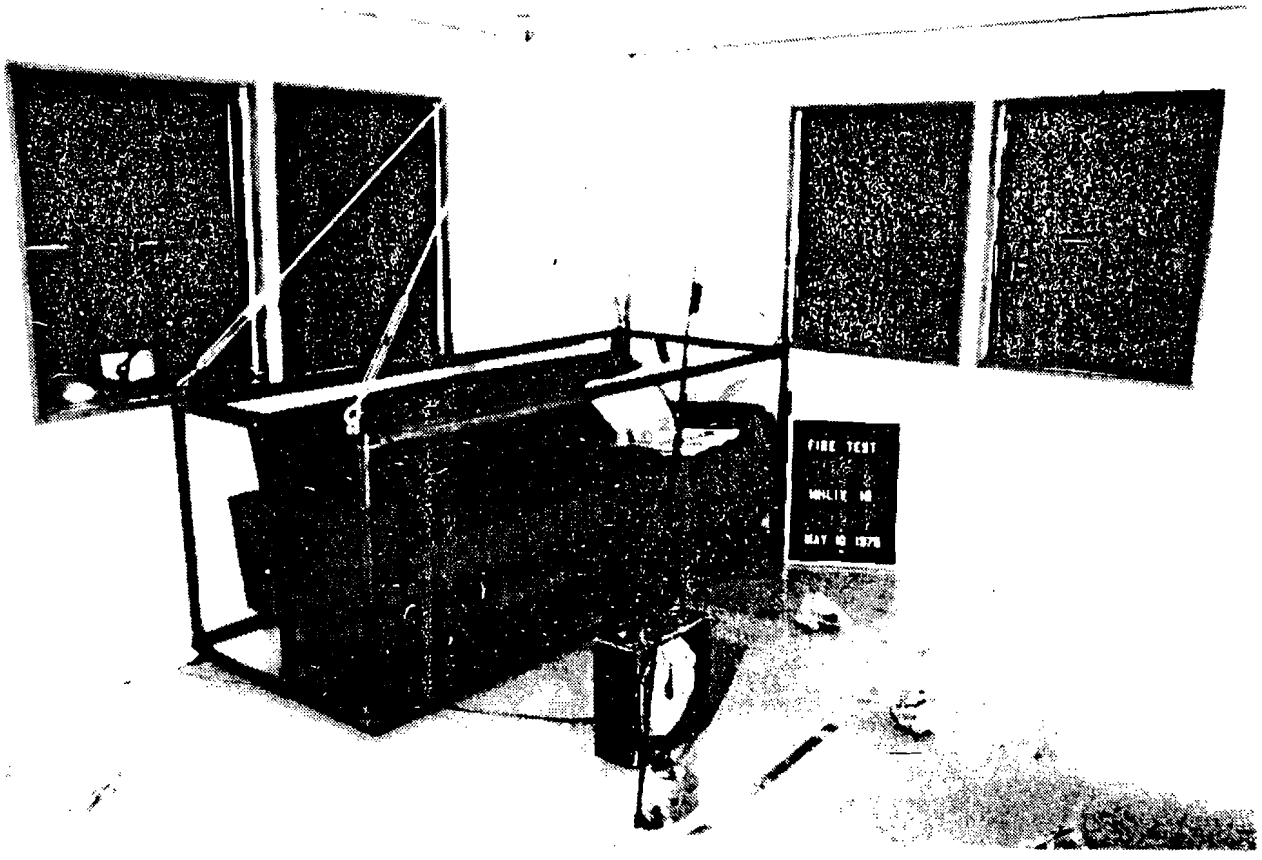


Figure A4. Typical Test Set-Up Illustrating Location and Positioning of the Upholstered Sofa as the Initial Burning Item

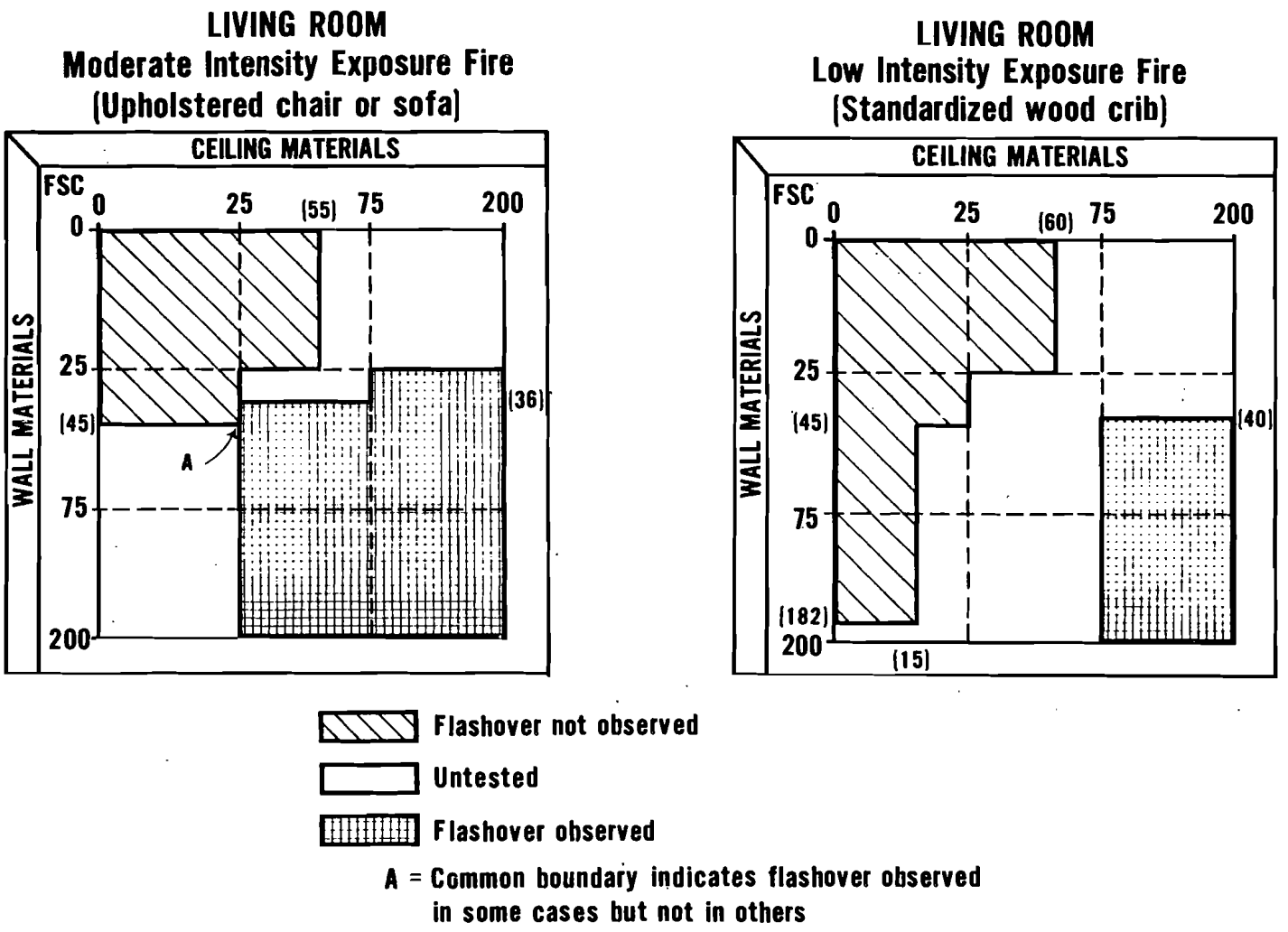


Figure A5. Material Hazard Matrices for Full-Scale Mobile Home Living Room Tests (Based on ASTM E-84)

Table A1. Description of Interior Finish Materials Used in Full-Scale Mobile Home Fire Tests (Supplemental Series)

Test No.	Description: Interior Finish Materials	NBS ID Code	ASTM E84 FSC[1]	Type of Exposure Fire
MHLIV 17	Walls: 4 mm (5/32 in) thick prefinished Lauan plywood Ceiling: 9.5 mm (3/8 in) thick taped and spackled gypsum board, painted with one coat latex flat	W-13 C-9	172 24	16 kg upholstered chair
MHLIV 18	Walls: 9.5 mm (3/8 in) thick taped and spackled gypsum board, painted with one coat latex flat Ceiling: 9.5 mm (3/8 in) thick taped and spackled gypsum board, painted with one coat latex flat	W-19 C-9	25 24	35 kg upholstered sofa
MHLIV 19	Walls: 9.5 mm (3/8 in) thick taped and spackled gypsum board, painted with one coat latex flat Ceiling: 13 mm (1/2 in) thick prefinished low density wood fiberboard	W-19 C-5	25 73	35 kg upholstered sofa
MHLIV 20	Walls: 9.5 mm (3/8 in) thick taped and spackled gypsum board, painted with one coat latex flat Ceiling: 13 mm (1/2 in) thick prefinished low density wood fiberboard	W-19 C-5	25 73	16 kg upholstered chair
MHLIV 21	Walls: 4 mm (5/32 in) thick Lauan plywood treated with two coats of fire retardant intumescent and one coat of a vinyl finish material Ceiling: 13 mm (1/2 in) thick wood fiberboard with unfinished surface exposed	W-17 C-8	45 55	16 kg upholstered chair
MHLIV 22	Walls: 9.5 mm (3/8 in) thick taped and spackled gypsum board, painted with one coat of latex flat Ceiling: 13 mm (1/2 in) thick wood fiberboard with unfinished surface exposed	W-19 C-8	25 55	16 kg upholstered chair
MHLIV 23	Walls: 4 mm (5/32 in) thick Lauan plywood treated with two coats of fire retardant intumescent and one coat of a vinyl finish material Ceiling: 13 mm (1/2 in) thick wood fiberboard with finished surface	W-18 C-10	36 25	16 kg upholstered chair
MHLIV 24	Walls: 4 mm (5/32 in) thick Lauan plywood treated with two coats of fire retardant intumescent and one coat of a vinyl finish material Ceiling: 9.5 mm (3/8 in) thick taped and spackled gypsum board, painted with one coat latex flat	W-21 C-9	45 24	16 kg upholstered chair

[1] Flame spread calculated by George Williams-Leir (GWL) method, adopted by ASTM in April, 1976.

Table A2. Test Conditions for Full-Scale Mobile Home Fire Tests (Supplemental Series)

Test No.	Interior Conditions			Exterior Conditions			Moisture Content %	
	Temperature		Humidity	Temperature		Humidity		
	(°C)	(°F)	(%)	(°C)	(°F)	(%)	Walls	Ceiling
MHLIV 17	19	66	40	16	60	62	6.0	8.5
MHLIV 18	20	68	36	19	66	43	9.0	9.0
MHLIV 19	24	74	46	22	71	59	10.5	6.5
MHLIV 20	21	70	34	19	66	70	6.3	9.0
MHLIV 21	27	80	55	26	79	88	7.5	5.5
MHLIV 22	21	70	72	24	75	88	14.0	8.0
MHLIV 23	22	72	46	24	75	60	8.0	7.8
MHLIV 24	13	56	50	13	55	54	7.5	9.5

Table A3. Mobile Home Living Room Test Series: Instrumentation Locations

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 A4. Selected Results of Full-Scale Mobile Home Living Room Tests (Supplemental Series)

Test No.	Time to Ignition of Wall	Time to Flashover	Temperature 25 mm Below Ceiling in Living Room		Incident Heat Flux at Floor Level in Center of Living Room			Final Data Record	Final Visual Test Observation	Activation of Suppression System
			Maximum TC 13	Elapsed Time	At Max. Temp. at TC 13	Maximum Level	Elapsed Time			
	(Min:sec)	(Min:sec)	(°C)	(Min:sec)	(W/cm^2)	(W/cm^2)	(Min:sec)	(Min:sec)	(Min:sec)	(Min:sec)
MHLIV 17	4:20	5:55	703	6:20	1.3	1.3	6:20	8:20	8:10	8:20
MHLIV 18	NR[a]	NR	453	3:40	0.5	0.5	3:40	18:50	19:00	18:45[b]
MHLIV 19	NR	NR	206	5:00	<0.1	<0.1	5:00	38:20	38:30	38:15[b]
MHLIV 20	5:05	8:45	688	9:20	1.1	1.4	23:40	23:50	23:25	23:25
MHLIV 21	5:00	6:43	801	7:10	5.0	6.7	7:00	8:20	7:40	7:22
MHLIV 22	14:50	NR	556	15:50	0.8	0.9	15:30	27:40	27:00	27:00
MHLIV 23	5:10	7:40	695	8:30	1.7	1.8	8:10	9:00	8:35	8:40
MHLIV 24	6:25	NR	538	9:30	0.7	0.7	9:30	19:40	19:25	19:30

[a] NR = Not reached.

[b] Hose line only.

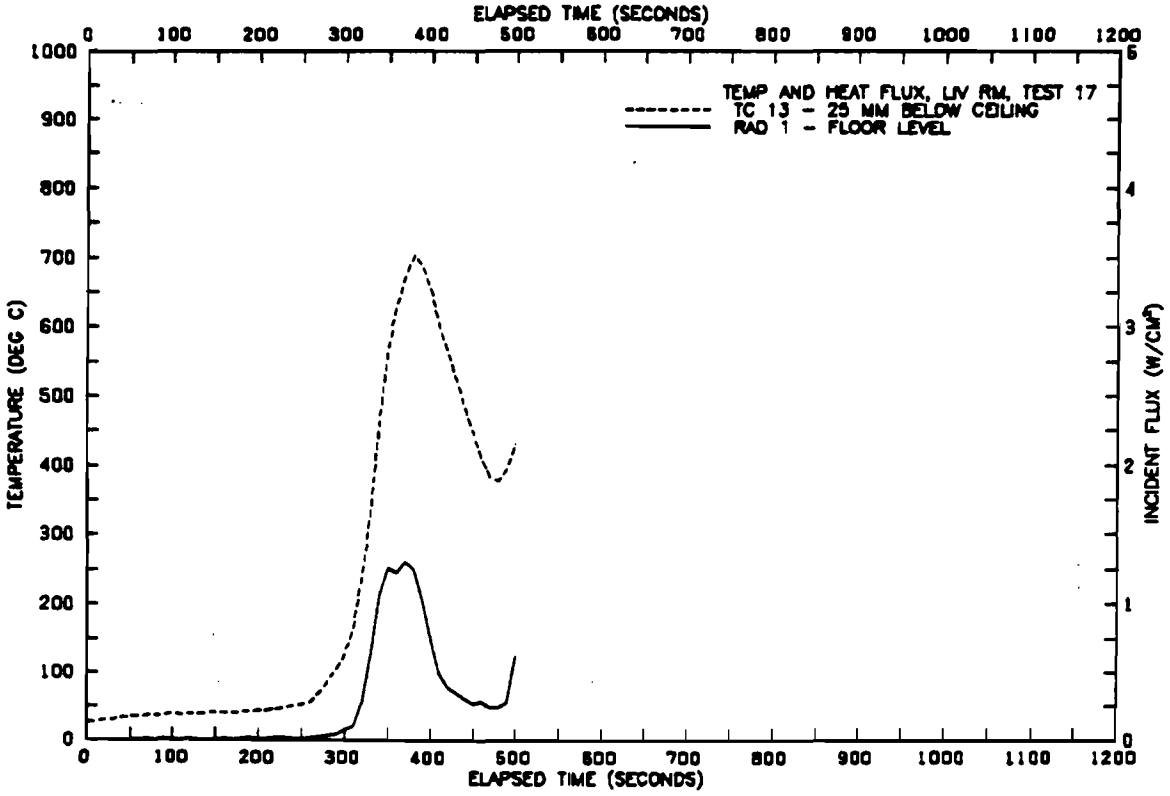
Table A5. Selected Levels of Temperature, Smoke Density, Carbon Monoxide and Oxygen Near the Back Exit Door (Supplemental Series - Mobile Home Full-Scale Living Room Series)

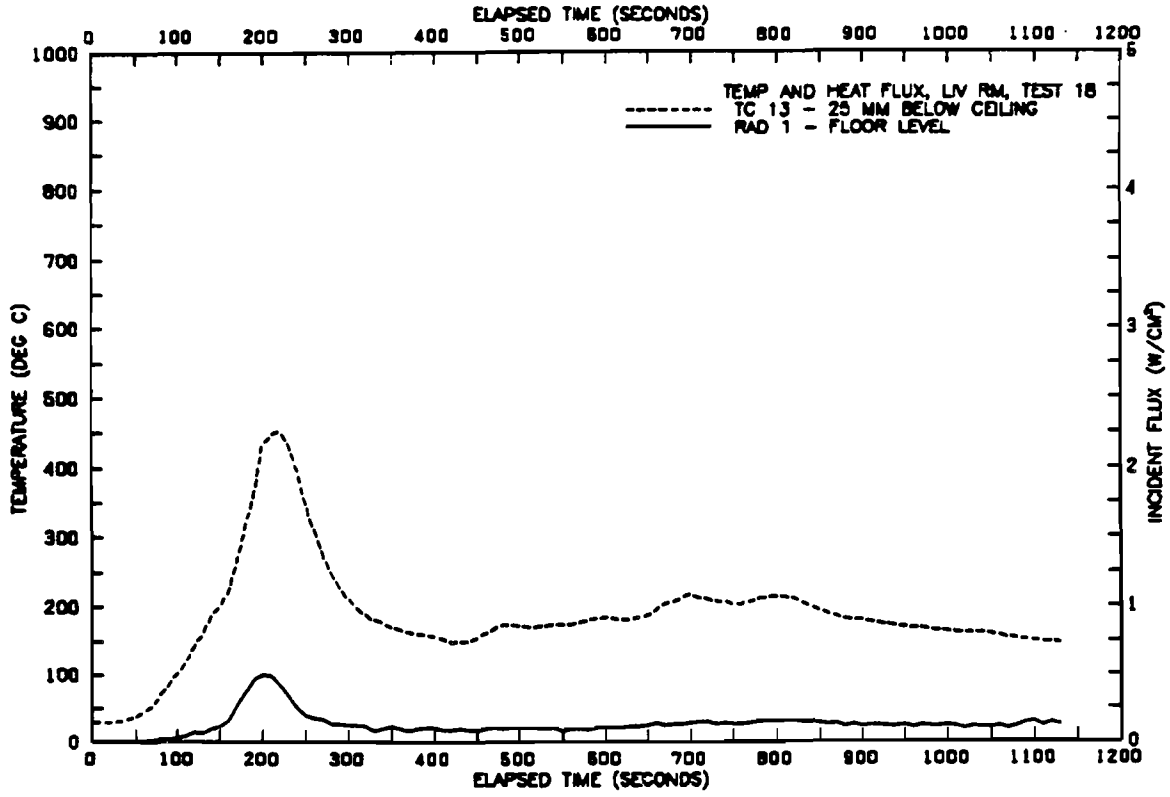
Test No.	Time to Reach 100°C @ TC37	Maximum Temp @ TC37	Time to Reach 0.26 OD/m Smoke Density in Corridor		Concentrations of CO at South End of Corridor: CO 16			Time Integrated CO at South End of Corridor			Concentrations of O_2 at South End of Corridor: $O_2$17		
			HSM 5	HSM 9	1.0%	Maximum Concentration		41,800 (ppm)$^{1.036}$(min)		Maximum	14%	Minimum Concentration	
	(Min:sec)	(°C)	(Min:sec)	(Min:sec)	(Min:sec)	(%)	(Min:sec)	(Min:sec)	(ppm)$^{1.036}$(min)	(Min:sec)	(Min:sec)	(%)	(Min:sec)
MHLIV 17	6:15	147	4:50	4:35	7:00[b]	2.0[b]	7:30[b]	7:45[b]	54,000[b]	8:70[b]	6:06	6.1	7:10
MHLIV 18	3:40	119	1:55	1:45	NR	0.4	3:50	NR	40,650	18:50	4:00	13.6	4:10
MHLIV 19	NR[a]	93	2:25	2:15	NR	<0.2	8:10	36:40	44,710	38:20	NR	18.4	6:30
MHLIV 20	9:00	159	7:10	7:00	9:45	1.5	10:20	11:20	130,300	23:50	9:25	11.8	10:20
MHLIV 21	6:45	180	5:15	4:55	6:45	2.7	7:45	7:50	60,290	8:20	7:25	11.4	7:50
MHLIV 22	15:55	112	14:35	14:40	NR	0.9	16:20	18:50	52,410	27:40	16:25	14.0	16:25
MHLIV 23	8:05	146	6:45	6:45	8:05	1.7	9:00	NR	25,870	9:00	NR	14.8	9:00
MHLIV 24	9:20	136	6:35	6:15	10:10	1.1	10:20	13:00	99,400	19:40	NR	17.7	10:20

[a] NR = Not reached.

[b] Data taken from backup source.

APPENDIX AA. PLOTTED DATA ILLUSTRATING KEY CHANGES IN MEASURED CONDITIONS FROM APPENDIX A.


ELAPSED TIME (SECONDS)
TEMP AND HEAT FLUX, LIV RM, TEST 17
TC 13 - 25 MM BELOW CEILING
RAD 1 - FLOOR LEVEL
TEMPERATURE (DEG C)
INCIDENT FLUX (W/CM²)
ELAPSED TIME (SECONDS)


ELAPSED TIME (SECONDS)
TEMP AND HEAT FLUX, LIV RM, TEST 18
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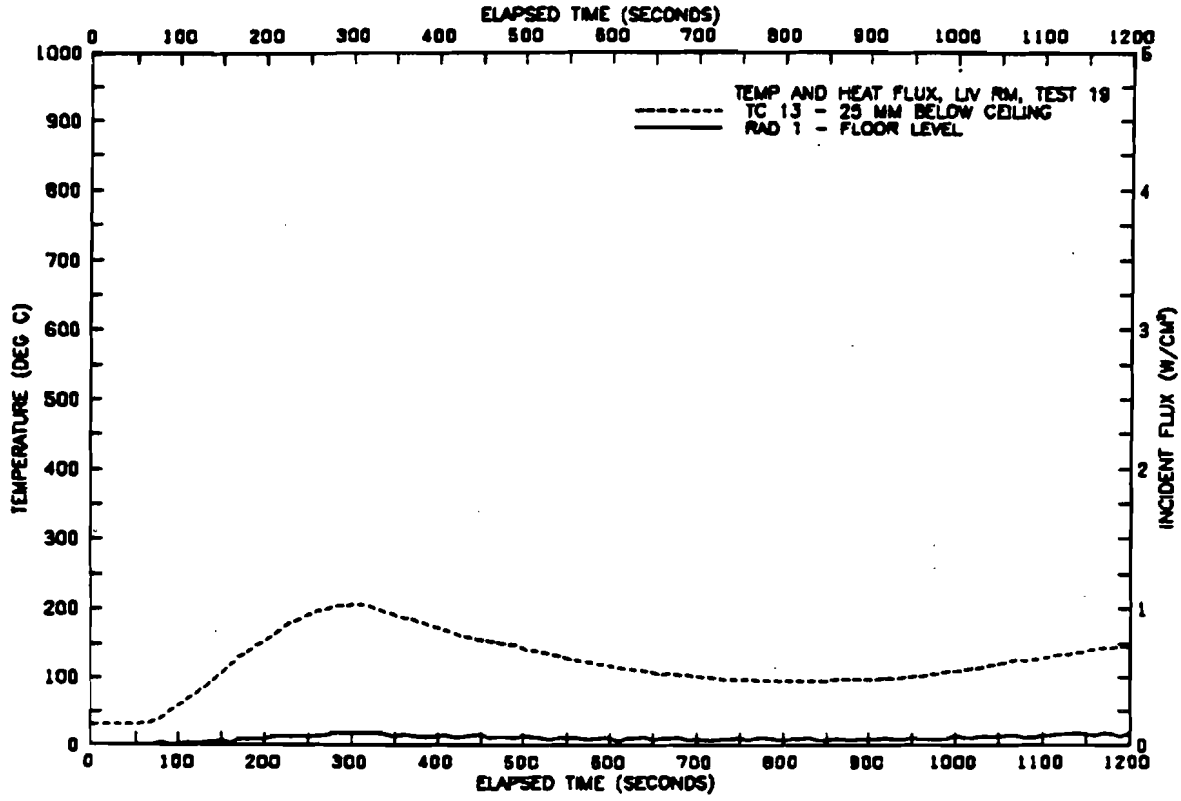
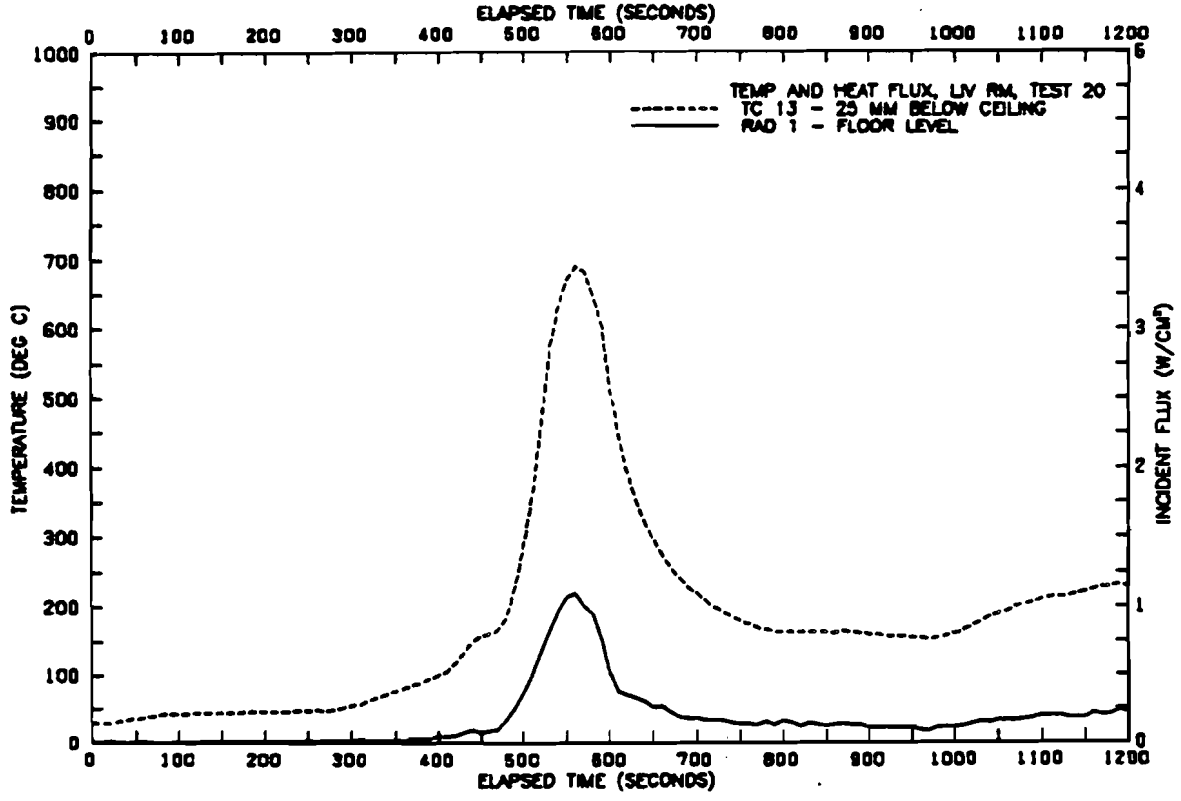
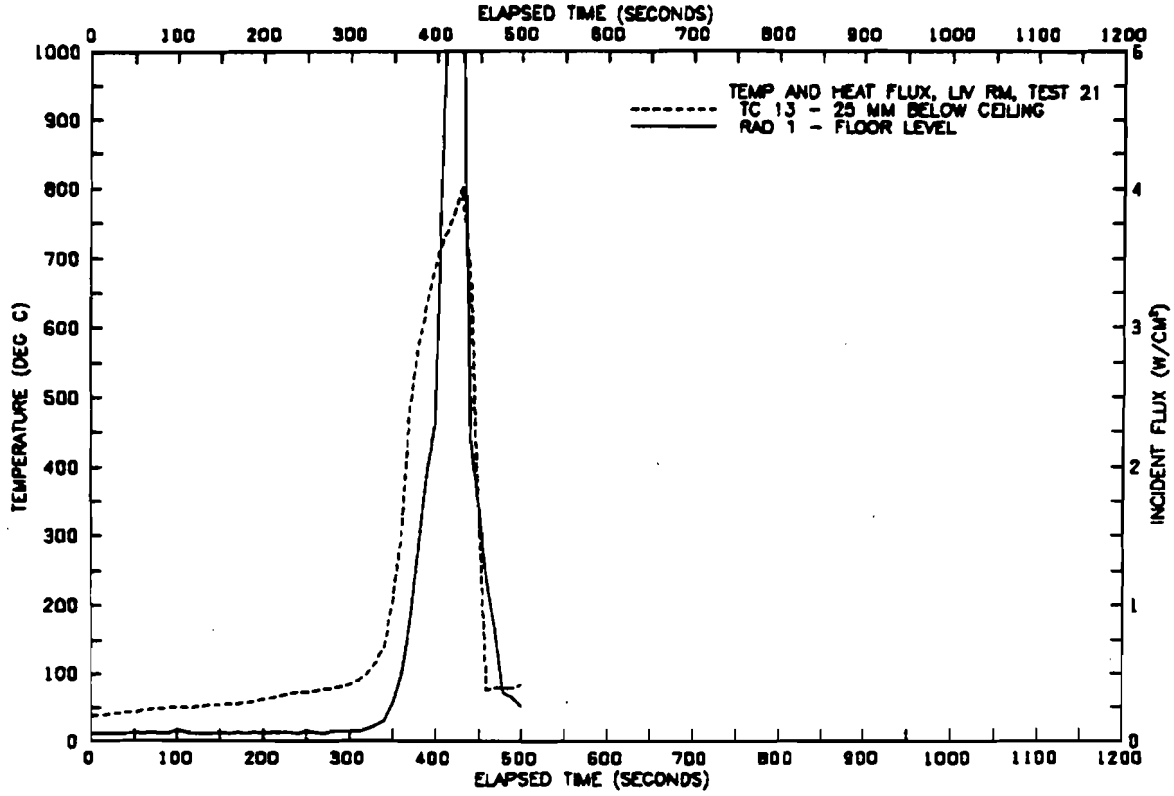
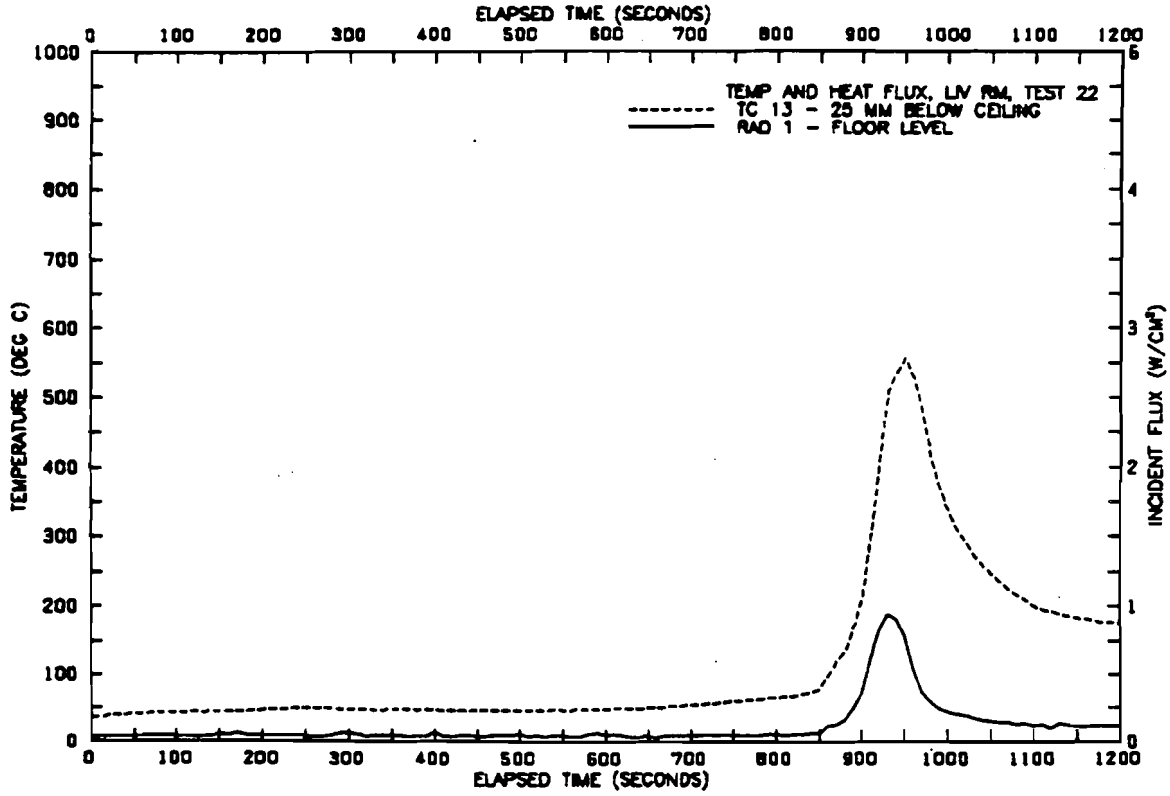
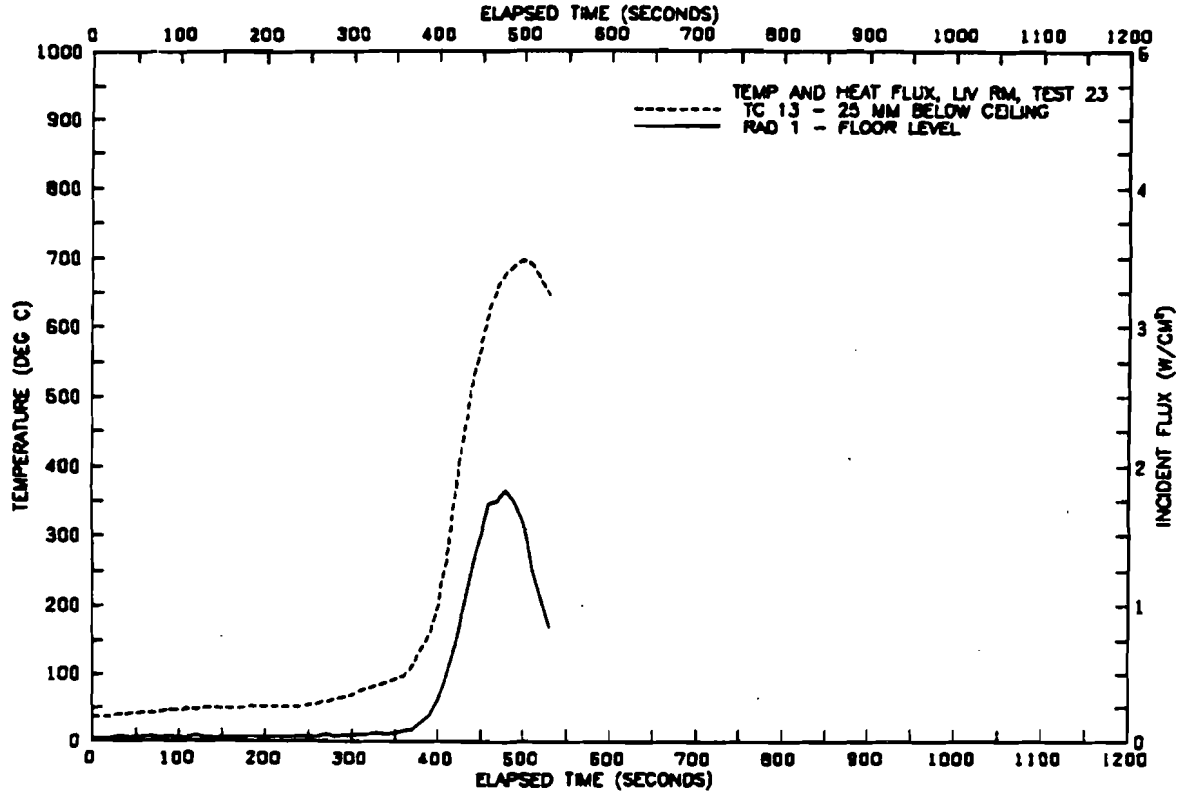
RAD 1 - FLOOR LEVEL
TEMPERATURE (DEG C)
INCIDENT FLUX (W/CM²)
ELAPSED TIME (SECONDS)


ELAPSED TIME (SECONDS)
TEMP AND HEAT FLUX, LIV RM, TEST 19
TC 13 - 25 MM BELOW CEILING
RAD 1 - FLOOR LEVEL
TEMPERATURE (DEG C)
INCIDENT FLUX (W/CM²)


ELAPSED TIME (SECONDS)
TEMP AND HEAT FLUX, LIV RM, TEST 20
TC 13 - 25 MM BELOW CEILING
RAD 1 - FLOOR LEVEL
TEMPERATURE (DEG C)
INCIDENT FLUX (W/CM²)


ELAPSED TIME (SECONDS)
TEMP AND HEAT FLUX, LIV RM, TEST 21
TC 13 - 25 MM BELOW CEILING
RAD 1 - FLOOR LEVEL
TEMPERATURE (DEG C)
INCIDENT FLUX (W/CM²)


ELAPSED TIME (SECONDS)
TEMP AND HEAT FLUX, LIV RM, TEST 22
TC 13 - 25 MM BELOW CEILING
RAD 1 - FLOOR LEVEL
TEMPERATURE (DEG C)
INCIDENT FLUX (W/CM²)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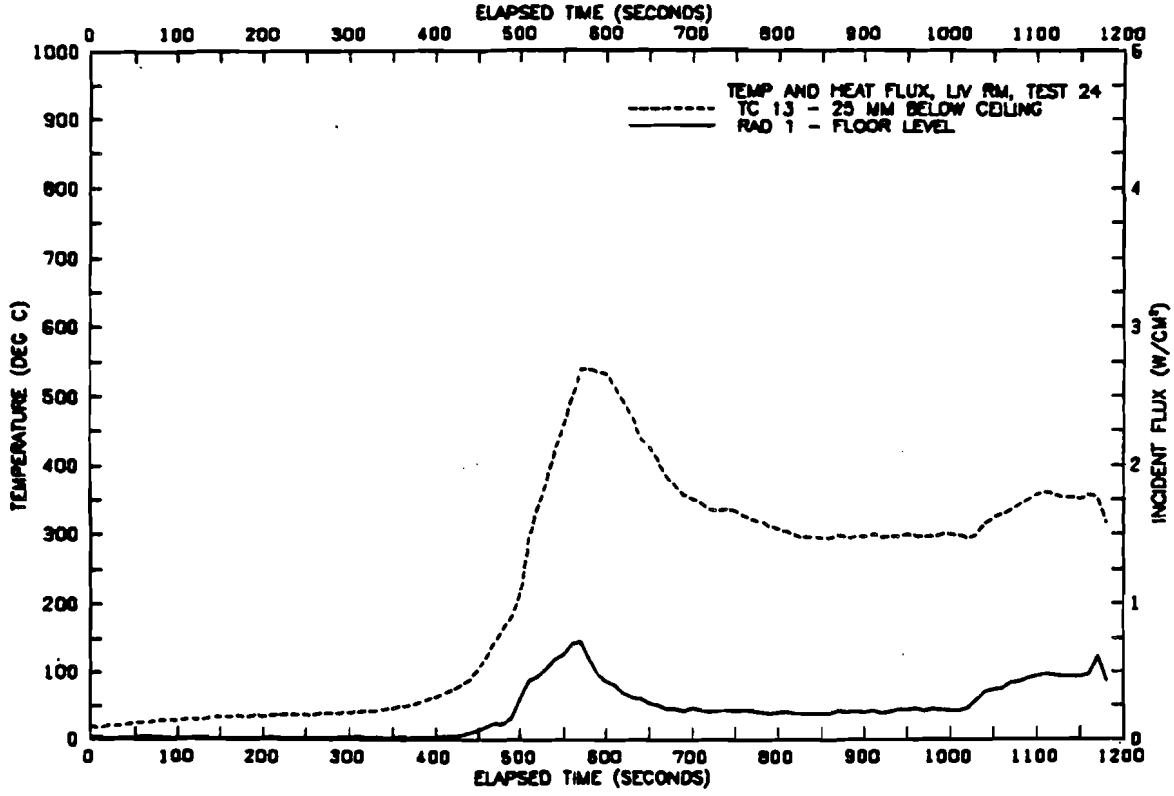
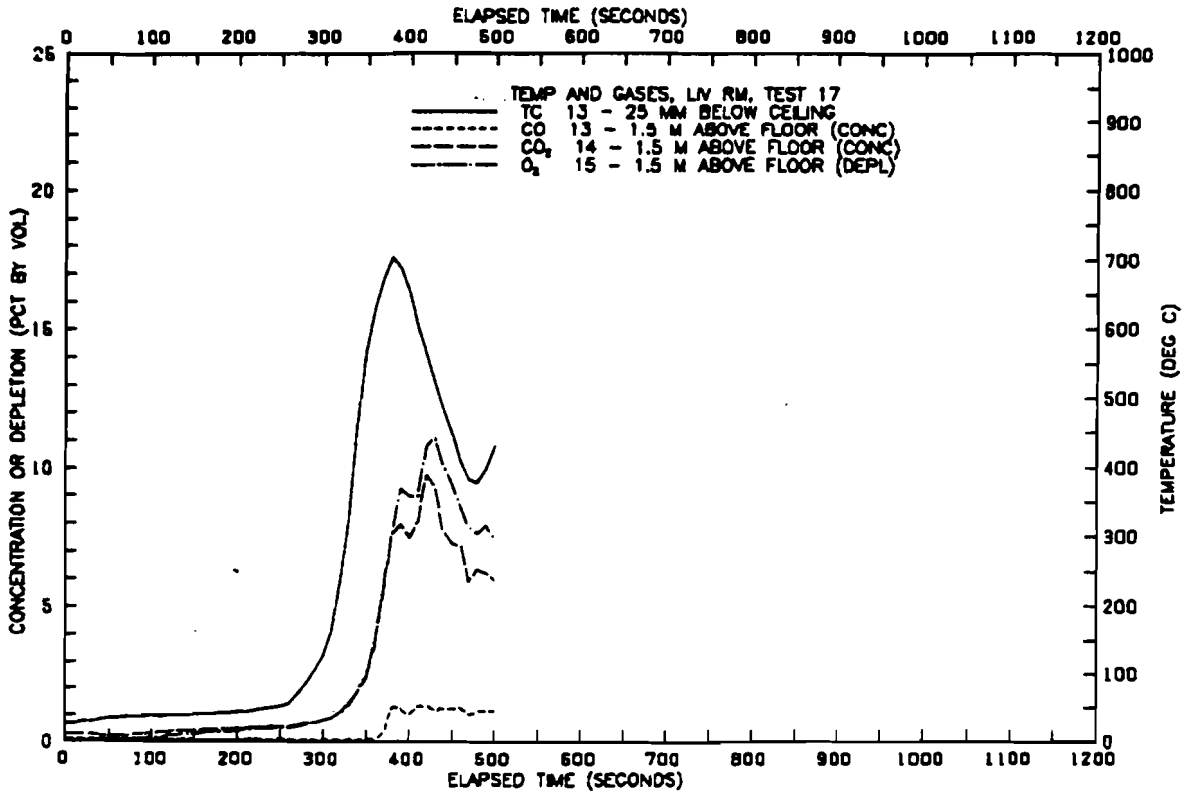
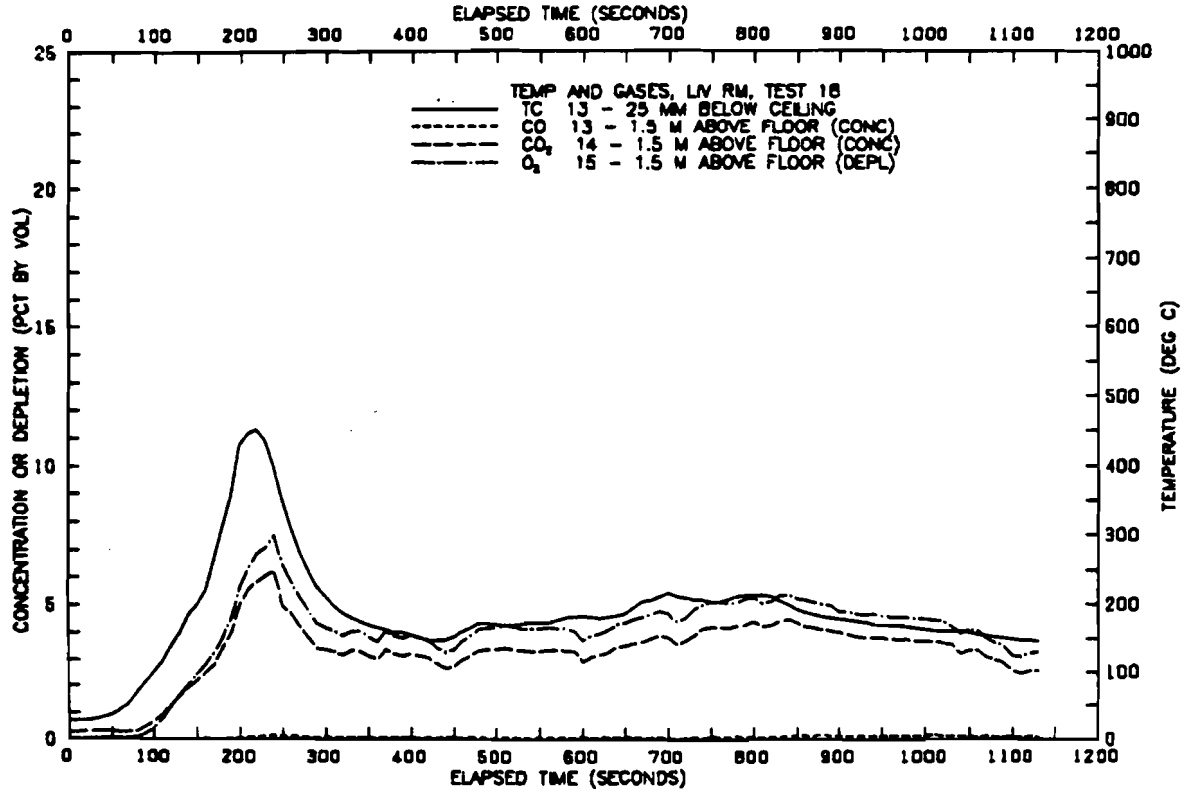
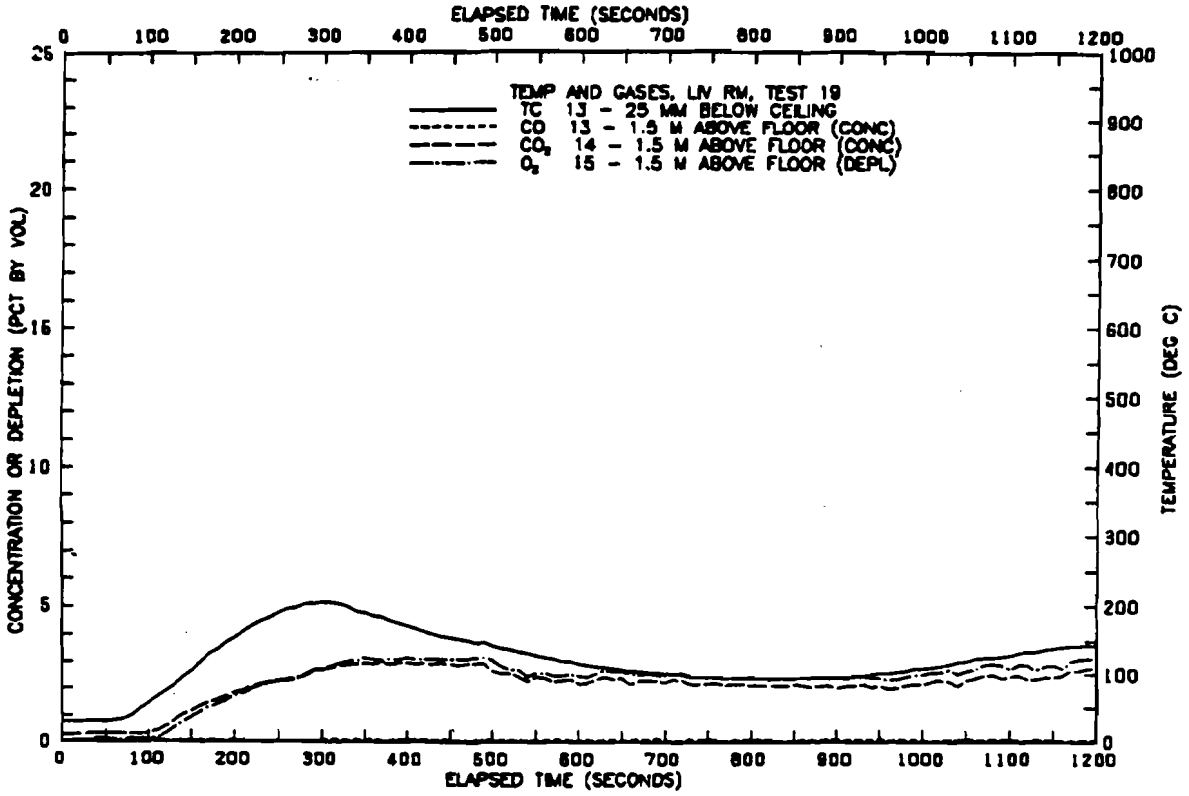
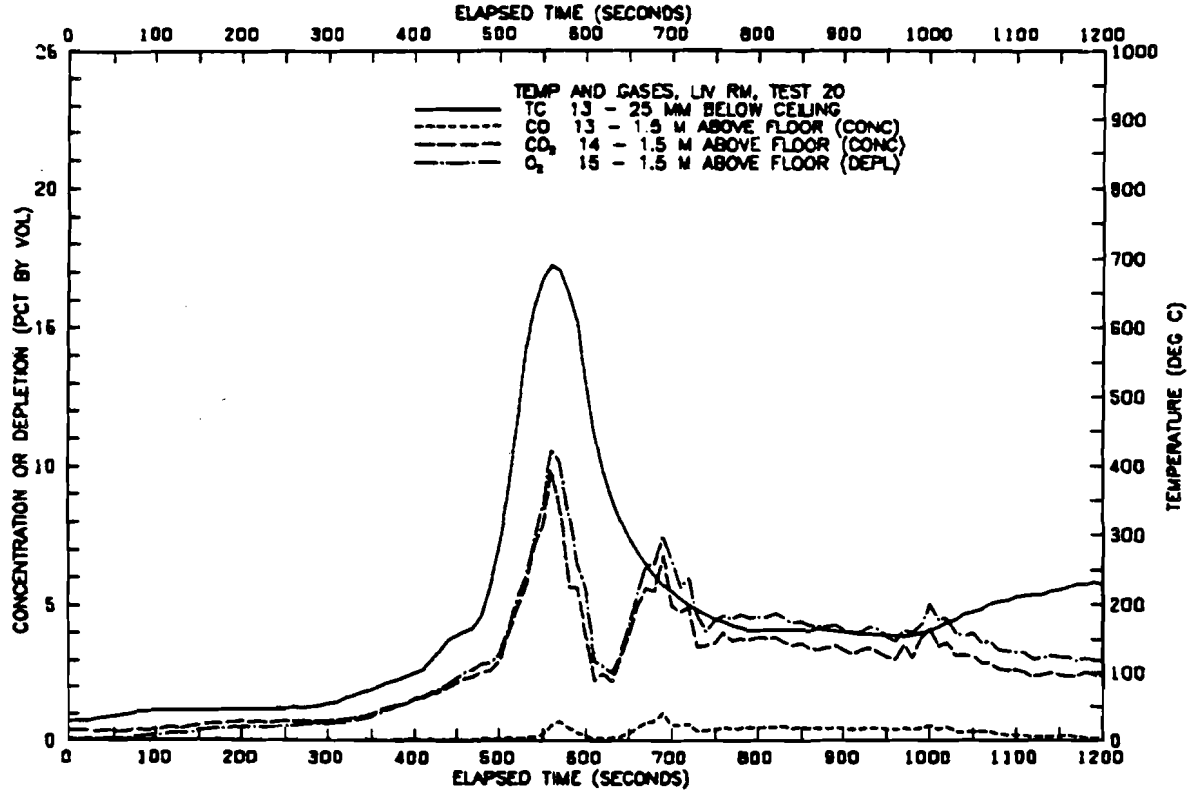
TEMP AND HEAT FLUX, LIV RM, TEST 23
TC 13 - 25 MM BELOW CEILING
RAD 1 - FLOOR LEVEL
TEMPERATURE (DEG C)
INCIDENT FLUX (W/CM²)

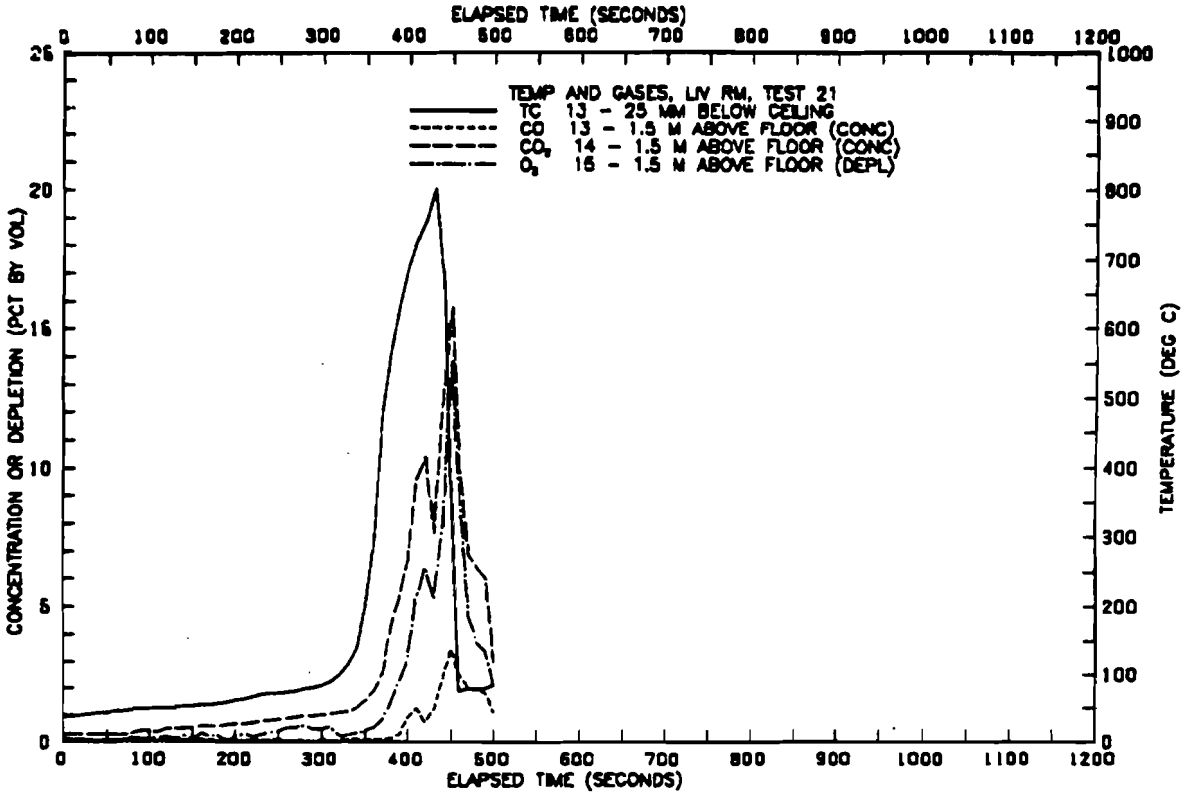

ELAPSED TIME (SECONDS)
TEMP AND HEAT FLUX, LIV RM, TEST 24
TC 13 - 25 MM BELOW CEILING
RAD 1 - FLOOR LEVEL
TEMPERATURE (DEG C)
INCIDENT FLUX (W/CM²)

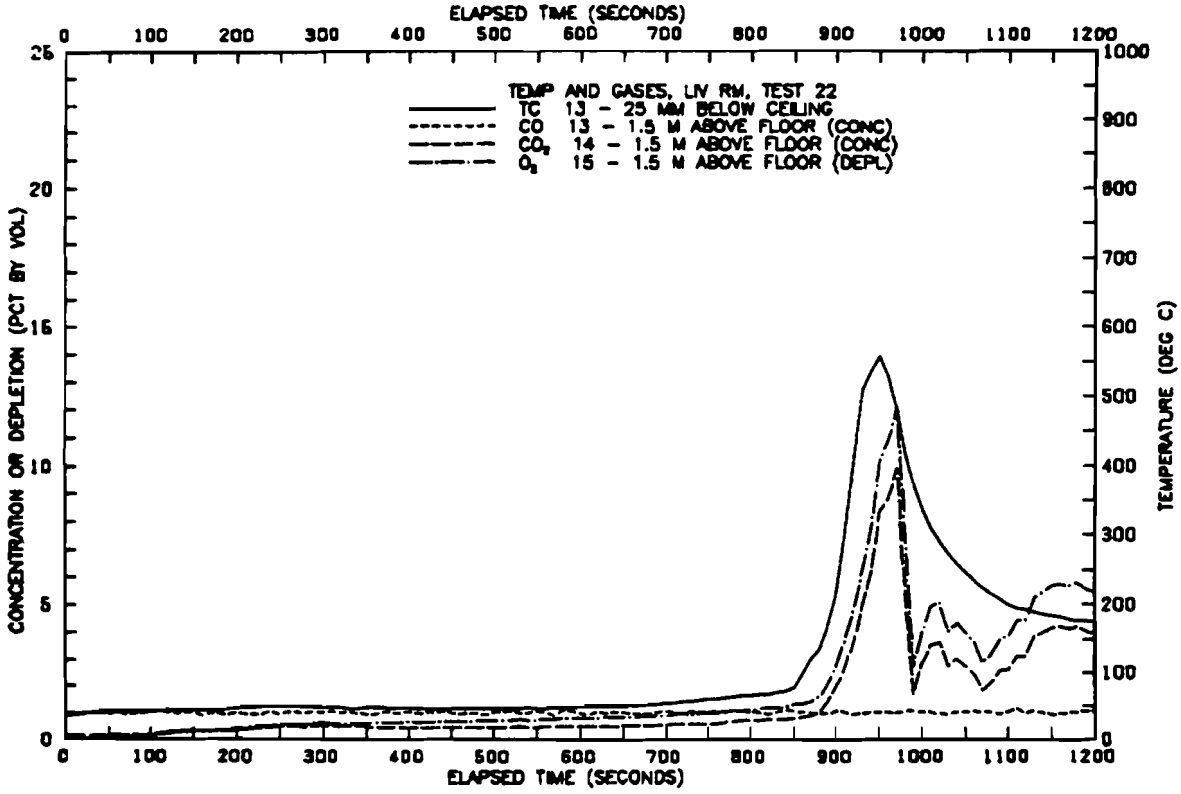

ELAPSED TIME (SECONDS)
TEMP AND GASES, LIV RM, TEST 17
TC 13 - 25 MM BELOW CEILING
CO 13 - 1.5 M ABOVE FLOOR (CONC)
CO_2 14 - 1.5 M ABOVE FLOOR (CONC)
O_2 15 - 1.5 M ABOVE FLOOR (DEPL)
CONCENTRATION OR DEPLETION (PCT BY VOL)
TEMPERATURE (DEG C)

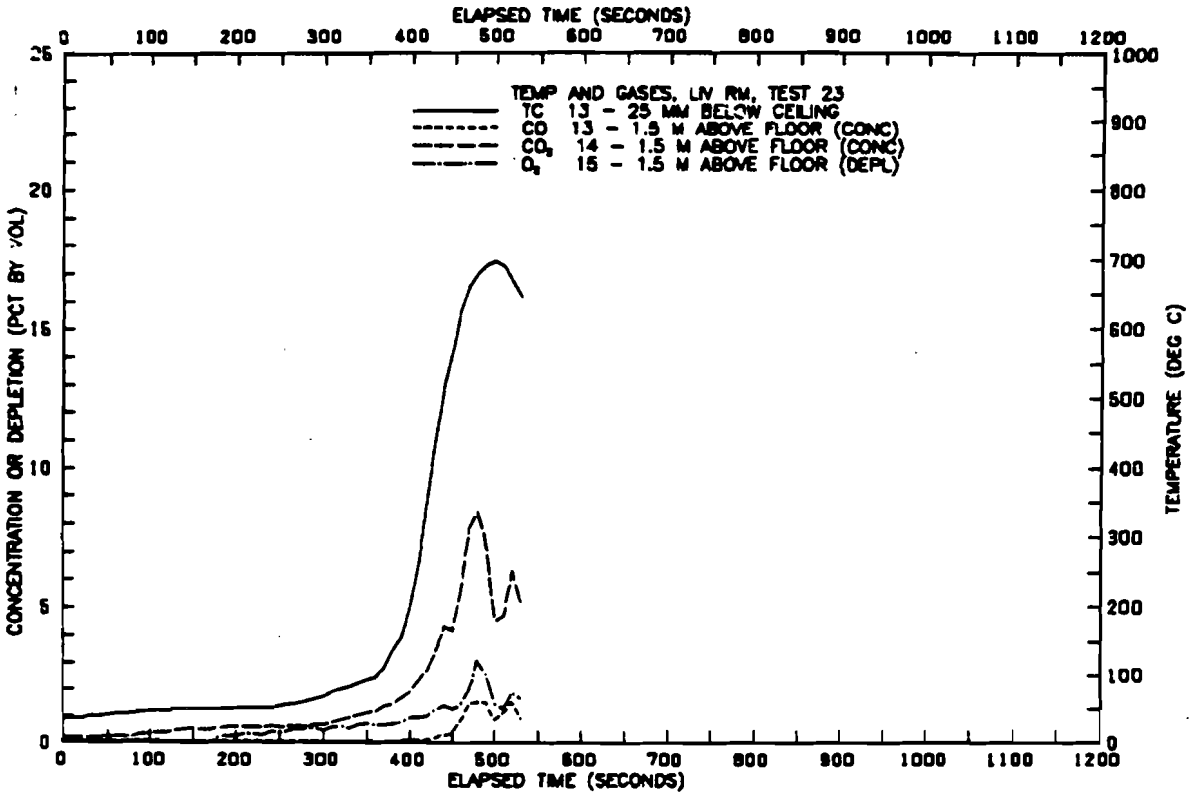

ELAPSED TIME (SECONDS)
TEMP AND GASES, LIV RM, TEST 18
TC 13 - 25 MM BELOW CEILING
CO 13 - 1.5 M ABOVE FLOOR (CONC)
CO_2 14 - 1.5 M ABOVE FLOOR (CONC)
O_2 15 - 1.5 M ABOVE FLOOR (DEPL)
CONCENTRATION OR DEPLETION (PCT BY VOL)
TEMPERATURE (DEG C)

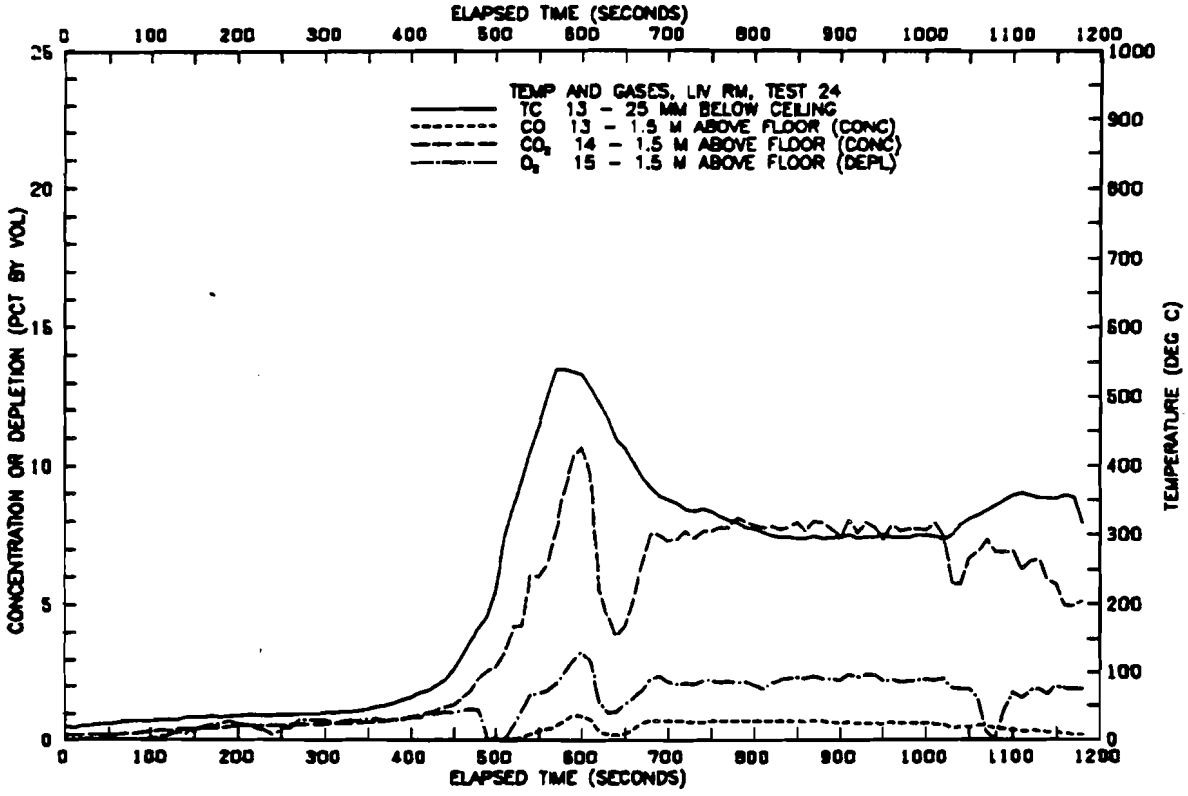

ELAPSED TIME (SECONDS)
TEMP AND GASES, LIV RM, TEST 19
TC 13 - 25 MM BELOW CEILING
CO 13 - 1.5 M ABOVE FLOOR (CONC)
CO2 14 - 1.5 M ABOVE FLOOR (CONC)
O2 15 - 1.5 M ABOVE FLOOR (DEPL)
CONCENTRATION OR DEPLETION (PCT BY VOL)
TEMPERATURE (DEG C)
ELAPSED TIME (SECONDS)

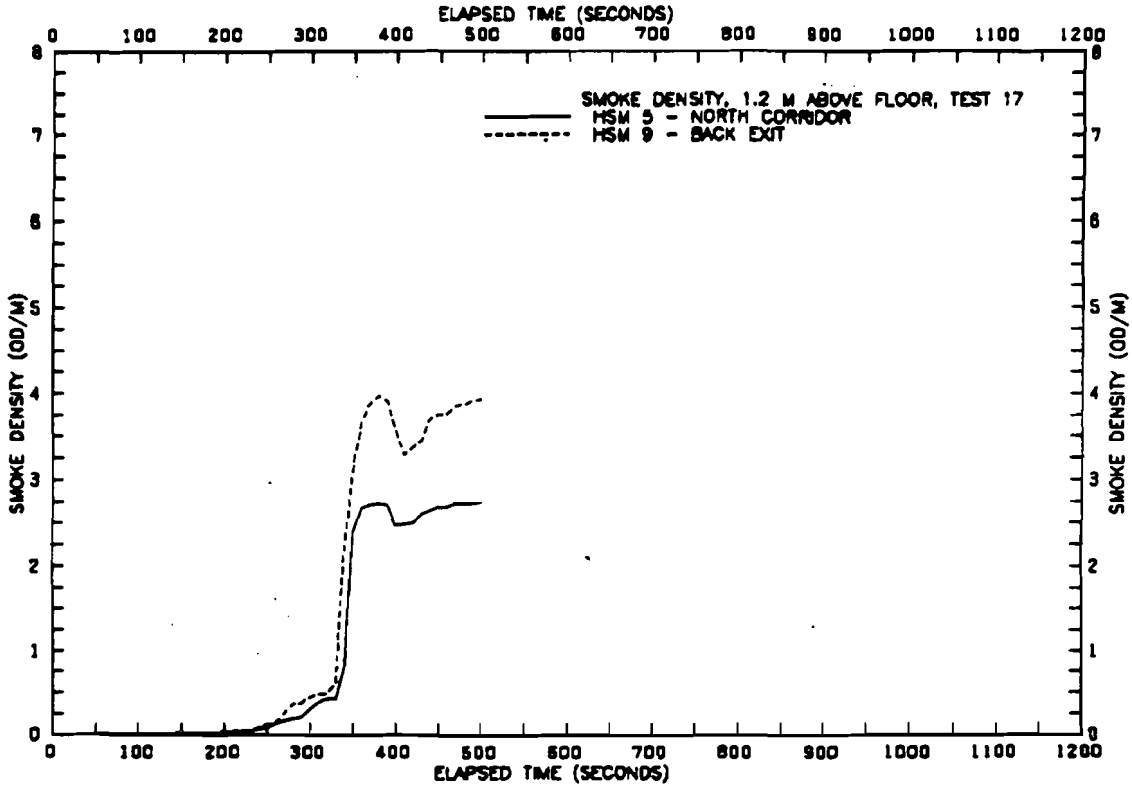

ELAPSED TIME (SECONDS)
TEMP AND GASES, LIV RM, TEST 20
TC 13 - 25 MM BELOW CEILING
CO 13 - 1.5 M ABOVE FLOOR (CONC)
CO2 14 - 1.5 M ABOVE FLOOR (CONC)
O2 15 - 1.5 M ABOVE FLOOR (DEPL)
CONCENTRATION OR DEPLETION (PCT BY VOL)
TEMPERATURE (DEG C)
ELAPSED TIME (SECONDS)

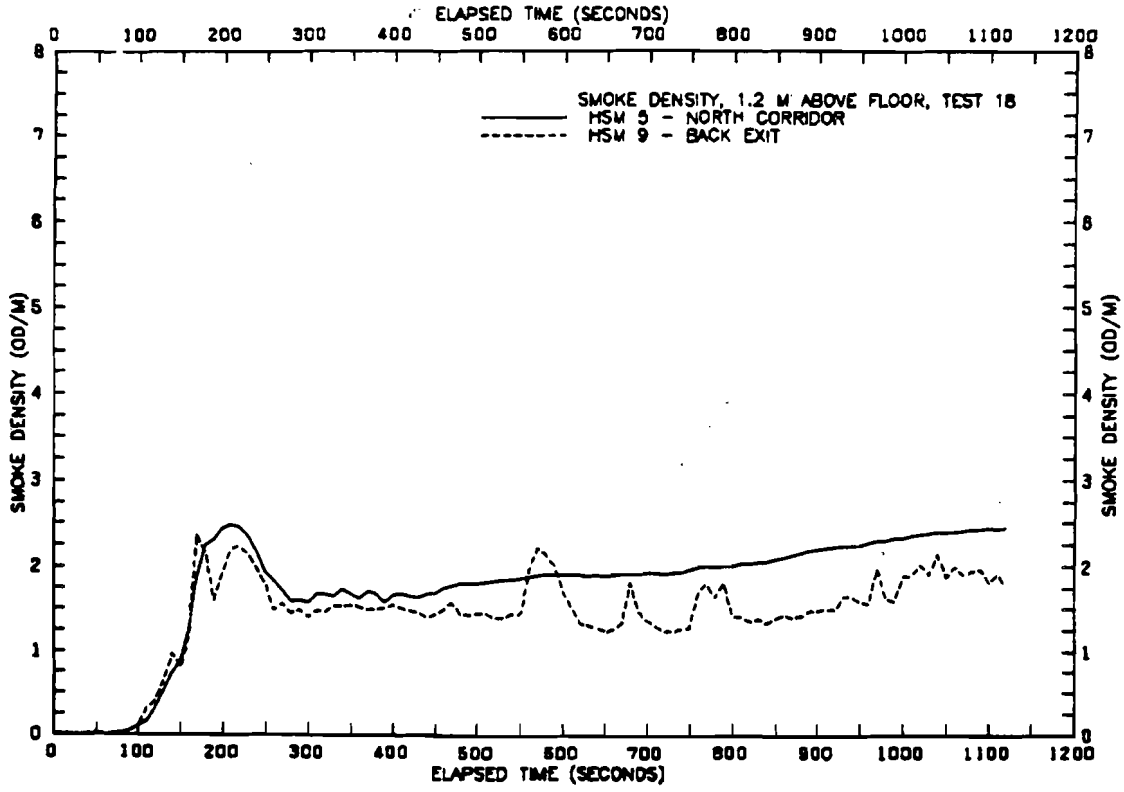

ELAPSED TIME (SECONDS)
TEMP AND GASES, LIV RM, TEST 21
TC 13 - 25 MM BELOW CEILING
CO 13 - 1.5 M ABOVE FLOOR (CONC)
CO_2 14 - 1.5 M ABOVE FLOOR (CONC)
O_2 15 - 1.5 M ABOVE FLOOR (DEPL)
CONCENTRATION OR DEPLETION (PCT BY VOL)
TEMPERATURE (DEG C)

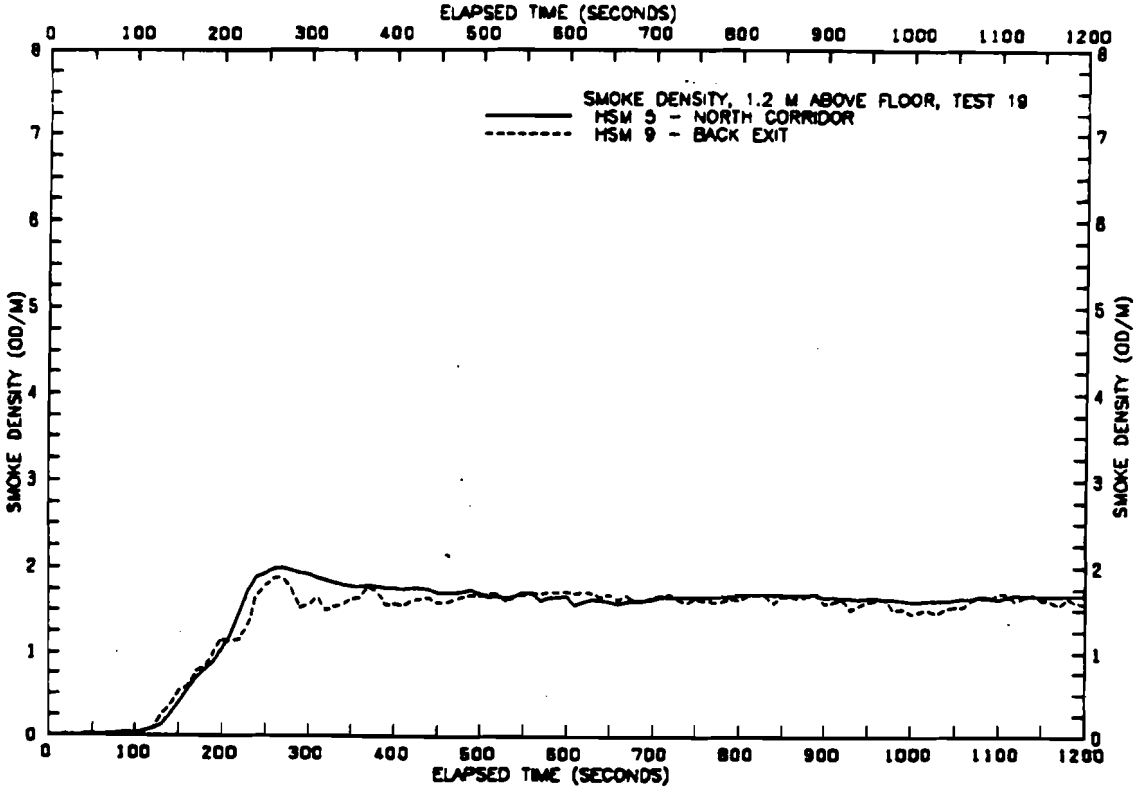

ELAPSED TIME (SECONDS)
TEMP AND GASES, LIV RM, TEST 22
TC 13 - 25 MM BELOW CEILING
CO 13 - 1.5 M ABOVE FLOOR (CONC)
CO_2 14 - 1.5 M ABOVE FLOOR (CONC)
O_2 15 - 1.5 M ABOVE FLOOR (DEPL)
CONCENTRATION OR DEPLETION (PCT BY VOL)
TEMPERATURE (DEG C)

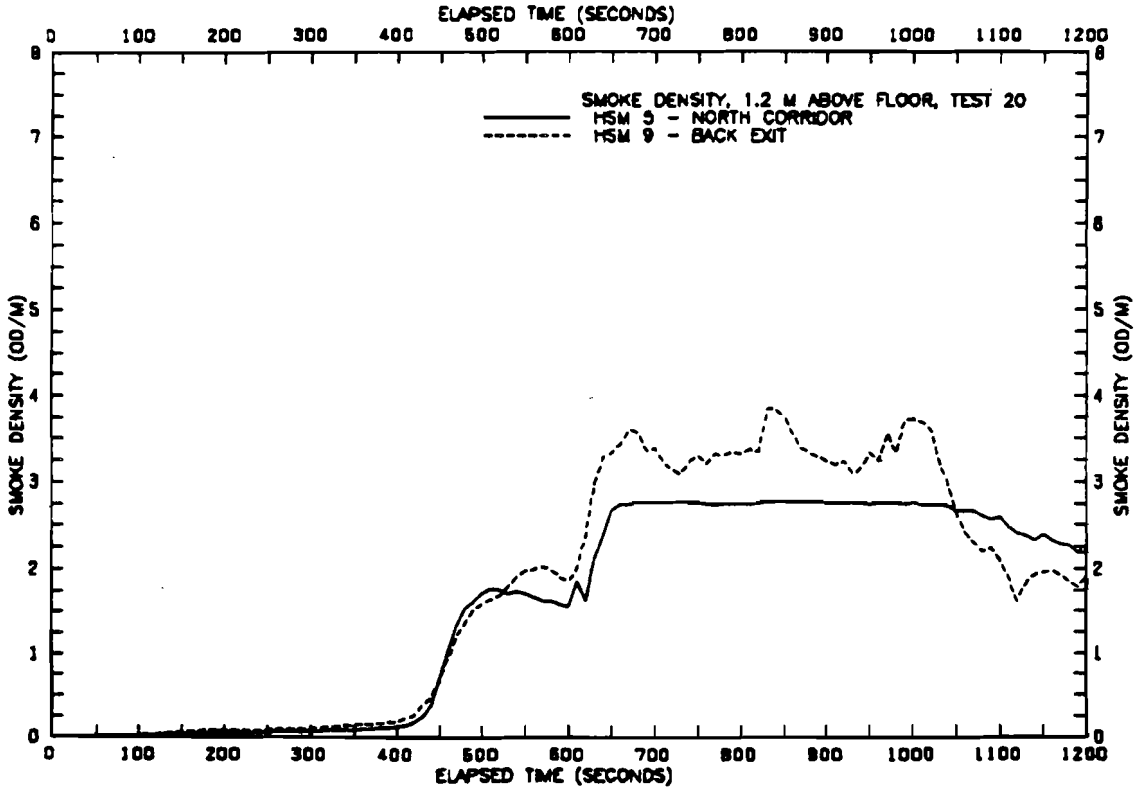

ELAPSED TIME (SECONDS)
TEMP AND GASES, LIV RM, TEST 23
TC 13 - 25 MM BELOW CEILING
CO 13 - 1.5 M ABOVE FLOOR (CONC)
CO_2 14 - 1.5 M ABOVE FLOOR (CONC)
O_2 15 - 1.5 M ABOVE FLOOR (DEPL)
CONCENTRATION OR DEPLETION (PCT BY VOL)
TEMPERATURE (DEG C)

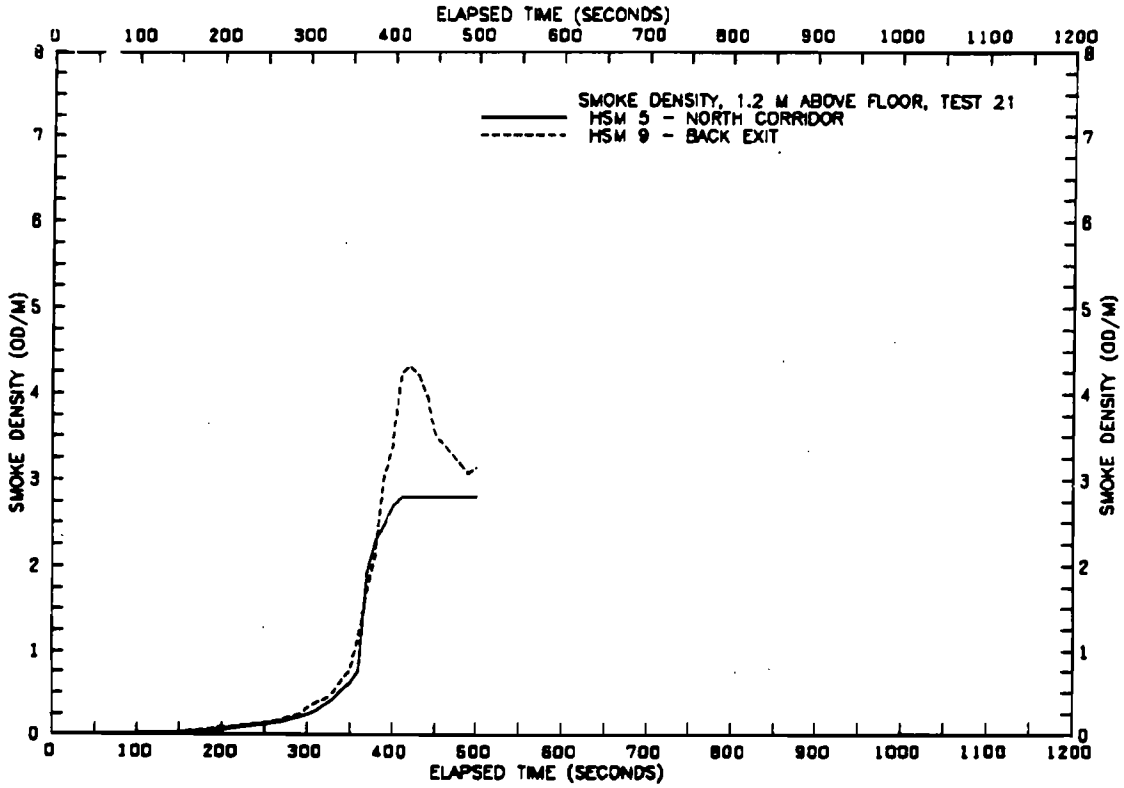

ELAPSED TIME (SECONDS)
TEMP AND GASES, LIV RM, TEST 24
TC 13 - 25 MM BELOW CEILING
CO 13 - 1.5 M ABOVE FLOOR (CONC)
CO_2 14 - 1.5 M ABOVE FLOOR (CONC)
O_2 15 - 1.5 M ABOVE FLOOR (DEPL)
CONCENTRATION OR DEPLETION (PCT BY VOL)
TEMPERATURE (DEG C)

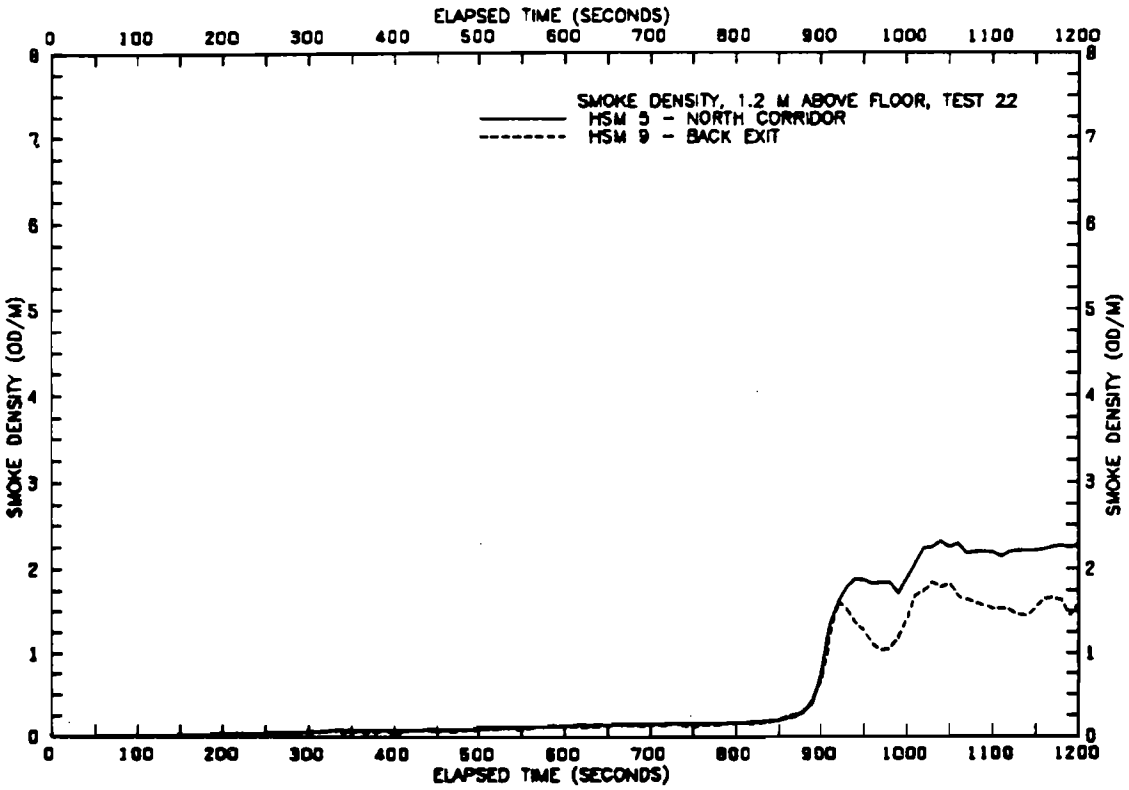

ELAPSED TIME (SECONDS)
SMOKE DENSITY, 1.2 M ABOVE FLOOR, TEST 17
HSM 5 - NORTH CORRIDOR
HSM 9 - BACK EXIT
SMOKE DENSITY (OD/M)
0 100 200 300 400 500 600 700 800 900 1000 1100 1200
0 1 2 3 4 5 6 7 8


ELAPSED TIME (SECONDS)
SMOKE DENSITY, 1.2 M ABOVE FLOOR, TEST 18
HSM 5 - NORTH CORRIDOR
HSM 9 - BACK EXIT
SMOKE DENSITY (OD/M)
0 100 200 300 400 500 600 700 800 900 1000 1100 1200
0 1 2 3 4 5 6 7 8


ELAPSED TIME (SECONDS)
SMOKE DENSITY, 1.2 M ABOVE FLOOR, TEST 19
HSM 5 - NORTH CORRIDOR
HSM 9 - BACK EXIT
SMOKE DENSITY (OD/M)
0 100 200 300 400 500 600 700 800 900 1000 1100 1200
0 1 2 3 4 5 6 7 8


ELAPSED TIME (SECONDS)
SMOKE DENSITY, 1.2 M ABOVE FLOOR, TEST 20
HSM 5 - NORTH CORRIDOR
HSM 9 - BACK EXIT
SMOKE DENSITY (OD/M)
0 100 200 300 400 500 600 700 800 900 1000 1100 1200
0 1 2 3 4 5 6 7 8


ELAPSED TIME (SECONDS)
SMOKE DENSITY, 1.2 M ABOVE FLOOR, TEST 21
HSM 5 - NORTH CORRIDOR
HSM 9 - BACK EXIT
SMOKE DENSITY (OD/M)
0 100 200 300 400 500 600 700 800 900 1000 1100 1200
0 1 2 3 4 5 6 7 8


ELAPSED TIME (SECONDS)
SMOKE DENSITY, 1.2 M ABOVE FLOOR, TEST 22
HSM 5 - NORTH CORRIDOR
HSM 9 - BACK EXIT
SMOKE DENSITY (OD/M)
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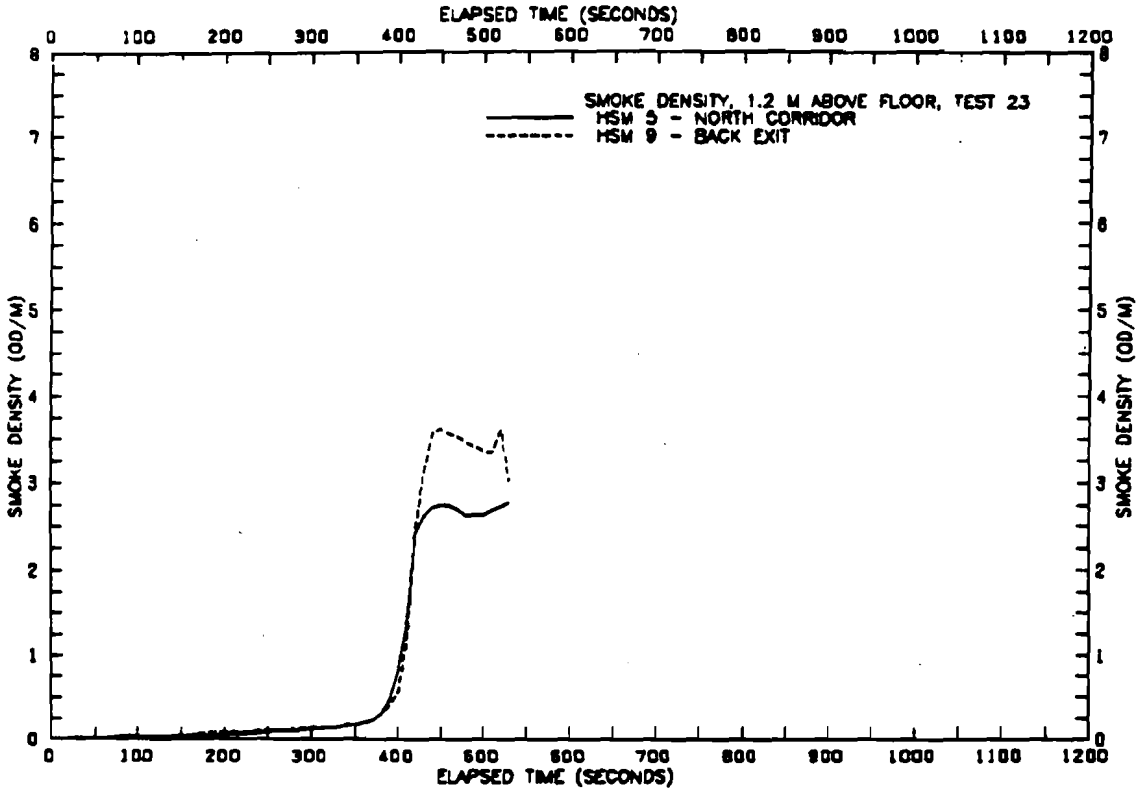
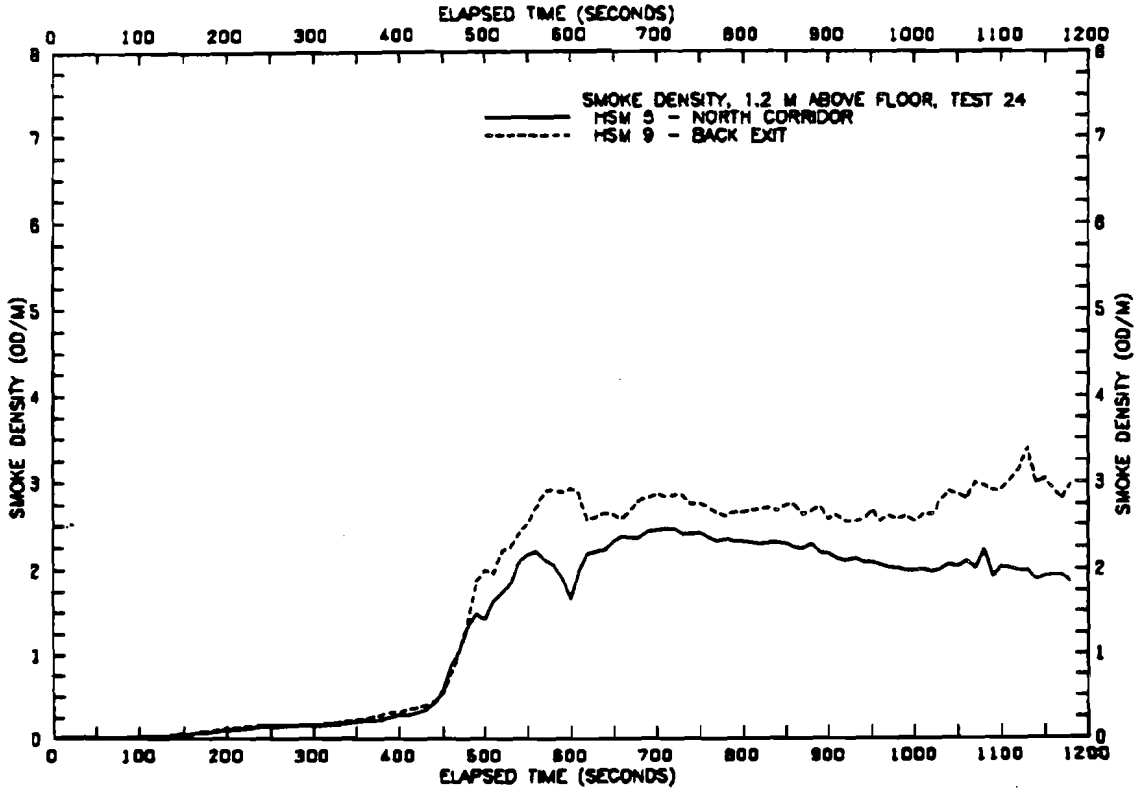
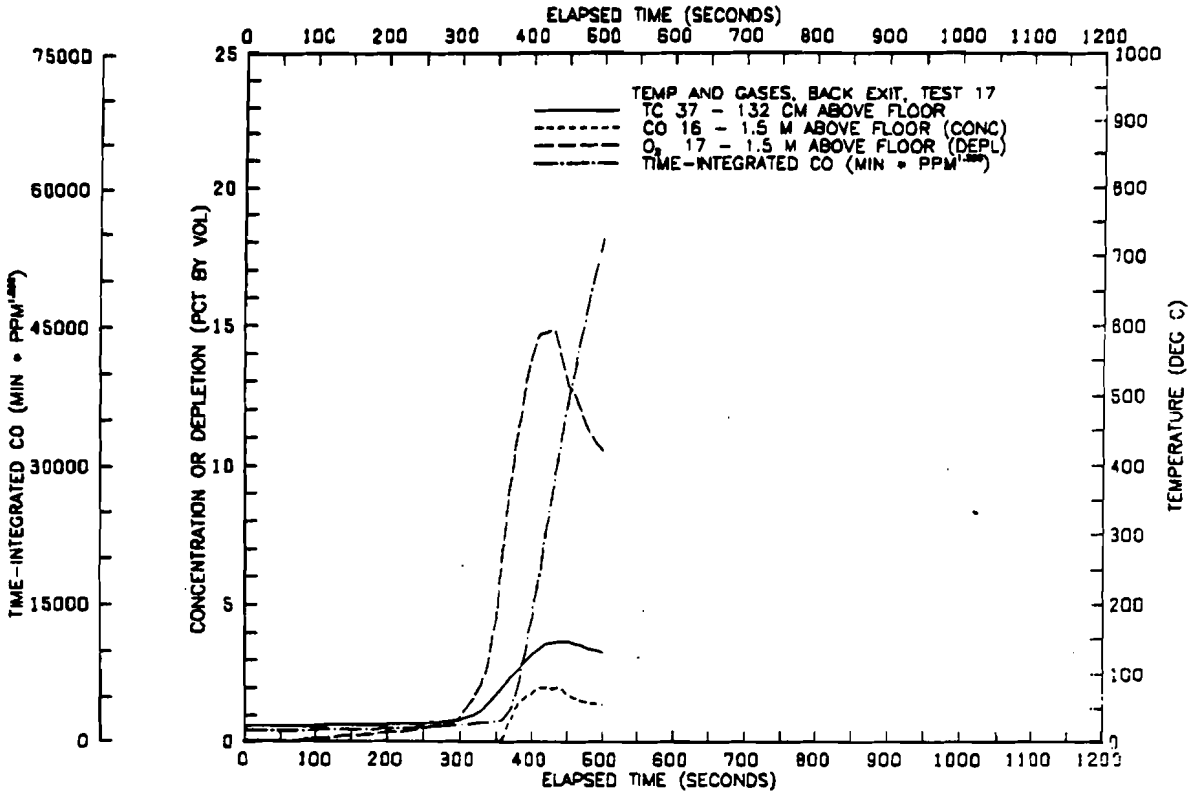
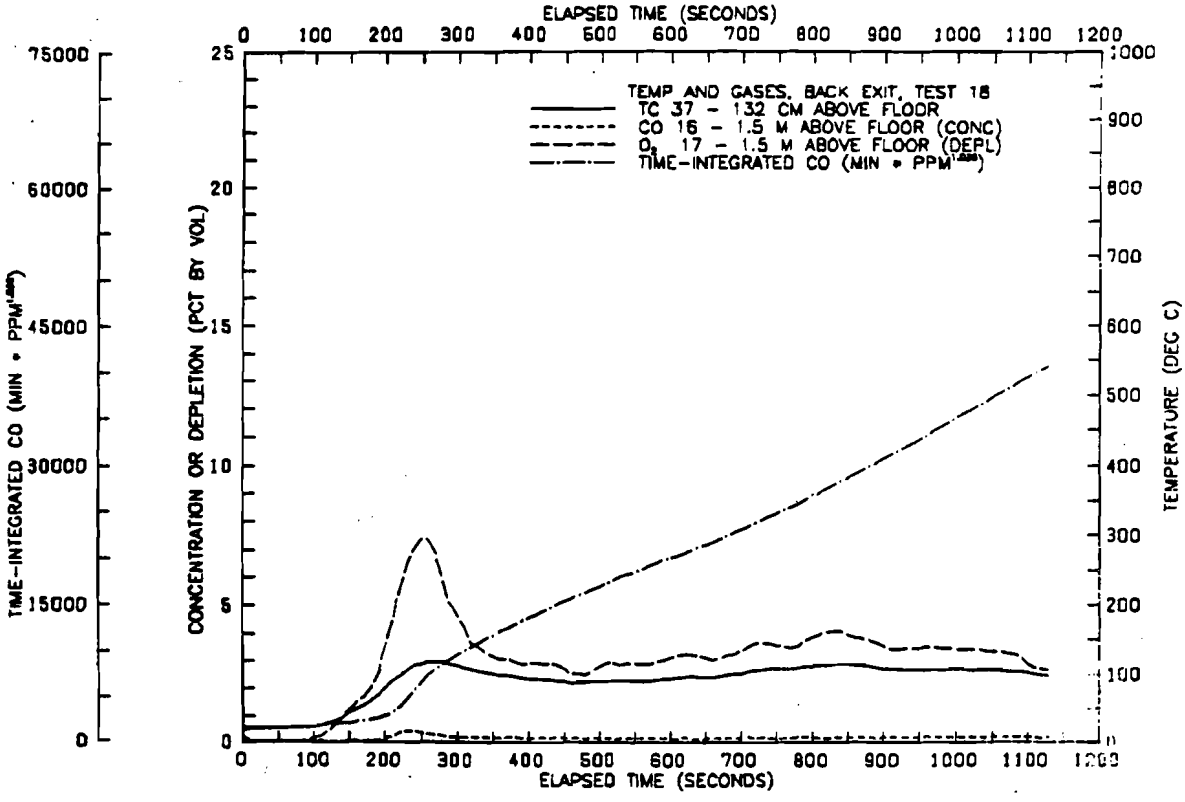
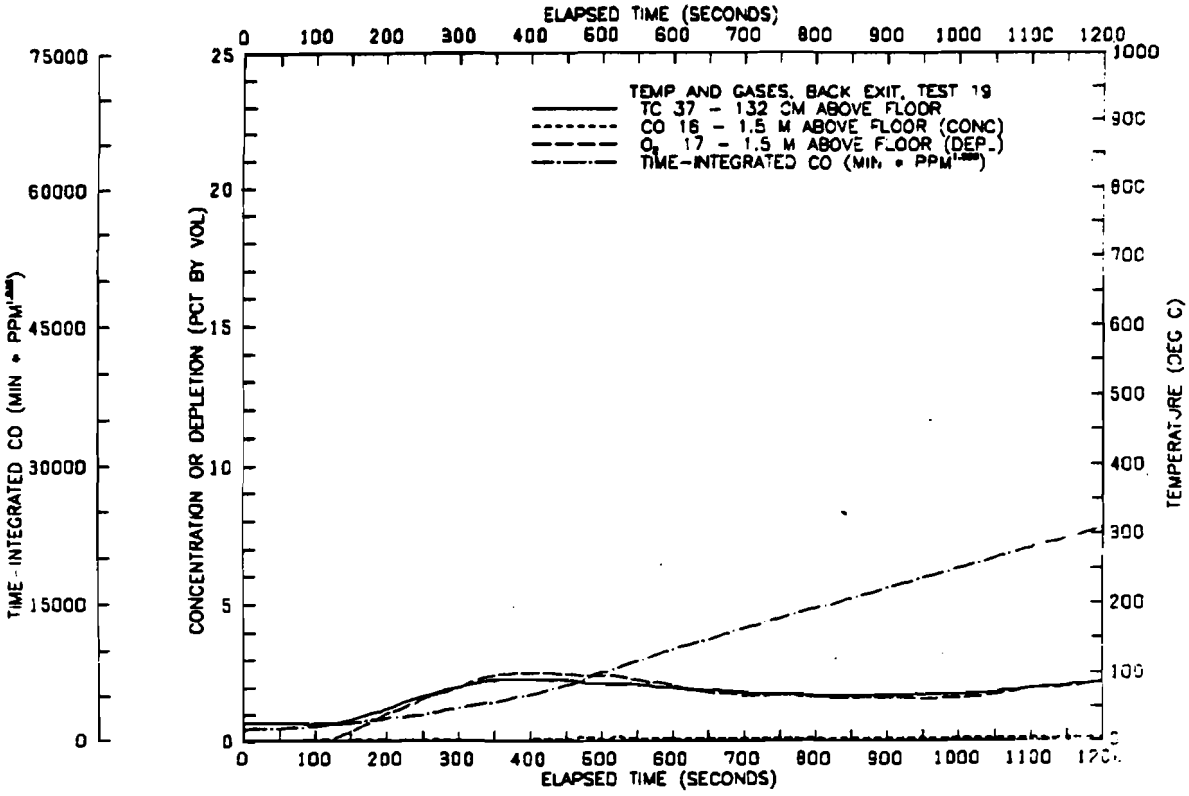
0 1 2 3 4 5 6 7 8

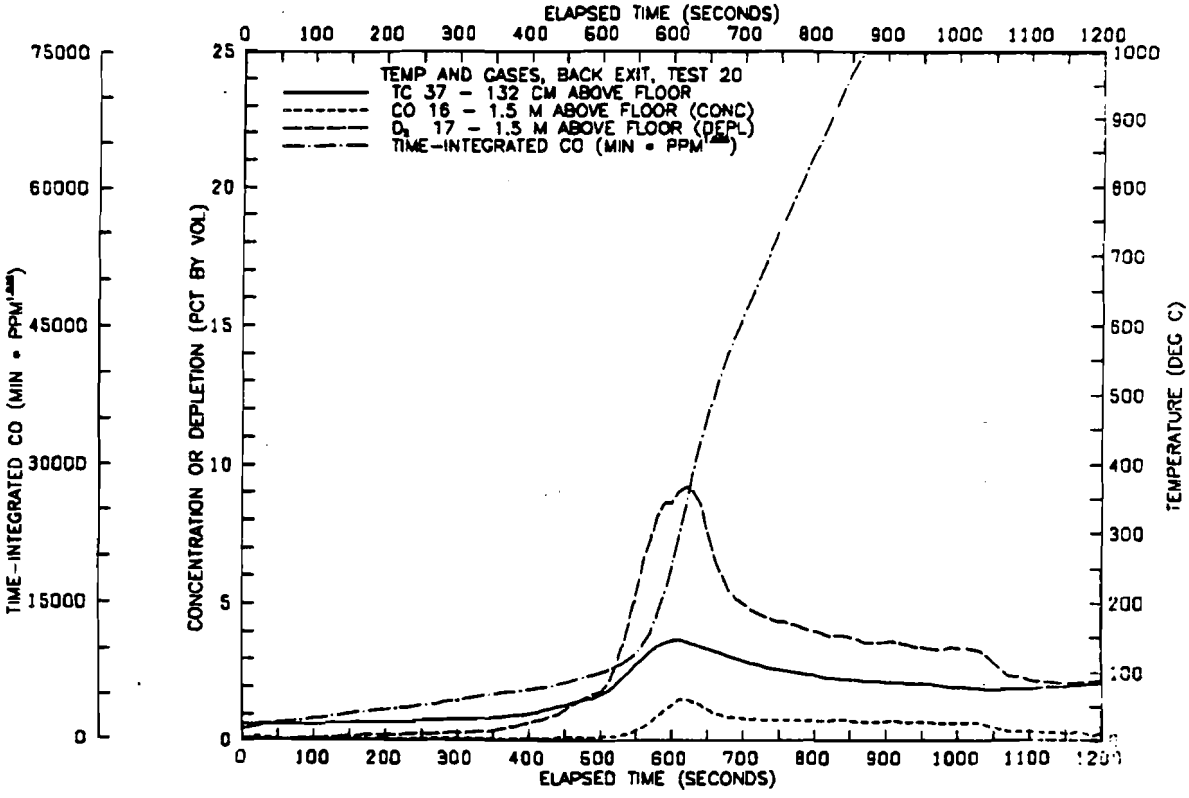

ELAPSED TIME (SECONDS)
SMOKE DENSITY, 1.2 M ABOVE FLOOR, TEST 23
HSM 5 - NORTH CORRIDOR
HSM 9 - BACK EXIT
SMOKE DENSITY (OD/M)

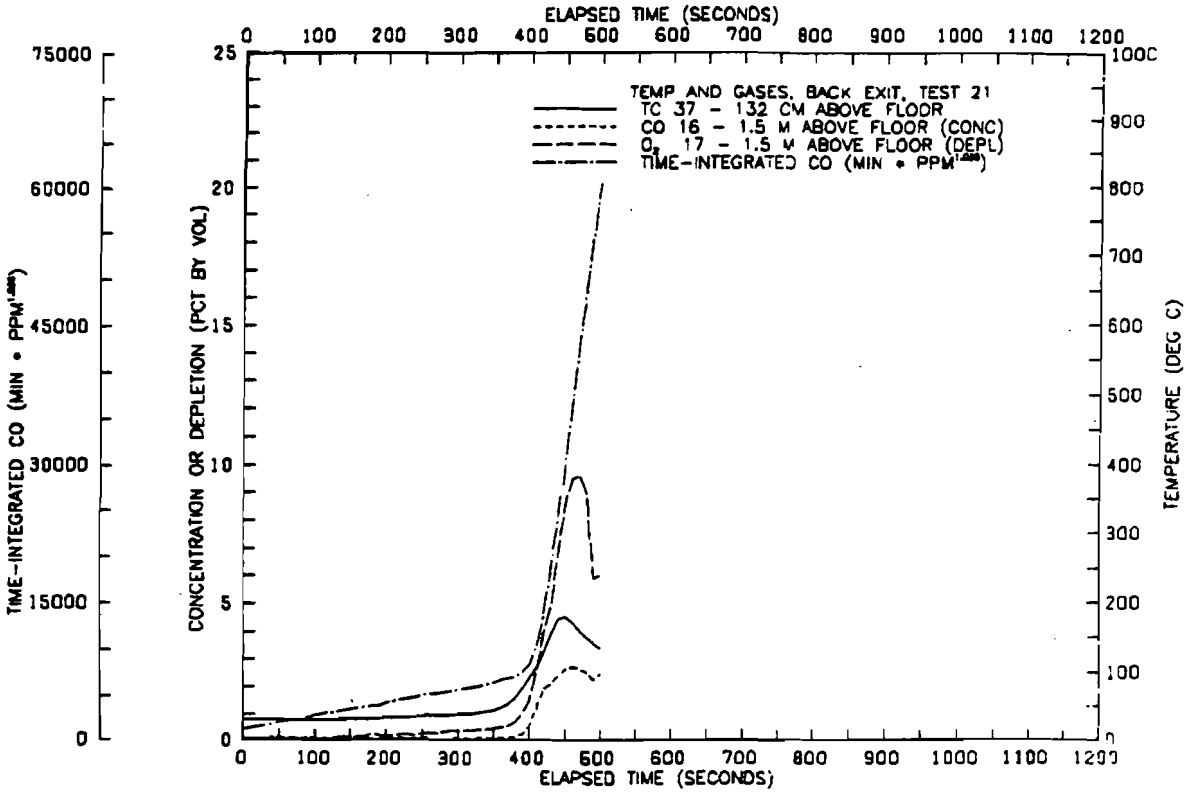

ELAPSED TIME (SECONDS)
SMOKE DENSITY, 1.2 M ABOVE FLOOR, TEST 24
HSM 5 - NORTH CORRIDOR
HSM 9 - BACK EXIT
SMOKE DENSITY (OD/M)

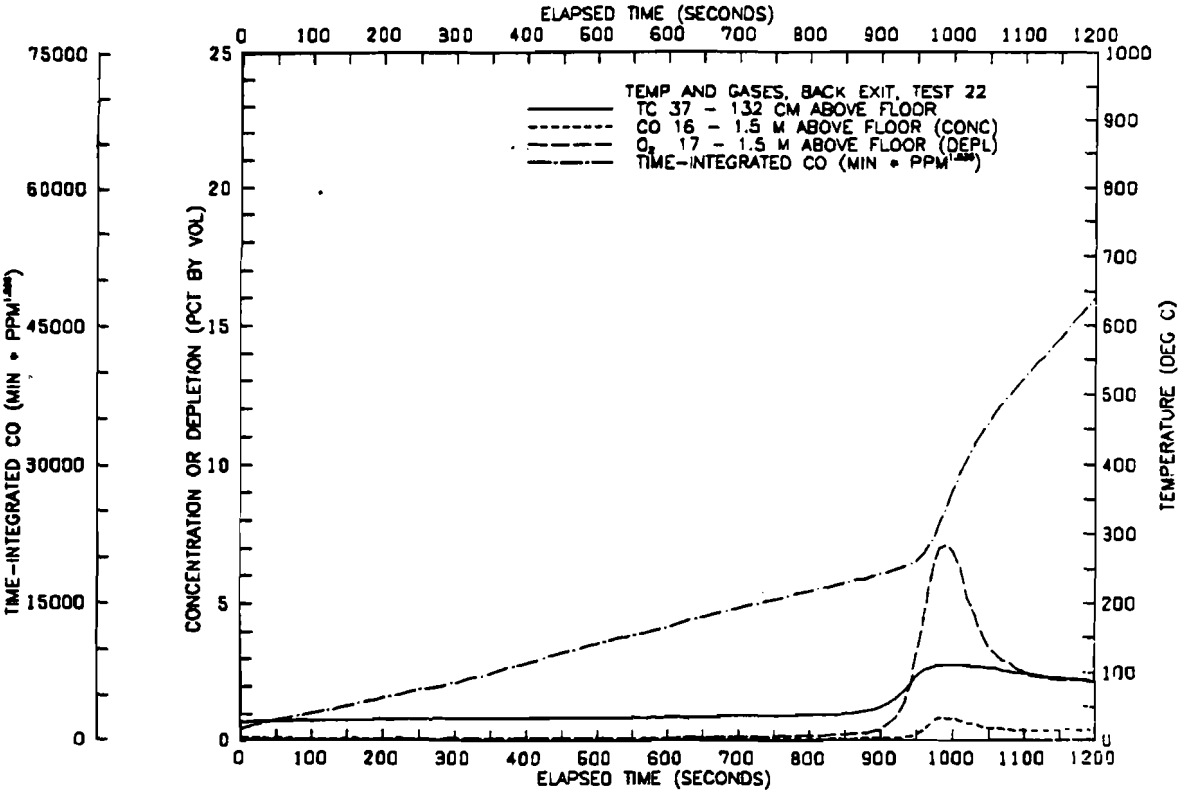

ELAPSED TIME (SECONDS)
TEMP AND GASES, BACK EXIT, TEST 17
TC 37 - 132 CM ABOVE FLOOR
CO 16 - 1.5 M ABOVE FLOOR (CONC)
O2 17 - 1.5 M ABOVE FLOOR (DEPL)
TIME-INTEGRATED CO (MIN • PPM^1.000)
TIME-INTEGRATED CO (MIN • PPM^1.000)
CONCENTRATION OR DEPLETION (PCT BY VOL)
TEMPERATURE (DEG C)

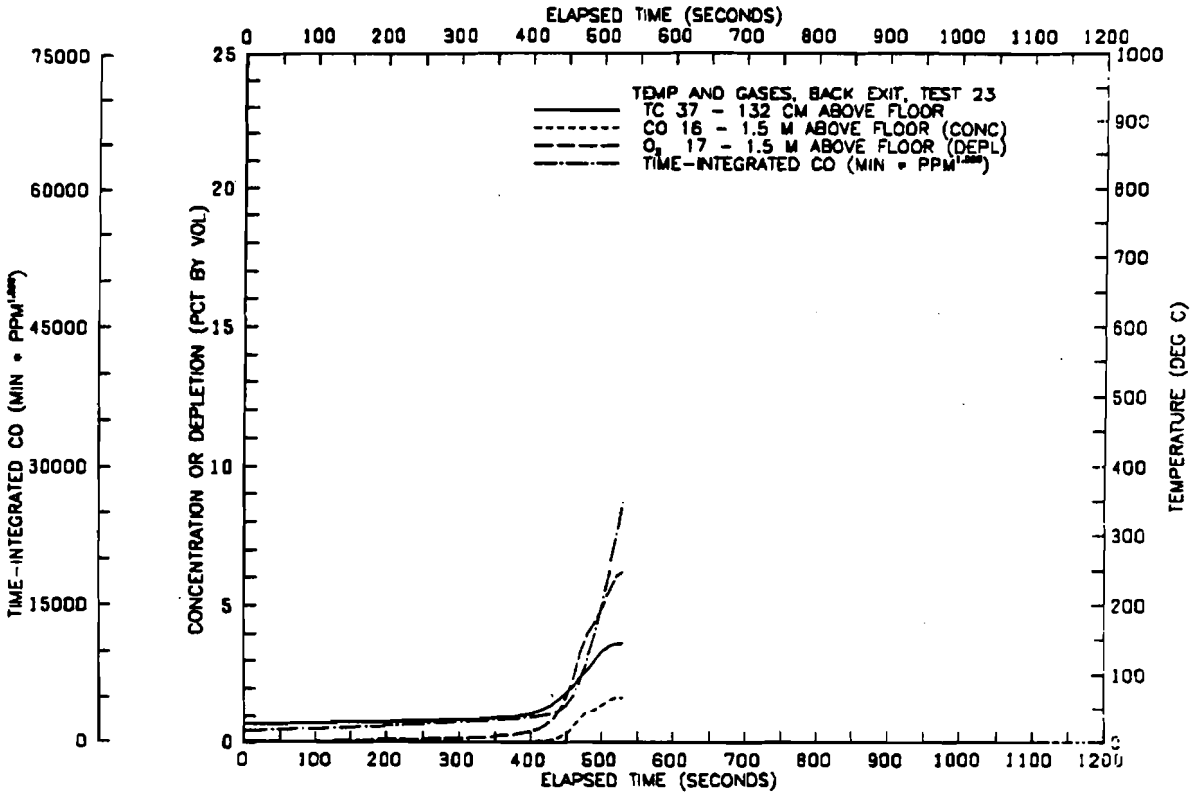

ELAPSED TIME (SECONDS)
TEMP AND GASES, BACK EXIT, TEST 18
TC 37 - 132 CM ABOVE FLOOR
CO 16 - 1.5 M ABOVE FLOOR (CONC)
O2 17 - 1.5 M ABOVE FLOOR (DEPL)
TIME-INTEGRATED CO (MIN • PPM^1.000)
TIME-INTEGRATED CO (MIN • PPM^1.000)
CONCENTRATION OR DEPLETION (PCT BY VOL)
TEMPERATURE (DEG C)

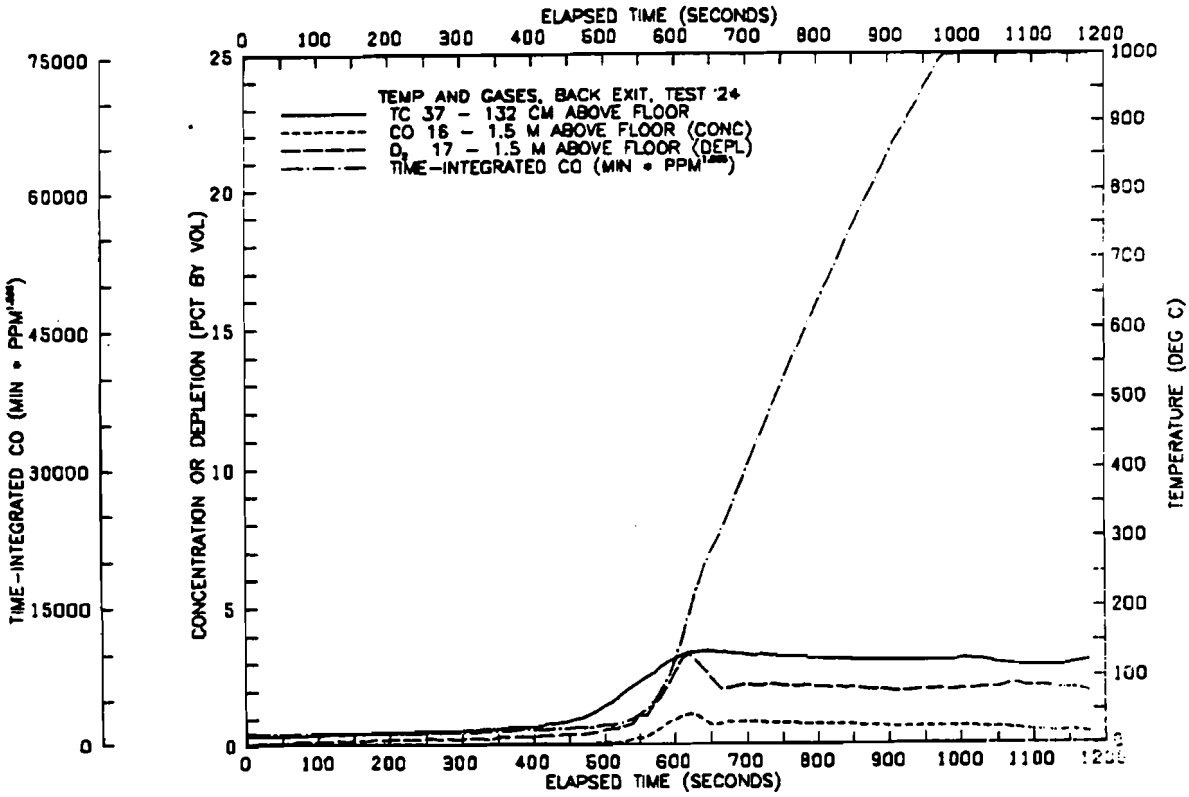

ELAPSED TIME (SECONDS)
TEMP AND GASES, BACK EXIT, TEST 19
TC 37 - 132 CM ABOVE FLOOR
CO 16 - 1.5 M ABOVE FLOOR (CONC)
O2 17 - 1.5 M ABOVE FLOOR (DEPL)
TIME-INTEGRATED CO (MIN • PPM)
TIME-INTEGRATED CO (MIN • PPM)
CONCENTRATION OR DEPLETION (PCT BY VOL)
TEMPERATURE (DEG C)
ELAPSED TIME (SECONDS)


ELAPSED TIME (SECONDS)
TEMP AND GASES, BACK EXIT, TEST 20
TC 37 - 132 CM ABOVE FLOOR
CO 16 - 1.5 M ABOVE FLOOR (CONC)
O2 17 - 1.5 M ABOVE FLOOR (DEPL)
TIME-INTEGRATED CO (MIN • PPM)
TIME-INTEGRATED CO (MIN • PPM)
CONCENTRATION OR DEPLETION (PCT BY VOL)
TEMPERATURE (DEG C)
ELAPSED TIME (SECONDS)


ELAPSED TIME (SECONDS)
TEMP AND GASES, BACK EXIT, TEST 21
TC 37 - 132 CM ABOVE FLOOR
CO 16 - 1.5 M ABOVE FLOOR (CONC)
O_2 17 - 1.5 M ABOVE FLOOR (DEPL)
TIME-INTEGRATED CO (MIN • PPM$^{1.666}$)
TIME-INTEGRATED CO (MIN • PPM$^{1.666}$)
CONCENTRATION OR DEPLETION (PCT BY VOL)
TEMPERATURE (DEG C)


ELAPSED TIME (SECONDS)
TEMP AND GASES, BACK EXIT, TEST 22
TC 37 - 132 CM ABOVE FLOOR
CO 16 - 1.5 M ABOVE FLOOR (CONC)
O_2 17 - 1.5 M ABOVE FLOOR (DEPL)
TIME-INTEGRATED CO (MIN • PPM$^{1.666}$)
TIME-INTEGRATED CO (MIN • PPM$^{1.666}$)
CONCENTRATION OR DEPLETION (PCT BY VOL)
TEMPERATURE (DEG C)


ELAPSED TIME (SECONDS)
TEMP AND GASES, BACK EXIT, TEST 23
TC 37 - 132 CM ABOVE FLOOR
CO 16 - 1.5 M ABOVE FLOOR (CONC)
O_2 17 - 1.5 M ABOVE FLOOR (DEPL)
TIME-INTEGRATED CO (MIN • PPM$^{1.666}$)
TIME-INTEGRATED CO (MIN • PPM$^{1.666}$)
CONCENTRATION OR DEPLETION (PCT BY VOL)
TEMPERATURE (DEG C)


ELAPSED TIME (SECONDS)
TEMP AND GASES, BACK EXIT, TEST 24
TC 37 - 132 CM ABOVE FLOOR
CO 16 - 1.5 M ABOVE FLOOR (CONC)
O_2 17 - 1.5 M ABOVE FLOOR (DEPL)
TIME-INTEGRATED CO (MIN • PPM$^{1.666}$)
TIME-INTEGRATED CO (MIN • PPM$^{1.666}$)
CONCENTRATION OR DEPLETION (PCT BY VOL)
TEMPERATURE (DEG C)

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15. SUPPLEMENTARY NOTES

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

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

Since 1974, a major research project has been ongoing at the National Bureau of Standards to investigate various aspects of fire growth and spread in typical single-wide mobile homes. The objective of this project is to provide recommendations for possible changes to the Federal Mobile Home Construction and Safety Standard promulgated in June, 1976 by the Department of Housing and Urban Development. These changes are intended to provide an improved level of fire safety in mobile home construction.

This report provides a summary of the important findings from previously reported parts of the project which involved the conduct of full-scale fire tests in the kitchen, corridor, living room and bedroom areas of typical mobile homes. Also included in this summary are the findings from a previously unreported series of full-scale living room tests, which are discussed in some detail in Appendix A.

This report describes the rationale upon which the overall experimental approach was based, and provides a series of recommendations, some in the form of design options, for possible changes to the standard. A limited impact assessment is included to provide a relative measure of the potential impact of each of three design options for flame spread requirements for interior wall and ceiling materials. This assessment is based on the likely effect of each option on fire severity, and does not include an economic analysis.

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

ASTM E-84 Tunnel Test; construction standard; fire growth; fire tests; flame spread; flashover; impact assessment; interior finish; kitchen fires; life safety; mobile homes; room fires.

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