NBSIR 77-1290

Combustion of Mattresses Exposed to Flaming Ignition Sources
Part I. Full-Scale Tests and Hazard Analysis

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Center for Fire Research
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September 1977

Final Report

Sponsored in part by

Department of Health, Education and Welfare
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EXECUTIVE SUMMARY

In the past few years a number of serious, multiple life loss fires have occurred in health care institutions, specifically nursing homes, and in prisons. In many of these cases mattresses have been the initial or main fuel items. A mattress cigarette ignition standard (FF 4-72) has been in force since 1973, but case histories indicate that additional measures may be necessary. In response to this need the National Bureau of Standards initiated a mattress flammability test program. The first part of the work has consisted of a series of full size room fire tests on institutional mattresses.

Two burn-rooms, simulating patient rooms, were used for making the tests. The rooms were set up so as to permit different ventilation conditions to be established. The rooms were instrumented for temperature, mattress weight loss, heat flux, smoke obscuration, gas concentration, and flow velocity measurements. Ten mattresses and a fiberglass control mattress were subjected to a total of 22 tests. Included was a mattress associated with a serious nursing home fire and one associated with a prison fire. Each mattress was tested with a set of standard hospital bedding in an otherwise unfurnished room and ignited with a small trash-filled polyethylene wastebasket.

To evaluate the test results a hazard assessment methodology was developed that considered the potential of a mattress alone for causing room flashover and the development of untenable conditions within the room of fire origin. Three tenability variables were identified — heat flux, gas concentration, and smoke obscuration.

The main findings of the study were the following:

1) The evaluation revealed four distinct groups into which the test mattresses could be placed, in order of safety:

   a. Those that did not cause any of the tenability criteria to be exceeded for the duration of the 30-minute test. This category included two cotton batting mattresses.
   b. Those that did not exceed the flashover criterion or the heat flux and gas criteria, but exceeded the smoke obscuration criterion. This category included two neoprene foam core mattresses.
   c. Those that exceeded all the tenability criteria but did not lead to full room involvement. This category included three polyurethane foam core mattresses and one of mixed fibers construction. The best performing of the polyurethane mattresses was associated with a multiple life loss prison fire.
   d. Those that failed all criteria. This category included one latex foam core and one polyurethane foam core mattress. The latex mattress was associated with a multiple life loss nursing home fire.

2) Mattress core material type and total fuel content were the main variables governing rate of fire development.

3) Mattress ticking was not an important variable in determining performance, when a sustained flaming ignition source was used.

4) The main effect of an innerspring was to reduce the combustible content of the mattress.

5) Polyurethane and latex foam mattresses showed a tendency to burn vigorously in a molten pool under the mattress. Thus, in testing, an ignition source should be used that can reveal this behavior.

6) Some mattresses showed a better performance than the control (which included the bedding and the wastebasket). This effect was interpreted as a possible quenching action, either chemical or physical, of the mattress.

7) The effect of restricted ventilation within a given compartment was to lower the peak burning rate but not the time to reach the peak. Increased carbon monoxide levels were also developed.

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COMBUSTION OF MATTRESSES EXPOSED TO
FLAMING IGNITION SOURCES

PART I. FULL-SCALE TESTS AND HAZARD ANALYSIS

Vytenis Babrauskas

Abstract

A test program was conducted to assess the hazards of institutional mattresses when subjected to a sustained flaming ignition source. This report gives results on full-scale room burns of ten different mattress types under several ventilation conditions. Tenability and rapid flame spread potential criteria were applied in a hazard assessment which showed a wide range of behavior among mattresses now being used in institutions. An extensive review of previous fire tests involving mattresses is included.

Key words: Bedding; beds; compartment fires; firesafety engineering; fire tests; health care facilities; hospitals; mattresses; prisons.

1. INTRODUCTION

The fire behavior of mattresses used in health care facilities and in penal institutions has recently come to be of concern. To explore several facets of the potential hazards posed by burning mattresses a mattress test program was formulated by the Center for Fire Research at the National Bureau of Standards. Initial work was started in mid-1976. The present report is the first of a series and contains some of the data gathered in full-scale room tests and an analysis of potential mattress fire hazards.

The test program was sponsored in part by:

-- Department of Health, Education and Welfare, HEW/NBS Life/Fire Safety Program, sponsored by the Public Health Service

-- Veterans Administration, Department of Medicine and Surgery

-- Department of Defense, Naval Facilities Engineering Command

-- Consumer Product Safety Commission, Bureau of Engineering Sciences.

2. REASON FOR STUDY

A mattress ignition standard (FF 4-72) [1][1] exists to prevent cigarette ignition, but it is not addressed to the burning behavior of mattresses after ignition by other sources. A study of mattress hazard under flaming ignition conditions is considered important since mattress and bedding fires account for about 35% of the fires originating in furniture, furnishings or clothing [2]. Other data indicate [3] that in residential occupancies open flame ignitions of furnishings account for 5% of total U.S. fire deaths (compared to 27% for ignitions by smoldering smoking materials). Comparable figures for institutional occupancies are not available.

Mattresses intended for use in institutions or other special hazard occupanices should be evaluated differently for flaming hazards than those used in residences. Mobility and potential for escape is quite different in a hospital or a prison than it is in a home. Effective fire performance specifications are needed and these can only be established if a common quantitative basis for assessing mattress fire behavior exists. The present study is intended to provide such a common basis, whereby the hazards of mattresses in institutional occupancies can be evaluated.

Concern in institutional occupancies has been focused on multiple life loss fires. Mattresses have been the initial or the main fuel items in many of these cases, particularly in nursing homes and prisons. The rate of fire development was typically much greater than had been anticipated by those involved. Three elements can be seen in these institutional fires: (1) short time between discovery of fire and the development of untenable conditions; (2) short total duration of the incident; and (3) catastrophic results.

Several instances exemplifying the concern can be cited. In 1974 a fire started [4] in a patient room at the Sac-Osage Hospital in Osceola, Missouri. The patient room had a low fuel loading but the major part of which was a latex foam mattress. The fire is believed to have originated in the bedding. Fire spread was limited to the room of origin but seven of nine patients in the wing of fire origin died.

A fire was started by a faulty electrical cord in 1976 at the Cermak House Nursing Home [5] in Cicero, Illinois. Rapid flame spread and smoke evolution are believed to be partially attributable to the involvement of the mattresses. The mattresses were examined and found to be constructed of layers of polyurethane foam, cotton batting, and sisal pad. The fire resulted in eight fatalities.

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[1] Numbers in brackets refer to the literature references listed in Section 15 at the end of this report.

A fire occurred in 1976 at the Shenandoah Homes in Roanoke, Virginia, a residence for the elderly, that claimed four lives [6]. Initial ignition was from cigarette smoking in bed. Ignition of the polyurethane foam mattress may have occurred through intermediate ignition of some bedding. The room of fire origin was burned out, with only smoke damage on the rest of the floor. Three of the four fatalities were in rooms other than the one of fire origin, pointing to a significant combustion rate and smoke generation problem.

Mattress fires in prisons have tended to be purposeful ignitions, often with the intent of creating a disturbance rather than causing fatalities. Multiple fatality prison fires have been common. A fire was set in the Seminole County Jail, Sanford, Florida in 1975 [7]. A pile of stored polyurethane foam mattresses was ignited with crumpled newspaper by a prisoner. The resulting fire in this otherwise largely fuel-free environment caused the death of ten prisoners and one guard. All except one were in areas somewhat removed from the fire origin cell.

A fire was set by prisoners in the Lycoming County Prison, Williamsport, Pennsylvania, also in 1975 [8]. Several prisoners piled three polyurethane foam mattresses at the bottom of a stairs and ignited them with a cigarette lighter. The fire progressed to such an extent between the time when first noticed and the guards' arrival near the area of origin, that they could not attempt rescue or extinguishment. Three prisoners died in the fire.

Whether the incidents cited above could have been mitigated depends to a large extent on knowledge of mattress burning characteristics. The purpose of the present study was to determine the comparative burning behavior of several currently available institutional mattresses in a full-scale room test, using a sustained flaming ignition source. Succeeding parts of this work will contain further analysis and a proposed small scale test methodology which may be used as a general test protocol. It must be emphasized that no correlation is known to exist between mattress behavior when exposed to flaming ignition sources, as explored in this investigation, and mattress resistance to cigarette ignition, as measured in the cigarette ignition standard [1].

3. REVIEW OF PREVIOUS WORK

Concern over the potential for mattress flammability can be traced at least to the early 1950's. In 1954 Segal [9], from the California State Fire Marshal's Office, compared the fire behavior of cotton and latex mattresses. He found the former more easily ignitable but the latter more flammable once ignited. He considered ignitability more important and thus assessed the hazard of latex mattresses to be lower. In 1963 Swanson and Adolph [10] decided to re-examine the question with special emphasis on usage in hospitals. They subjected the cotton mattresses, with and without innersprings, and a latex mattress to both glowing and flaming ignition sources. With glowing sources the latex mattress core only melted but did not flame or smolder. The cotton mattresses, by comparison, smoldered progressively after glowing ignition. With open flame ignitions, the latex mattress ignited and flamed, while those made of cotton again smoldered. Motivated partly by the superior hygienic and durability qualities of latex mattresses, Swanson and Adolph recommended that the latex mattresses be considered as superior.

The Los Angeles Fire Department became interested in mattress safety and in 1965 Hammack [11] briefly reported some experimental work. He investigated some details of cigarette combustion and then conducted cigarette ignition tests on small mattress mockups. Only cotton mattress materials were studied. The recommendations urged more materials development and more use of flame retardants in tickings and in mattress pads.

The three above studies dealt with exposures to small ignition sources. In the early 1960's concern over nuclear weapons effects prompted a program of large-scale fire testing at the IIT Research Institute (IITRI). As part of that work Vodvarka and Waterman [12] reported a series of 80 tests on upholstered furniture and beds. "Typical" living room and bedroom furniture arrangements were set up and ignited with a small amount of JP-4 fuel. The main variable considered was time to flashover. In living rooms containing furniture with cotton stuffing, flashover was reached in a median time of 17 min, while with latex furniture the time dropped to 8.5 min. Bedrooms were tested with cotton mattresses and either box springs or open springs. No latex mattresses were tested. With box springs the median was 9 min, while with open springs no flashover was recorded.

Statistics on mattress fires were compiled in Canada in the early 1960's. The large number of fatalities attributable to smoking in bed led Sumi and Williams-Leir [13] to conduct a cotton mattress flammability study in 1969. The first part of their study consisted of some small scale mattress experiments with cigarette ignition. Vinyl sheeting was shown in these tests to be sufficient to prevent mattress ignition. The second part of the study was a series of room fire experiments. A mattress was the only fuel and was ignited with a cigarette. Experiments were conducted with the room completely sealed and with the door ajar by 25 and 50 mm. Gas measurements were made for CO, CO_2, and O_2, but a consistent effect of ventilation was not observed. Temperature rise near the ceiling, however, increased significantly with ventilation. The authors noted that automatic sprinklers, even with low temperature (57 °C) heads would not have been effective due to the low temperatures associated with the predominantly smoldering combustion.

In the United States the 1967 amended Flammable Fabrics Act (81 Stat. 568) resulted in the Office of Flammable Fabrics being established at NBS. It was determined that mattress flammability was one area that needed to be investigated. Fire incidence and injury data showed [14] that mattresses are commonly the first item to ignite and that smoking materials are a frequent ignition source. Studies of mattress cigarette ignition were conducted from 1969 through 1972 and resulted in the 1972 Flammability Standard for Mattresses [1]. The studies have not been published, but brief synopses are given in annual reports [15-17].

During the same period NBS also sponsored a fire study of mattresses and upholstered chairs at Southwest Research Institute [18,19]. In that test series a succession of small ignition sources — cigarettes, matches, methenamine pills — was used. The specimens were located in a full-sized test room, where temperature, gas concentrations, and smoke obscuration were monitored. The test configuration involved an unusual feature of a dummy laid down to depress the mattress. Several variables were explored: mattress core type, ticking type, and bedding type. Neither the ticking nor the sheet type had a significant effect. A flame retardant treated mattress cover alone was not effective, but when the sheets and blanket were also retardant treated the combustion was significantly reduced (there was no sustained ignition source). It was further noted that laundered bedding did not perform as well as unlaundered bedding.

In the late 1960's the U.S. Navy was presented by a manufacturer with a design for a fiberglass core mattress. It was intended to provide an improved fire performance over the long-used neoprene core mattresses. NBS was asked to conduct comparative flammability tests. A program of small scale tests resulted. Flame spread was measured with the ASTM E-162 radiant panel, the potential heat was determined, and the NBS smoke chamber was used to determine both smoke density and five toxic gas species. This series marked the first reported use of small scale standard tests for assessing post-ignition mattress fire performance. The proposed fiberglass mattress performed better than the neoprene in the flammability tests but was not adopted because of comfort and wear problems [20].

The effects of highly fire resistive materials were examined in a 1973 test series by Battelle Columbus Laboratories [21]. Four bedroom tests were conducted. The mattresses included a cotton batting type and three polyurethane foam specimens with various retardant additives and improved tickings. The test rooms also had additional furnishings, which were varied in the tests. The ignition source was a wastebasket filled with newspaper. Because of the many fuel load variables that were simultaneously changed, a clear-cut assessment of mattress flammability could not be made. It was found that the best performance was obtained by using components of low intrinsic flammability, or retardant treated, or intumescent coated.

Hilado reported in 1973 on a series of mattress tests [22] conducted at Union Carbide. Two types of specimens were tested under a hood: small mattress mockups and full size mattresses. The mockups were without bedding and were subjected to a progressive series of cigarette, match, and methenamine pill ignitions. Mattresses tested were cotton, polyurethane, and latex, with and without retardants. With cigarette ignitions it was found that, contrary to the results of Swanson and Adolph, the latex mattresses progressively smoldered while the cotton and urethane ones did not. With match and pill ignitions cotton and urethane specimens could also be ignited. In the full-size mattress tests the effects of different pieces of bedding were examined. The pillow type was found to be the major variable. Down and feather pillows performed best, latex foam filled pillows worst, with polyester filled ones being intermediate.

A mattress evaluation project was conducted by Parker [23] at NBS for the Naval Ship Engineering Center in 1973. A neoprene and two types of retardant treated polyurethane mattresses with several types of ticking were burned in a full-size room under different orientations and ventilation conditions. The mattresses all passed the FF-4-72 test. The ignition source consisted of 500 ml of ethanol. The neoprene core mattress performed better than the urethane ones. A retardant treated ticking was sufficient to significantly protect the neoprene and one of the polyurethane mattresses against the ignition source used. The mattresses burned more completely when positioned vertically, as they might be in storage, than when in the normal horizontal position. In addition to the full-size room tests a variety of small scale tests were performed. These included ease of ignition, rate of heat release, smoke, flame spread, and a scaled down geometric modeling. No specific criteria were developed for minimum small scale performance.

In 1974 Stark [24] reported a study on polyurethane cushions and mattress core material. The main intent of this work was to measure toxic gases. Four urethane materials with different formulations were covered with cotton ticking and subjected to a newspaper and cotton cloth fire from below. Oxides of nitrogen (NO_x) values up to 900 ppm and hydrogen cyanide (HCN) up to 2400 ppm were detected at the top of the room doorway in the worst case. Tolylene diisocyanate was also investigated because of its potential contribution to the toxicity but was not observed above the detection level of 3 ppm. The fuel load of urethane used ranged between 12.7 and 32.2 kg and was taken to represent two mattresses.

The Urethane Safety Group of the Society of the Plastics Industry sponsored a series of room fire experiments at the Southwest Research Institute in 1974. Armstrong [25] tested both mattresses and other upholstered furniture in a room and corridor facility. The mattresses were tested without any bedding and were ignited with a gas pilot burner. A single ticking type was used for all mattresses. Of the 19 test specimens, the latex foam ones performed poorly, cotton batting ones performed well and urethane ones, with the exception of two high-resiliency retardant treated formulations, generally performed poorly. The behavior of the cotton and high-resiliency retardant treated urethane mattresses is difficult to interpret in view of the fact that, in the absence of bedding, the specimens had to be subjected to a continuous gas burner flame for the duration of the test to ensure that the fire would not go out. A systematic ranking of specimens was attempted by evaluating the habitability threats (temperature, toxic gases) in percent of allowable exposure, as a function of time. The above work has recently been summarized by Anyos [26].

In 1974 the Centre Scientifique et Technique du Bâtiment established an on-going mattress test program. Two series [27,28] of tests have so far been completed. In the first series four tests were conducted without bedding, while in the second an additional eight tests explored some bedding variables. The test mattresses were burned in a small standardized test chamber. The ignition source was a 100 g wood crib placed in contact with the edge of the mattress at the head of the bed. The igniting crib burned for six to eight minutes. Temperatures were measured inside the mattress, at the top of the mattress, and 0.2 m above the mattress. Weight loss was recorded and converted to approximate heat release values. Several types of mattresses were tested: "traditional" kapok innerspring specimens and three polyester urethane foam units — 17 kg/m^3 hot-cured, 25 kg/m^3 hot-cured, and 35 kg/m^3 cold-cured. Tickings examined included both plain and retardant treated fabrics. Two bedding combinations used were a cotton/linen sheet with a wool blanket and a polyester/cotton sheet with an acrylic/cotton blanket.

Of the bare mattresses, the kapok specimen burned the slowest; it smoldered without flaming for 6.5 hours. The 17 kg/m^3 foam specimen with non-retarded ticking burned very rapidly and was consumed in 12 minutes. The 35 kg/m^3 foam specimen with retarded ticking burned more slowly (29 min) but showed slightly higher temperatures. The addition of bedding to the kapok mattress did not significantly change its behavior. For the foam core mattresses the cotton/linen and wool bedding reduced the burning rate in each case. The polyester/cotton and acrylic/cotton bedding decreased the burning rate on the 35 kg/m^3 retarded ticking specimen but significantly increased the rate for the 17 kg/m^3 non-retarded ticking mattress. The above results seemed to point to the fact that the wood crib was not placed so as to assure a sustained source for ignition. To check this point a test which showed negligible heat release was repeated with the crib placed at the foot of the bed, in contact with the blanket. A greatly increased burning rate resulted.

The American Health Care Association [29] reported in 1975 on a number of fire tests of nursing home rooms conducted in association with the IIT Research Institute. The investigation of furnishings was not the primary objective, but a series of five room tests for exploring mattress flammability was included. The mattresses included four polyurethane and one cotton specimen and were ignited by a wastebasket fire. The rooms also included other additional furnishings. None of the bed tests produced a serious fire. The reasons for this limited burning were not investigated, even though prior IITRI testing [12] indicated the possibility of serious bedroom fires.

The Fire Research Station, at Borehamwood, conducted during 1975-76 three separate but related series of mattress tests [30-32]. In one series [30] the effects of bedding were tested. The test room was otherwise unfurnished and ignition was with newspapers under the bed. A woolen blanket was demonstrated to reduce fire intensities, while a retardant treated acrylic blanket showed increased intensity, and unretarded acrylic, cotton and polypropylene blankets gave greater intensities yet. In another series [31] rooms with additional furnishings were used, partly to explore the hazard increase from additional fuel. The involvement of the additional fuel was seen to depend strongly on the type of mattress used, as well as on the mode of ignition. Newspapers placed under the bed gave rise to the smallest fires, those ignited between the sheets produced larger fires, while the ignition of unmade heaped up bedding gave the most severe fires. A mattress of cellulosic material with a woolen blanket and feather pillow produced the least severe conditions and did not cause sustained ignition of wooden furniture 0.25 m away. A latex mattress with acrylic blanket and polyurethane pillow was sufficient to cause a rapid fire involving most of the combustibles in the room. A "standard" polyurethane mattress performed similarly to the latex one but an "improved" one performed somewhat better, mainly in not igniting significant additional fuels. In a third series [32] a larger number of mattresses was tested in an unfurnished room. Generally newspaper ignition on top was used, but it was observed that bottom ignition produced more severe, although slower to develop, fires. A wool blanket was shown not to reduce the fire if the bedding was largely unmade. Hair and fiberglass interliners reduced fire intensity considerably by inducing more smoldering and less flaming. Of the test mattresses, hair and cotton construction showed the best performance while polyurethane and latex were generally less satisfactory. The latex mattress produced the highest smoke concentrations. Urethane mattresses where both the core and the cotton cover were fire retardant treated showed considerably improved behavior over other urethane mattresses.

Mattresses were one of the major fuel items in a sequence of three bedroom tests [32-35] conducted in 1973-75 by Factory Mutual Research Corporation and Harvard University. Only a single urethane mattress and a single ignition source was used. The objective of the tests was to analyze theoretically the resulting flow fields, rather than to compare furniture. The work resulted in a detailed description [35,36] of mattress burning rates and a characterization of the flame spread behavior. The mass liberation rate was determined to be closely approximated as exponential growth. The flame spread velocity increased linearly with time within several discontinuous segments, corresponding to different burning regimes. The results showed a markedly non-one-dimensional spread; to what extent other types of mattresses exhibit this burning behavior is unknown. This same aspect of flame spread points to difficulties that may be encountered if predictive modeling, based on thermophysical properties, is attempted.

The National Bureau of Standards conducted in 1976 a test program for the Navy [37] that included some explorations of mattress combustion. The study explored the effects of wall lining materials, ventilation, and fuel configuration. In addition, quarter-scale geometric models were tested and basic materials characterization tests conducted. The standard Navy neoprene mattress [38] was the only mattress type tested, although a nylon ticking variant was also included. The simulated bunk area had representative bedding and other combustibles in addition to the mattresses. The results indicated that fire intensity was strongly influenced by ventilation supply and by the degree of bunk enclosure.

Another study treating mattress flammability was conducted by the Southwest Research Institute in 1976 under grant from the Products Research Committee [39]. A living room and bedroom were furnished with "traditional" and with "plastic" furniture. The two mattress types chosen were cotton batting and polyurethane foam. The furniture was ignited with a gas burner. The plastic-furnished rooms showed a faster developing and more severe fire.

The Naval Ship Engineering Center recently sponsored at NBS another study on neoprene mattresses. Breese [40] investigated the usefulness of a ceramic or glass fiber interliner to act as a fire barrier. Interliners of varying thicknesses were inserted under the ticking of Navy neoprene mattresses and subjected to rate of heat release tests and small-scale compartment burns. The interliners served to reduce the rate of heat release and the rate of compartment temperature rise. While reducing the flaming combustion hazard they permitted more heat buildup in the cores and induced smoldering which eventually consumed the mattress. The thickness of interliner required to adequately reduce the flaming hazard was sufficient to make the mattress uncomfortable from loss of resiliency. In view of that, and of the remaining smoldering problem, the interliners were not recommended.

Finally, Saito [41] recently reported on a series of mattress burns at the Building Research Institute of Japan. First, various ignition sources using newspapers in a wastebasket were investigated, varying the number of sheets, the tightness of the packing and the wastebasket type. Too much variability was attributed to these sources, so a small pan of ethanol was adopted as the ignition source. A cotton sleeping mat and four types of polyurethane mattresses were tested. Three of the urethanes were retardant treated. Preliminary bunsen burner tests showed that the treated specimens burned slower and generally produced less smoke per unit weight of material burned. In the full-scale tests the mattresses were tested without bedding and in two configurations — bare and with a cotton ticking. The burning rate of the untreated urethane mattress was reduced by more than a factor of two when a ticking was added. The ignition source was weak enough so that the remaining specimens did not show significant flame spread in either configuration.

None of the available investigations represented a comprehensive examination of mattress flammability. By considering their results together, however, certain general conclusions may be drawn. Prior to the adoption of the cigarette ignition standard most investigations focussed on ignition by cigarettes or other small sources. It was found that unretarded cotton batting mattresses will ignite and smolder, whereas synthetic foam mattresses will not. Cotton batting resists cigarette ignition if properly retardant treated. Boric acid treatment is probably the most common. Mattress ticking is also an important variable in determining cigarette ignition. Cotton cloth can be successfully retardant treated to resist ignition, while many synthetic ticking materials do not need any treatment.

Once the Federal cigarette ignition standard was established attention began to be focussed on other ignition sources. A reliable, realistic, sustained flaming ignition source was somewhat difficult to produce, as can be seen from various contradictory and anomalous results reported. Ignition with newspaper was shown to be quite unreliable in many configurations. Generally, mattress core or padding material was shown to be the dominant variable. Unretarded materials can be roughly grouped in the following order of decreasing performance: fiberglass, natural fibers (cotton, hair, kapok), neoprene, polyurethane, latex. Ticking generally has little influence, except for some experimental highly retardant treated materials. Some experimental flame-retardant foams can also show improved performance. If properly arranged, bedding and especially the pillow, will act as a continued source of ignition. Interliners have some potential for reducing flame spread but may induce smoldering. Ventilation can have a strong effect on mattress performance, but the appropriate variables have not been clarified. A detailed model of flame spread over one type of mattress is available; it has not been applied to other types.

A qualitative understanding of the flammability properties of several mattress types is available from the literature. With the exception of several of the NBS studies, however, none of the investigations have led to proposals for standardized small-scale tests. Instead, the investigations were more in the nature of demonstrations or ad hoc tests.

4. SCOPE OF WORK

The work reported here consists of a series of mattress burns conducted in a full-scale room. Several basic types of mattress construction were included to exemplify some of the types in use in institutions. The study was primarily designed to provide a set of room burn data to be used in developing small-scale flammability tests. It was also formulated to obtain information on several aspects of mattress flammability not available from earlier studies:

- effects of corridor airflow on mattress combustion
- contribution to fire of the kind of bedding that is customarily used in health care institutions. No box spring units were tested since these are normally not used in health care institutions.
- an ignition source which was both realistic and sustained
- extensive improved room instrumentation
- measurement of those variables needed for a consistent set of tenability criteria
- estimation of the effectiveness of detectors and sprinklers for institutional mattress fires
- comparative testing of some specimens of types of mattresses implicated in serious fires.

External fuel load variables were not examined — the burn rooms contained only a mattress with appropriate bedding and a wastebasket ignition source.

The present report includes the main data and findings. A hazard analysis of the test mattresses is given and a performance evaluation is presented. Future reports will present (1) a compartment heat and mass analysis, (2) a detector and sprinkler analysis, and (3) results of small-scale properties characterization tests and a comparison with full-scale results. The eventual goal is the development of guidelines for institutional purchase specifications that do not entail a need for full-scale testing.

5. DESCRIPTION OF EXPERIMENTAL FACILITIES AND INSTRUMENTATION

5.1. Test Rooms

The mattresses were tested in two different burn rooms, allowing three different ventilation conditions to be explored. Burn-room "A" is shown in figures 1 and 2. It was 3.40 m x 3.50 m x 2.44 m high (11.2 ft x 11.5 ft x 8.0 ft), and is described in table 1. The only opening to the room was an open doorway 0.91 m wide by 2.13 m high (3.0 ft x 7.0 ft). The doorway opened into another chamber, which connected to a corridor discharging into a hood and exhaust chimney containing an afterburner for smoke abatement. The flows through the doorway were essentially unobstructed in this arrangement and previous work [42] has determined that the effect of the exhaust system on room temperatures and flow was negligible. The ambient laboratory conditions during these tests were a temperature of 20 to 25 °C and a relative humidity of approximately 40%.

Wall and ceiling linings of both burn rooms consisted of 13 mm cement-asbestos board (Atlas Asbestos Co. "Superbestos"). On the walls and ceiling this was applied over a 16-mm layer of Type-X gypsum wallboard. The thermal properties of the cement asbestos board used are as follows [43,44].

	Temperature (°C)			
	30	183	433	721
Density (kg/m^3)	658	626	600	557
Thermal conductivity (W/m-K)	0.14	0.16	0.14	0.14
Heat capacity (J/kg-K)	1060	1330	1340	1440

Emissivity was not measured but is estimated to be ≃0.9. Floor covering, which did not influence test results, was cement-asbestos board in burn-room "A" and asphalt time in burn-room "B."

Burn-room "B" was located in a different building than room "A" and is shown in figures 3 and 4. It was 3.35 m x 4.22 m x 2.44 m high (11.0 ft x 13.8 ft x 8.0 ft), and is described in table 1. The only opening to the room was an open doorway 1.07 m wide by 2.03 m high (3.5 ft x 6.7 ft). The burn-room was located on a corridor, with the doors of all adjoining rooms closed. The corridor connected directly to a closed lobby at one end. A general plan of the facility is shown in figures 5 and 6. Burn-room "B" was constructed to enable corridor ventilation effects to be studied and for later use in extinguishment and detection studies for health care facilities.

Two ventilation conditions were provided in burn-room "B" tests. Under the first condition, termed "non-ventilated," all doors to the corridor and lobby were closed and no mechanical ventilation was provided. Only negligible leakage flow to the outside was present. The air volume contained within the burn-room, corridor, and lobby was 259 m^3. The non-ventilated mode was intended to simulate corridor conditions when the ventilating system is of such design that upon detection of fire, fire dampers close off all ventilation for a given zone. Systems with this operation are commonly found in institutional buildings.

Under the second condition, termed "ventilated," a forced airflow down the corridor was established. An exhaust fan in the ceiling of the lobby provided the ventilation. Intake was through a 0.91 m wide by 1.98 m high doorway at the opposite end of the corridor. This doorway opened into a chamber that had air intakes symmetrically located on opposite walls of the building. The dual intake arrangement was chosen to minimize any wind influence. The airflow in the corridor was measured (without a fire) by a nine-point velocity measurement at two locations using a hot wire anemometer. An average velocity of 0.275 m/s was obtained, giving a flow of 1.64 m^3/s. An additional check measurement was taken 50 mm below the fan louvers. An average velocity of 3.28 m/s was obtained at nine points over a fan area of 0.47 m^2, giving a flow of 1.54 m^3/s.

5.2. Instrumentation

The instrumentation used in these experiments is indicated in figures 1 and 2 and table 2 for burn-room "A," and in figures 3 through 6 and table 3 for burn-room "B." A total of 88 transducers was used in room "A" tests and 83 in room "B" tests. The locations are shown for thermocouples, heat flux meters, and fire detectors. Tell-tale sprinklers were also located in each room. (These are sprinkler heads not charged with water but electrically monitored to record time of activation.) The results of their operation will be described in a later report. The experiments were also recorded both on video film and with still photographs. All instrument data were taken at 10-second intervals on a high speed data acquisition system.

a) Thermocouples. Chromel-alumel 30-gage (0.25 mm) thermocouples were located at the points shown. These thermocouples were shielded with a metallic tube for most of their length except for the last 20-30 mm before the junction end.

This allowed fast response time but did not introduce problems of insulation degradation, which can be troublesome with unshielded flexible thermocouples. No radiation corrections have been made to the temperature data.

b) Heat flux meters. Gardon-foil type water-cooled radiometers and total heat flux meters were used.

c) Load cell. The weighing arrangement consisted of a BLH model U3G1 load cell mounted above the ceiling of the burn room. A cement-asbestos platform (1.22 m wide by 2.13 m long) was suspended by cable from the load cell. The test mattresses were placed on a thin bed-spring frame and suspended above the platform. The top of the mattress was adjusted to be 0.61 m above the floor in all cases. The cement-asbestos platform served to retain the wastebasket and any molten material on the weighing system (figure 8).

d) Velocity probes. Bidirectional low-velocity probes were located in the doorway as shown in figures 2 and 4. This type of probe was developed by Heskestad [45] for obtaining accurate low-velocity flow measurements under fire conditions, which can involve water condensation and flow reversal. McCaffrey and Heskestad [46] have provided calibration techniques for these probes. The probes used were 12.7 mm in diameter, with construction details as given in the above reference. The basic equation is

$$\frac{\sqrt{2\Delta p/\rho}}{u} = C(Re)$$

where ΔP = measured differential pressure, ρ = gas density (obtained from thermocouple reading adjacent to the probe), u = the gas velocity, and C(Re) is a constant which depends on the Reynolds number. For Reynolds numbers in the range of interest the constant can be approximately taken as C = 1.08 according to the recommendation of McCaffrey and Heskestad. Pressures were sensed with a Celesco P90D pressure transducer.

e) Gas sampling. Concentrations of CO, CO_2, and O_2 were measured at a single location in the doorway of burn-room "A" (see figures 1 and 2). In burn-room "B" two doorway locations were sampled; an additional sampling location was established at a point corresponding to the height of the head of a person lying in an adjacent bed of the same room (see figures 3 and 4). Gas analysis for CO and CO_2 in burn-room "A" was made with Beckman 315-B non-dispersive infra-red analyzers. A Beckman OM-11 magnetic susceptibility analyzer was used for O_2. Lira 303 non-dispersive infra-red analyzers were used for monitoring CO and CO_2 in burn-room "B" experiments. Bacharach electrolytic oxygen cells were used for making O_2 measurements. The sampling lines were fitted with a series of traps: a glass wool trap for removing particulates, a dry ice trap to remove water, and, finally, another glass wool trap.

f) Smoke meters. Light paths were established horizontally and vertically in the doorways at the locations shown in figures 2 and 4. In experiments at burn-room "B" additional light paths were established at several locations in the corridor. Smoke meter drawings for burn-room "A" tests are given in figure 7. The smoke meters were specially constructed for room burn experiments. The light sources consisted of a Sylvania DYH bulb (having a spectral output approximating a black body at 3200 K) for the vertical light paths and a Sylvania R30/FL 75 watt reflector spot (2900 K) for the horizontal paths. A collimated system was used since it has been shown [47] that in such case the error due to scattered light is small. Calibration was achieved by placement of known optical density filters in the light path. A differently designed smoke meter [48] was used for burn-room "B" tests, but one which gave same results in the density range of interest.

g) Fire detectors. Burn-room "B" was equipped with numerous fire detectors. Their descriptions are not given here since analysis of the detection systems will be the subject of a forthcoming report. The detectors were located at the points shown in the room plans (figures 3 and 4).

6. TEST PROGRAM

6.1. Test Procedure

The mattresses were tested in the two burn rooms described above. The mattresses were covered with a standard set of bedding and ignited with a standard ignition source. Figure 8 illustrates the made-up bed ready for test.

A total of 22 tests on ten mattresses were conducted. All mattresses, plus a control and a replicate, were tested in burn-room "A." Four mattresses were also tested in each of the two ventilation configurations of burn-room "B." Table 4 gives a schedule of the tests.

6.1.1. Bedding

Each mattress was tested with the following bedding: an institutional cotton drawsheet, two cotton/polyester sheets, a cotton/polyester bedspread, a cotton/polyester pillowcase, and a pillow. The pillow consisted of shredded polyurethane foam filling in a cotton cover. The drawsheet was placed on top of the bottom sheet and tucked under at each side. The bed linens were all commercially available products purchased from a hospital supplier and are intended to be representative of a typical institutional bed. The properties of the bed linens are listed in table 5. The bedding was not retardant treated and was not laundered.

The use of bedding was determined by preliminary tests to be necessary to ensure adequate sustained ignition. Furthermore, a review of prior work indicates that mattresses with marginal flammability characteristics might not exhibit continued flame spread without bedding but might significantly increase in burning rate when typical bed linens are included. The use of bedding was, thus, consonant with the test intent of inducing sustained ignition. Figure 8 illustrates the configuration of the made-up bed. It should be noted that the bedspread hangs loosely, rather than being tucked in, and that the covers are pulled back. The loose draping of the bedspread served to ensure that a continuous flame propagation path around the bed would be maintained. A non-combustible spring support was placed under the mattress.

6.1.2. Ignition Source

A small polyethylene wastebasket filled with trash was used as the ignition source. Table 6 gives a description of the wastebasket and its contents. The wastebasket was placed flush against the edge of the mattress as indicated in figure 8. The wastebasket was located on the side of the bed toward the wall and away from the doorway. This location served to direct flame across the bottom of the test mattress once the bedspread burned away. The top of the wastebasket was 0.2 m below the top of the mattress. Each test was initiated by touching a paper match to the contents of the wastebasket. The bed linens, being in contact with the wastebasket, ignited in approximately 23 seconds. The wastebasket choice was motivated by a desire to utilize a source which, on the one hand, was strong enough to ignite the test mattress and, on the other hand, was not strong enough to dominate the effects of the bed fire. Crumpled newspaper sheets were judged not adequate in view of the problems experienced by other laboratories [30]. Some characterization of wastebasket fires was already available [49]. Wastebaskets also represent a realistic actual fire ignition source; as a result the selection was considered appropriate.

6.2. Test Mattresses

A total of ten mattresses were subjected to the full-scale room experiments. The mattresses were "twin" size, approximately 1.0 m x 1.9 m (39 in x 75 in). Individual measurements, along with other tabulated data, are given in table 7. Details of mattress construction are given in table 8. Sufficient specimens of each type were procured to enable several full-scale experiments to be conducted for each type and additional bench-scale measurements to be made.

The mattresses were analyzed for composition using infra-red spectrophotometry and standard textile test methods. The presence of flame retardants was assumed if certain elements were detected by X-ray fluorescence (for phosphorus, antimony, bromine and chlorine compounds) and emission spectroscopy (for boron compounds).

Mattress M01 was a hospital mattress with solid foam core and retardant treated polyvinylchloride ticking (the ticking is the outermost mattress layer, or cover). The polyurethane core consisted of an inner layer and an outer enveloping layer. The inner core foam was retardant treated. The outer core material showed only slight retardants, not at an effective level.

Mattress M02 was a hospital mattress with an innerspring construction and contained unretarded polyurethane foam padding, an unretarded polypropylene interfacing fabric, and a ticking identical to that of mattress M01.

Mattress M03 was an innerspring hospital mattress with cotton felt padding, an interfacing fabric same as in mattress M02 and a vinyl ticking identical to that in mattress M01 and M02. The cotton padding was retardant treated.

Mattress M04 used a latex foam core (unretarded) and a retardant treated vinyl cover. The foam core was "pinned" by a regular pattern of holes. This mattress duplicates the mattress used in an Osceola, Missouri, hospital which was implicated in a multiple-life loss fire in 1974 [4]. An earlier room experiment with this mattress is reported in reference [4].

Mattress M05 was a commonly available commercial mattress with a solid foam polyurethane core. The ticking was composed of three layers — two rayon fabric layers with an intermediate layer of polyurethane foam. The mattress was asymmetrical in that the ticking assembly on top was quilted while on the bottom it was not. None of the materials were retardant treated.

Mattress M06 superficially resembled a cotton innerspring mattress in construction and appearance, but the padding consisted of cotton/polyester felt and a pad comprised of cotton, nylon and polyester fibers. A polyester ticking was used. None of the materials were retardant treated. (Note that, by comparison, an unretarded cotton batting mattress normally cannot pass the cigarette ignition test. Mattress M06, of course, successfully passed the cigarette ignition test.)

Mattress M07 was a prison mattress conforming to State of Connecticut specification 3748-M-339 [50] for mattresses. This specification was issued by the State in 1976 after several fires occurred, involving two fatalities [51,52]. The mattress was of innerspring construction, using boric acid treated cotton felt batting and a jute pad and covered with a retardant treated cotton ticking conforming to Type II ticking of Federal Specification CCC-C-436 [53].

Mattress M08 was a mattress conforming to U.S. Navy specification MIL-M-18351 [38], Type III, size 2. Core material was neoprene (polychloroprene) foam and conformed to specification MIL-R-20092 [54]. The above specification references standard MIL-STD-1623 [55] which is based on the ASTM E-162 radiant panel test. The neoprene performance is to be "Type II, class 4," which requires a flame spread index not greater than 10 on the radiant panel test. The ticking was a retardant treated cotton fabric conforming to CCC-C-436. The core consisted of three layers of black neoprene foam of different thicknesses and slightly different densities glued together. The foam was retardant treated.

Mattress M09 was a prison mattress which was tested because of implication in a recent prison fire [7]. It comprised a polyurethane core and vinyl ticking with nylon fabric reinforcement. Only the ticking was retardant treated.

Mattress M10 was a prison mattress of current manufacture which used a black neoprene foam similar to the one in M08 and was retardant treated. An unretarded vinyl ticking with nylon fabric reinforcement was used.

Control Mattress consisted of a 100-mm batt of fiberglass resting on a 12.7-mm cement-asbestos board. The cement-asbestos board was determined to be necessary, since if it was not used a significant airflow was established through the porous fiberglass. Such airflow is not representative of the test mattresses.

7. HAZARD ANALYSIS

7.1. Bases for Hazard Analysis

An analysis of the fire hazard of a mattress, or any other kind of fuel load that does not form an integral part of a building structure, can be performed in three different ways, giving rise to three different types of tests.

Type 1. A fire test under standardized conditions that are not related to the end-use condition. The scale of the test can be small or large. An example of such approach would be the use of a Steiner Tunnel (ASTM E-84) [56] to determine a "fire hazard classification" for a piece of furnishing. The lack of validity of testing that is not adequately related to end-use conditions has lately been recognized [57].

Type 2. A full-size fire test that models end-use conditions. The present series of mattress tests falls into this category. There are two main difficulties associated with this approach. First, full-scale tests are costly. And, second, it may be difficult to establish generalized test conditions covering all possible end-use conditions for a product. Variations can come in two aspects: ignition sequences may not be unique; also, the interaction between the product and the room or other fuels within the room may occur in different ways for different rooms sizes, wall materials, ventilation, or other properties. In the present series of tests it is believed that an adequately representative ignition method was used. The mattresses were tested with a typical, realistic medium-size flaming ignition source. (An established procedure [1], FF 4-72, is already available for testing the effects of a small-sized ignition source, such as a cigarette, on a mattress). A wastebasket was chosen as representing a common medium-size ignition source, once it itself is ignited by a match or otherwise.

Interaction among several pieces of fuel is an important issue and should be examined to construct a total hazard analysis. Such testing may be performed at a later date but was not included in the present study. It must be noted that this interaction, if present, would indicate hazard greater than for the isolated mattresses. Therefore, any findings of hazard from this study can be viewed as minimum levels, subject to increase with the addition of more fuel.

The interaction between a mattress and the room was treated in the present study by selecting a room configuration which would be generally typical of the end-use situation. Since ventilation is the most important room property to be considered, two different doorway sizes and three different corridor flows (free, forced, and non-ventilated) were considered.

Type 3. A series of physical property tests, which are a de-coupled characterization of product behavior and do not include any room effects. In this procedure a product constituting a piece of fuel would be tested to determine a series of fundamental thermophysical and thermochemical properties that are characteristic of the fuel and as independent as possible of the experimental apparatus or test environment. The actual hazard analysis would then be performed by using as inputs the properties characterization test results for the fuel together with known properties of the end-use room. An algorithm derived from a theoretical understanding of a room fire development would be used as the tool for analysis. An analysis of this kind has not often been attempted in the past because an adequate room fire theory has not been available. An example of analysis based on a theoretical model is the corridor test program [58-61] at NBS. Quintiere [62] has recently presented a useful model for room fire growth and reviewed the theoretical efforts. This third method of hazard analysis is the most desirable and can be expected to come into increasing use. Its main limitations are the required homogeneity of the specimen and the idealized pattern of fire development. In other words, the flame spread and material pyrolysis must be simple enough to be characterizable in terms of geometrical, heat flow, and fluid flow relationships.

The present test series was of Type 2. An attempt can be made to de-couple the behavior of the mattresses from the enclosure. Such analysis will be presented in a forthcoming report.

7.2. Dimensionality of Rating Variables

For a meaningful analysis of results to be possible, the proper units of measurement must be established. These units will differ, depending on the use of the test. For mandatory tests, such as the mattress flammability standard [1], the results are usually reported in go/no-go terms. This approach is not sufficient in those cases where an engineered firesafety design is desirable. The final evaluation of any firesafety system has to be performed on a go/no-go basis, but the test results needed for that evaluation should be in appropriate quantitative form. It has been well established that <u>time</u> is the most important variable for life safety. Wilson [63] advocated the importance of time as the unifying variable in firesafety over a decade ago. More recently Benjamin [64] emphasized the importance of reporting room burn results in units of time. Williamson [65] has found that the analysis of full-scale room burns can be systematically accomplished by the use of a state transition model. Time is the primary variable in that model. Time was chosen in this report as the primary variable for use in analysis of the hazard represented by the mattresses. It should be noted that if Type 3 testing were done, the basic results would not be reported in units of time. Units of time are applicable only when the product and the environment effects have been combined. For a Type 3 analysis, material properties, such as heats of combustion and gasification, thermal inertia, etc., would be reported in appropriate units. These properties would be combined with the room effects and the final calculated result reported in terms of the times at which critical values of dependent variables (e.g., temperature, smoke obscuration, gas concentration) are reached.

7.3. Specific Hazard Components

The hazards contemplated fall into two categories — direct human hazard and fire growth hazard. Fire growth hazard is not unrelated to human hazard. It is useful, however, to consider separately any factors that indicate tendencies for a fire to become threatening, even if this threat is fulfilled only under certain conditions of the external environment.

The human hazards consist of

- toxic gases
- high temperatures and heat fluxes
- visibility obscuration by smoke.

Each will be considered below in detail.

The fire growth hazard can be treated by considering all factors that shorten the time interval between ignition and room flashover. Flashover of a room is not only an indication that conditions have become untenable for life there, but also that the fire threat to other building spaces, beyond the room of origin, has been markedly increased. The main indicator of fire growth is the heat flux, thus the fire growth hazard will be considered in the section under heat fluxes.

7.4. Location of Hazard

From the viewpoint of human survival a building can be divided into two areas — the room of fire origin, and all other spaces. The latter include escape routes and refuge areas. The division is important because tenability criteria are applied in different ways to the two areas. Within the room of origin an actual numeric value of available time for escape can be computed insofar as the test room is "typical" and exact tenability criteria are known. While a de-coupled characterization would be superior and would obviate the need for a "typical" room, it is presumed that the test rooms selected are reasonably typical. The choice of appropriate criteria is much less certain, but enough work exists to permit some limits to be identified. A time for escape can then be calculated that is valid to the extent that the criteria are realistic.

Quantitative times for escape cannot, on the other hand, be assigned to the corridor environment. There is not any "typical" corridor or ventilating system. In consequence the problem must perforce be de-coupled. The flow rates of smoke and gases into the corridor can be determined; these values have to then be combined with a characterization of the building flows. Lacking this characterization for a specific building, only a relative ranking based on output flows can be made.

7.5. The Role of Time in the Room of Origin

The process of fire growth is, by definition, not steady state. All physical variables change markedly with time. The criteria for tenability are, by contrast, usually based on a steady exposure for a given length of time. Neither cumulative nor averaged measures are entirely correct or appropriate for most of the variables considered. The approach taken to make the problem tractable was to define the critical time as the first instance at which a given limit value is exceeded in the room of origin. For those criteria which are dependent on time of exposure the limit values selected are ones corresponding to a short exposure time producing serious, but sub-lethal, symptoms. The time considered was on the order of 5 minutes, which should be sufficient to permit an ambulatory individual to move out from the room of origin into the presumed safe corridor environment. According to this scheme the actual exposure to the limiting value is momentary, rather than 5-minute, thereby justifying limits associated with rather serious symptoms. These same criteria, obviously, would not be used for assessing the corridor or escape route tenability.

8. GENERAL FINDINGS

8.1. Observations

The development of fire in all cases was generally similar because the ignition source was the same and the specimen geometry similar. Differences in behavior can be expressed as the times for different events to be reached and as the magnitude for various measured variables. The visual observations for burn-room "A" tests are given in the Appendix. For burn-room "B" tests a table of ignition times is given in table 9. Corresponding values are not available for the "A" tests because photographic record was not made from the ignition side of the bed. Time t = 0 starts with ignition of wastebasket contents. The visual development of fire is indicated in figure 9 for the control specimen, figure 10 for specimen M01, figure 11 for specimen M07, and figure 12 for specimen M08.

The ignition wastebasket was placed right against the edge of the bedding, causing a rapid ignition of the bed spread, average 23 s. The standard deviation is 8 seconds, indicating reasonable repeatability. Mattress ignition then occurred at a time which varied significantly, depending on the mattress. The mattress ignition time does not appear to be correlated to any of the measures of hazard that are explored in the following sections. Pillow case ignition occurred generally some time after mattress ignition and the ignition of the pillow itself followed shortly.

Mattress flame spread was initiated by bedspread flame travel. The flame front along the bedspread sides generally moved out from the source in a circumferential manner, first involving the near side, then the foot of the bed, and then the far side. The burning at the head of the bed was largely controlled by pillow burning. On the top surface of the bed the burning generally proceeded in a radial fashion, away from the source. For some urethane mattresses flame spread over the top surface was preceded by a period of heavy pyrolyzing without visible combustion.

The severity of mattress flaming was observed to be governed by one main variable — whether or not the mattress had a tendency to melt and drip. The urethane and the latex mattresses showed this tendency. These first ignited on the underside near the source. A shower of flaming droplets ensued. Approximately a half to one minute after the ignition of the underside a floor pool fire ignited. In all cases the pool fire occupied the whole volume underneath the bed and produced significantly more flaming than on the topside of the same specimen. It must again be pointed out that no box spring units were tested. Thus these observations refer only to beds with flat springs. Visibility dropped rapidly during this period and peak burning rates were observed. This involvement lasted on the order of about two minutes and was terminated by rapid fuel exhaustion. Only the urethane and latex mattresses exhibited melting; none of the others burned significantly on the underside. The location of the wastebasket was significant for establishing the pool burning condition. A fire using an ignition source on the top of the bed or one located where the hot combustion products do not flow past the mattress underside would not be expected to reveal any pool burning potential.

8.2. Weight Loss

The weight loss record of the burning mattresses is shown in table 10. Table 10 shows that in three control tests a range of 0 to 1.1 kg, with an average of 0.55 kg, of fuel source and bedding was left unburnt after the test. The actual burning rate of the source and the bedding would not necessarily be the same when used with the different mattresses; but since it could not be determined separately, it will be assumed that in those cases where the combustibles were not completely burned 0.55 kg of the weight remaining consisted of bedding and source.

The weight remaining differed significantly for different types of mattress construction. The following weights remaining were recorded at the end of 30 minutes.

Basic Construction	Percent Weight Remaining
Polyurethane (M01, M02, M05, M09)	Negligible
Latex (M04)	Negligible (from visual observation)
Cotton (M03, M07)	78%, 85%
Neoprene (M08, M10)	88%, 88%
Cotton/Nylon/Polyester (M06)	7%

The weight loss behavior is seen to be divided into two distinct types — the polyurethane and the latex mattresses were almost totally consumed, while the cotton and neoprene mattresses lost only about 15% of their weight. Mattress M06 contained stuffing of cotton, nylon, and polyester and was almost totally consumed. The mattresses that were not totally consumed at the end of 30 minutes continued to smolder but at a low weight loss rate.

The instantaneous mass loss rates for all the specimens are given in figures 13 to 15. It was found that due to the large area of the mattress and platform a significant weighing error due to buoyancy was introduced. A buoyancy correction could be applied to the data from burn-room "A." A similar correction could not be applied to burn-room "B" data because temperature readings in the space above the mattress were not taken. The platform area is 2.6 m^2. The effective gas space height must be so chosen that after fuel exhaustion in any test no further weight change be noted. An effective height of 0.9 m was found to be appropriate, giving a volume of 2.34 m^3 whose buoyancy must be accounted for. The temperature was taken as average of the readings at thermocouples 35, 36, and 40. The density of air is 1.20 kg/m^3 at 20 °C. The relative importance of the correction can be judged by examining the magnitude of the correction for a specimen that produced high gas temperatures. In the case of mattress M01 this correction amounted to 2.08 kg at peak burning compared to a total fuel comprising 18 kg.

8.3. Gas Temperatures

The temperature histories are shown in figures 16 through 26 for two locations — the average upper gas space temperature was taken as TC09 for burn-room "A" and as TC01 for burn-room "B." The adjacent patient point was TC07 for burn-room "A" and TC17 for burn-room "B." The upper gas space readings are not exactly at the same level. The vertical temperature gradient in that region is very slight, however, and comparability is preserved.

Vertical temperature profiles, at the time of highest temperatures, are plotted in figures 27 through 37. For burn-room "A" three locations are shown: center (thermocouples 25-30), east (thermocouples 05-10), and west (thermocouples 47-52). The room temperature distributions are useful in establishing a fluid mechanical model of room fire development. They are not central to the hazard assessment of the fuel except insofar as temperature is a complementary measure to heat flux for human habitability and to the extent that temperatures can be used as an indication of flashover. Hägglund, et al. [66], found that flashover occurs when the gas temperature about 0.10 m below the ceiling reaches 600 °C.

In the present series of tests the average of the temperatures at the east and the west measuring locations of burn-room "A" can be examined under Hägglund's criterion. (Data from the center measuring location are somewhat influenced by the adjacent fire plume.) Only two specimens showed temperatures over 600 °C:

$$M01 \quad T_f = 938\ °C, \text{ at } 460\ s$$

$$M04 \quad T_f = 1055\ °C, \text{ at } 670\ s.$$

9. HEAT FLUXES

9.1. Criteria

9.1.1. Human Tenability

High levels of heat flux in a room can produce conditions untenable for life. Also, if a potential for continued flame spread or ignitions exists, the flux levels required for this spread of fire have to be determined. For human exposure a range of threshold values for pain or burn can be found in the literature. Radiant fluxes which are tolerable for extended periods of time, in excess of several minutes, have been reported to be as low as around 1.2 kW/m^2 (Simms and Hinkley [67]; Derksen, Monahan, DeLhery [68]) and as high as around 2.5 kW/m^2 (Dinman [69]; Parker and West [70]). The latter value corresponds to flux from a black body at a temperature of 183 °C; the former to one at 110 °C. For the present study a value of 2.5 kW/m^2 was selected as the critical level. Since an instantaneous, rather than sustained, level will be used, it is appropriate to take the higher value. For human exposure, the value of 2.5 kW/m^2 radiant flux specified by Dinman, and by Parker and West corresponds to a pain threshold for extended exposure. That flux-level could be viewed as an upper limit for tenability. A lower value may be appropriate if concomitant stresses were considered, such as smoke obscuration or toxic gases. Such combined stresses will not be considered here since no simple way of describing their total action exists.

9.1.2. Fire Growth Potential

For limiting rapid spread of fire it is desirable to keep fluxes below such values as would ignite thin combustibles outside the region of the source flames. Newsprint can be used as an indicator representative of cellulosic target fuels. Parker and Lee [71] have suggested using a criterion level of 20 kW/m^2 as the heat flux at floor level at which cellulosic fuels in the lower part of a room are likely to ignite.

Results from other investigators are not much different. Waterman [72] adopted a criterion of 13 kW/m^2 flux as an asymptotic value for ignition for times of heating greater than about 10 minutes. Peak exposures from mattress fires are significantly shorter than 10 minutes, thus a higher flux level is appropriate. Fang [73] found in a series of room burns that strips of newsprint placed at floor level ignited at fluxes of 17 to 25 kW/m^2 while 6.4 mm thick fir plywood specimens ignited at 21 to 33 kW/m^2. A range of materials has been tested by Smith [74] for ignition times and fluxes. For some common materials the following ignition fluxes are given for 60-second exposure:

	Flux (kW/m^2)	
	Piloted	Unpiloted
Newspaper Want Ads	46	48
Box Cardboard	33	43
Polyurethane Foam	19	--

The unpiloted values are considered more appropriate for determining of full room involvement since ignition at considerable distance away from the flames is involved. A value of 20 kW/m^2 represents, in Smith's data, an unpiloted ignition time of approximately 180 s for box cardboard and is close to an ultimate asymptotic value. It is, therefore, appropriate to consider that level as the ignition criterion.

The ignition flux level has a further implication. If sufficient combustibles are present in a room and if a large fraction of them ignites once a 20 kW/m^2 flux is reached, then room flashover[2] can follow shortly, as a consequence of the rapid fuel involvement. The 20 kW/m^2 flux level can then be viewed as a necessary — although not sufficient — condition for flashover. The additional requirements are for sufficient fuel and appropriate window ventilation openings. After flashover the potential for occupant survival is negligible.

The human tolerance and the ignition fluxes are sufficiently different that separate critical times for reaching each should be considered. A value of 2.5 kW/m^2 will denote intolerable conditions within the room. After the flux exceeds 20 kW/m^2 the room fire can present serious threat to the tenability of corridors and other rooms in the building.

9.2. Results of Measurements

The flux measurements as a function of time are given in figures 38 through 48. Peak values are summarized in table 11. The location for determining the human exposure flux is either at the place where an adjacent patient bed would be located or on the west wall.

[2] Flashover is defined as a change from localized burning to fully stirred burning in a room. Prior to flashover temperatures and heat fluxes are generally near-ambient except near localized zones of burning. After flashover essentially the entire room is filled with flames and the fire is out of occupant control.

The flux level at the floor is used for determining flashover potential. The times to reach untenable conditions are given in table 12. For the habitability criterion only total heat flux levels are available from the burn-room "B" series; for burn-room "A" series both radiant and total heat flux values are given. In those cases where markedly low readings for radiant flux are noted, as a fraction of total flux, some caution needs to be exercised in interpretation. The window of the Gardon-type radiometers show a tendency to occasionally become coated with soot and consequently produce erroneously low readings.

The results show that mattresses M01, M02, M04, M05, M06, and M09 were at some point in a test burn associated with flux levels in excess of a habitability level. The control specimen and mattresses M03, M07, M08, and M10 never reached that level. Furthermore, mattresses M01 and M04 exceeded the general room ignition, or flashover, level. The above two mattresses were the only two for which the newspaper target strips on the burn-room floor ignited. These ignition times were 486 s for mattress M01 and 724 s for mattress M04. These values compare very closely to the times required to exceed 20 kW/m^2, which were 470 s and 720 s, respectively. The close agreement gives further substance to the validity of using 20 kW/m^2 as the ignition criterion flux. The same two mattresses were also the only ones exceeding Hägglund's criterion, as discussed in section 8.3, confirming the equivalence of these two flashover criteria.

10. SMOKE LEVELS

10.1. Criteria

As with most human behavior questions associated with fires, the smoke level that precludes escape is not readily prescribed. Perhaps more than for other hazards, loss of visibility involves strong psychologic factors in addition to basic physiologic responses. In a test series, such as the present one, where no biologic responses were measured, only the obscuration effect of smoke can be evaluated. The smoke evaluation can be divided into two components: (1) determination of the visibility for a given amount of smoke density, and (2) determination of the minimum needed visibility. The numerous investigations of Jin [75,76] have led to an approximate equation

$$kV = 2$$

where k = extinction coefficient (m^{-1}) and V = visibility (m). Jin further observed desired limits on k, based on not permitting the walking speed to decrease below the speed for a blindfolded subject in a smoke-free environment. For "non-irritating" smoke a limiting value of $k = 1.2\ m^{-1}$ was obtained, while for "irritating" smoke $k = 0.5\ m^{-1}$ was the maximum.

The visibility needed for escape depends on the familiarity of the building occupants with their surroundings and the particulars of the escape path. Rasbash [77] has summarized the few studies available. In the present case for analyzing the smoke levels within the room of origin it will be assumed that the visibility in the corridor is sufficient once escape from room of origin has been accomplished. In view of the short travel distance involved before the corridor is reached, the limiting value of

$$k = 1.2 \text{ m}^{-1}$$

can be chosen, corresponding to a visibility distance of 1.67 m. The value can equivalently be expressed as optical density per meter (OD/m):

$$OD/m = \frac{k}{2.303} = 0.5 \text{ m}^{-1}$$

10.2. Results of Measurements

Extinction coefficients in the doorway, taken vertically and horizontally at 0.30 m below the top, are given as a function of time in figure 49 through 59. Peak values are listed in table 13. The times to reach a critical value of $k = 1.2 \text{ m}^{-1}$ are shown in table 14. The vertical measurement represents an average of both the smoky outflow region and the fresh air inflow. The vertical densities are thus generally 1/2 to 3/4 of the outflow region horizontal density. Under the non-ventilated condition, however, the fresh air supply becomes vitiated. Comparative data are not available for most specimens because of instrumentation difficulties (the smoke meters in the burn-room "B" series proved to be overly temperature sensitive). The burn-room "B" data for the control tests are believed to be reliable and can serve as a basis for comparison. In the ventilated case the horizontal extinction coefficient was about half of the vertical, while in the non-ventilated case the two became equal.

11. GAS CONCENTRATIONS

11.1. Criteria

Out of the hundreds of toxic species generated in the pyrolysis and combustion of various materials only the two most common, CO and CO_2, and oxygen depletion were measured. Additional products were not measured not because it was believed they were insignificant, but rather due to the costs and experimental uncertainties involved. Carbon monoxide and carbon dioxide are the only species that are known to be generated in significant quantities in all building fires. Thus, limit times based on their concentrations were used to indicate maximum tenability times.

Definite criteria for CO, CO_2, and O_2 levels are not readily arrived at. There are several reasons for this. These can be roughly grouped as population variations and exposure uncertainties. For the first category the health of the exposed person must be considered. Especially in any health care facility the healthiness of the individuals may vary greatly. Thus any values established for a "normal," working population would hardly be applicable. The second category involves consideration of exposure times, vertical and horizontal distribution of gases, and the activity of the person. Also, combined effects can be of importance.

Keeping in mind the above limitations, criteria can be found in the literature for exposures likely to cause incipient incapacitation of a healthy person in a short time of around 5 minutes. This time choice presumes that dangerous levels of the given species are present only in the room of origin, the corridor being a safe environment. Much lower concentration values in the corridor, therefore, have to be assured by ventilation design, otherwise the corridor atmosphere will become the limiting factor.

From Kimmerle's tabulation [78] a CO_2 limit of 8% can be selected. Pryor and Yuill's study [79] gives similar values for incipient incapacitation symptoms. From the same two studies a minimum oxygen concentration of 14% is established. The treatment of carbon monoxide is a bit more complex. The main effect of carbon monoxide is the reduction of the oxygen carrying capacity of the blood. The level of reduction can be measured by the carboxyhemoglobin (COHb) content of the blood. To enable an accurate assessment of CO toxicity to be made, the COHb rather than the CO concentration must be evaluated and limited. From Kimmerle's study [78] it can be seen that a COHb level of 25% implies incipient incapacitation. To determine the COHb level from the CO concentration an uptake equation must be used. The most applicable is the one developed by Stewart [80]. It is preferable to other equations because Stewart derived his equation from experiments where human volunteers were subjected to very high CO concentrations and their COHb levels measured. This equation is only applicable for exposure times shorter than about a half-hour, beyond which saturation and elimination can start taking effect. The relationship would also not hold beyond the time that incapacitation results. Different equations [81] would be used for low concentration, long duration exposures. The CO uptake is directly proportional to the ventilation (breathing) rate, which is about 6.5 ℓ/min for an individual at rest and increases with activity [82]. Another stimulation of breathing comes from CO_2 exposure. A 4% CO_2 concentration will more than double [83] the ventilation rate. Since both these factors will likely be present in a fire, an elevated ventilation rate of 18 ℓ/min was taken. This would be achieved alone by either a 5% CO_2 exposure or by light work. The resulting equation expressed in finite difference form is,

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

where Δt is time in minutes and [CO] is concentration in ppm. An initial value of COHb = 0.75% is taken [82]. Values are only computed up to the time of incipient incapacitation, i.e., COHb = 25%. For the sake of completeness an additional limit must be specified. If a CO concentration of 50,000 ppm is exceeded there is danger of cardiac arrythmia [84], independent of COHb level. This limit, of course, would hardly ever govern in room fires.

11.2. Results of Measurements

Gas concentrations, as a function of time, are given in figures 60 through 70. The values shown are measured at 0.025 m below the top of the doorway for the burn-room "A" tests and at the adjacent patient location for burn-room "B." Peak values are listed in tables 15, 16, and 17. Computed COHb values are given in table 18. The COHb limit was exceeded in only two cases, for mattresses M01 and M04; for these mattresses the CO_2 and O_2 limits were also exceeded. Mattresses M03, M07, M10 and M08 did not exceed any of the gas concentration criteria. Mattresses M02, M05, M06, and M09 exceeded either the CO_2 or the O_2 limits but not the COHb limit. Times to reach the first limit value are given in table 19.

11.3. Effect of Measurement Location and Ventilation

Since layering of hot gases proceeds from the ceiling down, it is to be expected that the highest gas concentrations and shortest time to peak concentration would occur at the highest elevations. The time to reach peak value is generally similar in the burn-room "B" series for both the ventilated and the unventilated experiments, if a definite peak was reached in both cases. Only specimen M01 showed a well-defined peak in both the ventilated and unventilated conditions. Mattresses M02 and M05 showed a definite peak only in the ventilated condition, while mattress M06 did not have one in either condition. All these specimens exhibited a well-defined peak in the burn-room "A" series. From figure 61 it can be seen that in the case of M01 the time to reach the peak was approximately equal in the ventilated and unventilated cases. Peak intensities were similar for CO_2 and O_2 but the CO was, as expected, higher in the non-ventilated case. Gas concentrations were also, as expected, proportional to the height of the measuring point above the floor, and the peak times shorter for higher measuring points. These data showed significant scatter, but roughly followed

$$C_{0.51} \sim 2\, C_{1.90}$$

$$t_{0.51} \sim 3/4\, t_{1.90}$$

where C are the concentrations, t are peak times, and the subscripts denote distance below top of door. The adjacent patient level measurements fell generally closer to readings near the bottom than the top of the door. The mattress evaluations were based on the doorway top readings, since a consistent set of measurements was only available at this location. The effective safety factor incorporated by the use of this measuring location could be reduced in future testing by standardizing on the adjacent patient location as the point of measurement. Additional doorway top measurements would still be necessary, however, in order to characterize the combustion products being released to the corridor. These same considerations are also applicable to smoke and heat flux measuring locations.

Comparison with the burn-room "A" series indicates that peak times were generally delayed by a factor of about 1.5 in the "B" experiments. This delay applies to a comparison of values at 0.025 and 0.51 m, respectively, below doorway top. Under equal burning conditions a significant peak delay could not be attributed to this limited difference in measurement location. A similar time shift can be seen in smoke, temperature, flux, and weight loss data. An attempt at analysis will be made later.

12. DISCUSSION OF RESULTS

12.1. Replication and Precision

Two tests of mattress M02 samples were run under identical conditions in the burn-room "A" configuration to evaluate the repeatability of the test procedure. In room fire experiments a large amount of data scatter is customarily expected due to difficulties in replicating the ignition process. In the present test series the wastebasket placed in intimate contact with the bedding provided better than usual ignition constancy.

There are at least three ways that the test agreement for any given variable could be compared: peak value, time to reach peak, and time to reach limit criteria. The three sets of values are shown in table 20. Of the values tabulated only three show a difference in excess of 15%. The median difference is 5%. For heat fluxes and gas concentrations the time to reach peaks or limit values shows closer agreement than the actual peak values themselves. The better agreement for times rather than peak values provides an additional justification for the desirability of using time as the main variable.

It is not difficult to see why time to reach a peak is better replicated than the value of the peak. The behavior of most variables in many of the tests conformed to a pattern of gradual rise at first, then a rapid rise, rising to a sharp peak, and, finally, a sharp decay. The peaks were sharp, rather than plateaus. The top portion of any peak could fail to be registered since scanning was done only at 10 s intervals. The time to reach a peak did not change much, however; thus, the error associated with the time was not much more than the ± 10 s precision implied by the scanning rate.

The above peak description does not apply to the cotton mattresses, M03 and M07, and the neoprene mattresses, M10 and M08. Their burning was more nearly steady, without any pronounced peaks. Thus, time to peak, while noted, was not a particularly meaningful variable for those mattresses that showed a smoldering type burning. The time to limit value is, of course, still a valid measure.

12.2. Comparison with Control

The temperatures, heat fluxes, gas concentrations and smoke levels of the control test represent the severity of a fire of the bedding alone. None of the tenability limits were exceeded for the control case. Many mattresses, as shown above, performed significantly worse than the control. It is interesting to observe that two mattresses performed better than the control and two more were approximately comparable. Mattresses M03 and M07 performed somewhat better than the control for all measured variables. Mattresses M08 and M10 performed approximately comparably to the control except for smoke, where the behavior was significantly worse. Based on the close agreement in the replication tests, these findings are considered to have a physical basis and are not merely due to statistical variation. A mattress of low flammability could improve the behavior of the bedding in two ways. In the absence of significant heat release from the mattress the higher thermal inertia of the mattress could act as a heat sink for the bedding. Or, a gas-phase flame inhibition could be postulated, coming from either specifically introduced flame retardants or from other unidentified components that happen to have an inhibitive action. For a mattress of low flammability even the release of its moisture could be sufficient to show some quenching effect.

12.3. Evaluation of Mattresses

The criteria used to evaluate the mattresses are summarized in table 21. Only the effects within the room of fire origin have been considered. Burn-room "A" data only were used in the evaluation because the burn-room "B" series was exploratory and not all samples were included. The procedure adopted was as follows. The greatest hazards are associated with room flashover. Thus mattresses failing the full room involvement criterion were judged potentially the most hazardous. For mattresses passing the full room involvement criterion three tenability criteria were applied: gas concentration, heat flux, and smoke obscuration. Some mattresses passing the full room involvement criteria failed all the tenability criteria and were placed in the second lowest category. Some mattresses passed the full room involvement criterion and exceeded only the smoke obscuration criterion, these were next higher. Finally, the mattresses that passed all criteria were judged to be the safest. The results are given in table 22.

Group A. Two mattresses, M03 and M07, did not fail any of the criteria and were ranked equally as best performing. Both are of cotton innerspring construction.

Group B. The two neoprene mattresses, M10 and M08 passed the heat flux and gas concentration criteria but did not pass the visibility criterion. They were placed in the second group.

Group C. Three of the polyurethane mattresses, M09, M05, and M02 and the mixed fiber mattress, M06, exceeded all the tenability criteria but did not lead to room flashover. The best performing urethane mattress was M09, the mattress associated with the Seminole County Prison fire. These four mattresses were placed in the third group.

Group D. The remaining two mattresses, M04, a latex mattress, and M01, a polyurethane mattress, failed all the criteria and were placed in the lowest group.

Of the generic types tested here the cotton mattresses could be considered the best, the neoprene acceptable, and the urethane and latex ones as presenting a high hazard. It is noteworthy that the performance of M06, a mixed fiber specimen, was significantly worse than the performance of the cotton batting mattresses. The implication is that batting of mixed cotton/thermoplastic fibers, may be more hazardous under flaming ignition conditions than cotton batting.

12.4. Effect of Fuel Load

The fuel load of mattresses of a given type would be expected to correlate with the heat flux and gas concentration measurements. Thus the fuel load of a mattress might be expected to predict its performance, as compared to other mattresses of the same type and construction, provided that smoke production characteristics were similar and no retardants or barriers were used. The polyurethane construction mattress can best be used to illustrate this point, in view of the number of samples available.

Mattress	Time to Reach Critical Radiant Heat Flux (s)	Combustible Weight (kg)
M09	670	3.2
M05	380	6
M02	300	6
M01	230	14

A correlation of this kind does not imply that a polyurethane mattress could not be produced which has improved burning characteristics for a given weight of mattress.

The fuel load alone is not sufficient to make any comparisons between mattresses of different types. The performance of mattress M03, is, for example, better than that of M09, despite the much higher fuel content. The fuel load can be expected to be an important variable in determining corridor tenability, since it is associated with the total amount of combustion products that can be released into the corridor. An analysis of corridor parameters will be presented in a later report.

12.5. Effect of Ticking

As noted in Section 3, some previous studies have reported significant or dominant effects of mattress ticking on its performance. In those studies either cigarettes or small, non-sustained flaming ignition sources were used. In the present study a sustained flaming ignition source was used. That no significant performance dependence on ticking was found can be seen by comparing the performance of mattresses M01, M02, and M03. Each of these specimens had an identical ticking, yet mattress M03 ranked in the first group while M01 placed in the last group. Conversely, mattresses M03 and M07 can be compared. Their inner construction was very similar but the tickings used were PVC in one case and cotton fabric in the other. No significant difference was seen between the performance of these two mattresses.

None of the test specimens had an interliner for increasing flame resistance. Thus, the potential merits of an interliner have not been evaluated and no conclusions may be drawn.

12.6. Effect of Ventilation

One ventilation condition was provided in burn-room "A" and two different conditions were established in burn-room "B." Sufficient systematic differences in room geometry, mattress location, and instrumentation existed between the two burn-room series that a simple general comparison cannot be made. A comparison can, however, be made by using an appropriate theoretical model to de-couple the room effects, an analysis that will be given in a later report.

Flashover potential is the most revealing comparison, and can be compared for mattress M01, which was tested in all three conditions. A definite flashover was recorded under the fully ventilated burn-room "A" conditions. In burn-room "B" under the ventilated conditions upper gas temperatures somewhat exceeded 600 °C, indicating marginally developing flashover. Under the non-ventilated condition a peak of only around 400 °C was registered, a temperature not sufficient for flashover. The oxygen minimums in the intake air were 19 and 16.5%, respectively, for the two ventilation conditions. An oxygen level of 19% is only moderately depressed and would not be expected to be a serious limit to combustion. A further reduction to 16.5%, however, is significant and can account for the diminished burning in the non-ventilated condition.

Another effect of lowered ventilation has already been observed in Section 11.3. For mattresses M02 and M05 the gas concentration values showed a definite peak in the ventilated case, but only a shallow plateau when non-ventilated. Heat flux data suggest a similar pattern. For burn-room "B" data, no systematic time shift, however, was noted, as might be caused, for example, by ignition difficulties. The time shift between burn-room "A" and "B" data is not yet fully explained.

13. SUMMARY

The following major conclusions emerge from the analysis of the data collected on ten different mattresses tested in full-scale burn-rooms.

1) The ignition source, which consisted of a polyethylene wastebasket filled with simulated trash and placed against a set of hospital type bedding, was adequate. For a test of post-ignition performance, the bedding must be viewed as the main ignition source and must be so arranged as to reliably and reproducibly stay ignited. The source used was reproducible, sustained, and did not dominate the room fire.

2) Repeatability was good — measurements of heat flux, smoke, gas concentration and temperature from two replicate tests differed by about 5%.

3) An evaluation methodology could be established based on time to reach untenable levels for human exposure in the room of fire origin and time to reach heat flux levels sufficient to cause flashover.

4) Time to reach untenable conditions was determined by the smoke production tendency in addition to those variables that determine the rate of fire development.

5) Mattress core material type and total fuel content were the main variables governing rate of fire development.

6) The evaluation revealed four distinct groups into which the test mattresses could be placed:

   a. Those that did not cause any of the criteria to be exceeded for the duration of the 30-minute test. The cotton batting mattresses were in this group.

   b. Those that did not exceed the flashover criterion and exceeded only the smoke obscuration criterion. The neoprene foam core mattresses were in

c. Those that exceeded all the tenability criteria but did not lead to full room involvement. Three polyurethane foam core mattresses and one of mixed fibers construction were in this group.

d. Those that failed all criteria. One latex foam core and one polyurethane foam core mattress were in this group.

7) Mattress ticking was not an important variable in determining performance based on a sustained flaming ignition source.

8) The main effect of an innerspring was to reduce the combustible content of the mattress.

9) Polyurethane and latex foam mattresses showed a tendency to burn vigorously in a molten pool under the mattress. Thus, in testing, an ignition source should be used that can reveal this behavior.

10) Some mattresses showed a better performance than the control (which included the bedding and the wastebasket). The effect is interpreted as a quenching action, either chemical or physical, of the mattress.

11) The effect of restricted ventilation within a given compartment was to lower the peak burning rate but not the time to reach the peak. Increased carbon monoxide levels were also developed.

14. ACKNOWLEDGMENTS

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APPENDIX

LOG OF OBSERVATIONS — FROM VIDEO TAPE

Test 2-3

Mattress M01

Time (s)	
10	Flames just above bed, about pillow height
125	Bedspread burning
190	Smoke begins to obscure
234	No target visibility
281	Increased flame height
285	Pillow case aflame
330	Far side of bedspread involved; total smoke obscuration
486	Paper test strips ignite
507	Smoke begins to clear; mattress burning less but vigorous burning of droppings on pan
600	Smoke cleared more
662	Only local burning on mattress
690	Fire dying out
746	All active flaming out

Test 2-2

Mattress M02

Time (s)	
27	Flames just above bed
88	Not much change
100	Start of bedding involvement
120	Black smoke
165	Pillow heavily involved, bedspread burning rapidly
220	Significant pyrolyzing from mattress
242	Mattress drippings burn
272	Ignition side all involved
298	Total involvement; obscuration; heavy under-bed fire
425	Fire dying down
487	Small fires; one at end of bed, one at ignition source
630	No change
735	Only source burning

Test 2-9

Mattress M02

Time (s)	
26	Flames just above bed
122	Pillow burning
130	Flaming droplets at side
170	Active flaming of bedspread
222	Black smoke from underneath of bed
240	Start of fire underneath
252	Very large involvement of pillow side area
295	Bed totally involved - underneath and on top
303	Negligible visibility
450	Flaming decreasing due to fuel exhaustion
500	Only foot of bed and source areas burning
610	Smoke somewhat clears
720	Flames out except for source and one flamelet at foot of bed

Test 2-1

Mattress M03

Time (s)	
23	Flames just above bed
140	Bedding ignited
165	Large fire on side of bed
230	Dying down; smoke increasing
305	Pillow case ignited
360	Pillow burning slowly; bedspread slowly flaming at foot of bed
420	1/4 pillow involved
448	Top of bedspread ignites from pillow
520	Smoke clearing (never was dark)
575	Some slow burning
620	Other side of bed involved; flaming starts underneath
675	Flaming underneath diminishes
782	Bedspread and ticking 3/4 consumed
920	Pillow flares up and is all (not part) engulfed in flames; otherwise very little flaming
1046	No change
1530	Pillow burned out; only small flamelets remain on bed

Test 2-14

Mattress M04

Time (s)	
7	Flames just above bed
100	Very little flaming
168	Bedspread burning
190	Localized smoke
233	Increased burning and smoking
275	Flame spread to foot of bed
320	Smoke smoke obscuration; pillow case involved
345	Active pillow area flaming
397	Largish pool fire from mattress drippings; heavy smoke
446	Half of underneath of bed involved
465	Flames lapping vigorously over sides
478	All of underneath involved
489	Loss of visibility
724	Paper test strips ignite

Test 2-13

Mattress M05

Time (s)	
21	Flames just above bed
120	Light smoke in room
195	Bedspread begins to burn vigorously
245	Underneath of bed pyrolyzing heavily
260	Significant flaming underneath
330	Large pool fire engulfing bed; underneath and above bed
385	Intense totally involved burning of bed accompanied by melting of urethane
590	Flaming decreasing; bed burning out
626	Localized burning; good visibility
670	Pillow burning strongly; limited bed flaming
710	Pillow more smoldering than flaming
730	No more mattress flaming
740	No more pillow flaming; only source still burning

Test 2-11

Mattress M06

Time (s)	
17	Flames just above bed
125	Active flaming of bedspread
188	Visibility decreasing
280	Bedspread flaming at end of bed
300	Bedspread involved on both sides
400	Top of bed involved in small flames
492	Rapid increase in flaming, starting at the foot of the bed
496	All top of bed involved in tall flames
520	Further decrease in visibility
550	Vigorous burning topside; slight pyrolysis underneath
613	Small flaming of underneath begins
800	Burning subsiding
827	Burning begins to be localized
870	Flames at head and foot; also source still flaming
1040	Small flamelets at foot
1070	Only source still burning

Test 2-10

Mattress M07

Time (s)	
34	Flames just above bed
146	Active flaming of bedspread
245	Involvement of pillow
310	Fire concentrated at pillow
405	Flaming of bedspread at foot of bed
460	Foot of bed actively flaming; but flames only about 5 cm above bed
590	Flaming of bedspread increases
620	Bedspread burning out on sides and foot
672	Pillow flaming increases
740	Pillow flaming actively; rest of bed flaming sporadically
880	Pillow burning decreasing
960	No vigorous flaming; but fairly steady pyrolysis and smolder
1092	Flames localized to pillow; mattress still smoldering
1524	Flames out

Test 2-8

Mattress M08

Time (s)	
16	Flames just above bed
138	Active flaming of bedspread
206	Whole side of bed flaming; visibility decreasing
280	Significant smoke generation
370	No change; only side burning but much smoke
480	Bedspread burning at foot of bed
620	Bedspread burning intensifies; involved on all sides
650	Pillow fully involved in flames
699	Slight flaming underneath at foot; bedspread flaming actively
780	Small flames over top surface
1145	Only pillow area actively flaming; rest of bed still pyrolyzing; occasional flamelets
1295	Pillow area slightly flaming less but producing black smoke
1390	Large amounts of smoke, both black and white
1780	No more flaming but still active smoldering

Test 2-6

Mattress M09

Time (s)	
25	Flames just above bed
100	Not much flaming but black smoke being emitted
170	Active flaming of bedspread
225	Increase of bedspread burning
261	3/4 of side of bed involved; taller flames
298	Whole side of bed involved
320	Rapid smoke build-up; large soot streamers
350	Soot streamers diminish
418	Small fire underneath bed at head of bed
440	Flame involvement of other side of bed
473	Fire on underneath of mattress; mostly under pillow
500	Most of top of bed involved
570	Flames on other side of bed burning slowly
605	Rapidly increasing fire underneath
625	Violent fire underneath
650	Whole bed involved in flames, both top and underneath
675	Negligible visibility
760	Flames decreasing; some visibility regained; pillow charred and no longer burning
810	Fire mainly at foot of bed; also source and pillow melt
845	Visibility quite good
920	No change
1029	Fire out at foot of bed

Test 2-5

Mattress M10

Time (s)	
9	Flames just above bed
132	Active flaming of bedspread
196	Most of side of bed involved
240	Flames at foot of bed
280	Flames decreasing
356	Small flames at side and foot of bed
420	White smoke from pillow area
615	Half of pillow flaming
677	Pillow all involved in flames
800	Pillow and source actively flaming; no flames elsewhere on bed
948	Pillow decreases in flaming but puts out more black smoke
1047	Smoke turning white
1440	Fire essentially out; but still significant pyrolysis

Test 2-12

Control

Time (s)	
9	Flames just above bed
153	Active flaming of bedspread
188	Pillow area involvement
332	Bedding at head of bed burning
570	Pillow mostly involved in flame
665	Foot of bed wholly involved
773	Flame involvement of other side; pillow dying down
860	Most of bedding charred; flaming subsides except at source and pillow
1015	Pillow out
1200	Only very tiny flickers of flame left at source and bedding

Table 1.

Summary of Burn-Room Characteristics

	Room "A"	Room "B"
Height/width/depth (m)	2.44/3.40/3.50	2.44/4.22/3.35
Floor area (m^2)	11.90	14.14
Doorway height (m)	2.13	2.03
Doorway width (m)	0.91	1.07
Doorway area (m^2)	1.94	2.17
Doorway $A\sqrt{h}$ ($m^{5/2}$)	2.83	3.09
Soffit depth* (m)	0.31	0.41
Surface area (excluding floor and doorway) (m^2)	43.63	49.91
Doorway area/surface area	0.0445	0.0444
Doorway $A\sqrt{h}$ /surface area ($m^{1/2}$)	0.0649	0.0632

* Distance from ceiling to top of door.

Table 2.

List of Instrumentation — Burn-Room A

Number	Thermocouples
01	On E wall, 1.22 m from S wall, 1.83 m from ceiling
02	On unexposed wall surface, behind TC 01
03	On E wall, 1.22 m from S wall, 0.61 m from ceiling
04	On unexposed wall surface, behind TC 03
05	On floor, 0.92 m from E wall, 2.75 m from S wall
06	0.92 m from E wall, 2.75 m from S wall, 2.14 m from ceiling
07	0.92 m from E wall, 2.75 m from S wall, 1.53 m from ceiling
08	0.92 m from E wall, 2.75 m from S wall, 0.92 m from ceiling
09	0.92 m from E wall, 2.75 m from S wall, 0.31 m from ceiling
10	On ceiling, 0.92 m from E wall, 2.75 m from S wall
11	On unexposed wall surface, behind TC 10
12	On S wall, 0.92 m from E wall, on floor
13	On S wall, 0.92 m from E wall, 2.14 m from ceiling
14	On S wall, 0.92 m from E wall, 1.83 m from ceiling
15	On S wall, 0.92 m from E wall, 1.53 m from ceiling
16	On S wall, 0.92 m from E wall, 1.22 m from ceiling
17	On S wall, 0.92 m from E wall, 0.92 m from ceiling
18	On S wall, 0.92 m from E wall, 0.61 m from ceiling
19	On S wall, 0.92 m from E wall, 0.31 m from ceiling
20	On S wall, 0.92 m from E wall, 0.15 m from ceiling
21	On S wall, 0.92 m from E wall, 0.08 m from ceiling
22	On S wall, 0.92 m from E wall, on ceiling
23	On N wall, 1.22 m from E wall, 1.83 m from ceiling
24	On unexposed wall surface, behind TC 23
25	Center of room, on floor
26	Center of room, 2.14 m from ceiling
27	Center of room, 1.53 m from ceiling
28	Center of room, 0.92 m from ceiling
29	Center of room, 0.31 m from ceiling
30	Adjacent to tell-tale sprinklers
31	On unexposed ceiling surface, center of ceiling
35	1.83 m from E wall, 0.92 m from S wall, 0.92 m from ceiling
36	1.83 m from E wall, 0.92 m from S wall, 0.31 m from ceiling
37	On ceiling, 1.83 m from E wall, 0.92 m from S wall
38	On unexposed ceiling surface, behind TC 37
39	1.83 m from E wall, 0.15 m from S wall, 2.14 m from ceiling
40	1.83 m from E wall, 0.15 m from S wall, 1.53 m from ceiling
41	1.83 m from E wall, 0.15 m from S wall, 0.92 m from ceiling
42	1.83 m from E wall, 0.15 m from S wall, 0.31 m from ceiling
43	On N wall, 2.44 m from E wall, 0.61 m from ceiling
44	On unexposed wall surface, behind TC 43
45	On S wall, 2.44 m from E wall, 1.83 m from ceiling
46	On S wall, 2.44 m from E wall, 0.61 m from ceiling
47	On S wall, on floor, 2.44 m from E wall
48	2.75 m from E wall, 2.75 m from S wall, 2.14 m from ceiling
49	2.75 m from E wall, 2.75 m from S wall, 1.53 m from ceiling
50	2.75 m from E wall, 2.75 m from S wall, 0.92 m from ceiling
51	2.75 m from E wall, 2.75 m from S wall, 0.31 m from ceiling
52	On ceiling, 2.75 m from E wall, 2.75 m from S wall
53	On unexposed ceiling surface, behind TC 52
54	2.75 m from E wall, 0.92 m from S wall, 2.14 m from ceiling
55	2.75 m from E wall, 0.92 m from S wall, 1.53 m from ceiling
56	2.75 m from E wall, 0.92 m from S wall, 0.92 m from ceiling
57	2.75 m from E wall, 0.92 m from S wall, 0.31 m from ceiling
58	At doorway centerline, 0.13 m below top
59	At doorway centerline, 0.31 m below top
60	At doorway centerline, 0.66 m below top
61	At doorway centerline, 1.07 m below top

Table 2. (continued)

Number	Thermocouples
62	At doorway centerline, 1.37 m below top
63	At doorway centerline, 1.91 m below top
64	At doorway centerline, 0.46 m below top
65	At doorway centerline, 0.92 m below top
66	At doorway centerline, 1.68 m below top
67	On W wall, 0.61 m from S wall, 0.61 m from ceiling
68	On ceiling, 1.70 m from S wall, 2.89 m from E wall
69	On floor, 1.70 m from S wall, 2.59 m from E wall
	Smoke Meters
90	Horizontal in doorway, 0.31 m from ceiling (1.0 m light path)
91	Horizontal in doorway, 0.91 m from ceiling (1.0 m light path)
92	Horizontal in doorway, 1.52 m from ceiling (1.0 m light path)
93	Vertical in doorway centerline (2.44 m light path)
	Velocity Probes
94	At doorway centerline, 1.91 m below top
95	At doorway centerline, 1.37 m below top
96	At doorway centerline, 1.07 m below top
97	At doorway centerline, 0.66 m below top
98	At doorway centerline, 0.31 m below top
99	At doorway centerline, 0.13 m below top
	Heat Flux Meters
100	Radiometer, on W wall, 0.61 m from S wall, 0.61 m from ceiling
101	Total heat flux meter, same location as HFM100
102	Radiometer, on floor, 1.70 m from S wall, 2.58 m from E wall
103	Total heat flux meter, same location as HFM102
104	Radiometer, on ceiling, 1.70 m from S wall, 2.89 from E wall
105	Total heat flux meter, same location as HFM104
106	Radiometer, on ceiling, center of room
107	Total heat flux meter, same location as HFM106
	Load Cell
108	Load cell
	Gas Concentration Probes
112	Carbon dioxide, at doorway centerline, 0.025 m below top
113	Carbon monoxide, at doorway centerline, 0.025 m below top
114	Oxygen, at doorway centerline, 0.025 m below top

Table 3.

List of Instrumentation — Burn-Room "B"

Number	Thermocouples
00	Center of Room, 0.05 m from ceiling
01	Ceiling air, average of 8 TC's, 0.05 m from ceiling
02	Wastebasket plume, average of 9 TC's (0.30 m circle), 0.05 m from ceiling
03	On E wall, 1.82 m from S wall, 0.31 m from ceiling
04	On N wall, 2.12 m from W wall, 0.31 m from ceiling
05	On W wall, 1.82 m from S wall, 0.31 m from ceiling
06	On S wall, 2.12 m from W wall, 0.31 m from ceiling
07	Adjacent to tell-tale sprinkler 1
08	Adjacent to tell-tale sprinkler 2
09	Adjacent to tell-tale sprinkler 3
10	At doorway centerline, 0.05 m below top
11	3.25 m from E wall, 1.68 m from S wall, 0.05 m from ceiling
12	3.25 m from E wall, 1.68 m from S wall, 0.15 m from ceiling
13	3.25 m from E wall, 1.68 m from S wall, 0.31 m from ceiling
14	3.25 m from E wall, 1.68 m from S wall, 0.61 m from ceiling
15	3.25 m from E wall, 1.68 m from S wall, 0.91 m from ceiling
16	3.25 m from E wall, 1.68 m from S wall, 1.22 m from ceiling
17	3.25 m from E wall, 1.68 m from S wall, 1.53 m from ceiling
18	At doorway centerline, 1.19 m below top
19	At doorway centerline, 1.63 m below top
20	At doorway centerline, 0.13 m below top
21	At doorway centerline, 0.30 m below top
22	At doorway centerline, 0.66 m below top
23	At doorway centerline, 1.02 m below top
25	At doorway centerline, 1.37 m below top
26	At doorway centerline, 1.91 m below top
27	Corridor station B, 0.13 m from ceiling
28	Corridor station C, 0.13 m from ceiling
29	Corridor station A, 0.91 m from ceiling
30	Corridor station D, 0.13 m from ceiling
31	Corridor station E, 0.13 m from ceiling
32	Corridor station C, 0.05 m from ceiling
33	At doorway centerline, 0.48 m below top
34	Corridor station C, 0.46 m from ceiling
35	Corridor station C, 0.76 m from ceiling
36	Corridor station C, 1.07 m from ceiling
37	Corridor station C, 1.37 m from ceiling
38	Corridor station C, 1.68 m from ceiling
39	Corridor station C, 1.98 m from ceiling
40	Corridor station C, 2.29 m from ceiling
41	Corridor station D, 0.05 m from ceiling
42	At doorway centerline, 0.84 m below top
43	Corridor station D, 0.46 m from ceiling
44	Corridor station D, 0.76 m from ceiling
45	Corridor station D, 1.07 m from ceiling
46	Corridor station D, 1.37 m from ceiling
47	Corridor station D, 1.68 m from ceiling
48	Corridor station D, 1.98 m from ceiling
	Load Cell
50	Load cell

Table 3. (continued)

Number	Gas Concentration Probes
51	Carbon monoxide, at doorway centerline, 1.90 m below top
52	Carbon dioxide, at doorway centerline, 1.90 m below top
53	Carbon monoxide, 1.12 m from W wall, 0.36 m from S wall, 0.89 m from floor
54	Carbon dioxide, 1.12 m from W wall, 0.36 m from S wall, 0.89 m from floor
55	Carbon monoxide at doorway centerline, 0.51 m below top
56	Carbon dioxide, at doorway centerline, 0.51 m below top
57	Oxygen, at doorway centerline, 1.90 m below top
58	Oxygen, 1.12 m from W wall, 0.36 m from S wall, 0.89 m from floor
59	Oxygen, at doorway centerline, 0.51 m below top
79	Carbon monoxide, lobby, 1.55 m from E wall, 3.58 m from S wall
	Velocity Probes
60	At doorway centerline, 0.13 m below top
61	At doorway centerline, 0.30 m below top
62	At doorway centerline, 0.66 m below top
63	At doorway centerline, 1.02 m below top
64	At doorway centerline, 1.37 m below top
65	At doorway centerline, 1.91 m below top
66	Corridor station B, 0.13 m from ceiling
67	Corridor station C, 0.13 m from ceiling
68	Corridor station D, 0.13 m from ceiling
69	Corridor station E, 0.13 m from ceiling
	Smoke Meters
70	Horizontal in doorway, 0.13 m below top (1.219 m light path)
71	Horizontal in doorway, 0.30 m below top (1.219 m light path)
72	Horizontal in doorway, 0.66 m below top (1.219 m light path)
73	Horizontal in doorway, 1.02 m below top (1.219 m light path)
74	Horizontal, corridor station C, 0.06 m from ceiling (1.219 m light path)
75	Horizontal, corridor station C, 0.91 m from ceiling (1.219 m light path)
76	Horizontal, corridor station D, 0.06 m from ceiling (1.219 m light path)
77	Horizontal, corridor station D, 0.91 m from ceiling (1.219 m light path)
78	Horizontal, corridor station E, 0.06 m from ceiling (1.219 m light path)
82	Vertical in doorway centerline, (1.772 m light path)
83	Horizontal, lobby station F, 0.91 m from ceiling (1.219 m light path)
84	Horizontal, corridor station B, 0.06 m from ceiling (1.219 m light path)
	Heat Flux Meters
80	Total heat flux meter, facing up, 1.12 m from W wall, 1.19 m from S wall, 0.74 m from floor
81	Total heat flux meter, facing horizontally toward burn-room, on doorway centerline, 2.44 m N from doorway, 1.02 m from floor
	Detector Board
--	At ceiling, 1.52 m from W wall, 1.80 m from S wall
--	At ceiling, corridor center, 5.10 m E from doorway center
--	At ceiling, corridor center, 5.10 m W from doorway center
	Tell-Tale Sprinklers
--	At ceiling, 1.92 m from W wall, 1.22 m from S wall

Table 4.

Schedule of Tests

Specimen	Core Type	Description	Test Number		
			Burn-Room A	Burn-Room B Non-ventilated	Burn-Room B Ventilated
Control	Fiberglass	(Control)	2-12	N-8	N-11
M01	Polyurethane	Hospital	2-3	N-13	N-10
M02	Polyurethane Innerspring	Hospital	2-2,2-9	N-5	N-9
M03	Cotton Innerspring	Hospital	2-1	--	--
M04	Latex	Osceola	2-14	--	--
M05	Polyurethane	Commercial	2-13	N-7	N-14
M06	Cotton/Nylon/Polyester Innerspring	Commercial	2-11	N-6	N-12
M07	Cotton Innerspring	Connecticut State	2-10	--	--
M08	Neoprene	Navy	2-8	--	--
M09	Polyurethane	Seminole Prison	2-6	--	--
M10	Neoprene	Prison	2-5	--	--

Table 5.

Properties of Bedding

	Size (WxL) (m)	Composition	Thickness (mm)	Density (kg/m^3)	$\rho\tau$ (kg/m^2)	Total Weight (kg)
Drawsheet	1.07 x 0.69	Cotton	0.14	775	0.108	0.40
Sheets	1.83 x 2.64	50% Cotton, 50% Polyester	0.22	570	0.125	0.60
Spread	1.93 x 2.79	86% Cotton, 14% Polyester	0.38	525	0.200	1.07
Pillow - filling	--	Polyurethane	--	—	--	0.67
- cover	0.52 x 0.69	Cotton	0.40	575	0.230	0.16
Pillow Protector	0.53 x 0.69	Polyvinylchloride	0.14	775	0.108	0.09
Pillow Case	0.53 x 0.91	50% Cotton, 50% Polyester	0.21	595	0.125	0.60

Table 6. Ignition Source

Wastebasket — polyethylene wastebasket

Size: 248 mm x 178 mm x 254 mm high
Weight: 282 g

Trash contents, in order of stacking

1 — Polyethylene liner
16 — Sheets of newspaper
1 — Paper cup, 3 oz., crumpled
2 — Sheets of writing paper
3 — Tissues, paper handkerchief, crumpled
1 -- Cigarette pack, crumpled
1 -- Milk carton, 8-oz.
2 — Paper cup, 3-oz., crumpled
1 -- Cigarette pack, crumpled
1 -- Sheet of writing paper, crumpled
2 -- Tissues, paper handkerchief, crumpled

Total weight of contents: 443 g

Combined weight, wastebasket and contents: 725 g

Table 7. Mattress Sizes and Weights

Mattress	Size (over-all)			Total Weight (kg)	Weight of Combustibles (kg)	Weight of Innerspring (kg)
	Width (m)	Length (m)	Thickness (m)			
M01	0.89	2.03	0.17	14	14	—
M02	0.89	2.03	0.17	15	6	9
M03	0.89	2.03	0.17	20	11	9
M04	0.92	2.11	0.11	19	19	—
M05	0.95	1.88	0.13	6	6	—
M06	0.99	1.91	0.18	20	12	8
M07	0.99	1.91	0.18	25	13	12
M08	0.88	1.93	0.15	18	18	—
M09	0.66	1.84	0.08	3.2	3.2	—
M10	0.66	1.84	0.08	6	6	—

Table 8. Physical Properties of Mattresses

Mattress	Innersprings	Layer	Composition	Thickness (mm)	Density (kg/m^3)	$\rho\tau$ (kg/m^2)	Flame Retardants
M01	no	Ticking	Polyvinyl chloride (1)	0.34	1100	0.378	yes
		Outer Padding	Polyurethane, (TDI/polyether type)	36.8	25	0.921	slight
		Inner Core	Polyurethane, (TDI/polyether type)	86.9	64	5.561	yes
M02	yes	Ticking	Polyvinyl chloride (1)	0.34	1120	0.385	yes
		Interliner	Polypropylene fabric	0.25	260	0.064	no
		Padding	Polyurethane, (TDI/polyether type)	37.5	19	0.712	no
M03	yes	Ticking	Polyvinyl chloride (1)	0.34	1100	0.379	yes
		Interliner	Polypropylene fabric	0.22	320	0.070	no
		Padding	Cotton felt	49.6	38	1.883	yes
M04	no	Ticking	Polyvinyl chloride (2) with cotton backing	0.56	730	0.410	yes
		Core	Latex (butadiene-styrene)	101.6	81	8.23	no
M05	no	Ticking	Rayon fabric (outer) (3)	0.25	620	0.154	no
		Interliner	Polyurethane foam	0.71	110	0.075	no
			Rayon fabric (inner)	0.10	200	0.020	no
		Core	Polyurethane	127.	20	2.54	no
M06	yes	Ticking	Polyester	0.25	680	0.170	no
		Padding	Cotton/polyester felt	7.62	230	1.76	no
		Padding	Cotton/nylon/polyester Pad	12.7	43	0.54	yes

(1) With decyl-2-ethyl-hexyl phthalate plasticizer

(2) With a fatty acid nitrile plasticizer

(3) Top quilted, bottom not quilted

Table 8. (continued)

Mattress	Innersprings	Layer	Composition	Thickness (mm)	Density (kg/m^3)	$\rho\tau$ (kg/m^2)	Flame Retardants
M07	yes	Ticking	Cotton	0.46	650	0.300	yes
		Padding	Cotton felt	38.1	38	1.46	yes
		Padding	Jute pad	6.4	120	0.788	no
M08	no	Ticking	Cotton	0.46	550	0.252	yes
		Core	Polychloroprene foam	152.	67	10.18	yes
M09	no	Ticking	Polyvinyl chloride with nylon fabric reinforcement	0.36	790	0.284	yes
		Core	Polyurethane (TDI/ polyether type)	76.2	22	1.68	no
M10	no	Ticking	Polyvinyl chloride with nylon fabric reinforcement	0.33	1070	0.354	no
		Core	Polychloroprene foam	76.2	50	3.81	yes

Table 9. Time of Ignition Events

Mattress	Test	Bed Spread Ignition (s)	Mattress Ignition (s)	Pillow Case Ignition (s)	Pillow Ignition (s)
Control	N-8	25	--	N.A.	N.A.
	N-11	25	--	300	390
M01	N-13	31	174	532	630
	N-10	23	255	N.A.	N.A.
M02	N-5	15	95	255	357
	N-9	40	120	N.A.	390
M05	N-7	14	85	145	180
	N-14	15	165	350	405
M06	N-6	20	195	105	215
	N-12	17	150	N.A.	245
	Mean	23	155	276	351
	Standard Deviation	8	56	155	143

N.A. - not available

Table 10. Weight Loss Record

Mattress	Test	Mattress Combustible Weight (kg)	Bedding and Source Weight (kg)	Total Combustible Weight (kg)	Weight Remaining After Test (kg)
Control	2-12	≃0	4.2	4.2	0
	N-8	≃0	4.5	4.5	N.A.
	N-11	≃0	4.3	4.3	1.1
M01	2-3	13.6	4.4	18.0	N.A.
	N-13	13.6	4.3	17.9	0
	N-10	14.5	4.2	16.7	N.A.
M02	2-2	5.5	4.5	10.0	N.A.
	2-9	5.5	4.5	10.0	0
	N-5	6.4	4.3	10.7	2.5
	N-9	6.4	4.4	10.8	1.6
M03	2-1	11.4	4.3	15.7	10.2
M04	2-14	18.6	4.3	22.9	N.A.
M05	2-13	5.9	4.6	10.5	0
	N-7	6.4	4.3	10.7	1.1
	N-14	6.4	4.3	10.7	1.2
M06	2-11	11.2	4.4	15.6	0
	N-6	11.8	4.4	16.2	0
	N-12	12.7	4.4	17.1	3.0
M07	2-10	12.7	4.4	17.1	10.5
M08	2-8	18.2	4.5	22.7	16.6
M09	2-6	3.2	4.2	7.4	0
M10	2-5	6.4	4.3	10.7	6.2

N.A. - Not Available

Table 11. Heat Flux Peak Values

Mattress	Test	Adjacent Patient Level		West Wall			Floor			Ceiling - Room Center			Center - Near Doorway		
		Total Flux (kW/m^2)	Time (s)	Total Flux (kW/m^2)	Radiant Flux (kW/m^2)	Time (s)	Total Flux (kW/m^2)	Radiant Flux (kW/m^2)	Time (s)	Total Flux (kW/m^2)	Radiant Flux (kW/m^2)	Time (s)	Total Flux (kW/m^2)	Radiant Flux (kW/m^2)	Time (s)
Control	2-12			2.21	0.63	640	1.12	0.85	690	4.42	1.13	740	1.91	0.88	720
	N-8	N.A.	N.A.												
	N-11	N.A.	N.A.												
M01	2-3			N.A.	16.5	390	32.6	23.0	490	108.	16.7	440	61.8	12.8	390
	N-13	18.0	840												
	N-10	37.4	820												
M02	2-2			N.A.	7.55	390	13.2	8.56	390	38.1	9.57	390	28.3	5.31	380
	2-9			19.3	7.16	340	12.4	10.5	350	36.7	13.5	340	19.6	13.2	340
	N-5	6.52	430												
	N-9	5.85	510												
M03	2-1			1.62	0.46	1290	0.59	0.57	640	2.49	0.81	1280	2.12	0.78	1300
M04	2-14			106.	14.1	620	45.8	27.6	750	136.	27.4	590	131.	45.1	680
M05	2-13			30.7	13.4	470	12.9	10.0	490	43.1	13.5	450	17.4	16.8	430
	N-7	2.08	880												
	N-14	N.A.	N.A.												
M06	2-11			18.2	5.64	540	9.50	5.56	670	28.8	7.06	550	14.2	7.04	540
	N-6	7.13	650												
	N-12	N.A.	N.A.												
M07	2-10			1.19	0.41	600	0.76	0.66	530	3.08	1.03	600	1.11	0.64	590
M08	2-8			1.55	0.45	230	0.88	0.80	670	2.53	0.68	750	1.28	0.55	740
M09	2-6			13.1	3.76	700	5.51	2.90	700	14.2	1.53	680	18.4	2.87	700
M10	2-5			2.28	0.80	250	0.50	0.67	560	3.24	0.89	560	2.51	0.70	570

N.A. - Not Available

Table 12. Time to Reach Critical Flux Values

Mattress	Test	Habitability Level 2.5 kW/m²			Ignition Level 20 kW/m²
			West Wall		
		Adjacent Patient Level (Total Flux) Time (s)	(Radiant Flux) Time (s)	(Total Flux) Time (s)	Floor Level (Total Flux) Time (s)
Control	2-12		*†	*	*
	N-8	N.A.†			
	N-11	N.A.†			
M01	2-3		230	N.A.	470
	N-13	670			
	N-10	610			
M02	2-2		310	N.A.	*
	2-9		290	240	*
	N-5	330			
	N-9	490			
M03	2-1		*	*	*
M04	2-14		460	420	720
M05	2-13		380	350	*
	N-7	290			
	N-14	N.A.			
M06	2-11		500	460	*
	N-6	420			
	N-12	N.A.			
M07	2-10		*	*	*
M08	2-8		*	*	*
M09	2-6		670	630	*
M10	2-5		*	*	*

†Not Reached

††Not Available

Table 13. Peak Extinction Coefficients

Mattress	Test	Doorway Vertical		Doorway Horizontal 0.30 m below Top		Corridor Horizontal Station D 1.52 m from Floor	
		k (m^{-1})	Time (s)	k (m^{-1})	Time (s)	k (m^{-1})	Time (s)
Control	2-12	0.39	320	0.58	300		
	N-8	1.82	970	1.80	1710	1.13	630
	N-11	1.01	940	1.96	920	0.48	790
M01	2-3	2.58	370	5.55	350		
	N-13	2.30	600	N.A.	N.A.	3.29	670
	N-10	3.57	640	5.41	570	3.73	610
M02	2-2	2.44	360	4.54	330		
	2-9	*	330	4.77	310		
	N-5	3.50	340	3.87	280	2.58	370
	N-9	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
M03	2-1	0-58	790	1.20	790		
M04	2-14	*	480	6.68	480		
M05	2-13	2.21	430	2.76	430		
	N-7	N.A.	N.A.	1.66	690	0.99	430
	N-14	2.42	1040	2.19	500	1.17	670
M06	2-11	2.99	550	4.26	560		
	N-6	3.06	590	2.63	570	N.A.	N.A.
	N-12	N.A.	N.A.	N.A.	N.A.	2.16	670
M07	2-10	>0.46	>1900	0.88	>1890		
M08	2-8	1.66	1390	3.13	1260		
M09	2-6	*	680	4.47	710		
M10	2-5	1.38	710	2.40	758		

* Exceeds range of instrument

N.A. - not available.

Table 14. Time to Reach Critical Level of Extinction Coefficient

Mattress	Test	Time to Reach $k = 1.2\ m^{-1}$ 0.30 m below Top of Doorway (s)
Control	2-12	N.R.
	N-8	540
	N-11	740
M01	2-3	300
	N-13	250
	N-10	240
M02	2-2	200
	2-9	260
	N-5	200
	N-9	300
M03	2-1	N.R.
M04	2-14	370
M05	2-13	380
	N-7	310
	N-14	390
M06	2-11	470
	N-6	180
	N-12	360
M07	2-10	N.R.
M08	2-8	280
M09	2-6	450
M10	2-5	630

N.R. - Not Reached

Table 15. O_2 Minimums

Mattress	Test	Adjacent Patient Level		Doorway 0.025 m below Top		Doorway 0.51 m below Top		Doorway 1.90 m below Top	
		Min. (%)	Time (s)	Min. (%)	Time (s)	Min. (%)	Time (s)	Min. (%)	Time (s)
Control	2-12			19.4	750				
	N-8	19.5	890			19.3	1000	N.A.	N.A.
	N-11	< 19.5	>1800			19.5	780	20.5	1440
M01	2-3			0.75	470				
	N-13	12.2	910			N.A.	N.A.	16.5	1200
	N-10	10.8	810			6.31	820	19.0	880
M02	2-2			8.08	410				
	2-9			7.36	380				
	N-5	N.A.	N.A.			17.7	860	N.A.	N.A.
	N-9	17.3	610			16.1	610	20.1	610
M03	2-1			19.5	1280				
M04	2-14			0.13	820				
M05	2-13			8.01	460				
	N-7	17.7	1380			18.1	1660	N.A.	N.A.
	N-14	17.8	880			16.6	840	19.6	850
M06	2-11			12.2	560				
	N-6	N.A.	N.A.			N.A.	N.A.	14.1	670
	N-12	19.6	1010			N.A.	N.A.	20.3	930
M07	2-10			19.6	630				
M08	2-8			19.4	250				
M09	2-6			13.3	720				
M10	2-5			19.4	270				

N.A. - Not available

Table 16. CO_2 Concentrations

Mattress	Test	Adjacent Patient Level		Doorway 0.025 m below Top		Doorway 0.51 m below Top		Doorway 1.90 m below Top	
		Peak (%)	Time (s)	Peak (%)	Time (s)	Peak (%)	Time (s)	Peak (%)	Time (s)
Control	2-12			1.46	760				
	N-8	0.51	890			1.73	580	N.A.	N.A.
	N-11	N.A.	N.A.			0.93	760	0.14	910
M01	2-3			17.8	480				
	N-3	6.68	910			6.32	870	3.14	940
	N-10	8.20	860			12.8	790	1.22	920
M02	2-2			10.5	410				
	2-9			13.8	400				
	N-5	1.52	930			4.24	450	1.80	690
	N-9	N.A.	N.A.			4.21	540	N.A.	N.A.
M03	2-1			1.21	240				
M04	2-14			21.1	630				
M05	2-13			14.0	470				
	N-7	2.47	1150			2.71	880	1.66	1530
	N-14	N.A.	N.A.			N.A.	N.A.	0.31	890
M06	2-11			11.7	570				
	N-6	3.01	1090			5.65	660	2.82	1000
	N-12	N.A.	N.A.			3.37	620	0.42	950
M07	2-10			1.11	620				
M08	2-8			1.29	260				
M09	2-6			9.22	720				
M10	2-5			1.39	270				

N.A. - Not available

Table 17. CO Concentrations

Mattress	Test	Adjacent Patient Level		Doorway 0.025 m below Top		Doorway 0.51 m below Top		Doorway 1.90 m below Top	
		Peak (ppm)	Time (s)	Peak (ppm)	Time (s)	Peak (ppm)	Time (s)	Peak (ppm)	Time (s)
Control	2-12			740	760				
	N-8	390	1860			580	1250	360	1600
	N-11	80	1440			280	270	30	1060
M01	2-3			17600	450				
	N-13	3050	780			3100	780	1600	1920
	N-10	1930	790			4280	790	360	960
M02	2-2			8260	410				
	2-9			6850	460				
	N-5	1620	1000			2810	430	1080	920
	N-9	1950	610			2750	560	250	650
M03	2-1			970	1410				
M04	2-14			20800	570				
M05	2-13			2940	480				
	N-7	730	1660			1040	1490	590	1720
	N-14	370	850			510	820	70	840
M06	2-11			3090	580				
	N-6	>1620	>1550			2460	1370	>1210	>1550
	N-12	250	1210			1270	1080	110	1260
M07	2-10			1410	1670				
M08	2-8			950	810				
M09	2-6			4270	720				
M10	2-5			1040	720				

Table 18. Computed COHb Levels at Different Times *

Mattress	Test	300 s (%)	600 s (%)	900 s (%)	1200 s (%)	1500 s (%)	1800 s (%)	Time to Reach COHb = 25% (s)
Control	2-12	1.7	3.5	5.8	7.9			--
	N-8	0.8	1.4	2.5	3.6	4.8	6.1	--
	N-11	0.8	1.0	1.1	1.3	1.5	1.7	--
M01	2-3	1.9	>25.0	>25.0				480
	N-13	1.2	4.6	12.7	18.7	24.4	>25.0	1530
	N-10	0.8	1.0	5.2	8.1	8.4	8.5	--
M02	2-2	2.8	17.3	18.8				--
	2-9	1.8	18.8	21.0				--
	N-5	0.8	2.9	8.3	14.2			--
	N-9	0.8	1.7	4.4	4.9	5.1	5.2	--
M03	2-1	1.9	4.0	6.2	8.7	11.8	14.8	--
M04	2-14	1.4	>25.0	>25.0	>25.0	>25.0	>25.0	600
M05	2-13	1.5	6.6	8.5				--
	N-7	0.8	1.5	3.0	5.2	7.8	10.3	--
	N-14	0.9	1.0	1.6	2.1	2.3	2.5	--
M06	2-11	1.9	7.1	14.9	20.1			--
	N-6	0.8	1.0	2.6	7.0	12.7		--
	N-12	0.8	1.0	1.5	2.2	2.9	3.2	--
M07	2-10	1.6	4.1	8.0	12.9	18.1	23.4	--
M08	2-8	1.9	4.4	7.3	10.2	13.4	15.0	--
M09	2-6	1.3	3.8	10.6	12.1			--
M10	2-5	1.7	3.8	6.8	8.6	9.7	10.6	--

* Data for burn-room "A" tests taken 0.025 m below top of doorway
Data for burn-room "B" tests taken at adjacent patient level
Calculations based on Stewart's Equation

Table 19. Time to Reach Critical Gas Concentrations

Mattress	Test	Critical Concentration 0.025 m below Top of Doorway	
		Time (s)	Species
Control	2-12	N.R.	
M01	2-3	360	O_2
M02	2-2 2-9	350 340	O_2 O_2
M03	2-1	N.R.	
M04	2-14	490	O_2
M05	2-13	410	CO_2
M06	2-11	540	O_2
M07	2-10	N.R.	
M08	2-8	N.R.	
M09	2-6	710	CO_2, O_2
M10	2-5	N.R.	

N.R. - not reached

Table 20. Values for Replicate Tests

Quantity		Test 2-2	Test 2-9	Difference % of Mean
Heat Flux				
Peak, total, west wall	kW/m^2	N.A.	19.3	--
Peak, radiant, west wall	kW/m^2	7.55	7.16	2.7
Peak, total, floor	kW/m^2	13.2	12.4	3.1
Peak, radiant, floor	kW/m^2	8.56	10.5	10.2
Peak, total, ceiling center	kW/m^2	38.1	36.7	1.9
Peak, radiant, ceiling center	kW/m^2	9.57	13.5	17.0
Peak, total, ceiling near doorway	kW/m^2	28.3	19.6	18.2
Peak, radiant, ceiling near doorway	kW/m^2	5.31	31.2	42.6
Time, peak, west wall	s	390	340	6.9
Time, peak, floor	s	390	350	5.4
Time, peak, ceiling center	s	390	340	6.9
Time, peak, ceiling near doorway	s	380	340	5.6
Smoke				
Peak, vertical	m^{-1}	2.44	--	--
Peak, doorway, horizontal	m^{-1}	4.54	4.77	2.5
Time, peak, vertical	s	360	330	4.4
Time, peak, doorway, horizontal	s	330	310	3.1
Time, limit, doorway, horizontal	s	200	260	13.0
Gas Concentration				
CO, peak	ppm	8260	6850	9.3
CO_2, peak	%	10.5	13.8	13.6
O_2, minimum	%	8.08	7.36	4.7
CO, time, peak	s	410	460	5.7
CO_2, time, peak	s	410	400	1.2
O_2, time, minimum	s	410	380	3.8
Time, O_2, limit	s	350	340	1.4
Temperature				
Peak, TC09	C	554	614	5.1
Peak, TC51	C	511	529	1.7
Time, peak	s	400	350	6.7

N.A. - Not available

Table 21. Evaluation Criteria

Flame Spread Potential Criterion

Heat Flux ≤ 20 kW/m^2 at Floor

Tenability Criteria (levels at which incipient incapacitation can be expected for occupants within the room of fire origin)

A. Heat Flux

Exposure ≤ 2.5 kW/m^2

B. Gas Concentrations

$CO_2 \leq 8\%$

$O_2 \geq 14\%$

COHb level $\leq 25\%$ (subject to an instantaneous ceiling for CO of 50,000 ppm)

C. Smoke Obscuration

Extinction Coefficient ≤ 1.2 m^{-1}

Table 22. Mattress Evaluation Results

Group	Mattress	Core Type	Description	Flashover Criterion	Tenability Criteria -- Time to Reach Critical Values		
				Time to Reach Full Room Involvement (s)	Gas Concentration (s)	Radiant Heat Flux (s)	Smoke Obscuration (s)
A	M03	Cotton	Hospital	N.R.	N.R.	N.R.	N.R.
	M07	Cotton	Connecticut State	N.R.	N.R.	N.R.	N.R.
B	M10	Neoprene	Prison	N.R.	N.R.	N.R.	630
	M08	Neoprene	Navy	N.R.	N.R.	N.R.	280
C	M09	Polyurethane	Seminole Prison	N.R.	710	670	450
	M06	Cotton/Nylon/ Polyester	Commercial	N.R.	540	500	470
	M05	Polyurethane	Commercial	N.R.	410	380	380
	M02	Polyurethane	Hospital	N.R.	345	300	230
D	M04	Latex	Osceola	720	490	460	370
	M01	Polyurethane	Hospital	470	360	230	300

N.R. - Not Reached

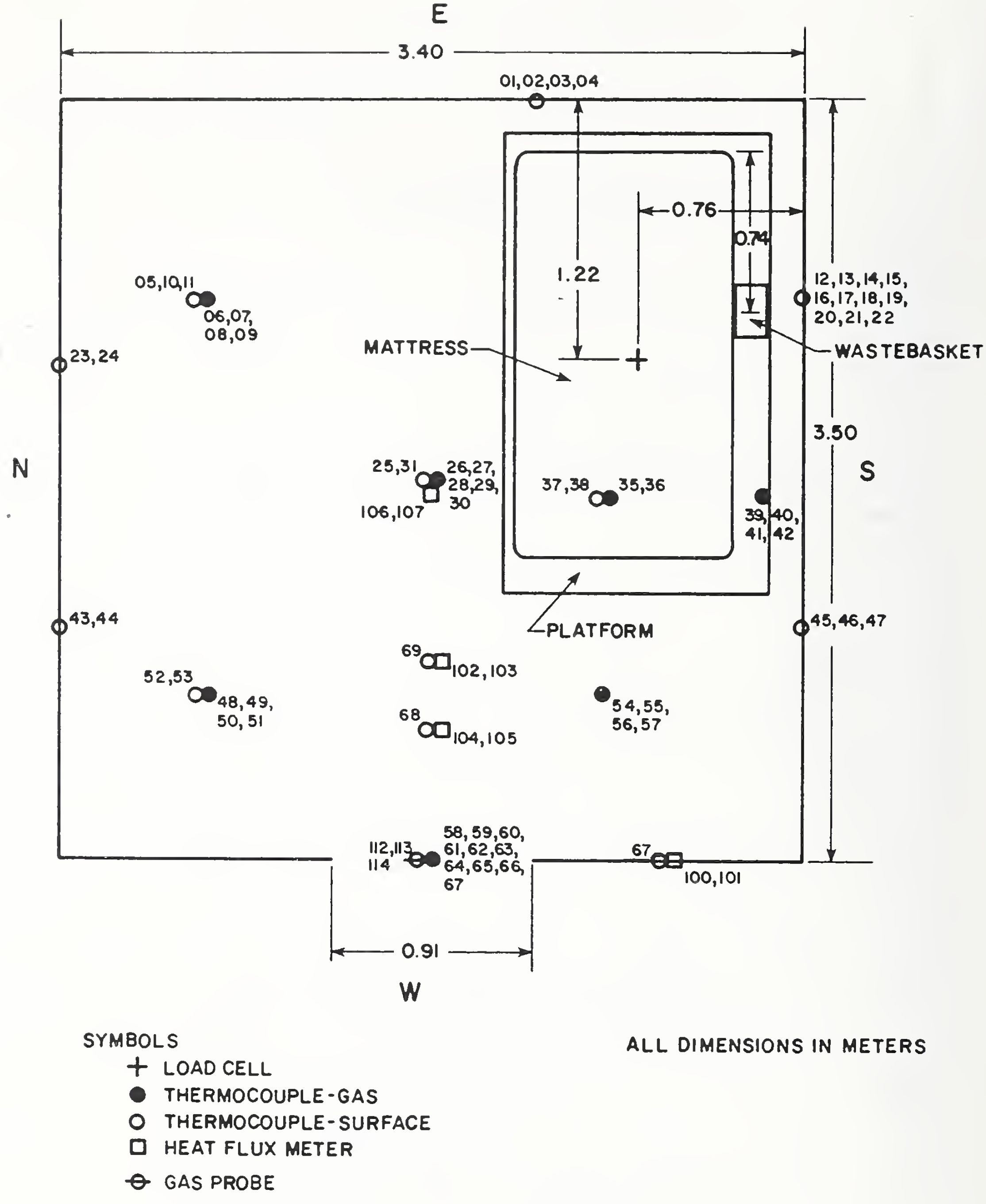


Figure 1. Burn-Room A Plan View

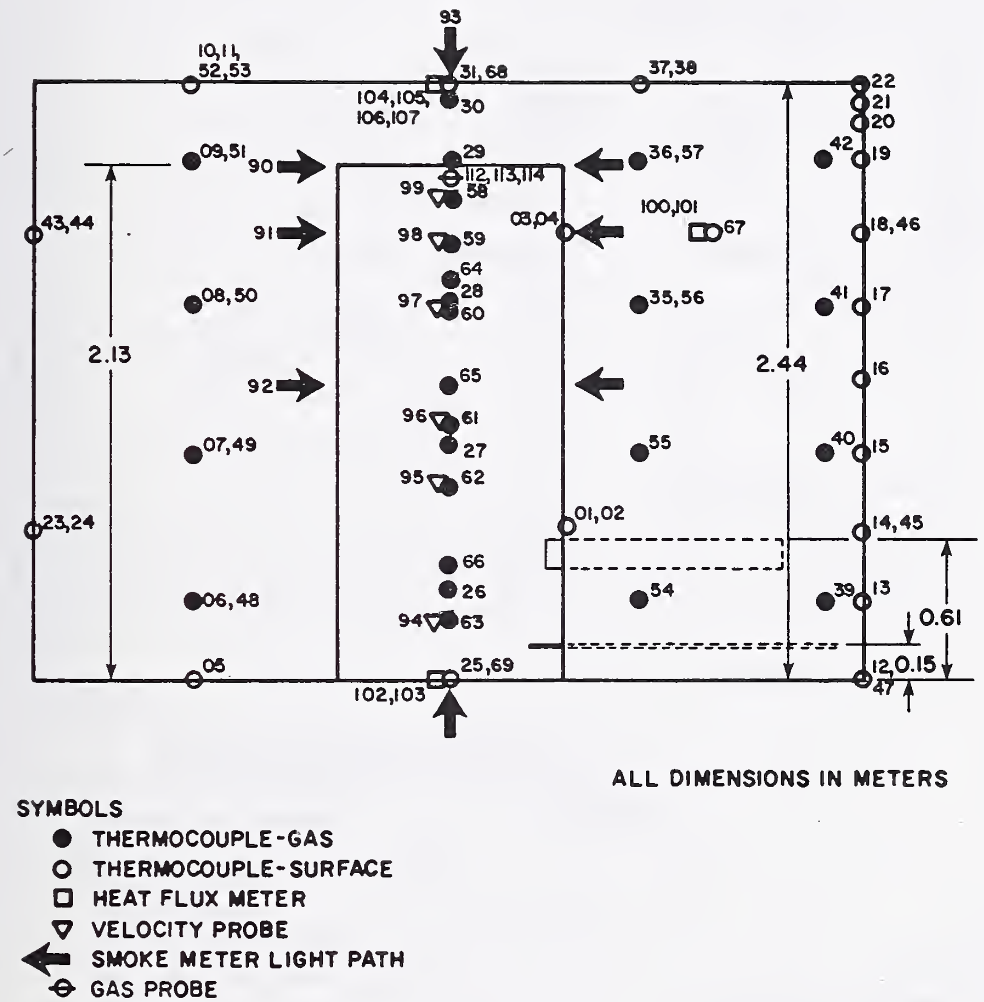


Figure 2. Burn-Room A Doorway Elevation

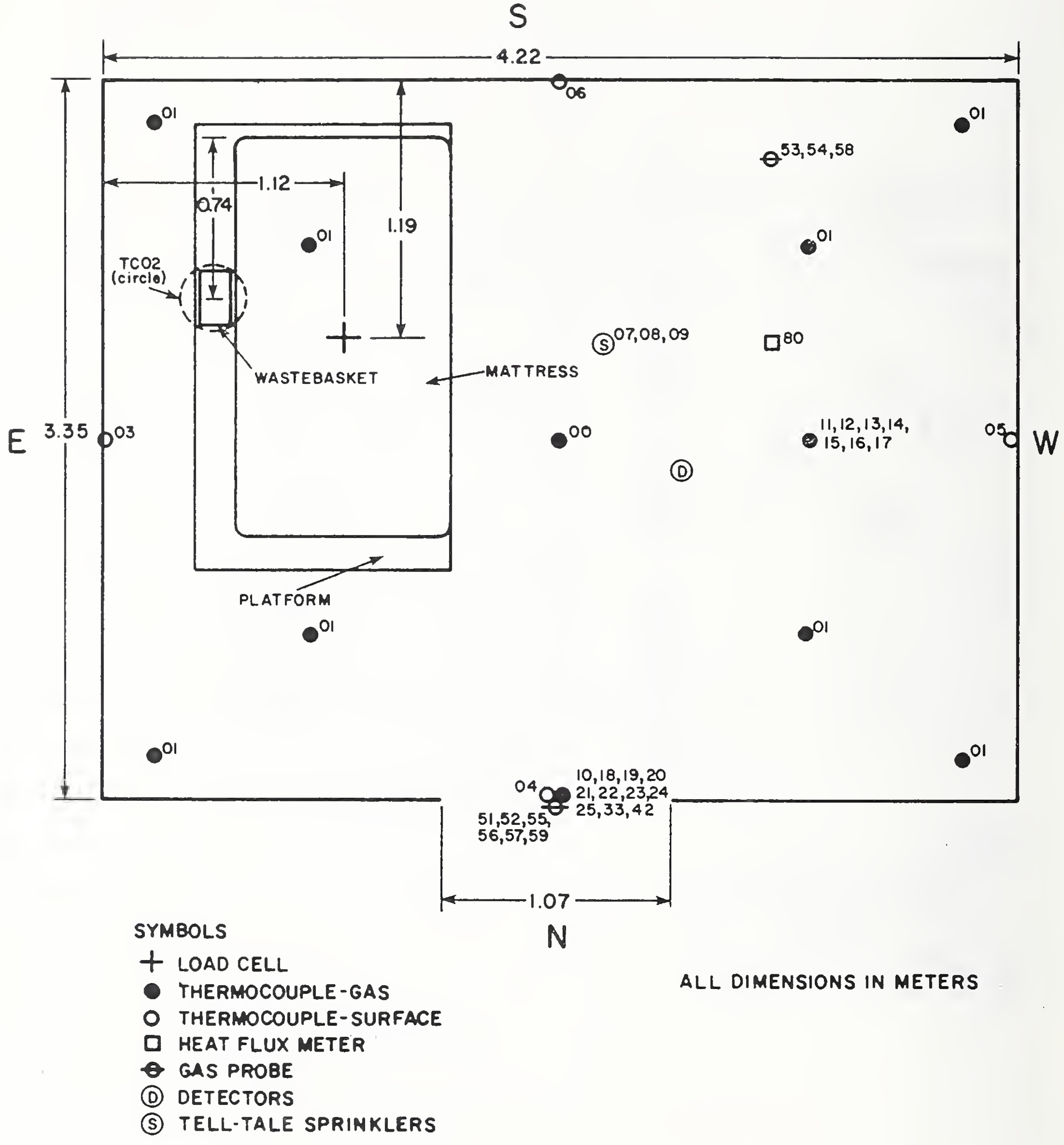


Figure 3. Burn-Room B Plan View

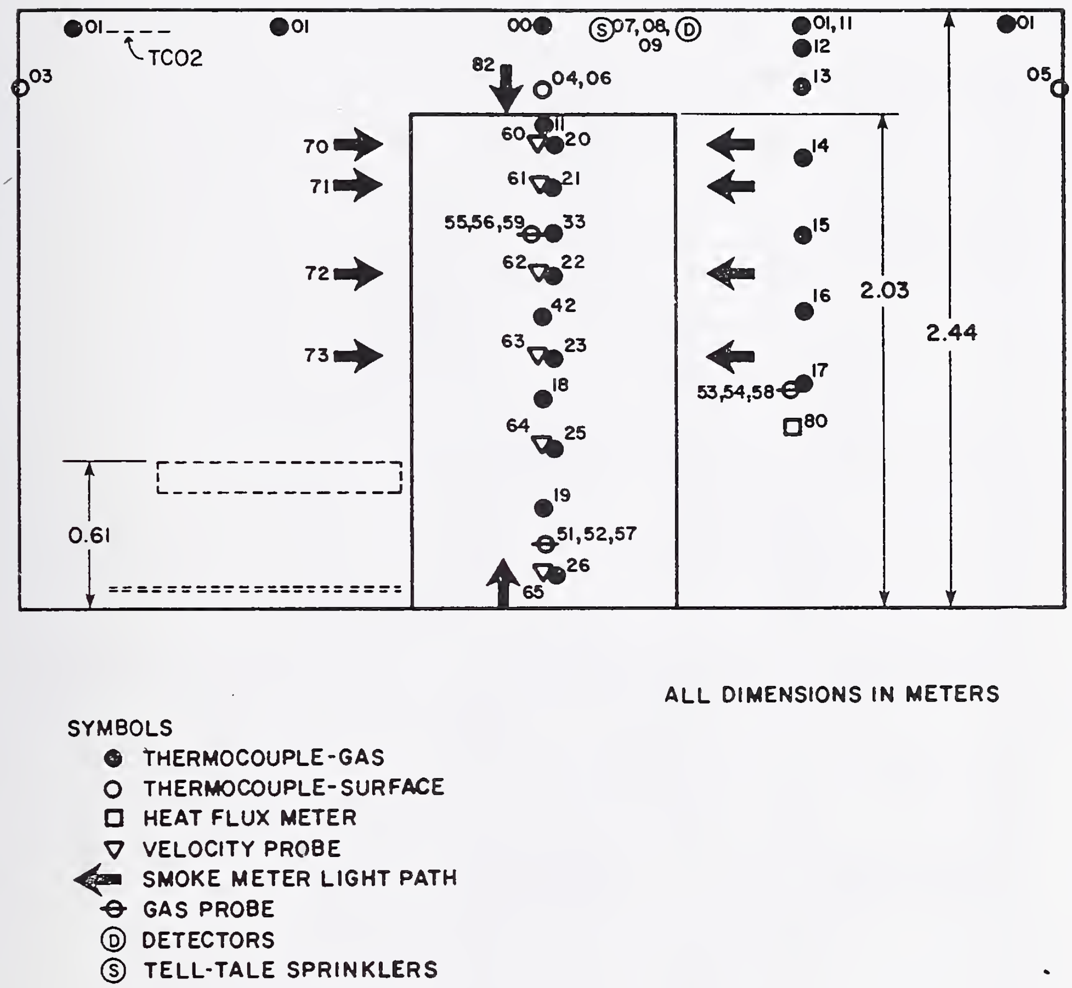


Figure 4. Burn-Room B Doorway Elevation

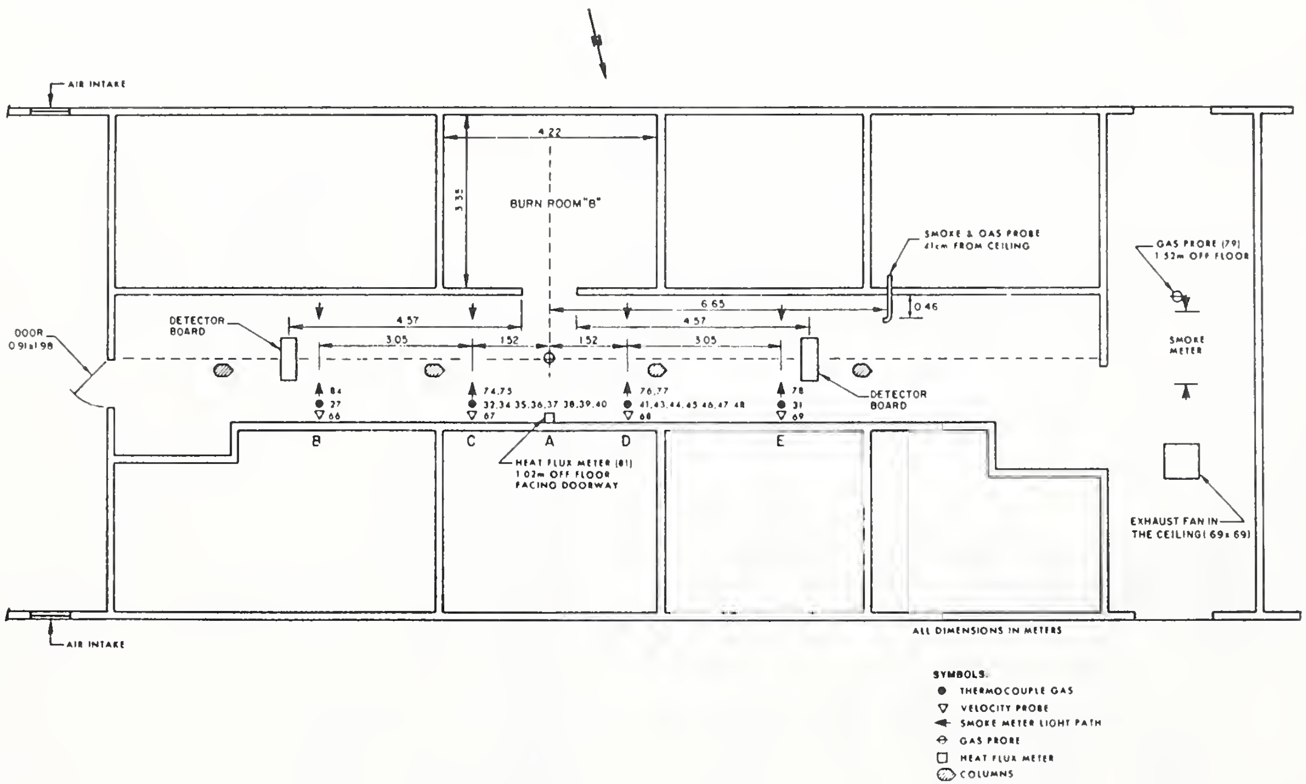


Figure 5. Corridor Plan View

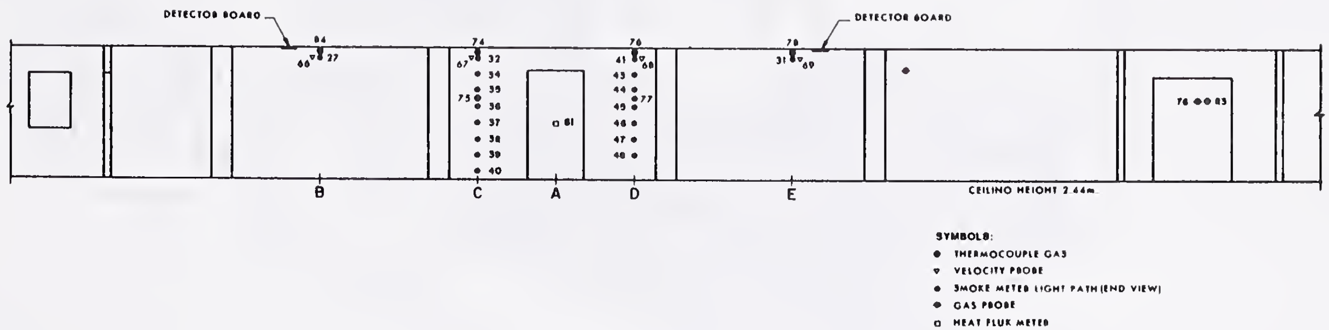


Figure 6. Corridor Elevation

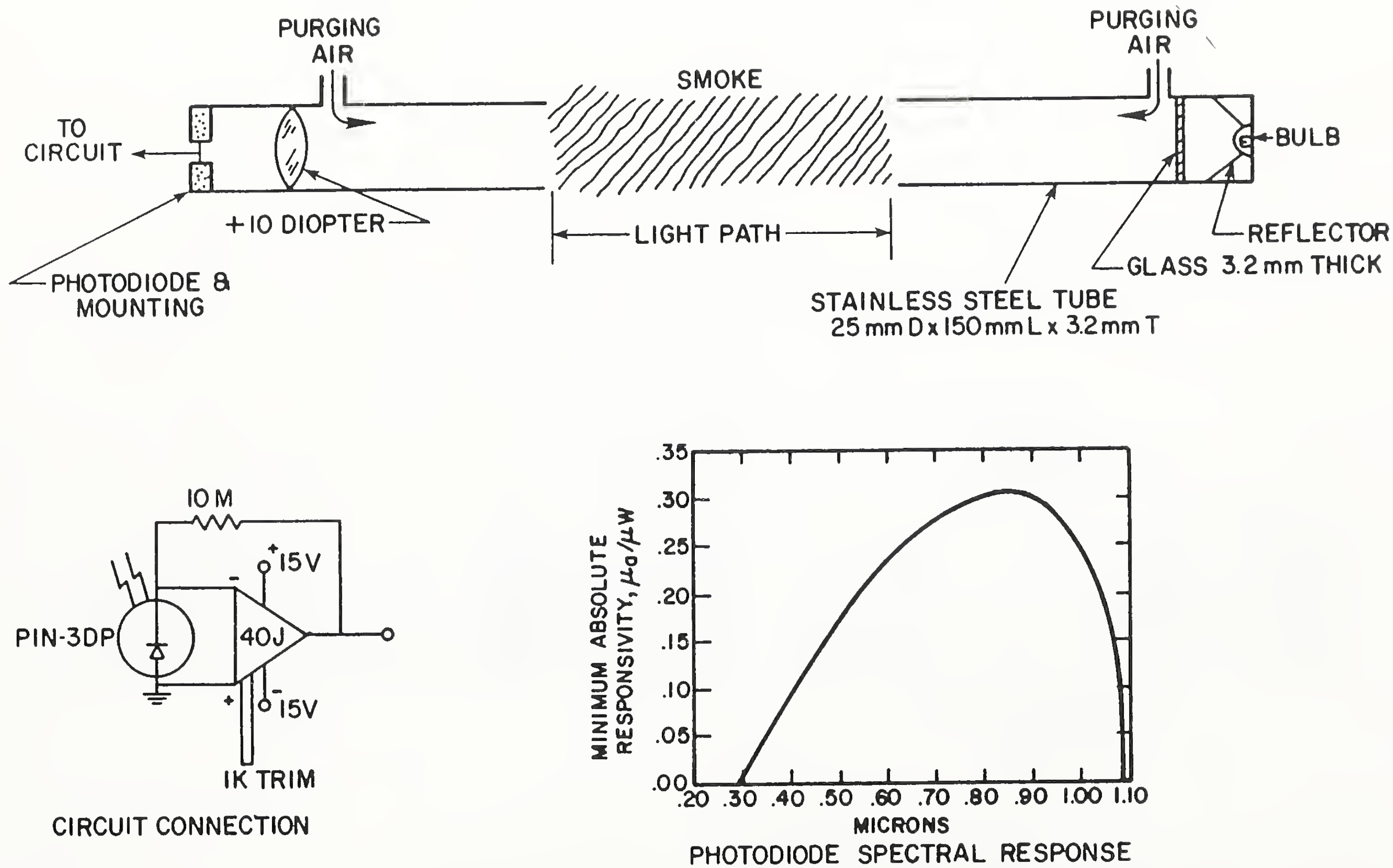


Figure 7. Smoke Meter

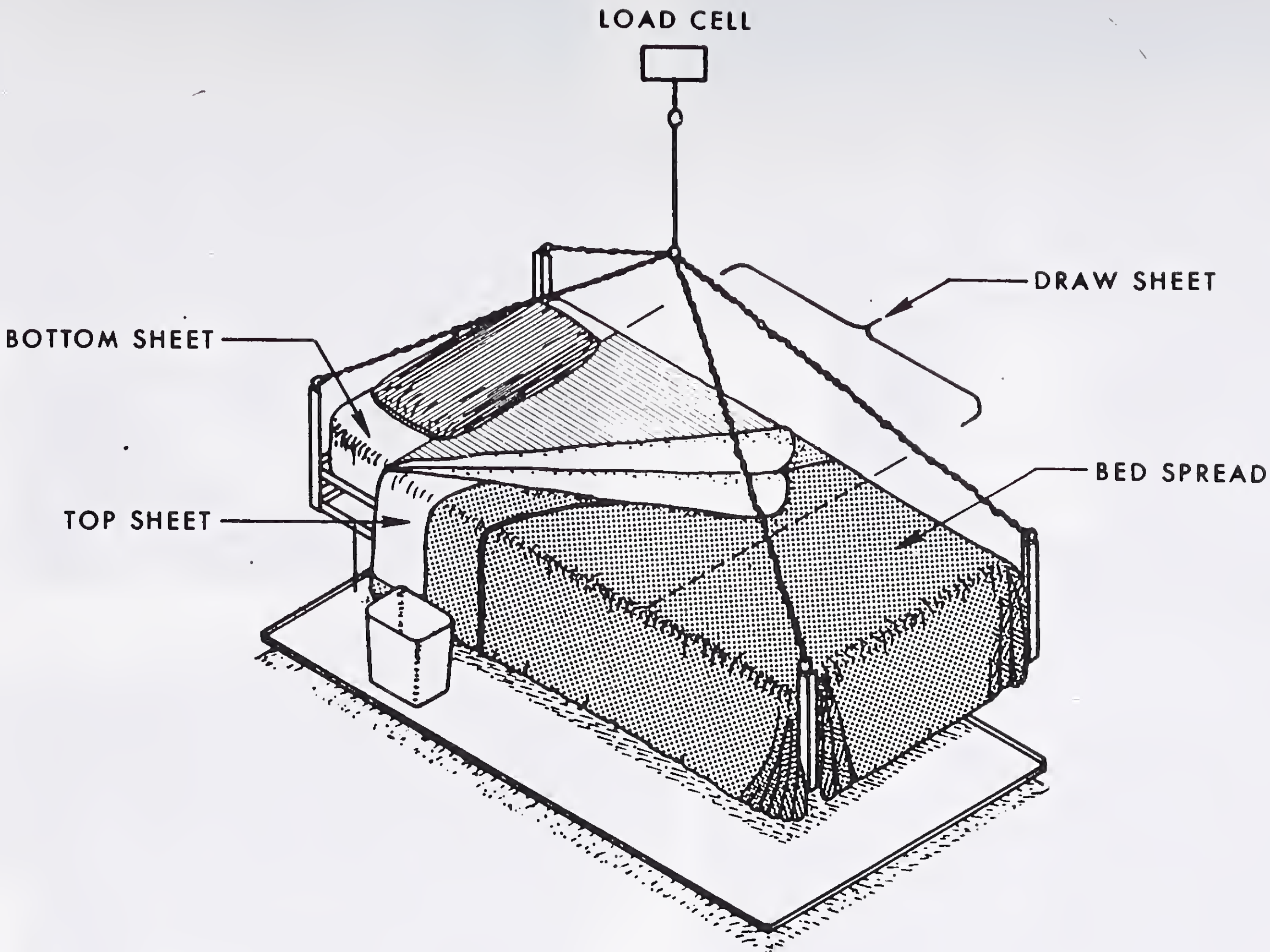
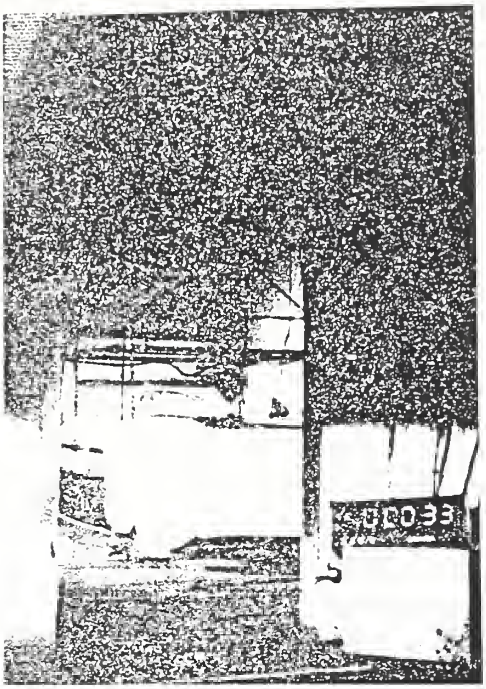
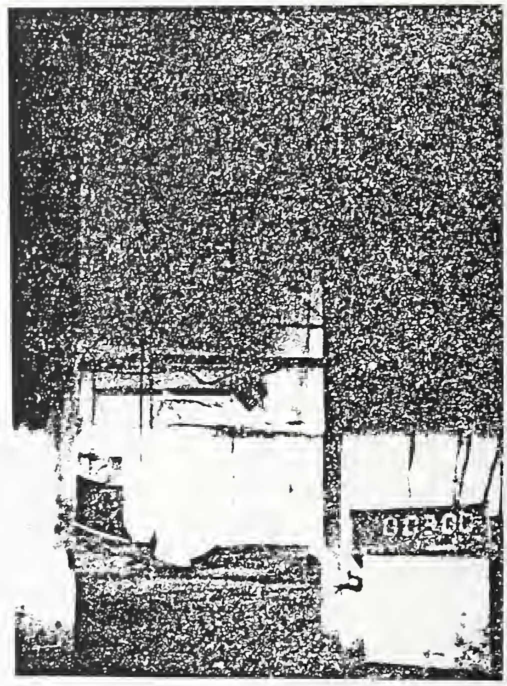


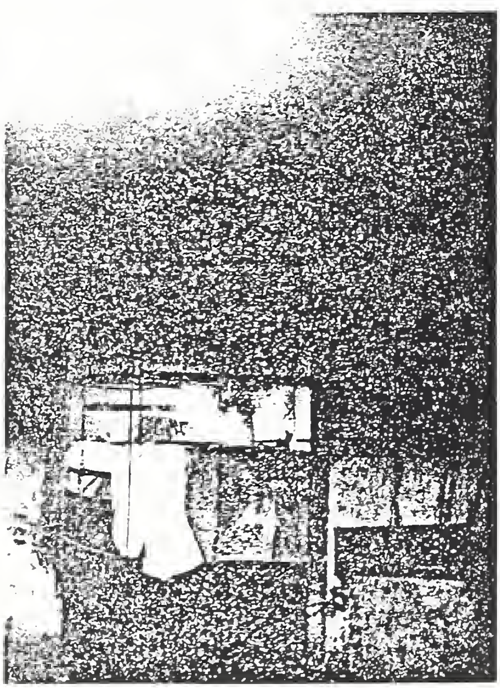
Figure 8. View of Test Bed



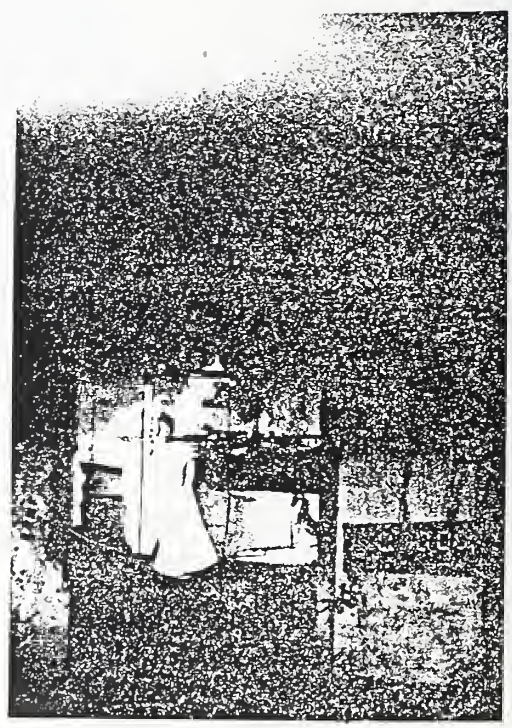
Time = 33 s



Time = 180 s

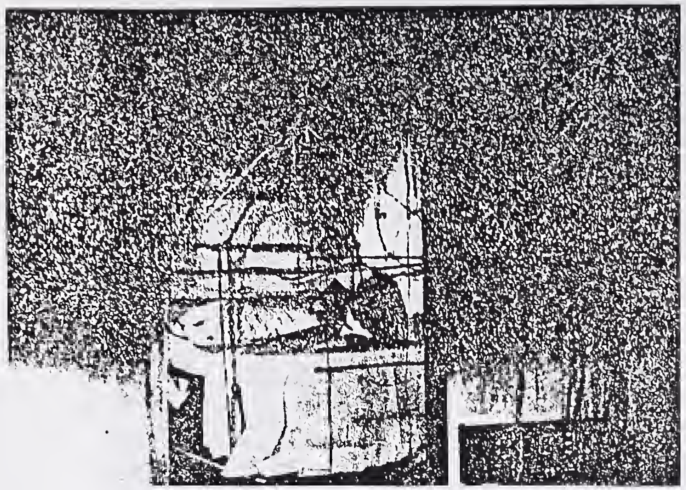


Time = 270 s

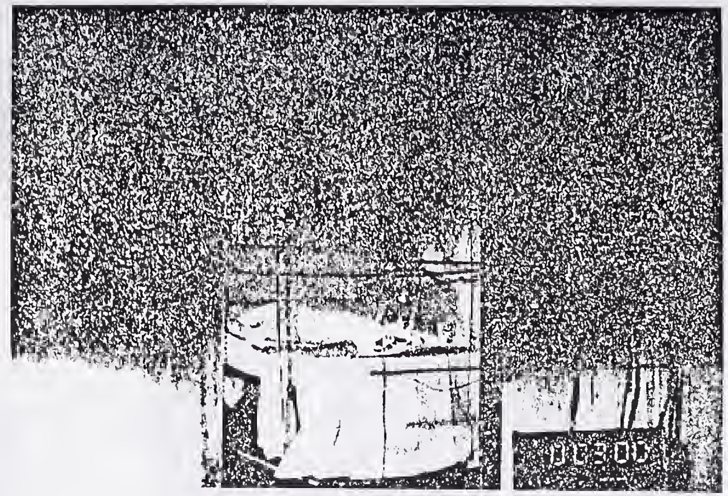


Time = 600 s

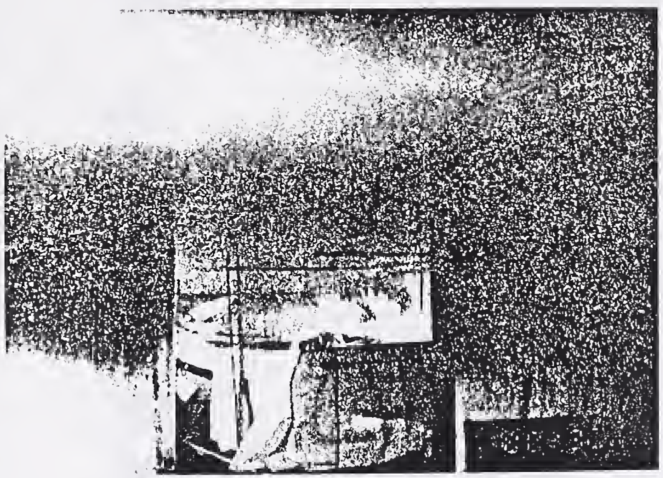
Figure 9. Fire Development in Test 2-12 (Mattress - Control)



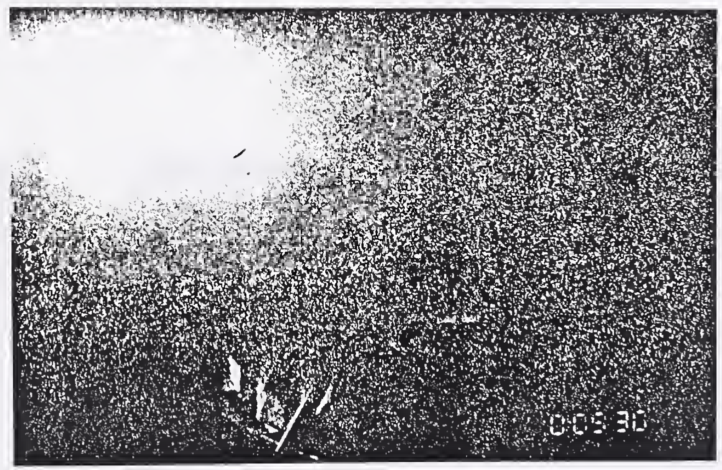
Time = 30 s



Time = 180 s

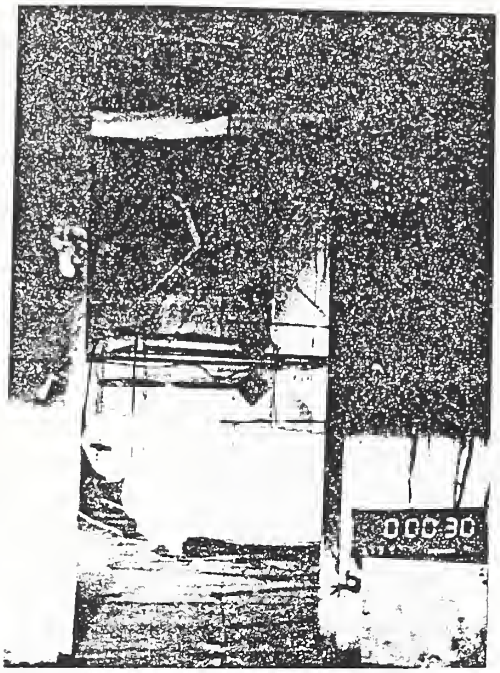


Time = 270 s

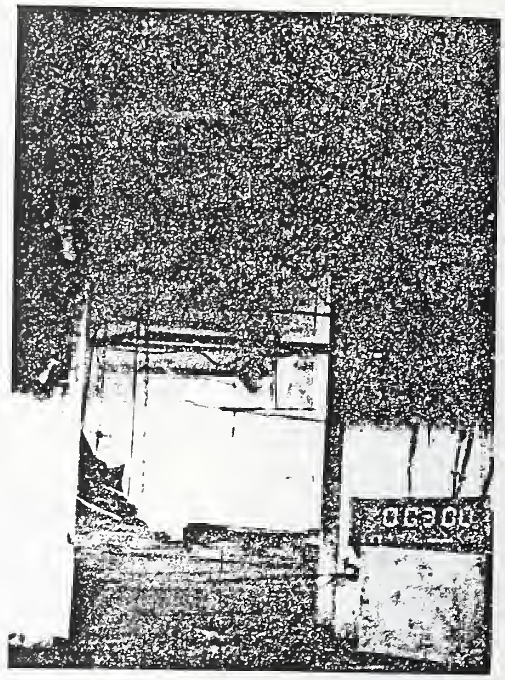


Time 330 s

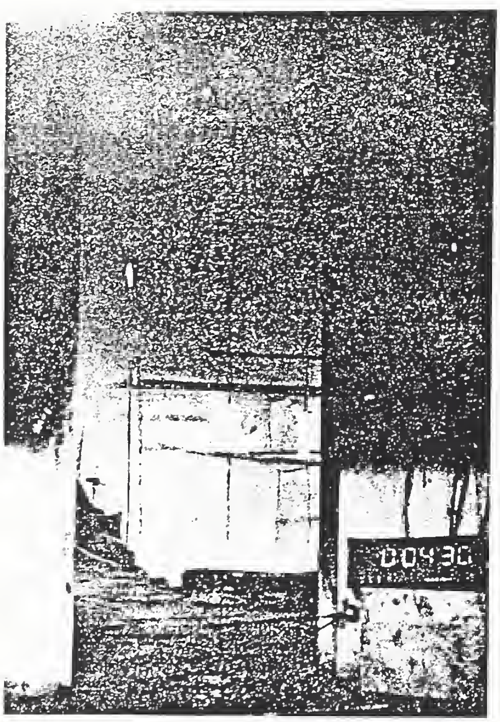
Figure 10. Fire Development in Test 2-3 (Mattress M01)



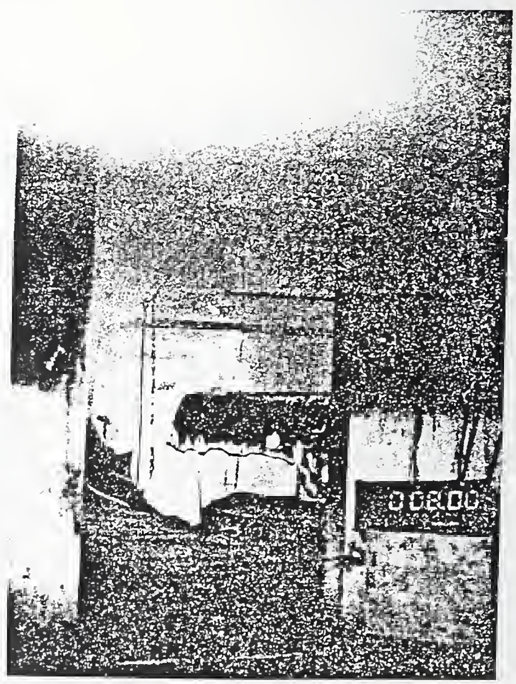
Time = 30 s



Time 180 s

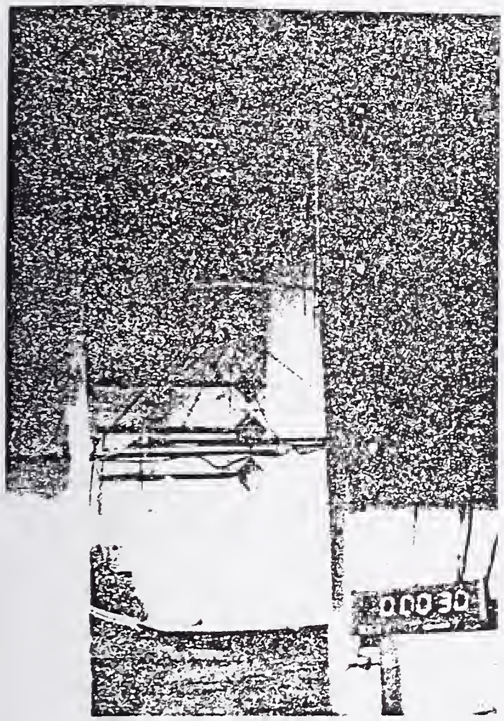


Time 270 s

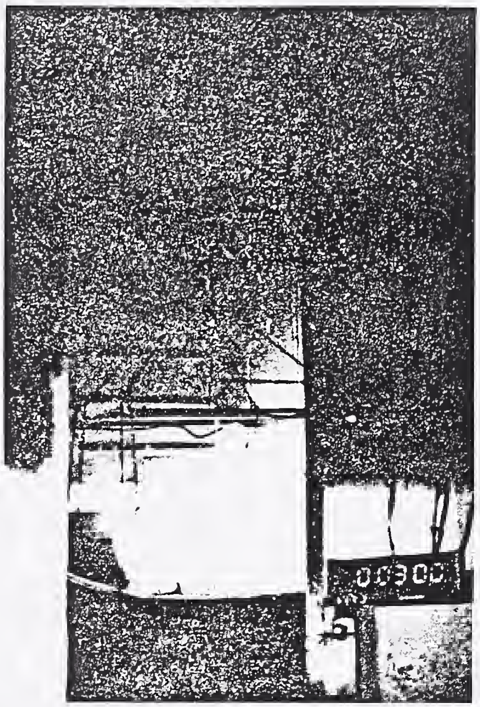


Time = 480 s

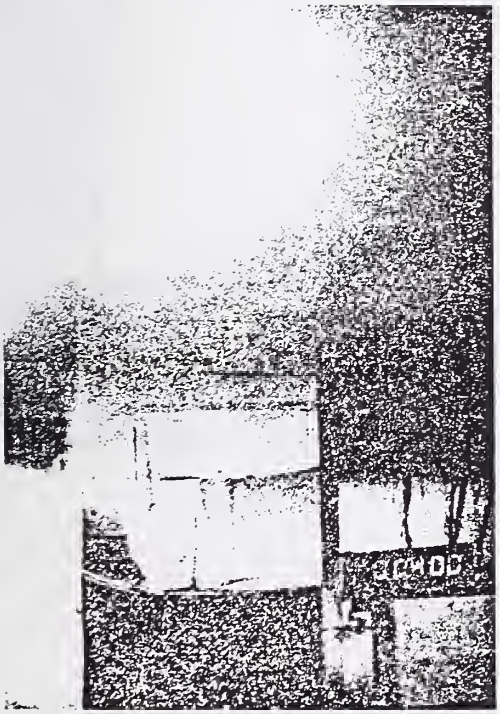
Figure 11. Fire Development in Test 2-10 (Mattress M07)



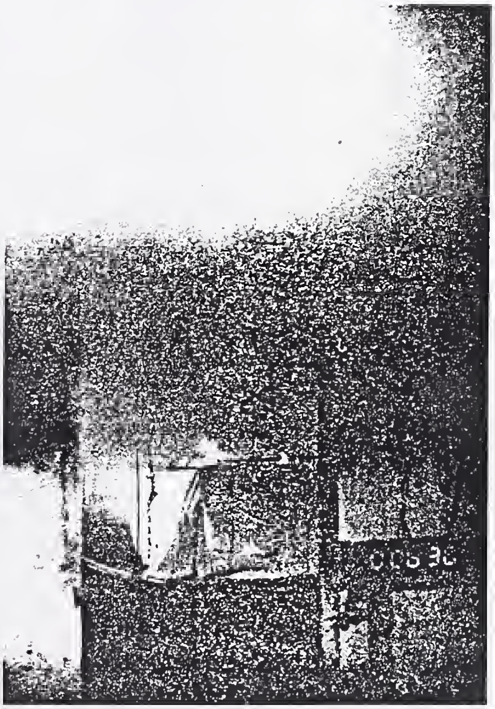
Time = 30 s



Time = 180 s



Time = 240 s



Time = 390 s

Figure 12. Fire Development in Test 2-8 (Mattress M08)

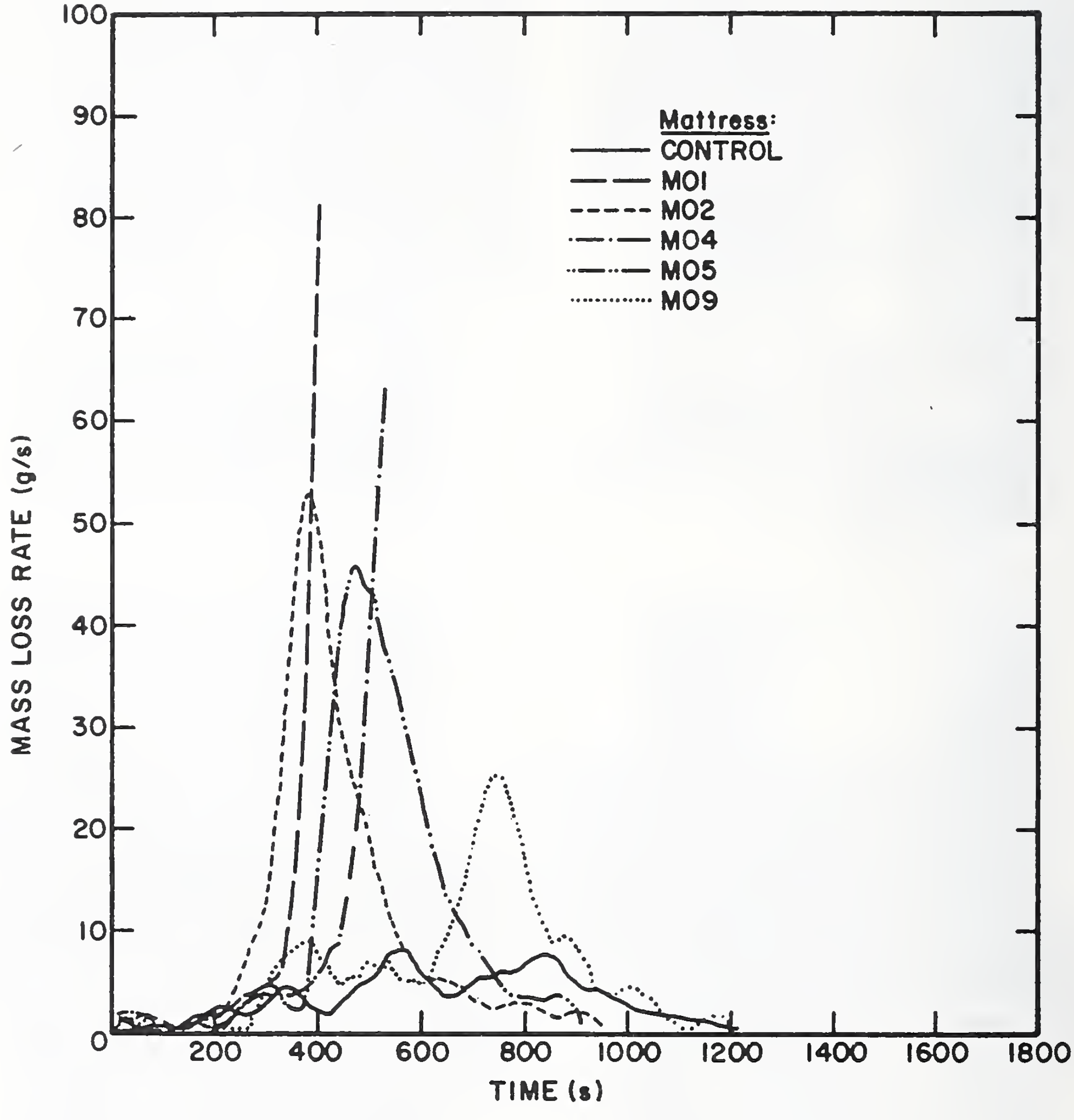


Figure 13. Weight Loss for Polyurethane and Latex Core Specimens

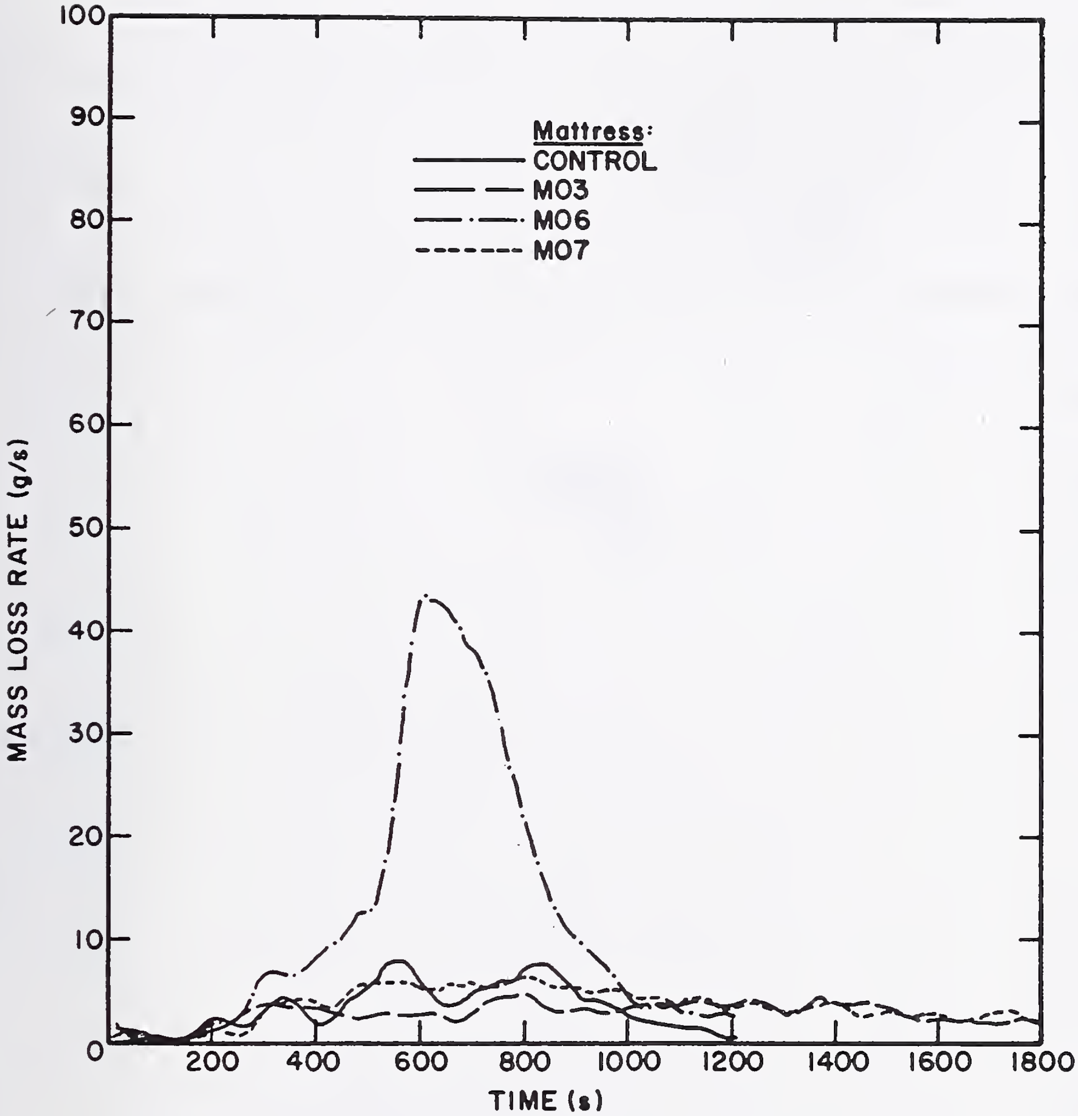


Figure 14. Weight Loss for Cotton and Mixed Fiber Core Specimens

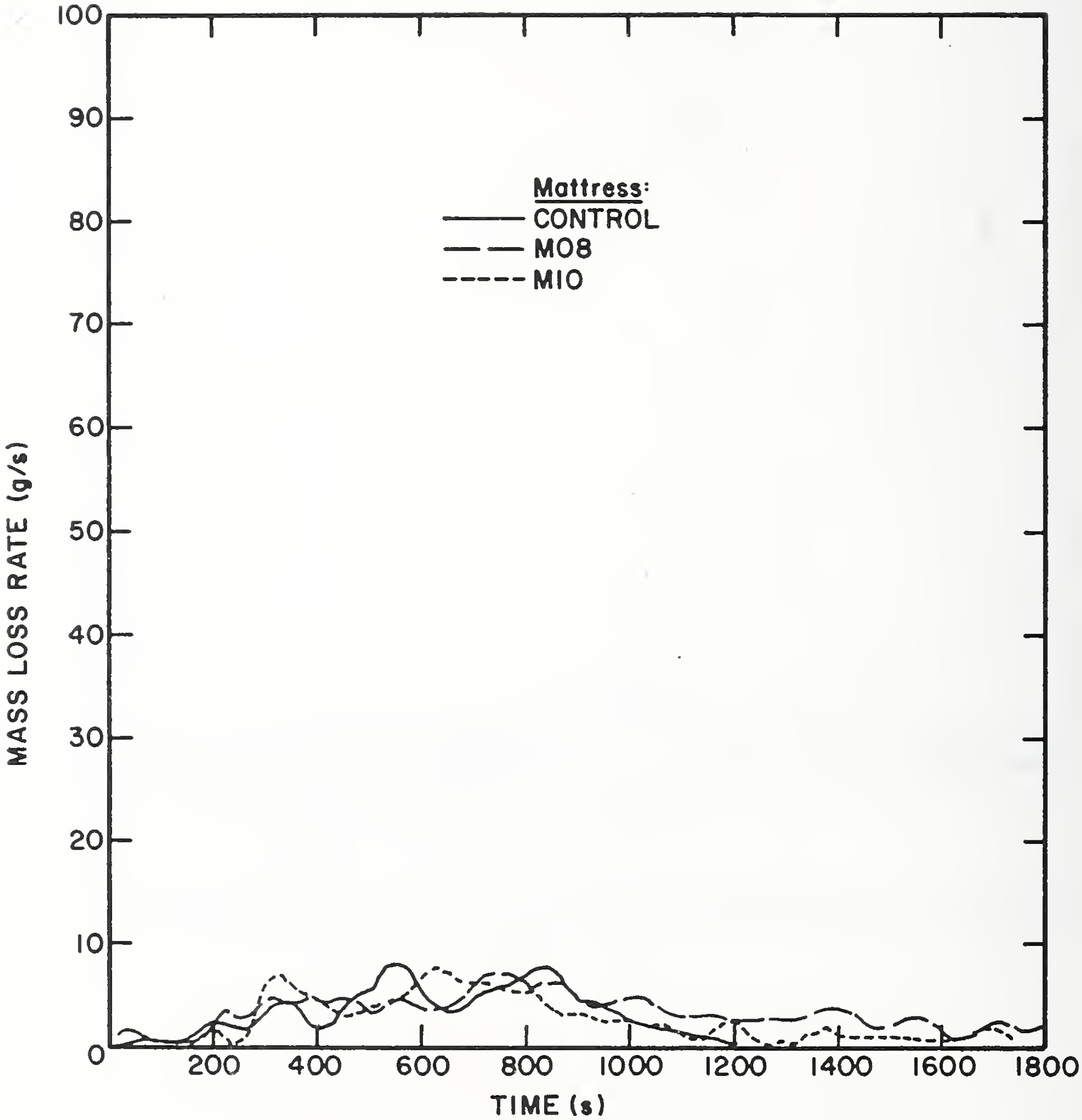


Figure 15. Weight Loss for Neoprene Core Specimens

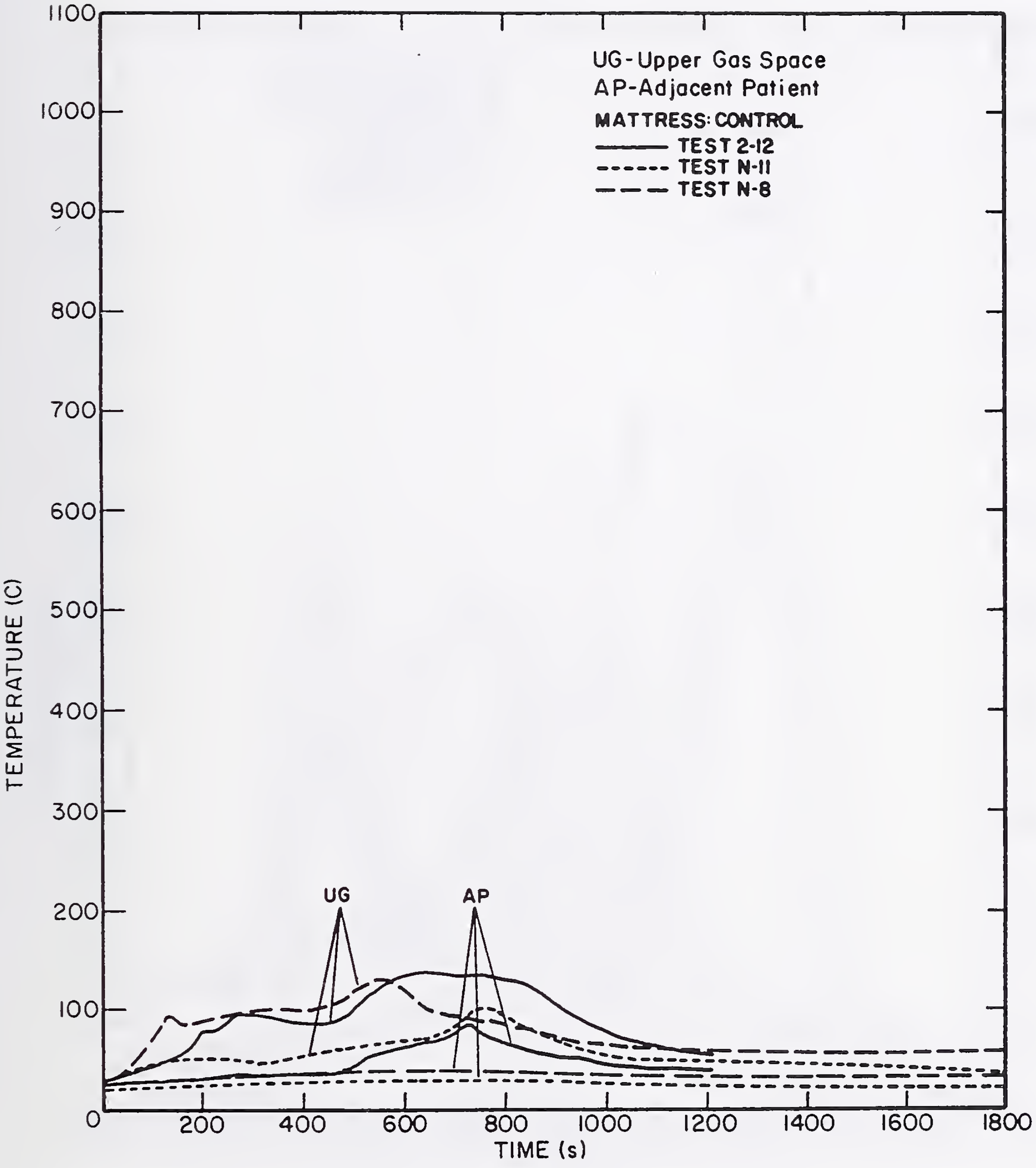


Figure 16. Gas Temperatures for Control Mattress

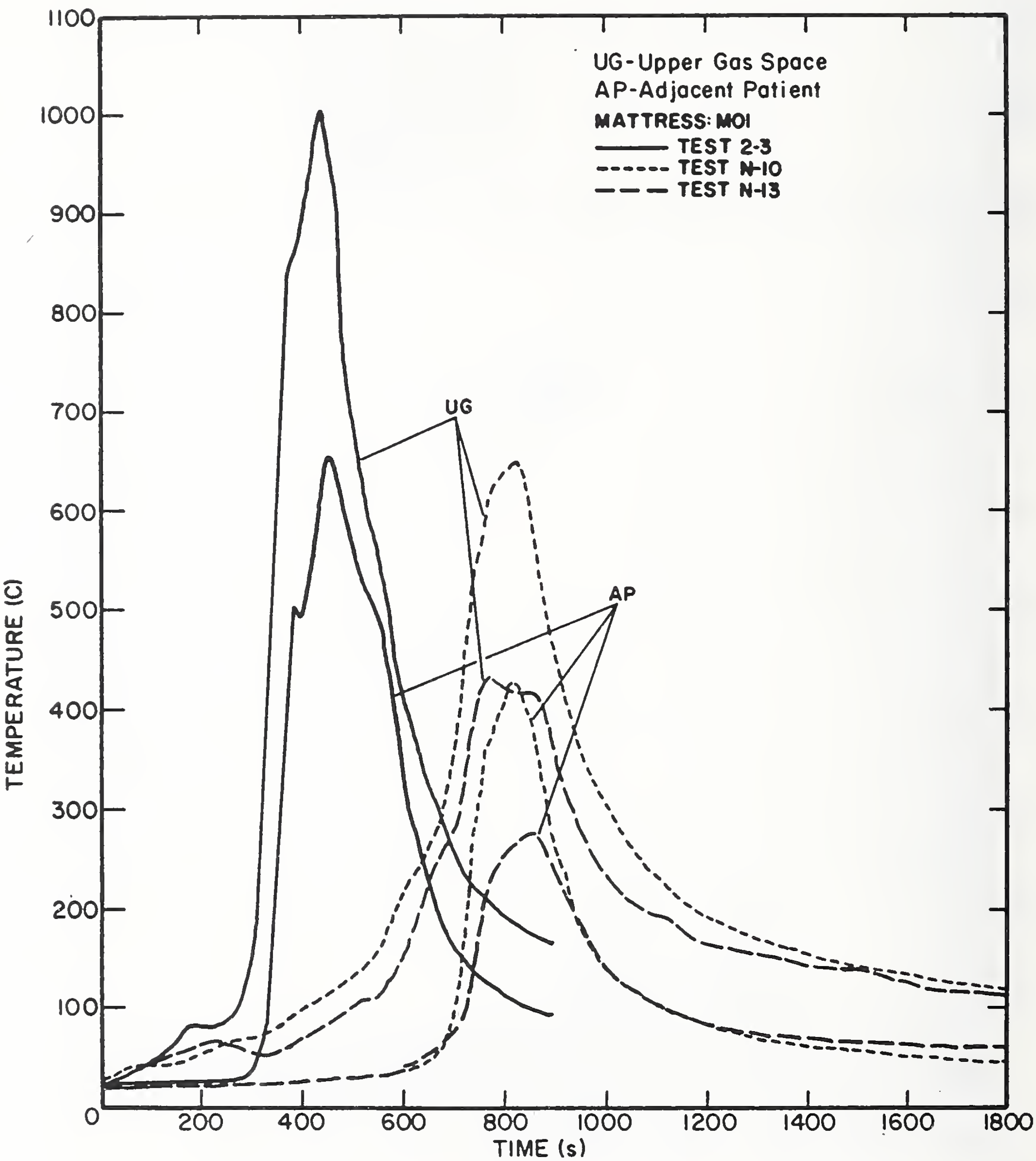


Figure 17. Gas Temperatures for Mattress M01

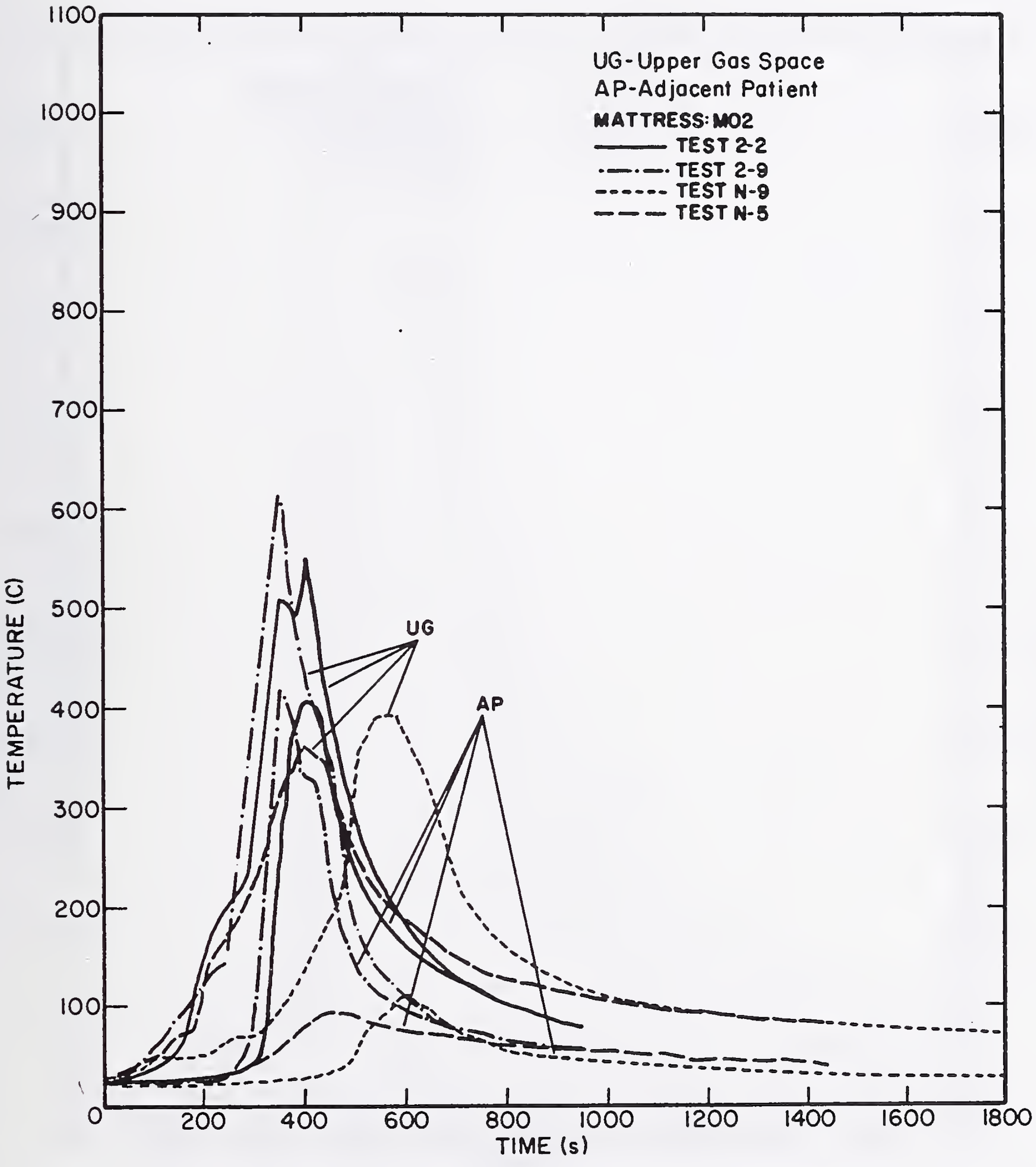


Figure 18. Gas Temperatures for Mattress M02

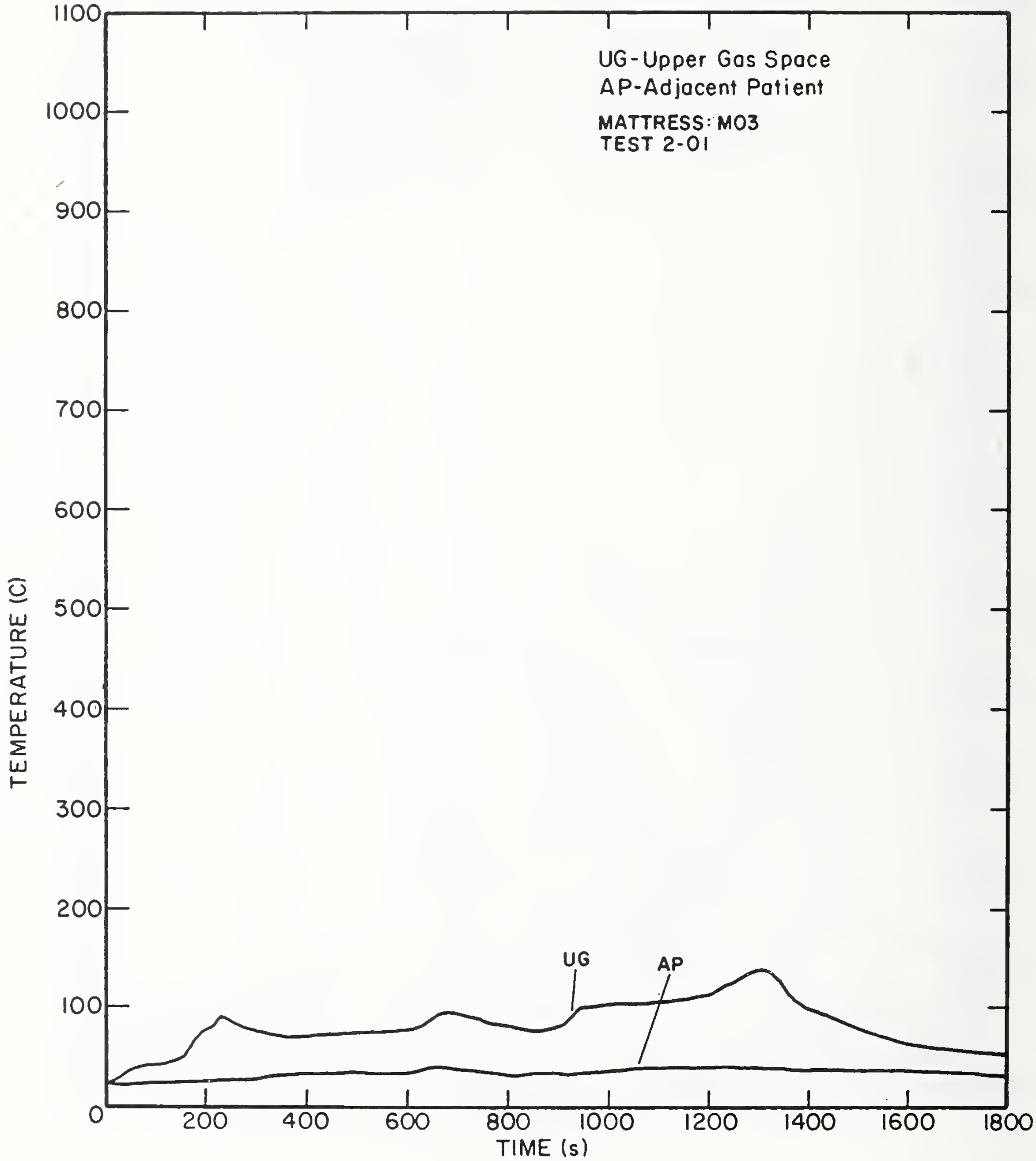


Figure 19. Gas Temperatures for Mattress M03

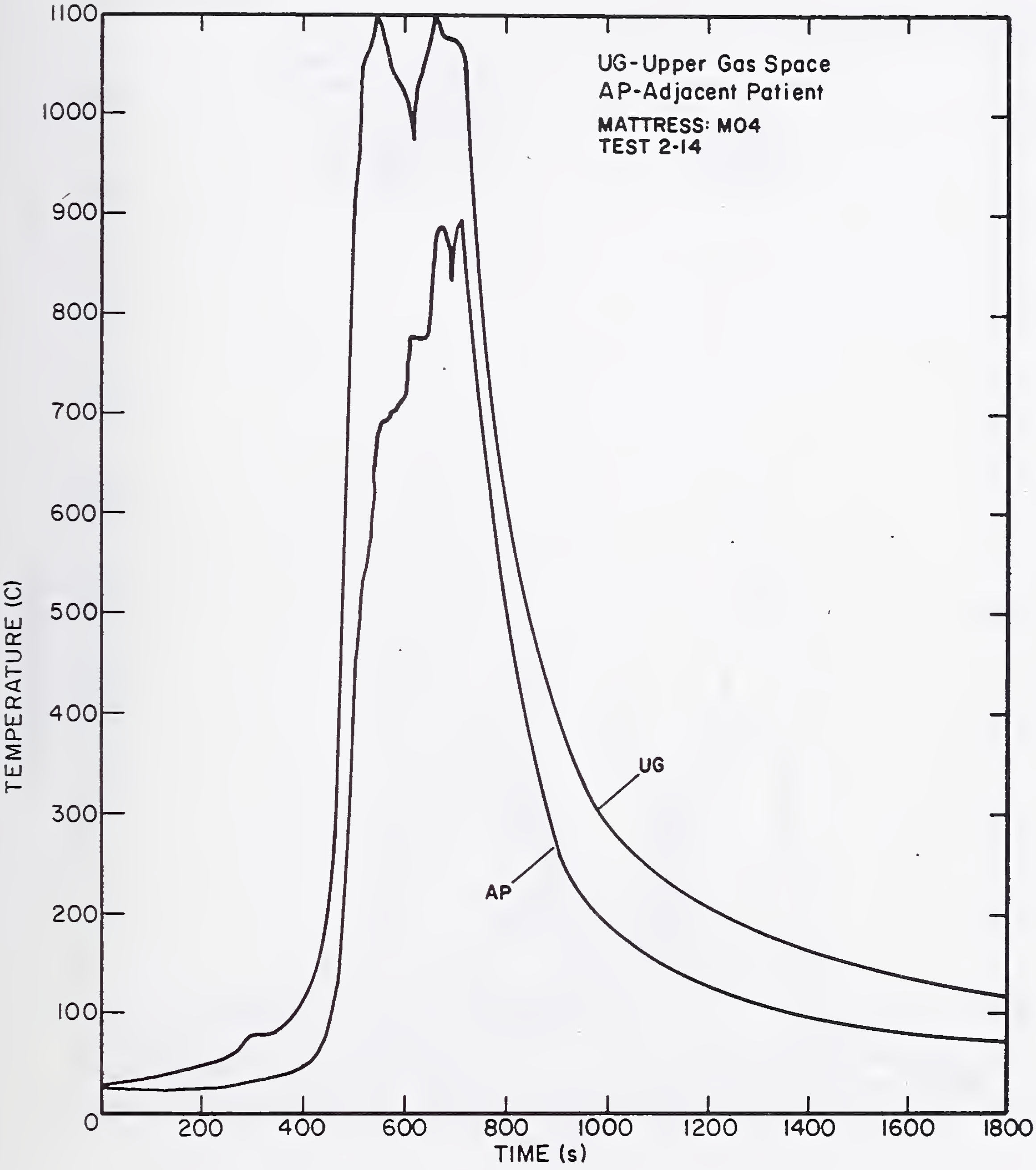


Figure 20. Gas Temperatures for Mattress M04

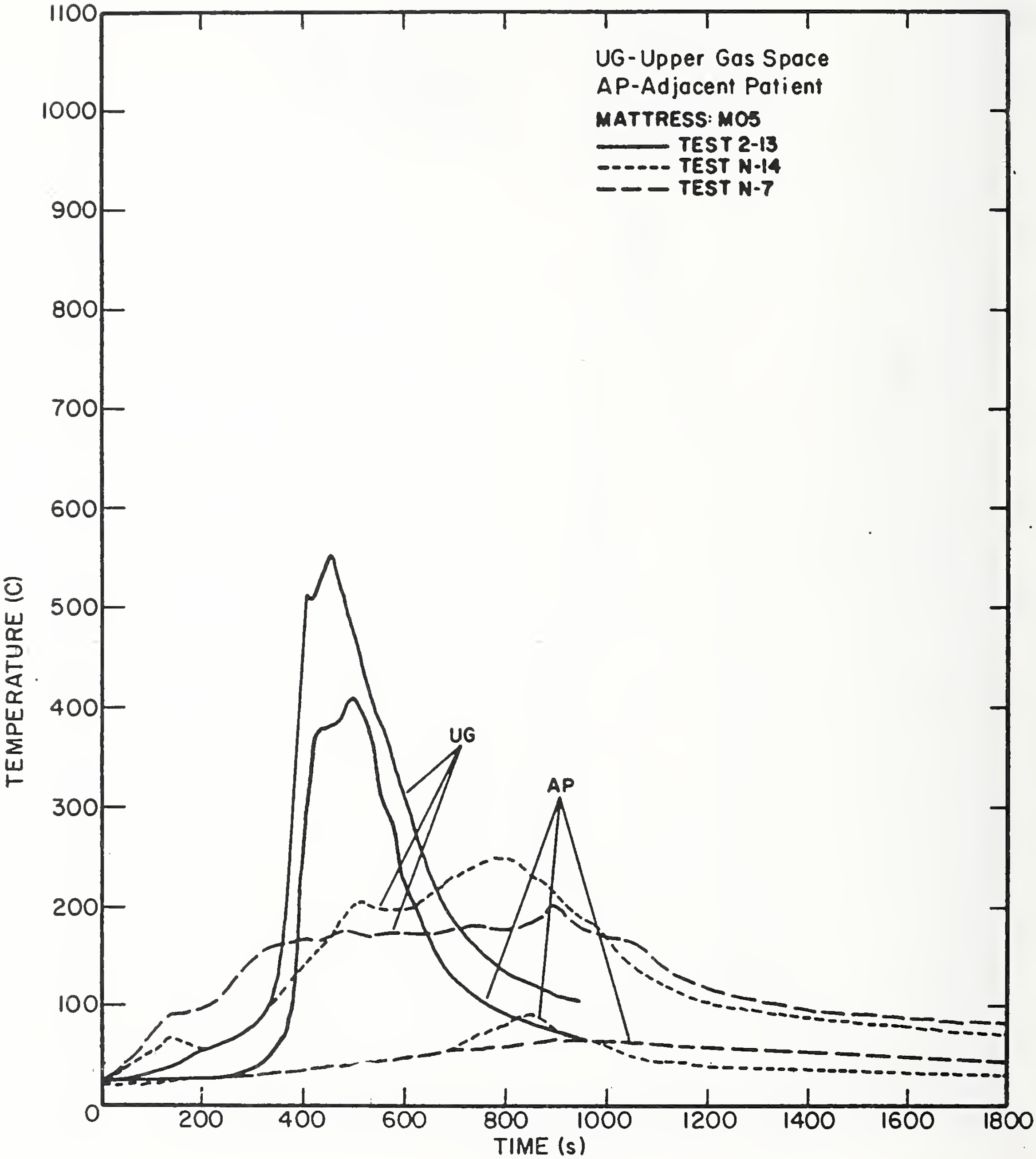


Figure 21. Gas Temperatures for Mattress M05

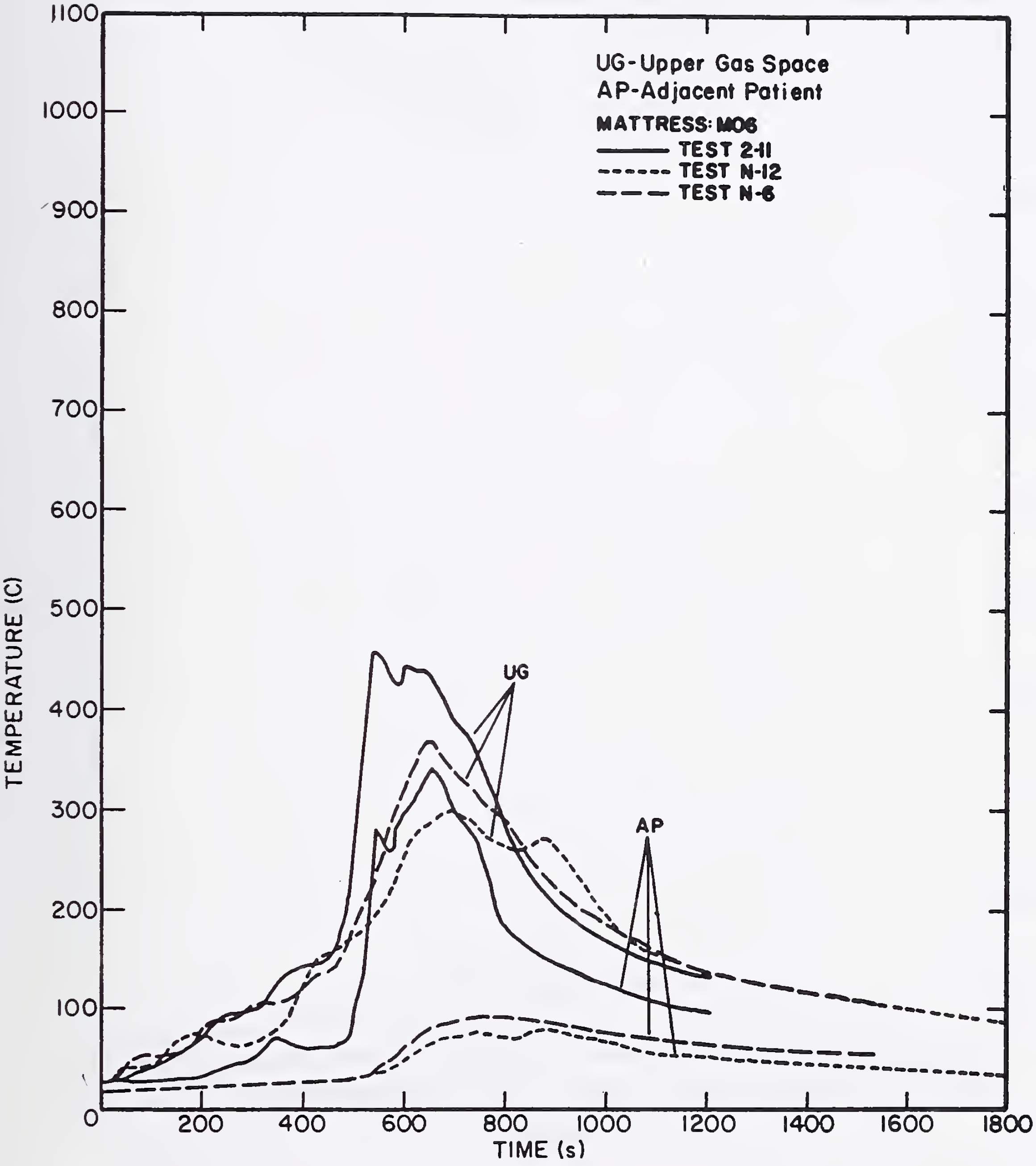


Figure 22. Gas Temperatures for Mattress M06

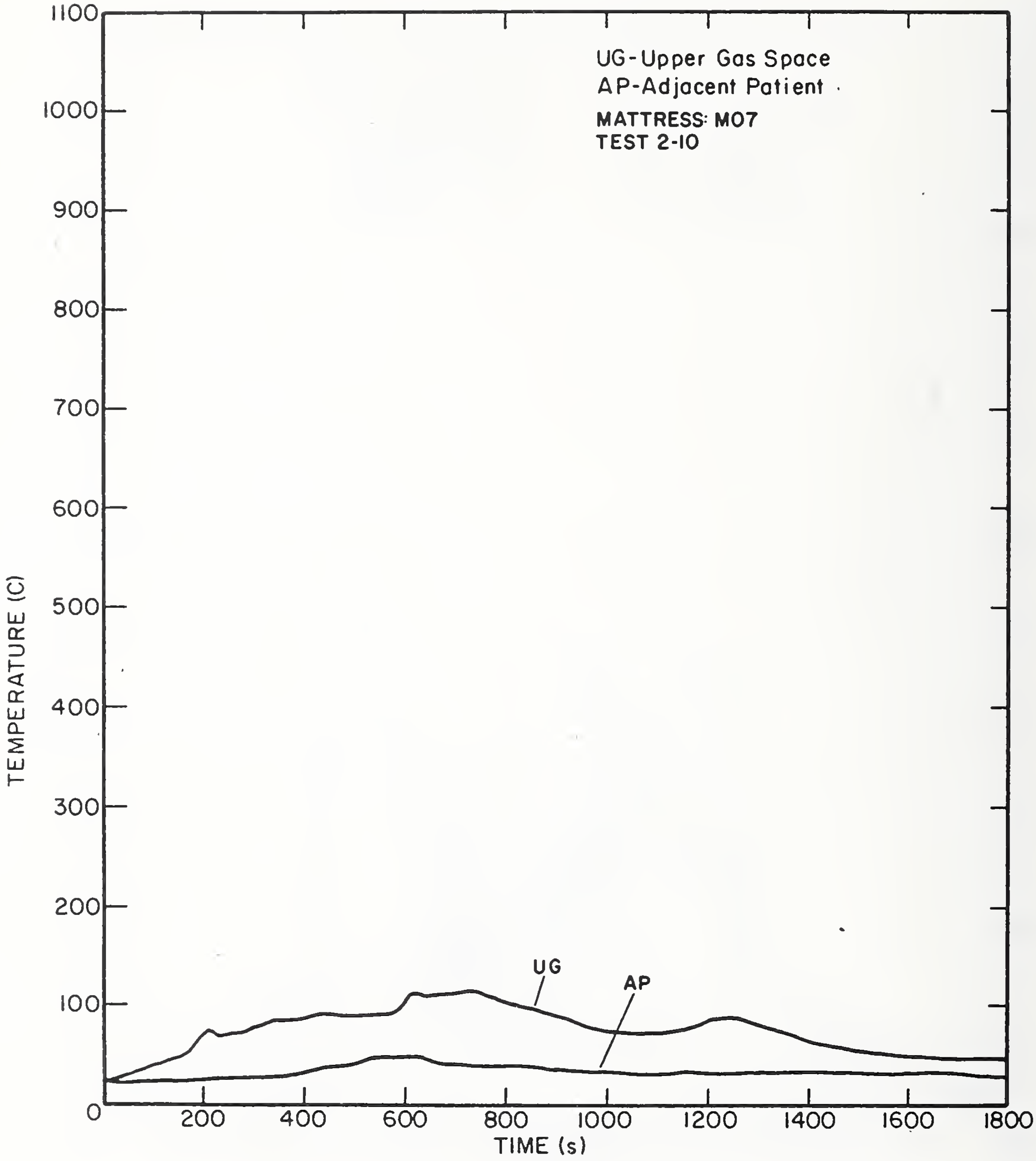


Figure 23. Gas Temperatures for Mattress M07

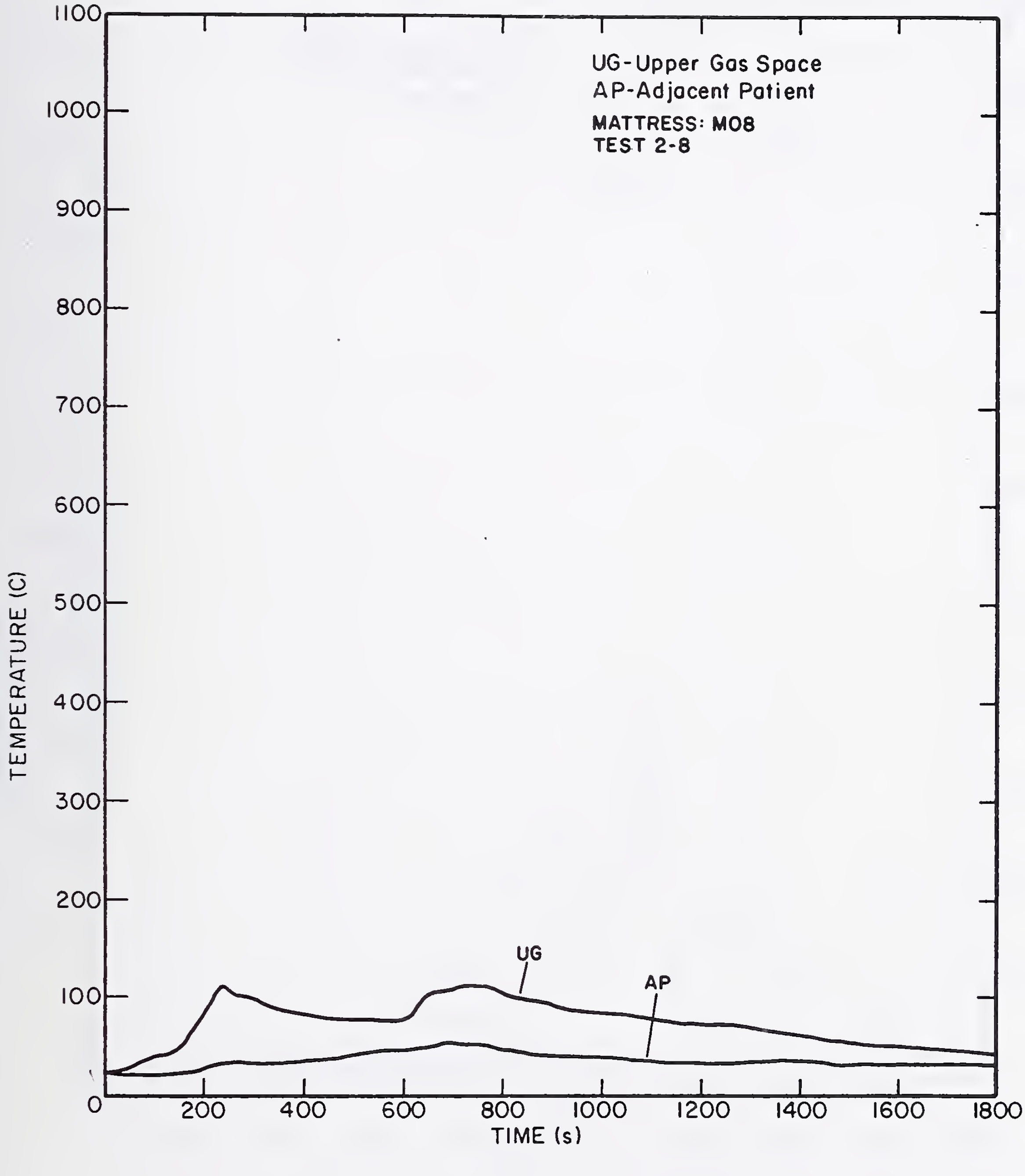


Figure 24. Gas Temperatures for Mattress M08

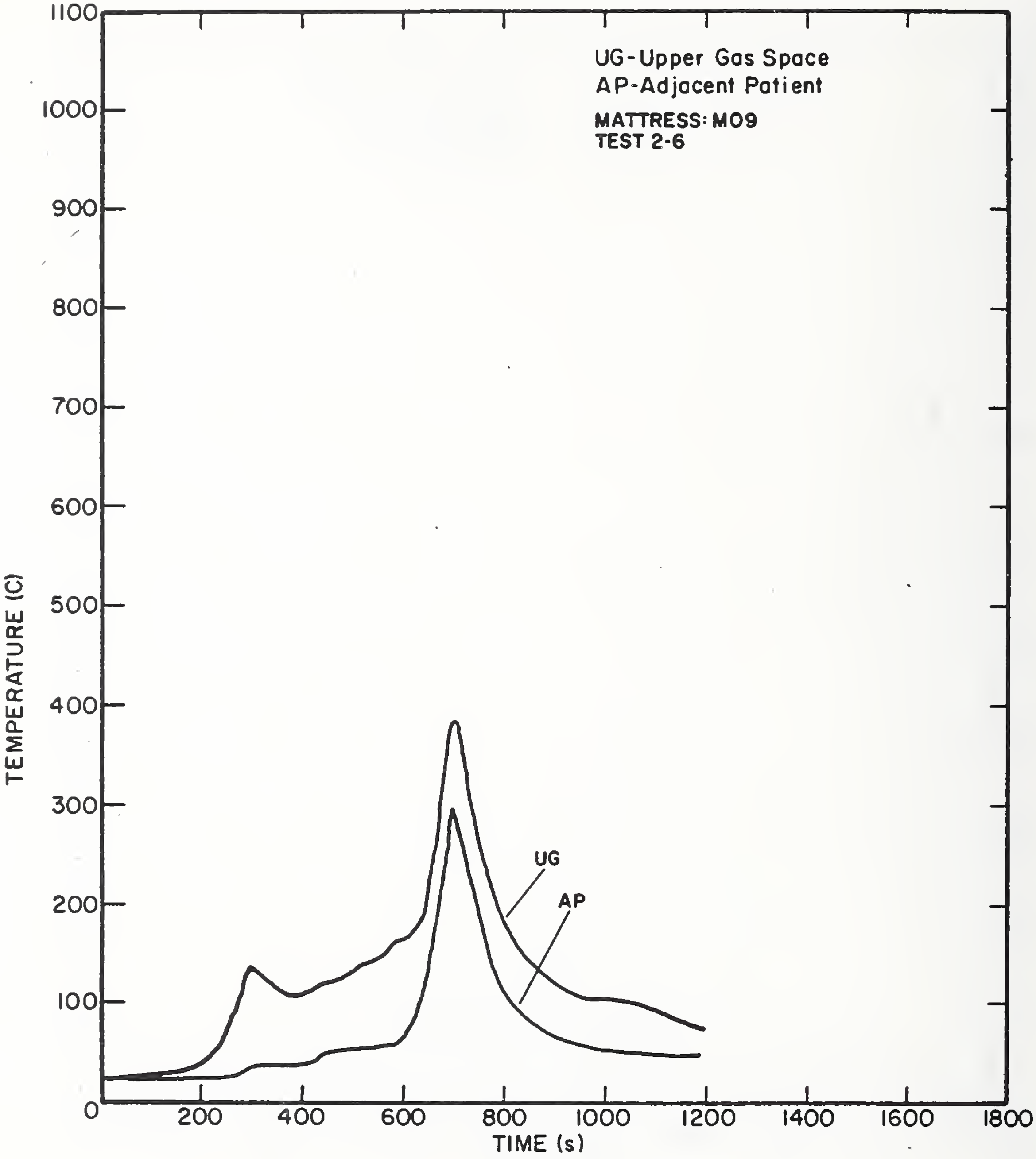


Figure 25. Gas Temperatures for Mattress M09

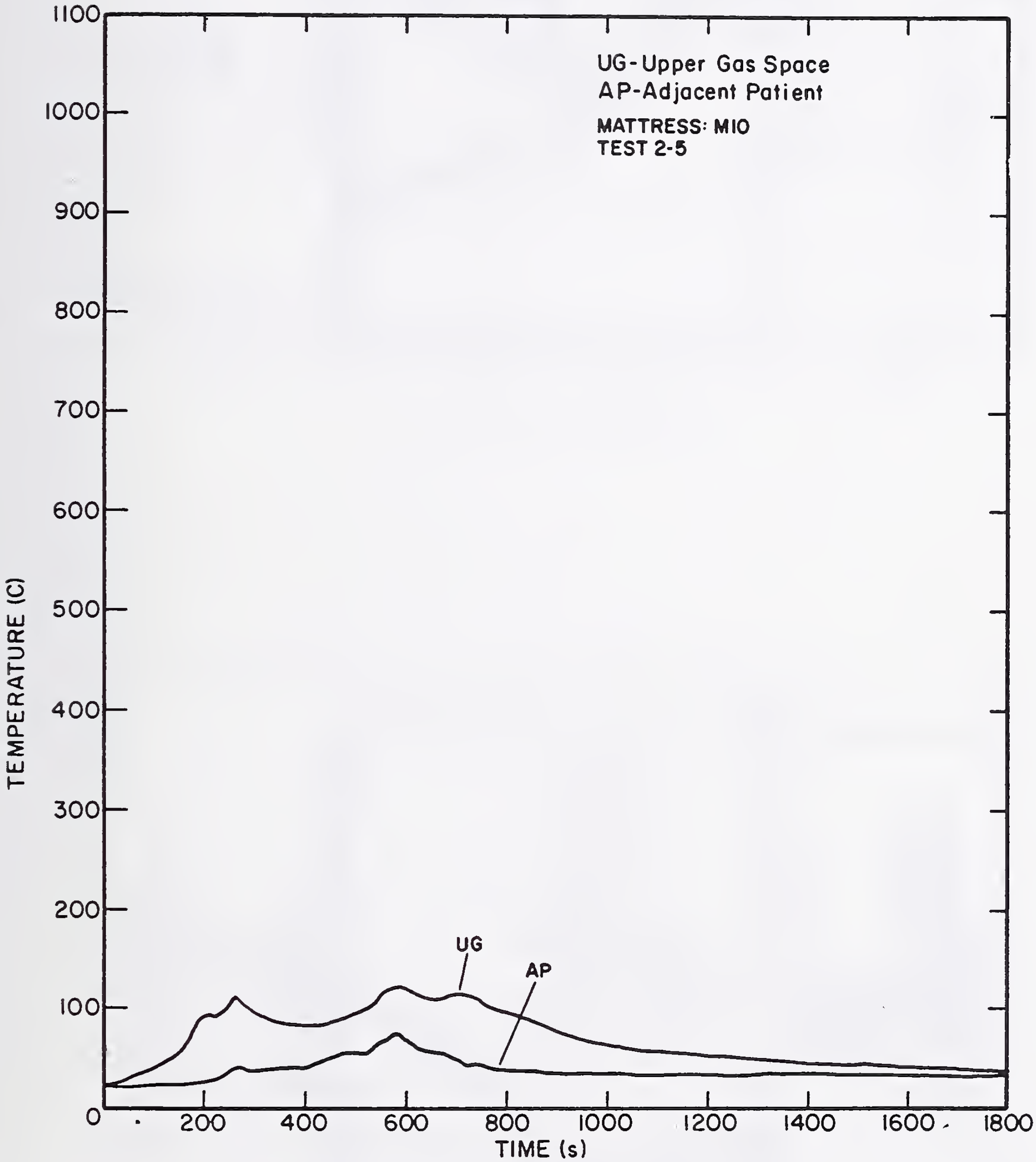


Figure 26. Gas Temperatures for Mattress M10

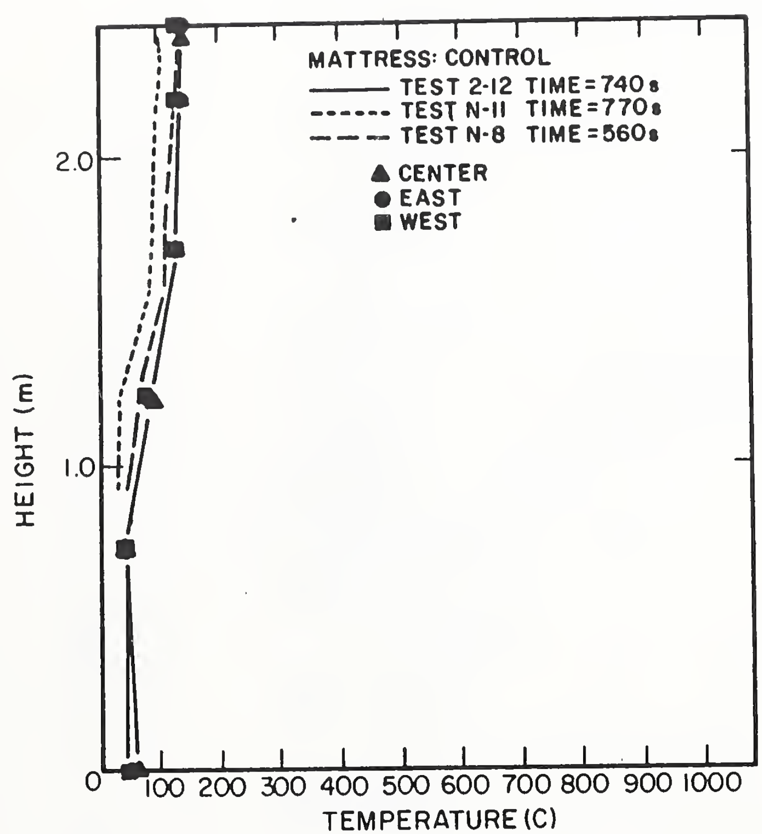


Figure 27. Vertical Temperature Profile for Control Mattress

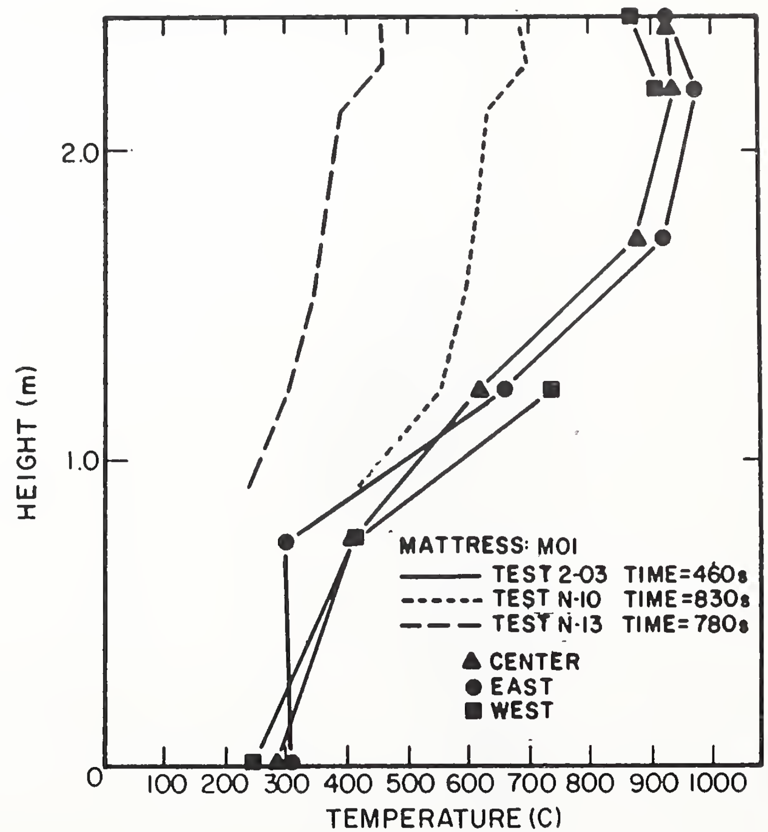


Figure 28. Vertical Temperature Profile for Mattress M01

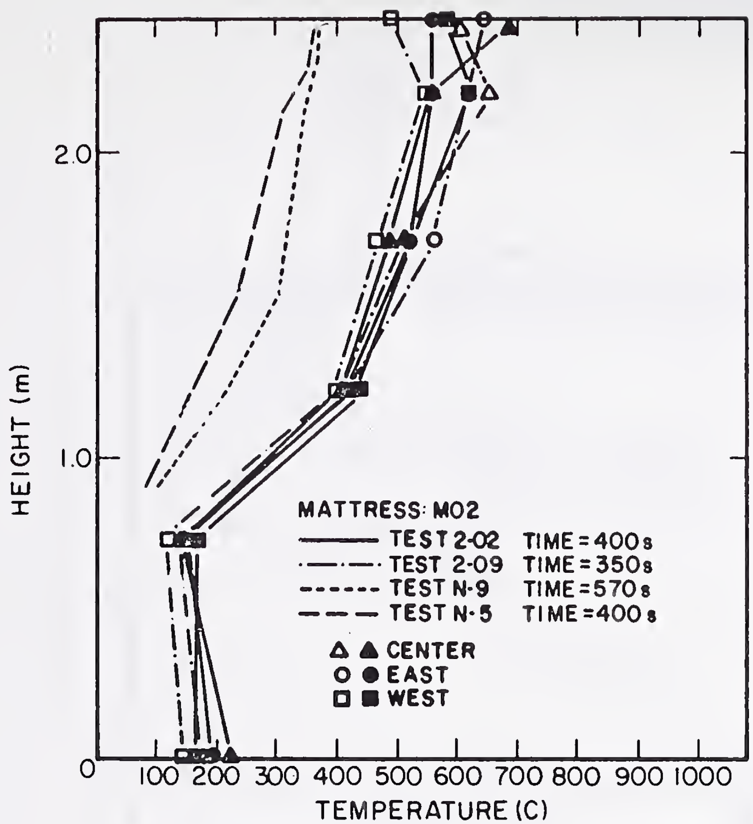


Figure 29. Vertical Temperature Profile for Mattress M02

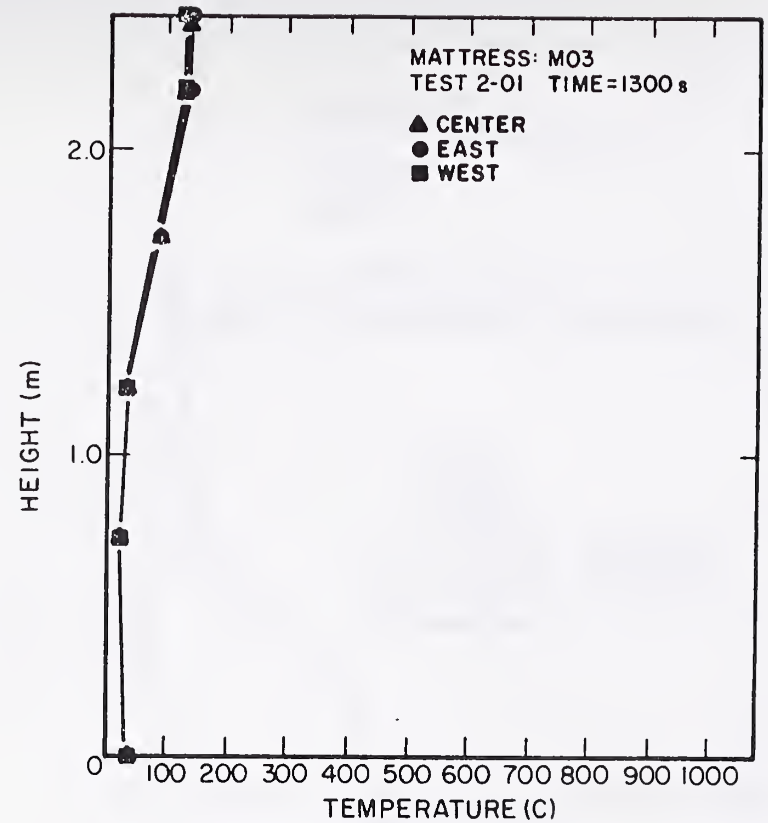


Figure 30. Vertical Temperature Profile for Mattress M03

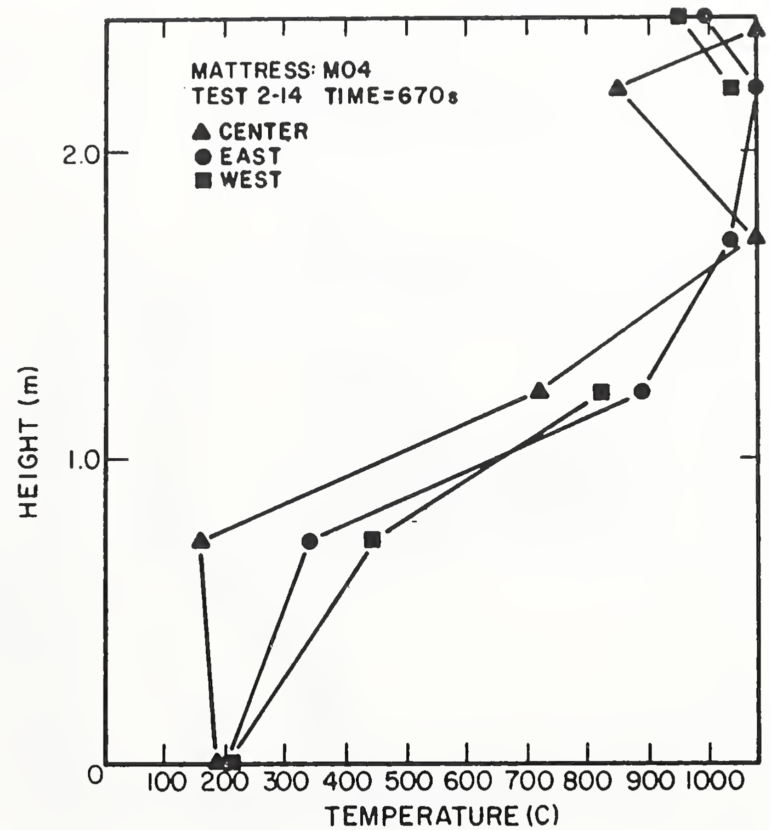


Figure 31. Vertical Temperature Profile for Mattress M04

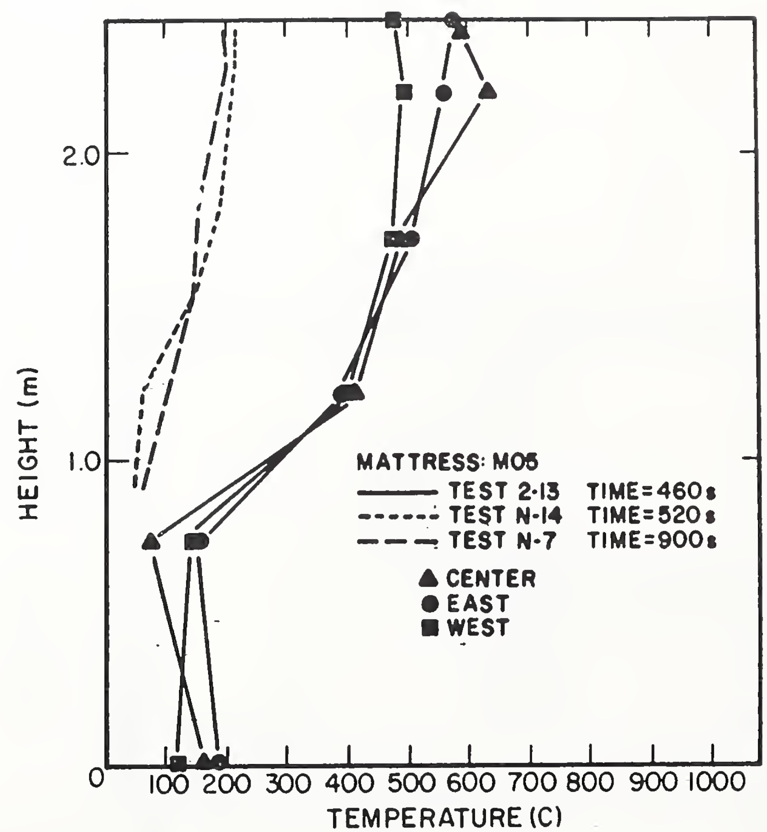


Figure 32. Vertical Temperature Profile for Mattress M05

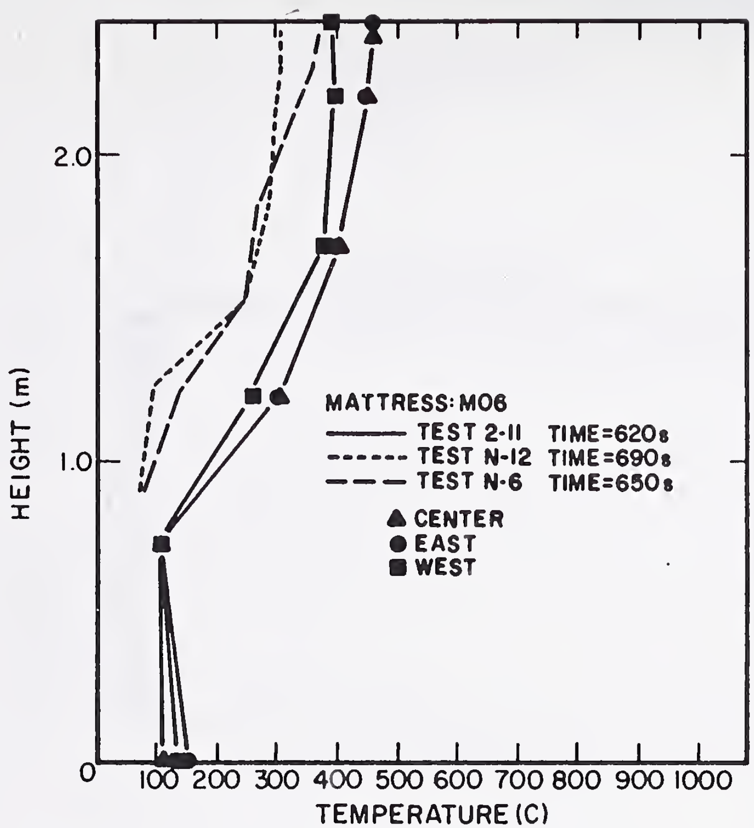


Figure 33. Vertical Temperature Profile for Mattress M06

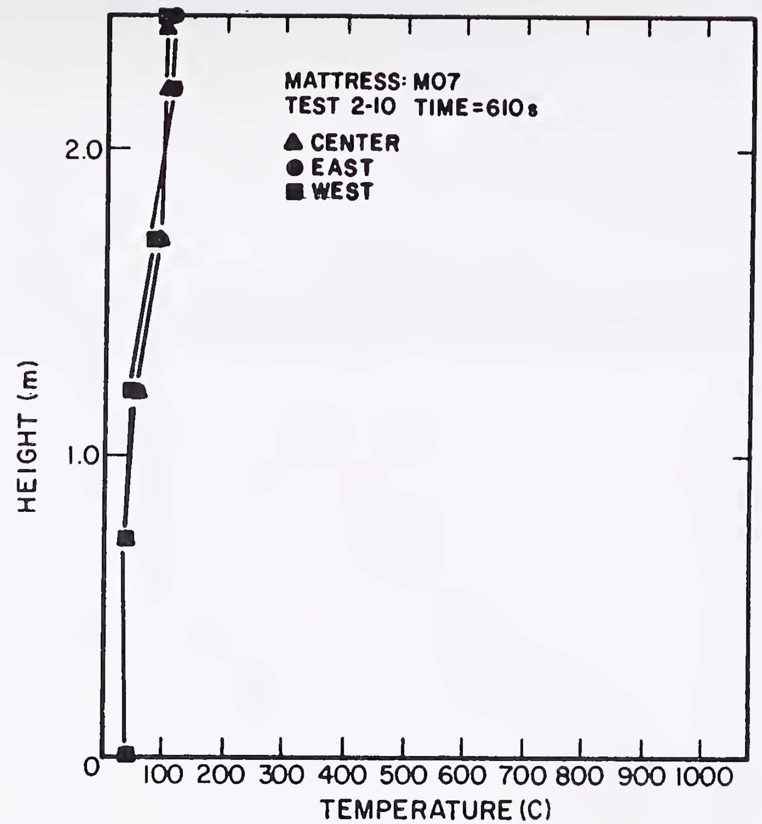


Figure 34. Vertical Temperature Profile for Mattress M07

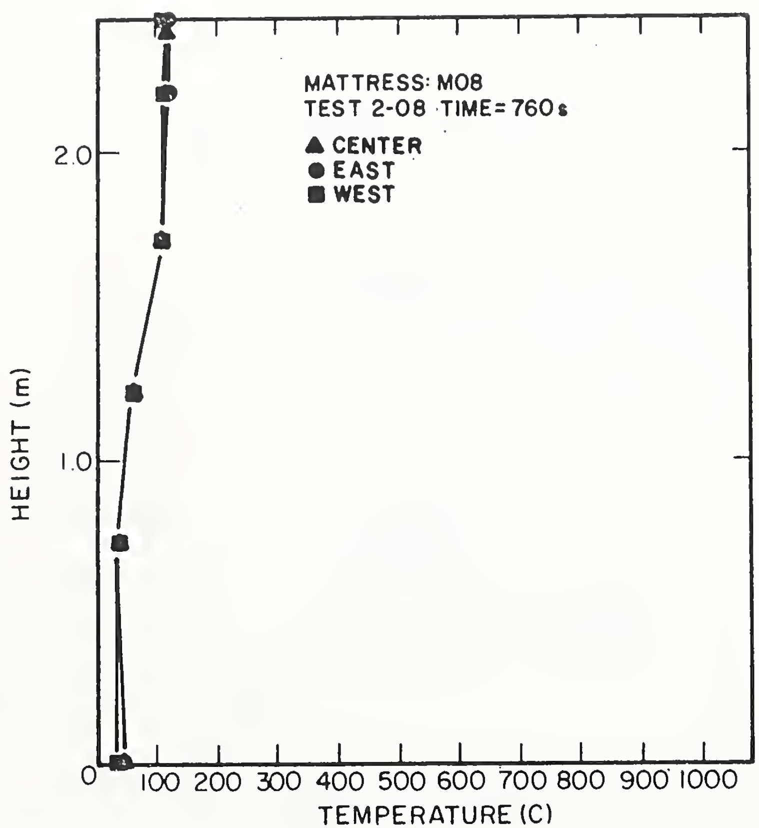


Figure 35. Vertical Temperature Profile for Mattress M08

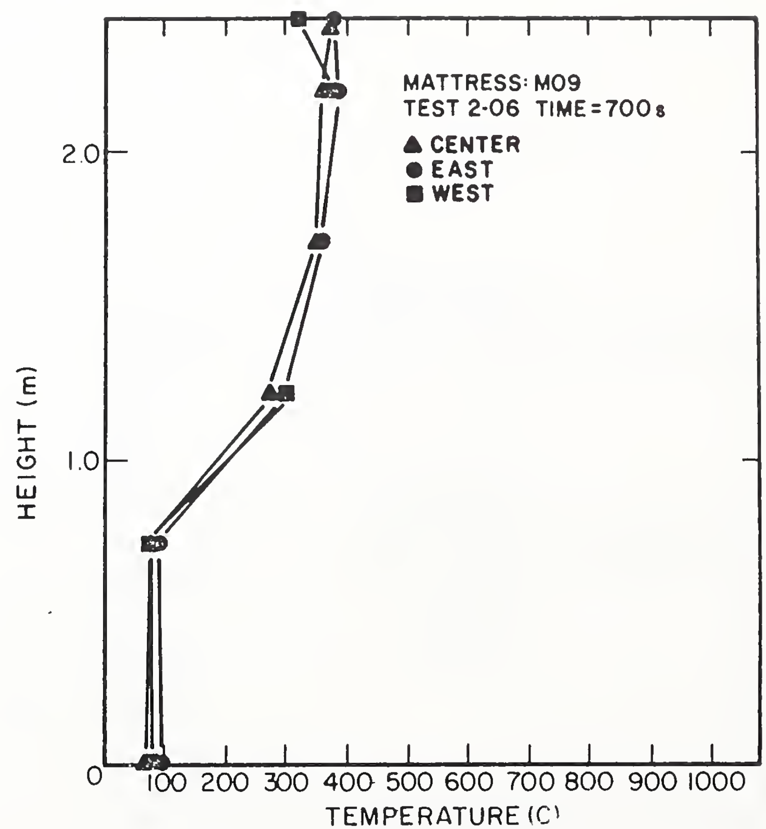


Figure 36. Vertical Temperature Profile for Mattress M09

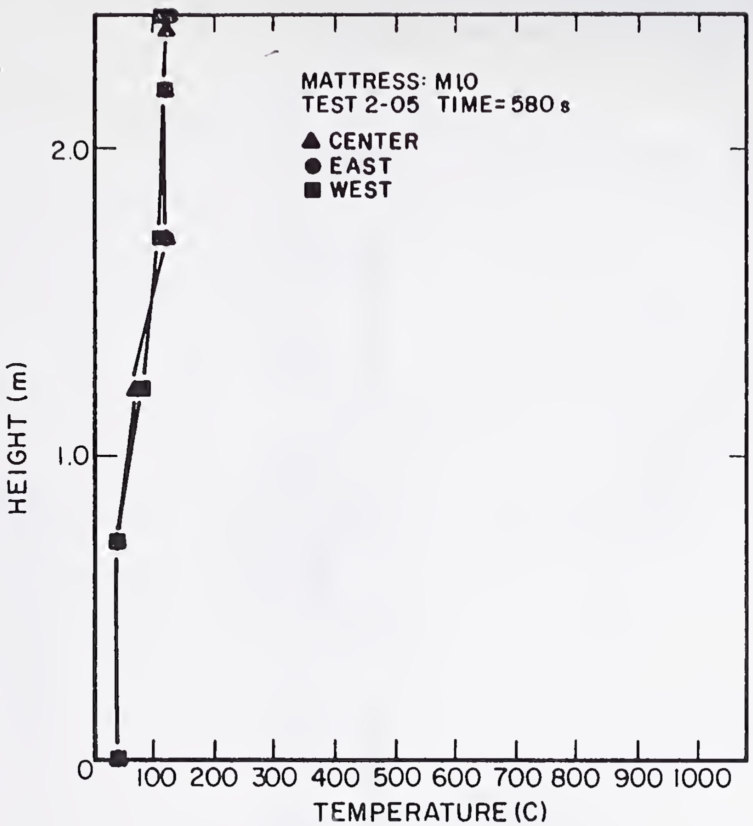


Figure 37. Vertical Temperature Profile for Mattress M10

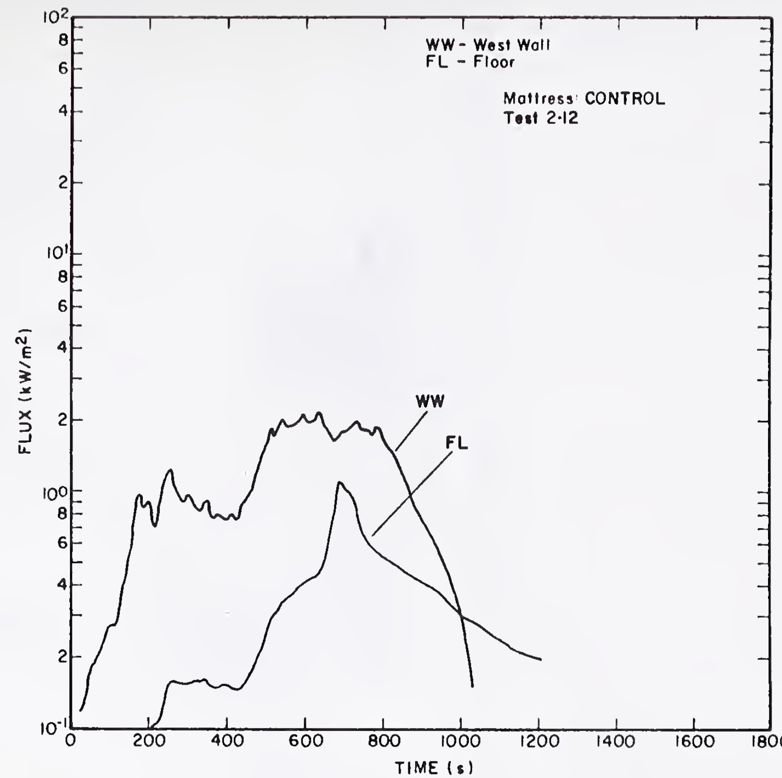


Figure 38. Heat Fluxes for Control Mattress

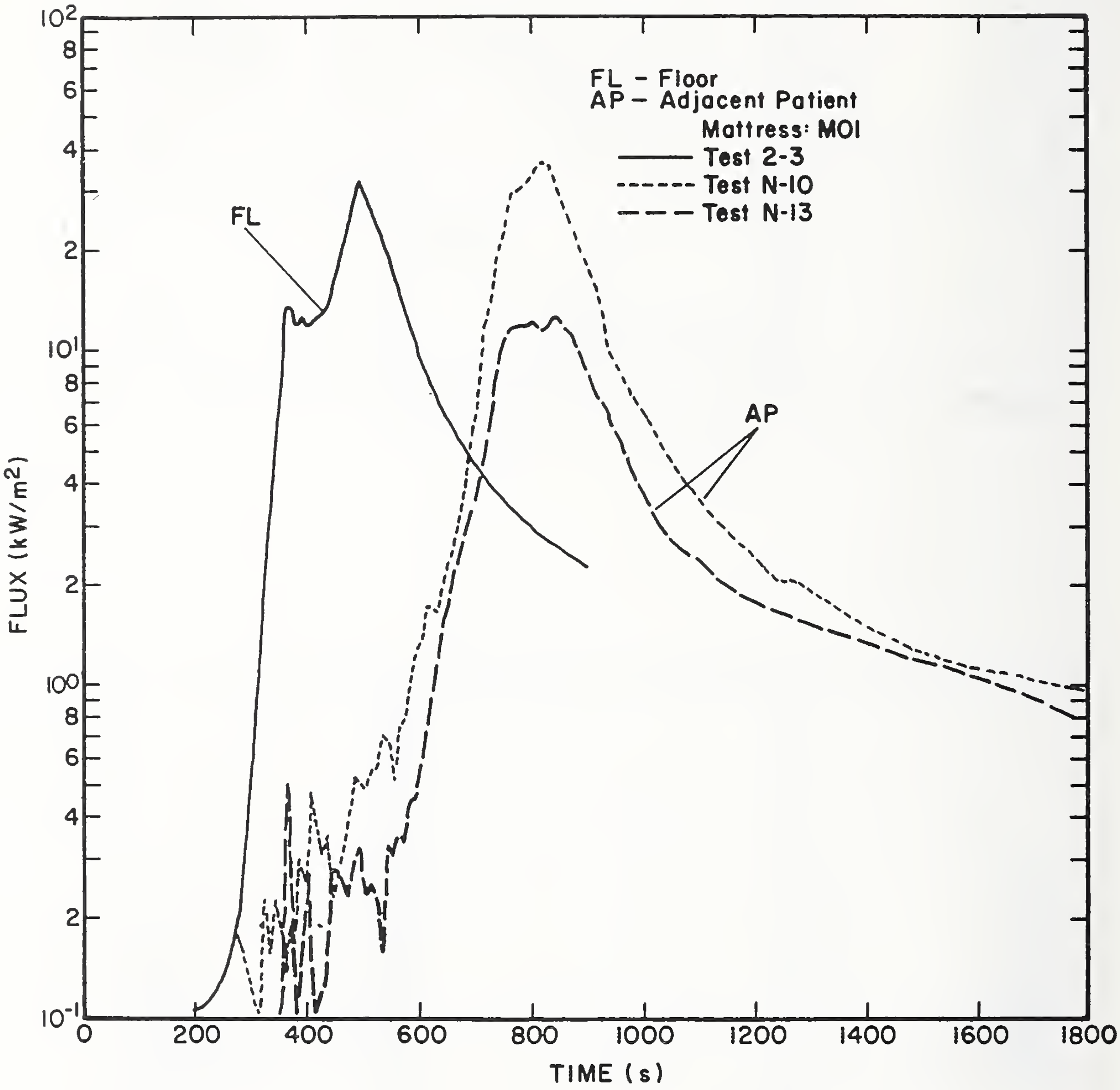


Figure 39. Heat Fluxes for Mattress M01

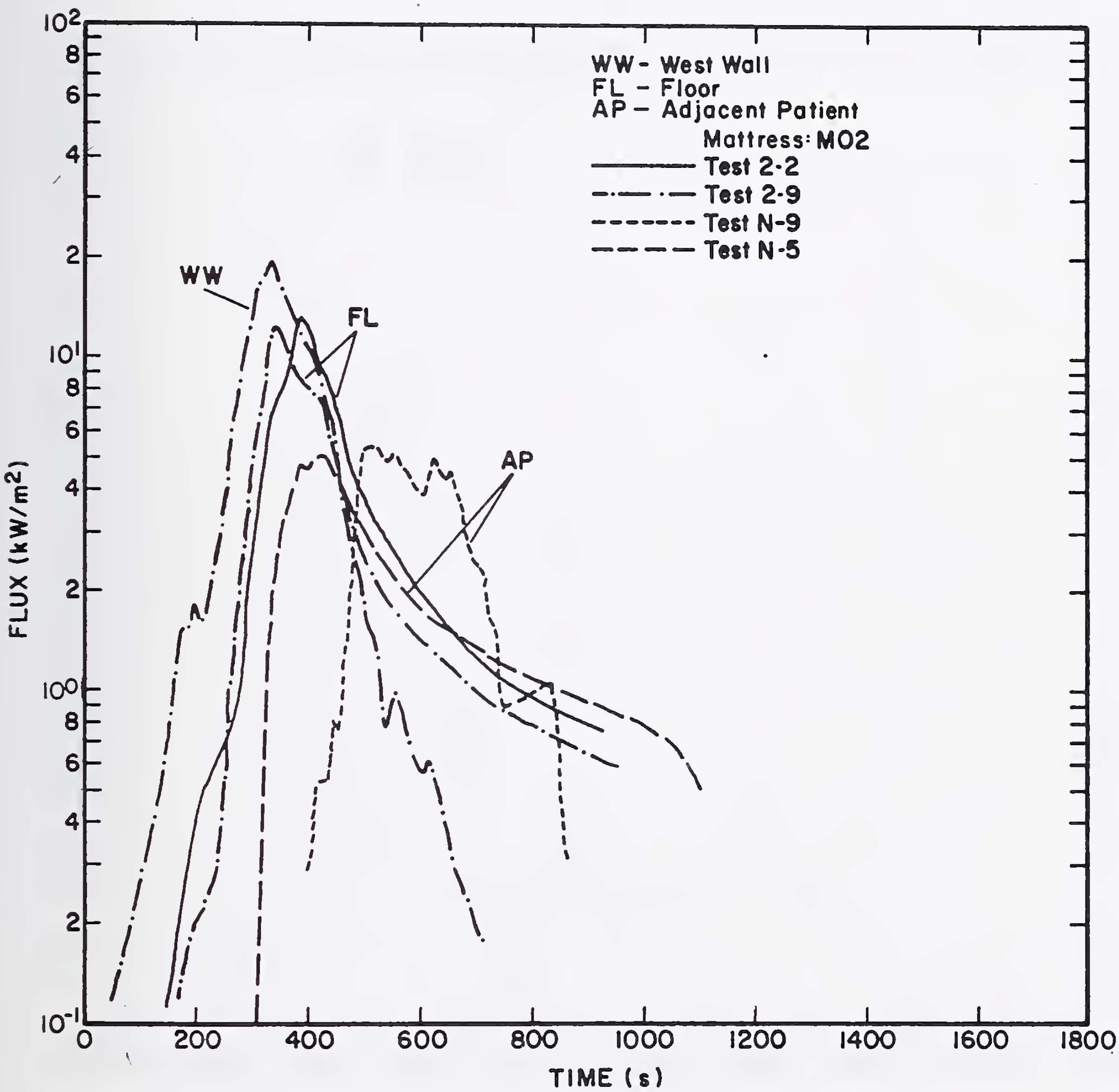


Figure 40. Heat Fluxes for Mattress M02

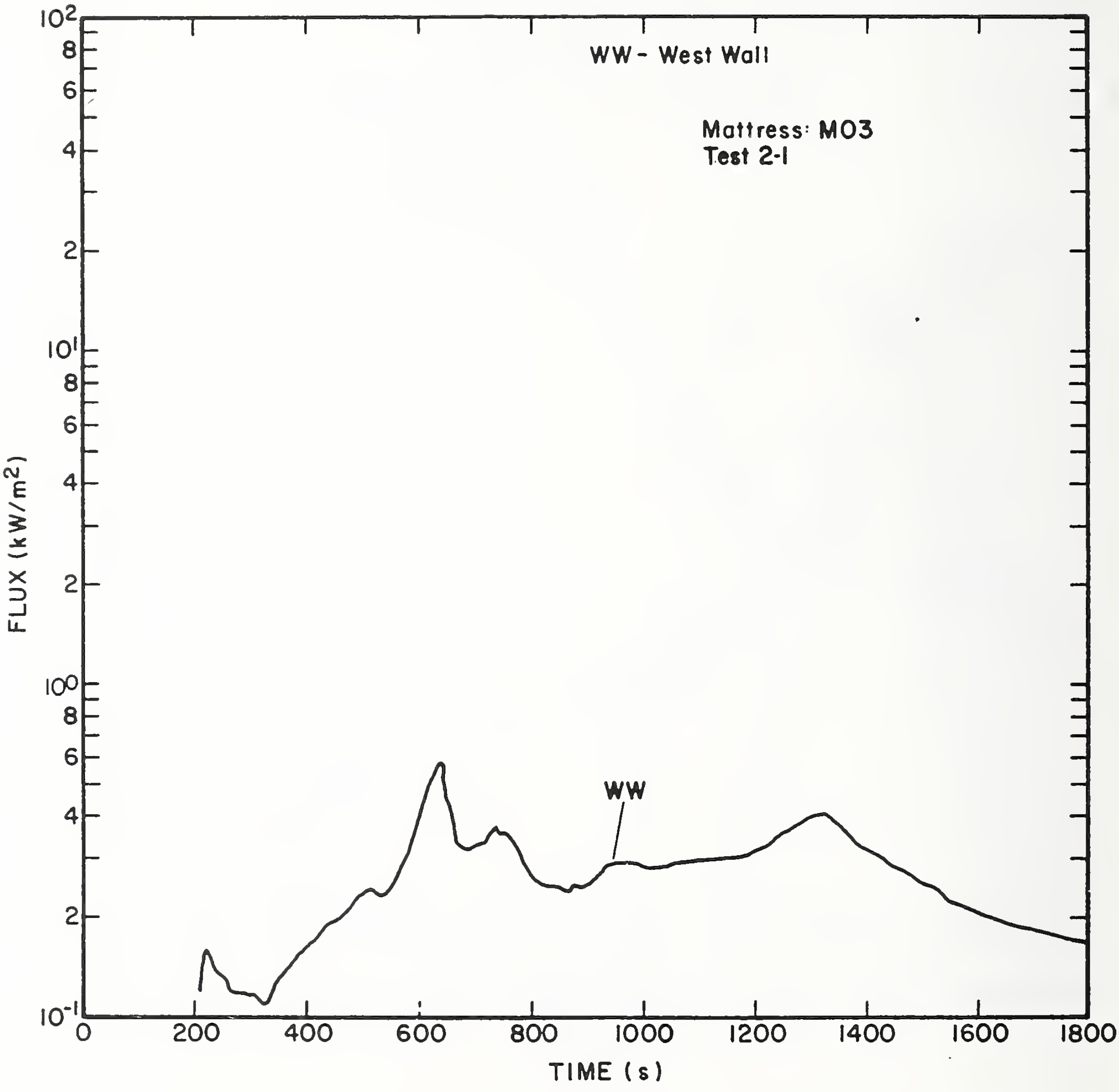


Figure 41. Heat Fluxes for Mattress M03

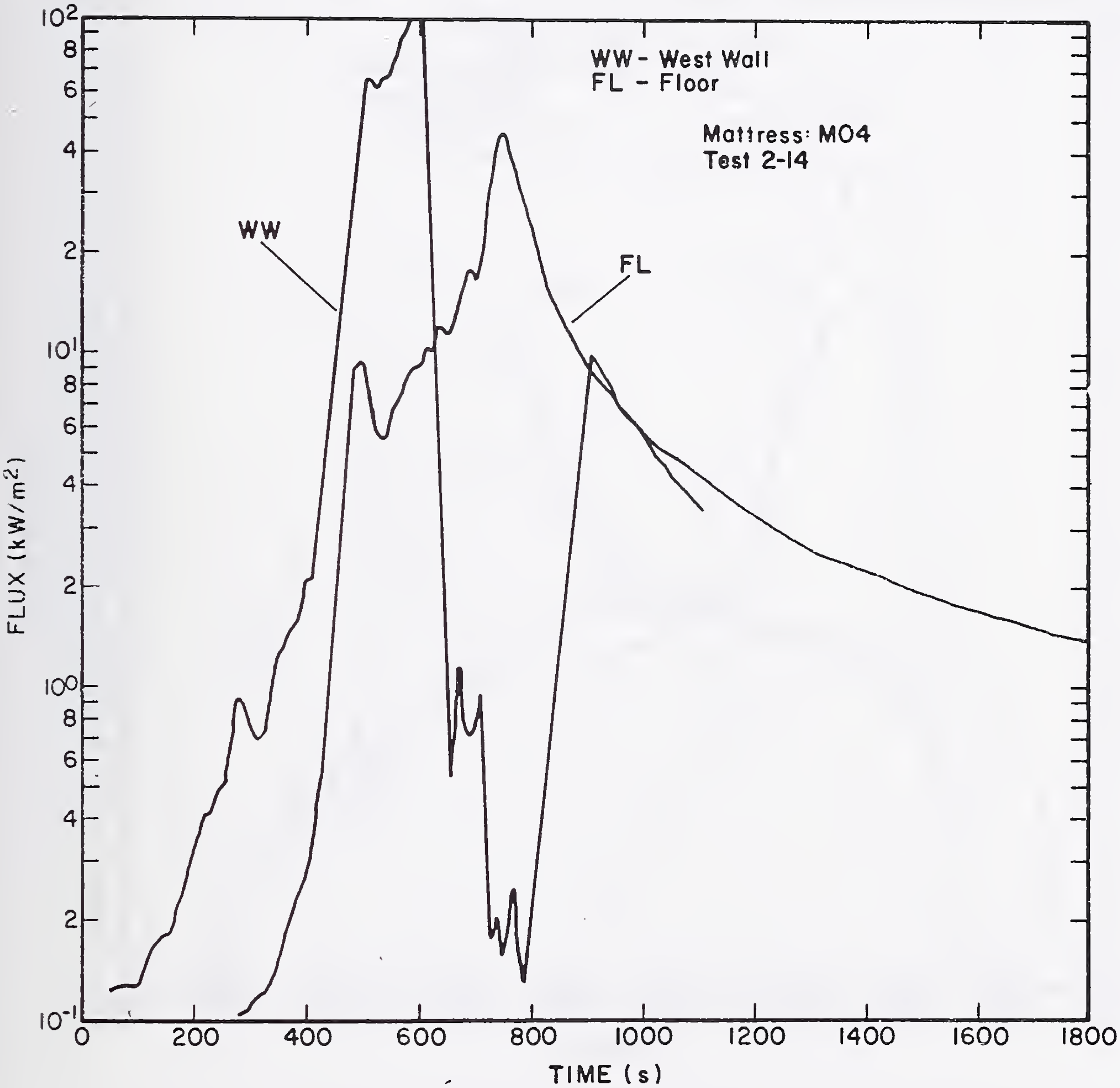


Figure 42. Heat Fluxes for Mattress M04

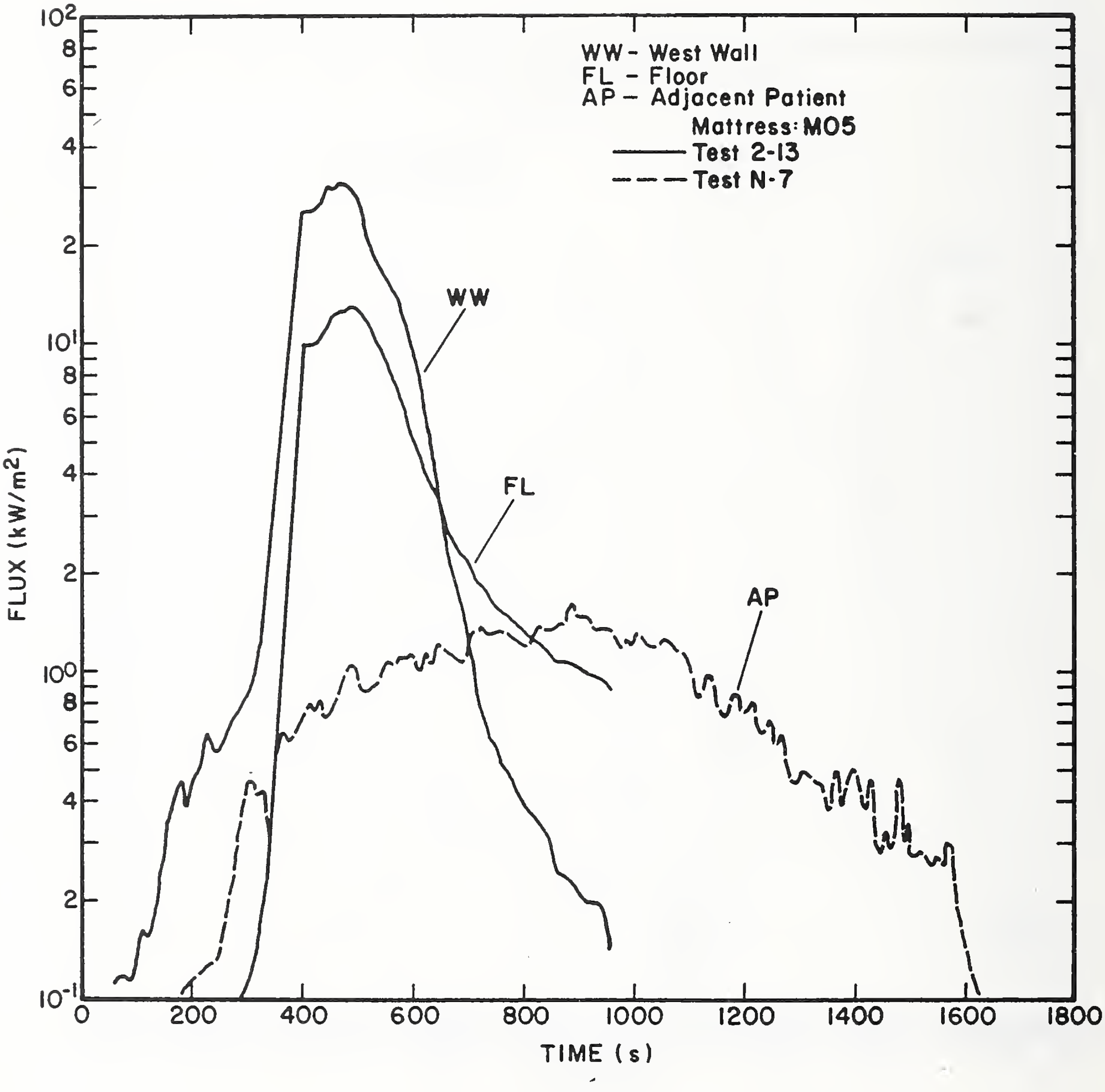


Figure 43. Heat Fluxes for Mattress M05

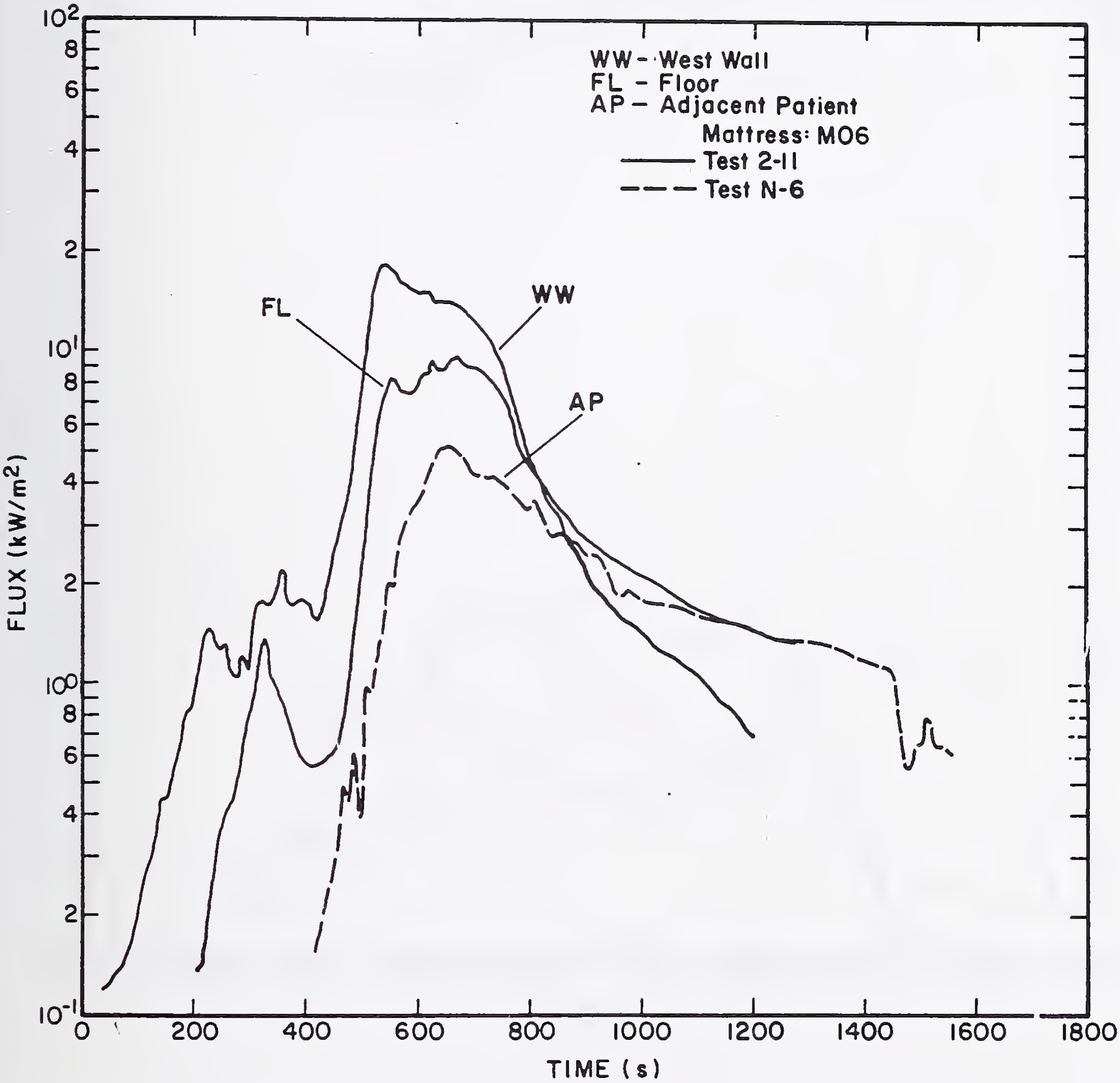


Figure 44. Heat Fluxes for Mattress M06

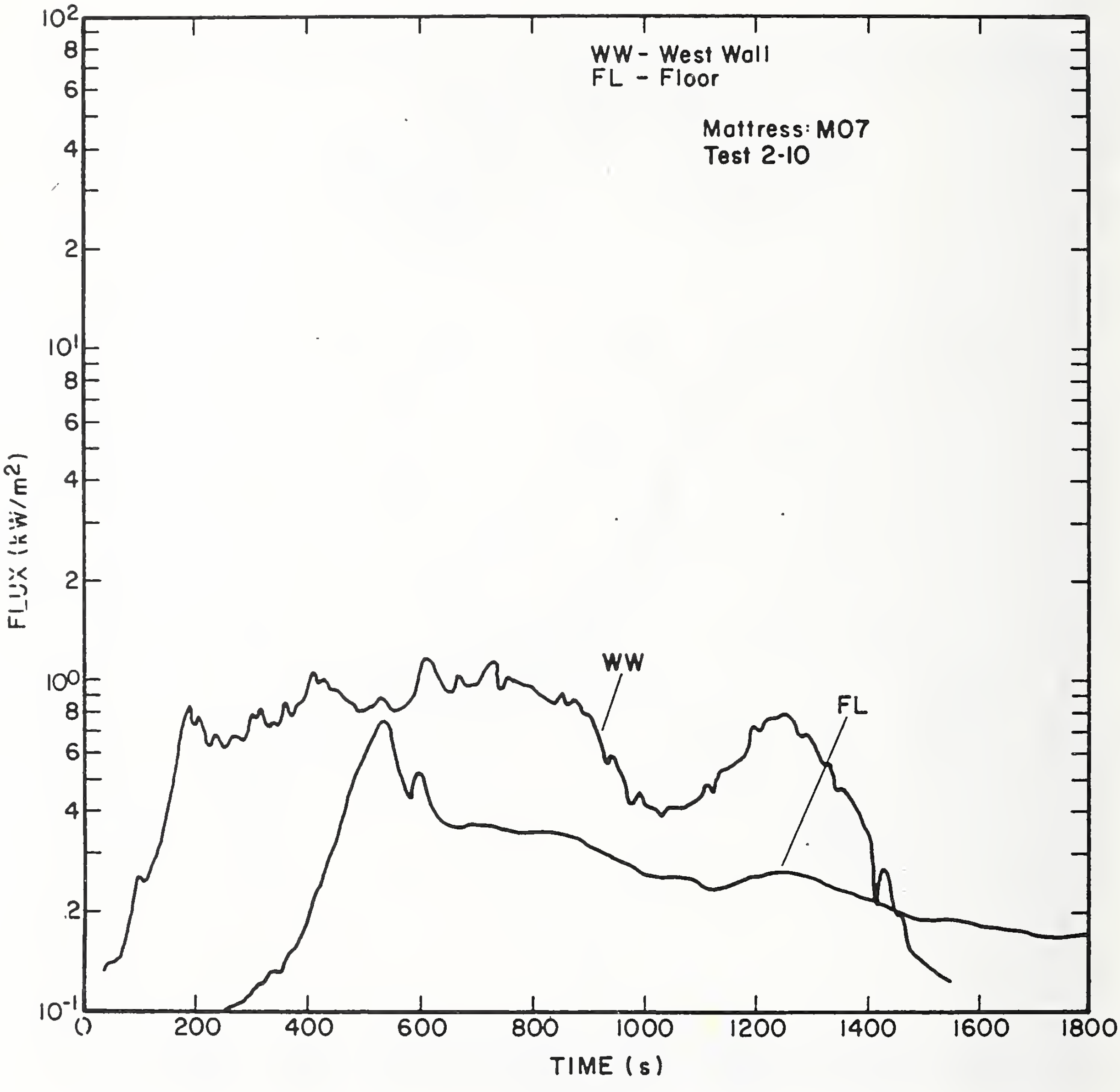


Figure 45. Heat Fluxes for Mattress M07

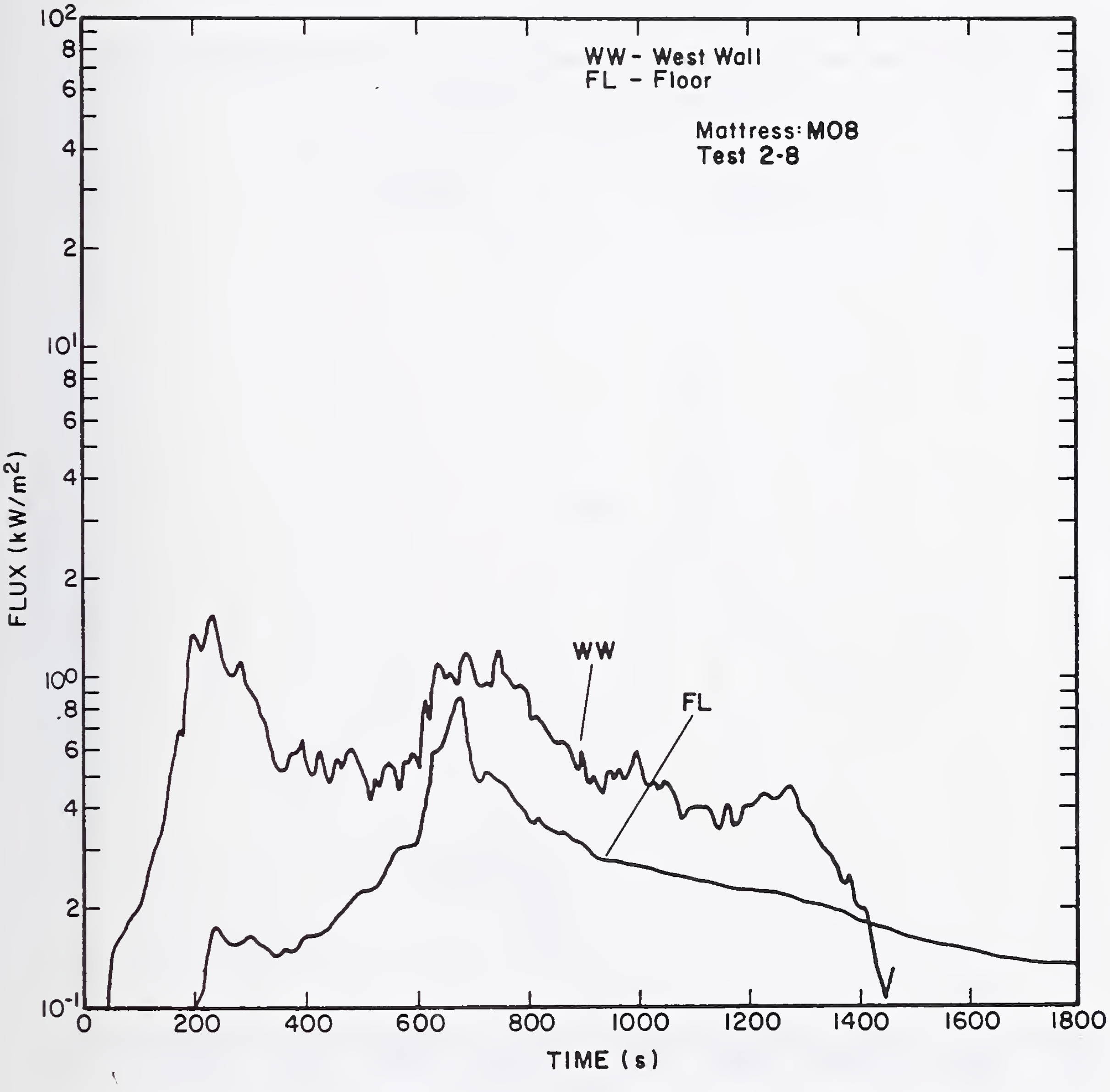


Figure 46. Heat Fluxes for Mattress M08

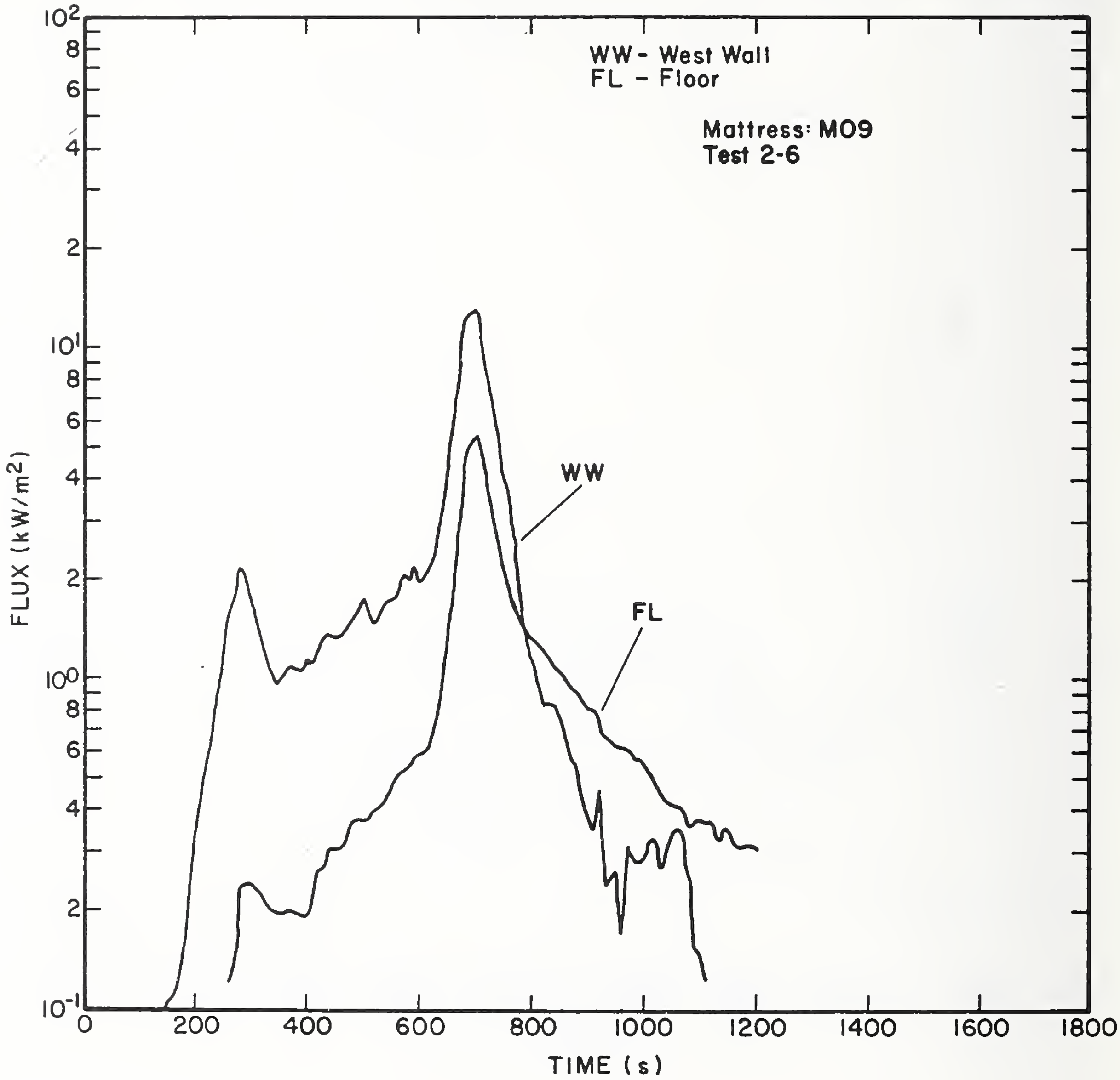


Figure 47. Heat Fluxes for Mattress M09

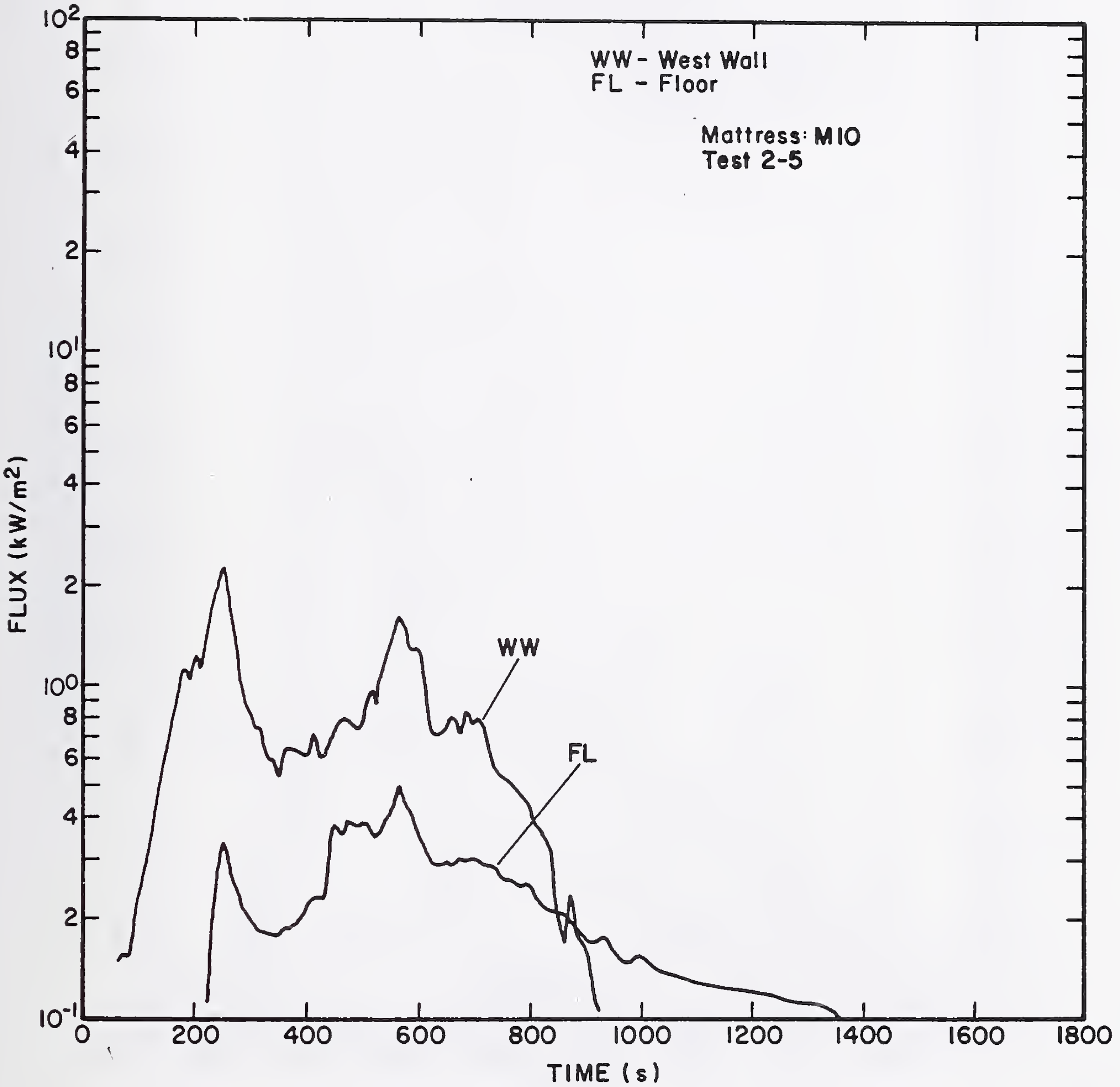


Figure 48. Heat Fluxes for Mattress M10

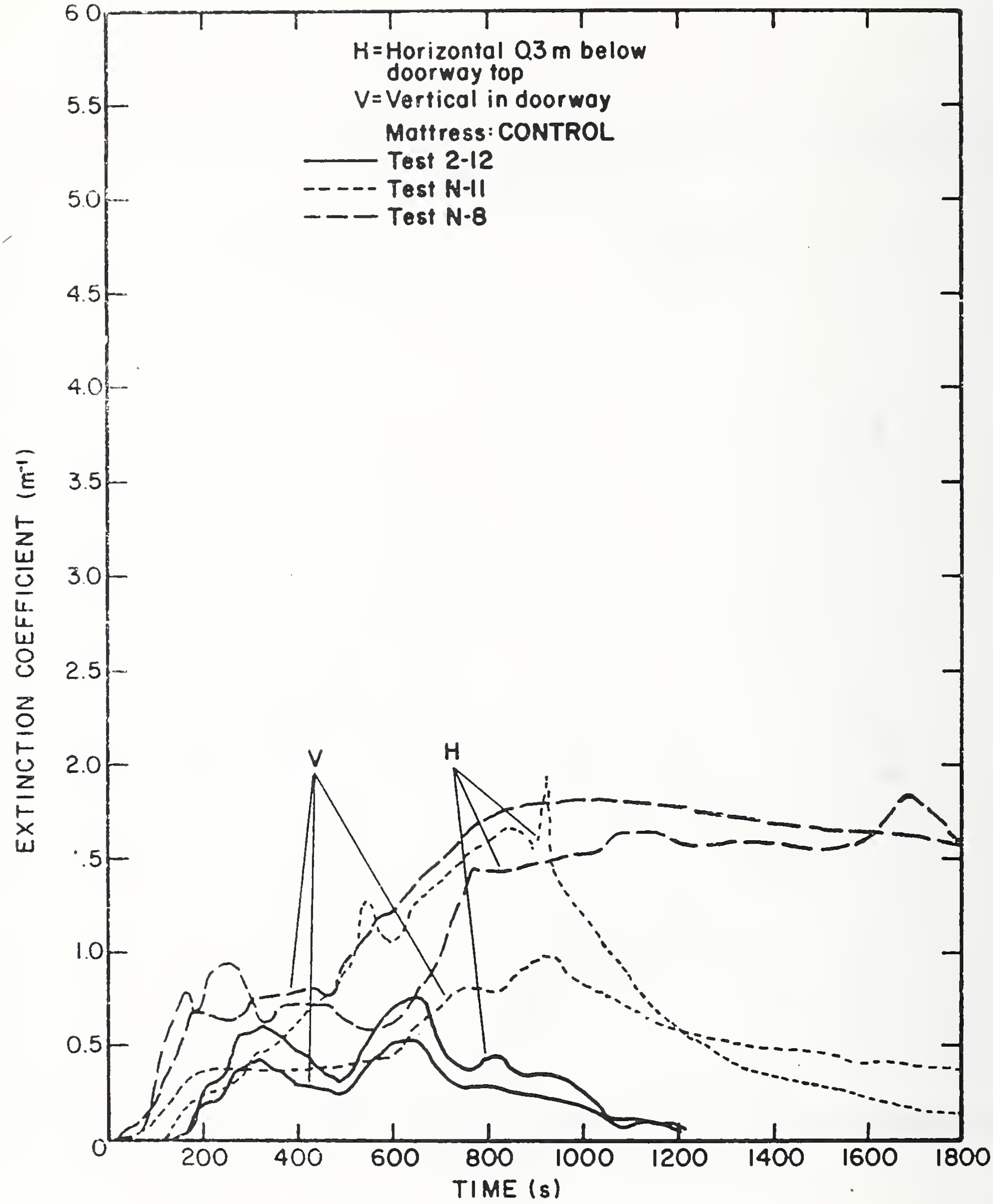


Figure 49. Smoke Levels for Control Mattress

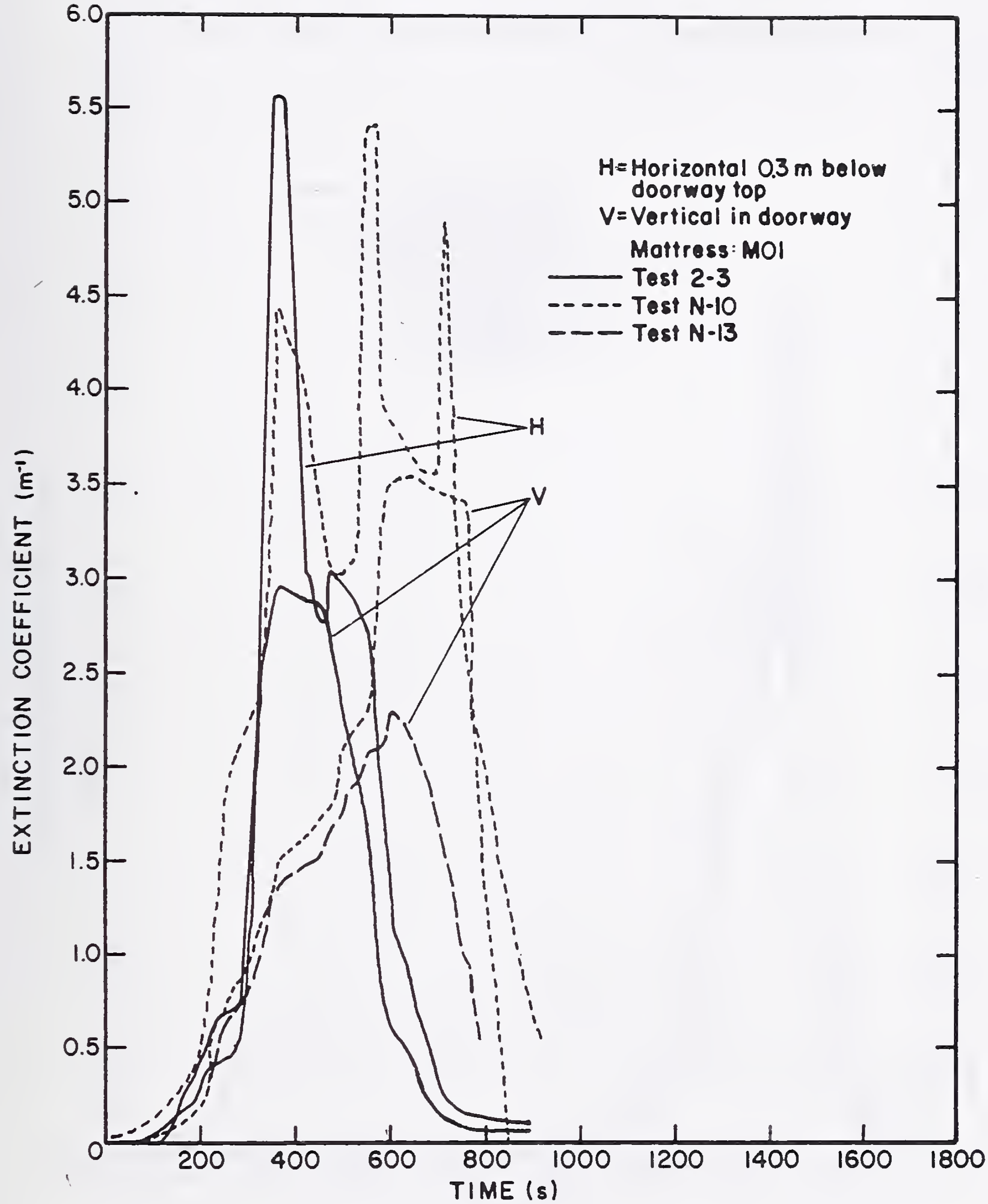


Figure 50. Smoke Levels for Mattress M01

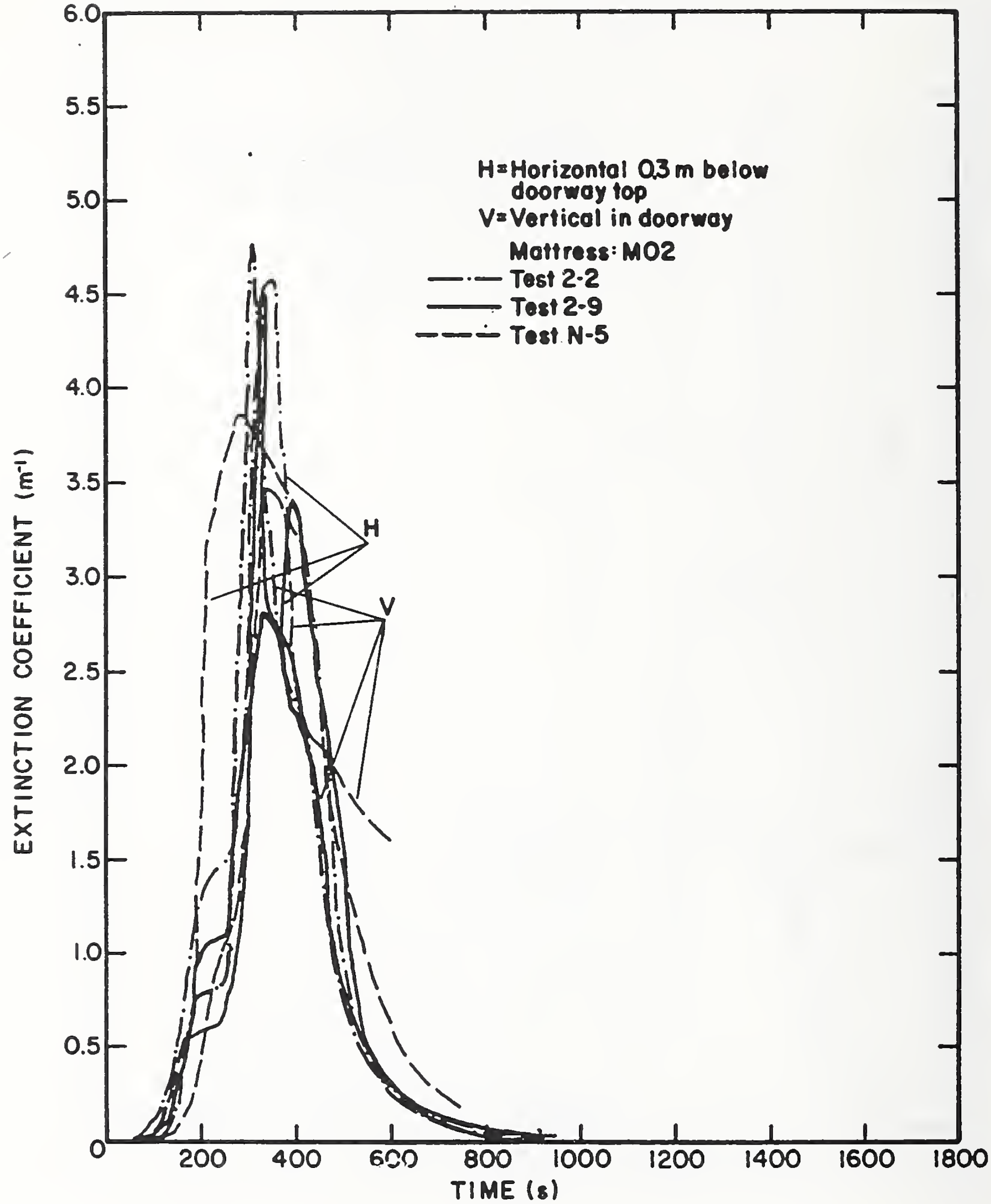


Figure 51. Smoke Levels for Mattress M02

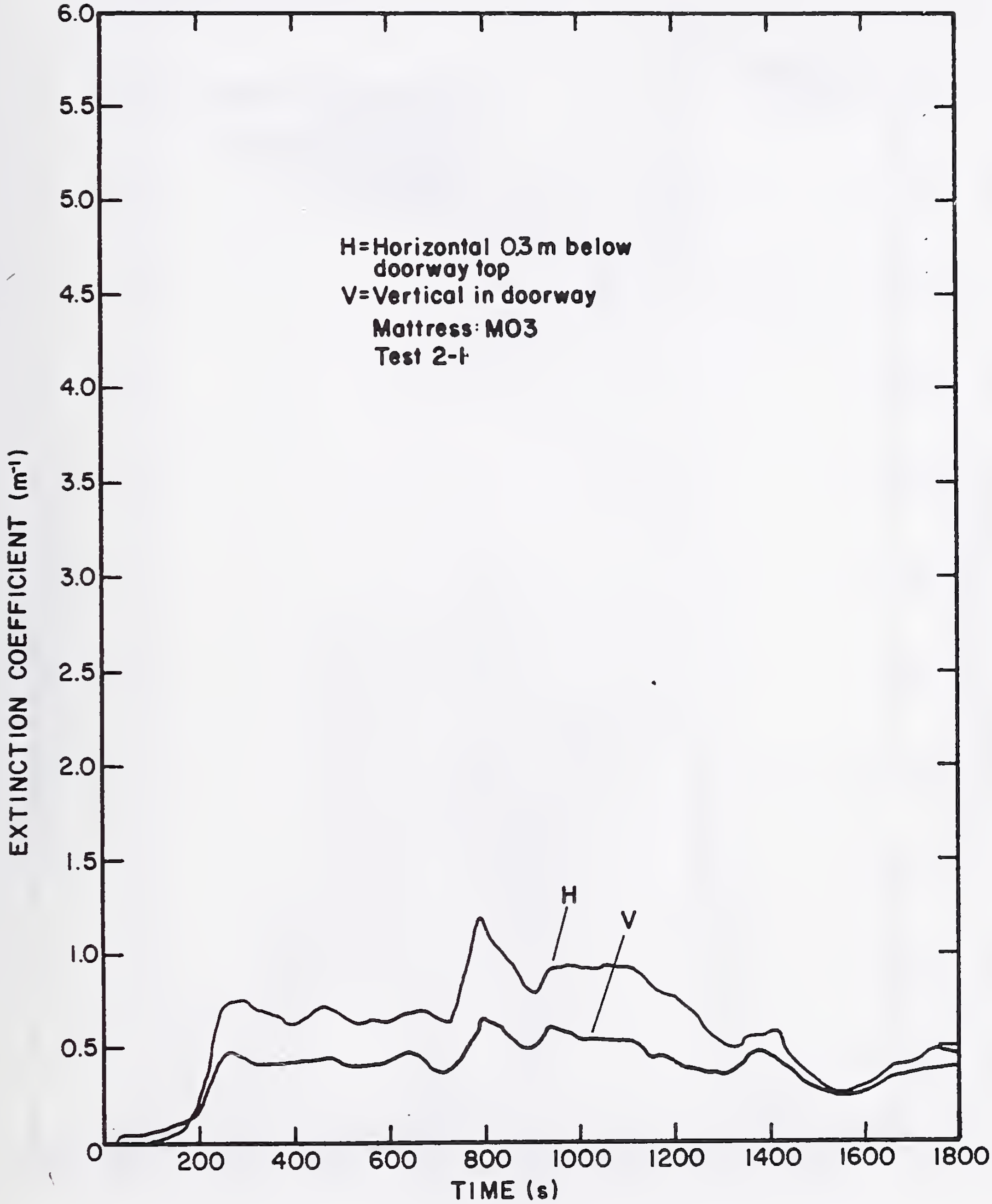


Figure 52. Smoke Levels for Mattress M03

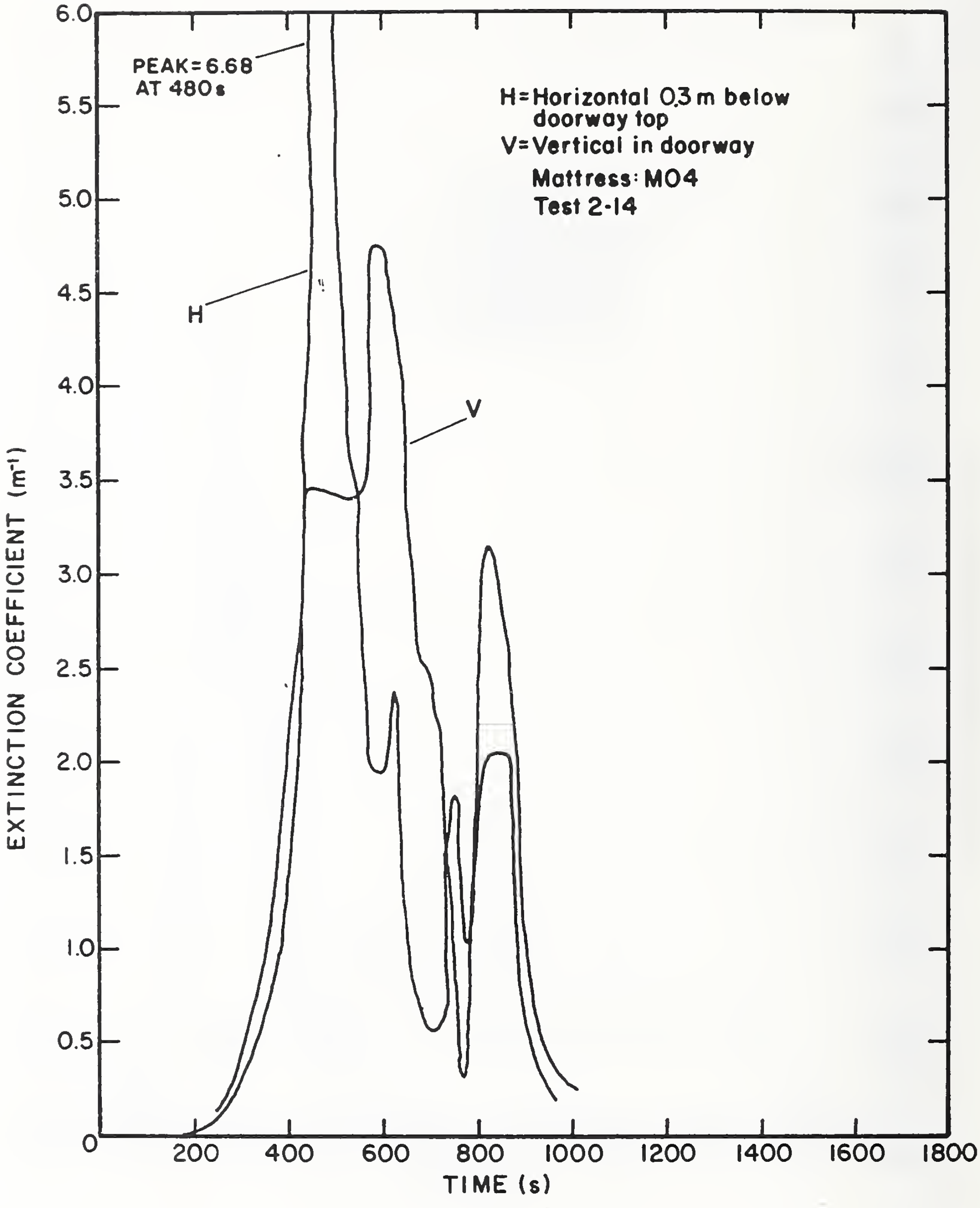


Figure 53. Smoke Levels for Mattress M04

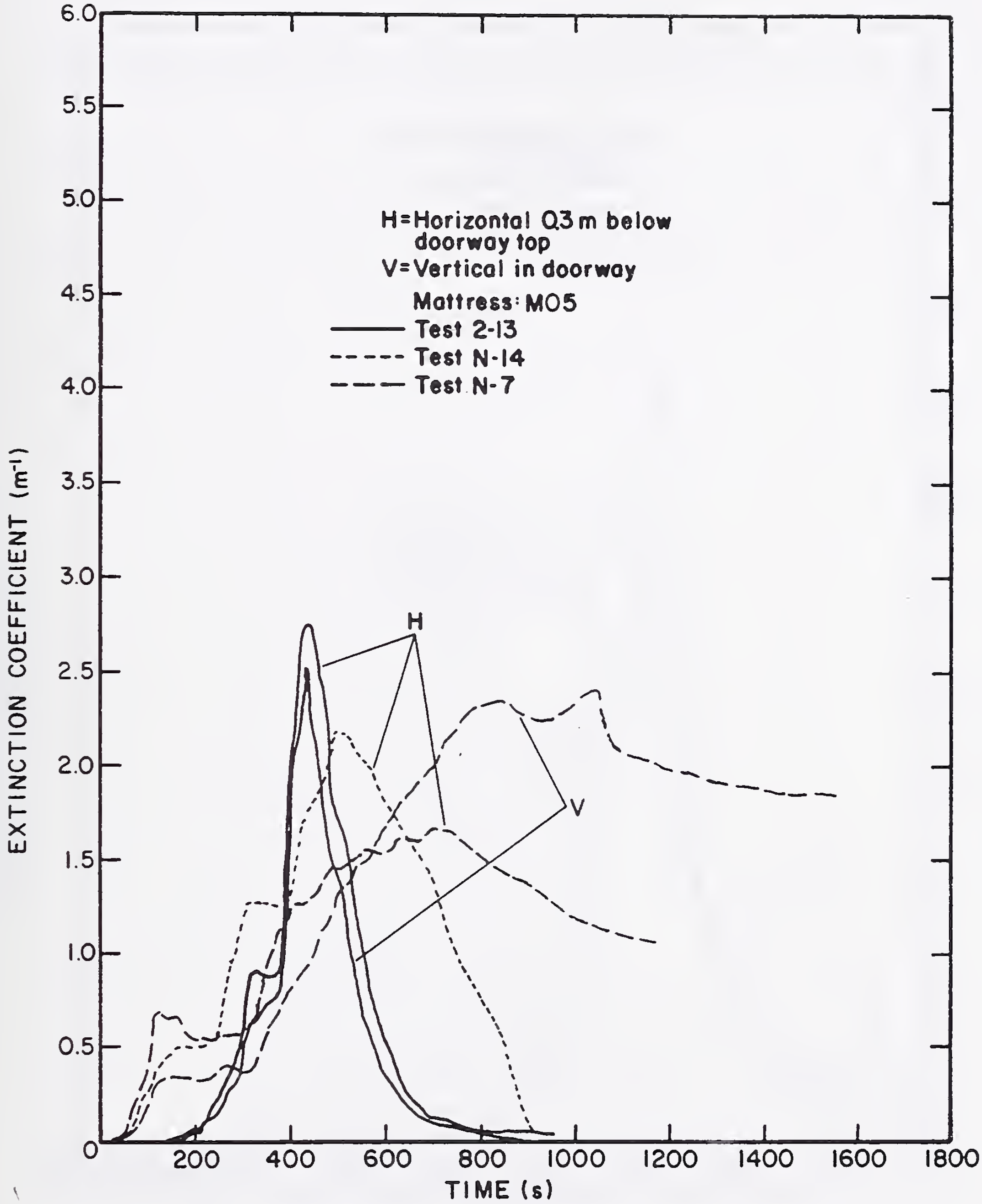


Figure 54. Smoke Levels for Mattress M05

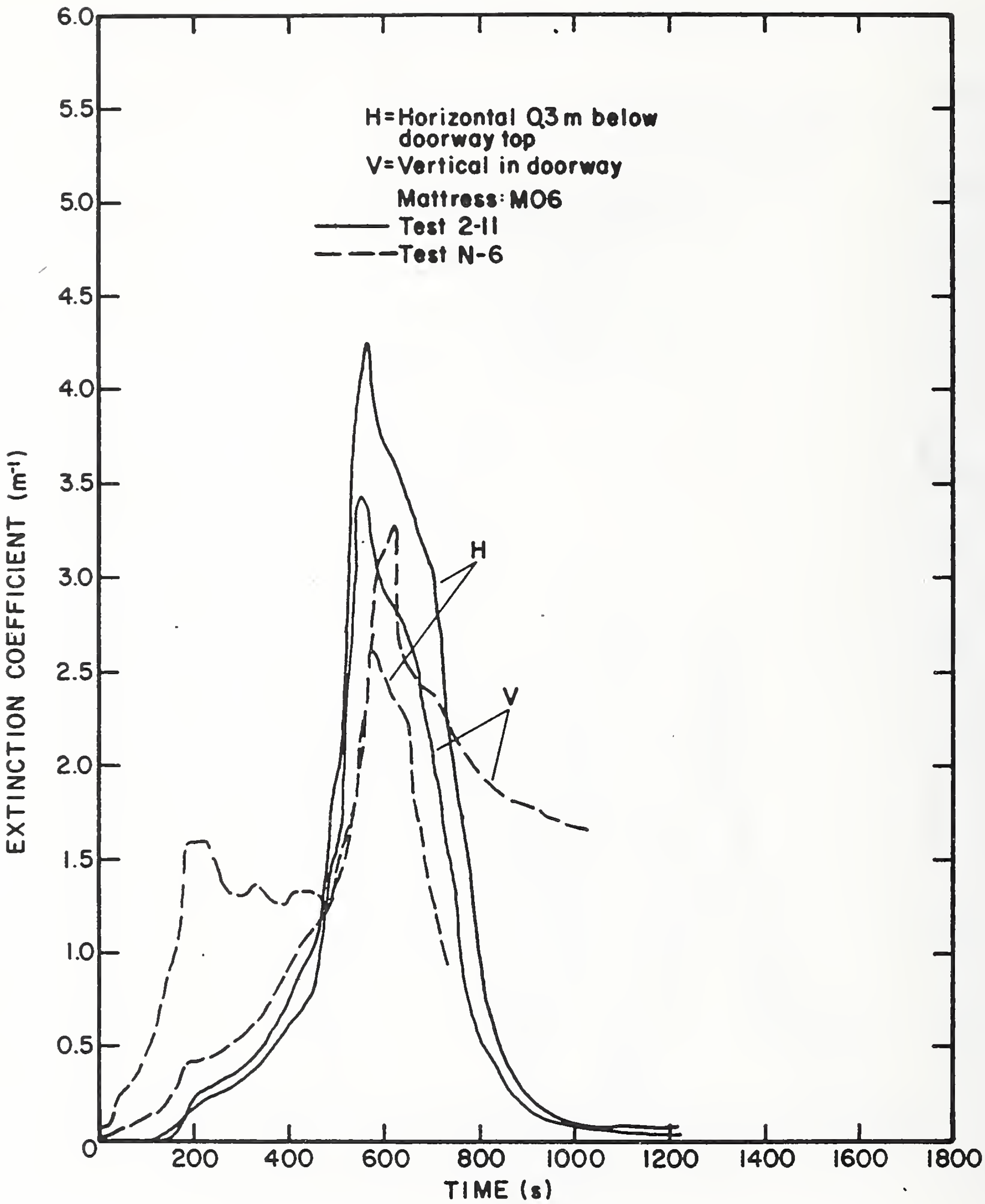


Figure 55. Smoke Levels for Mattress M06

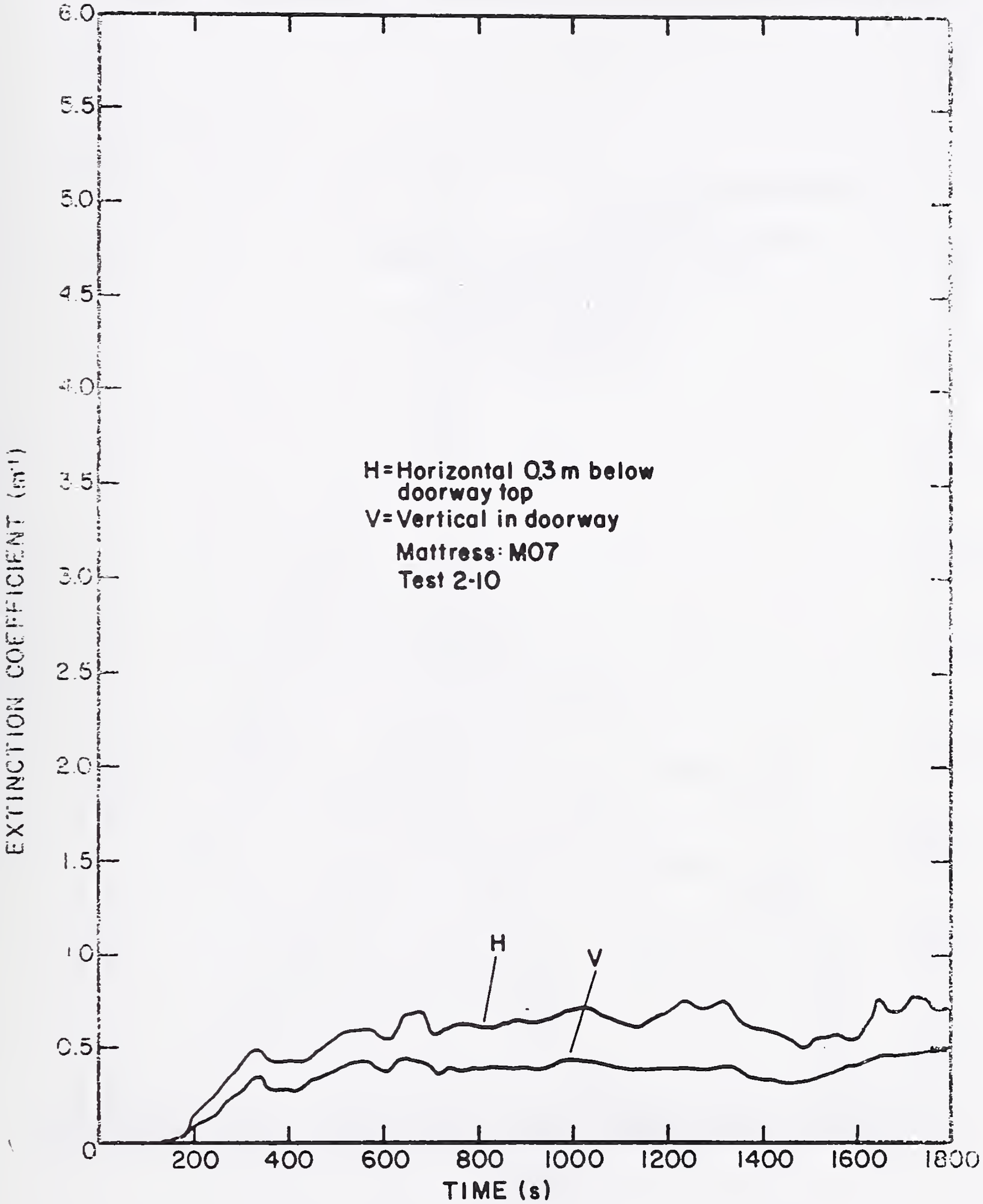


Figure 56. Smoke Levels for Mattress M07

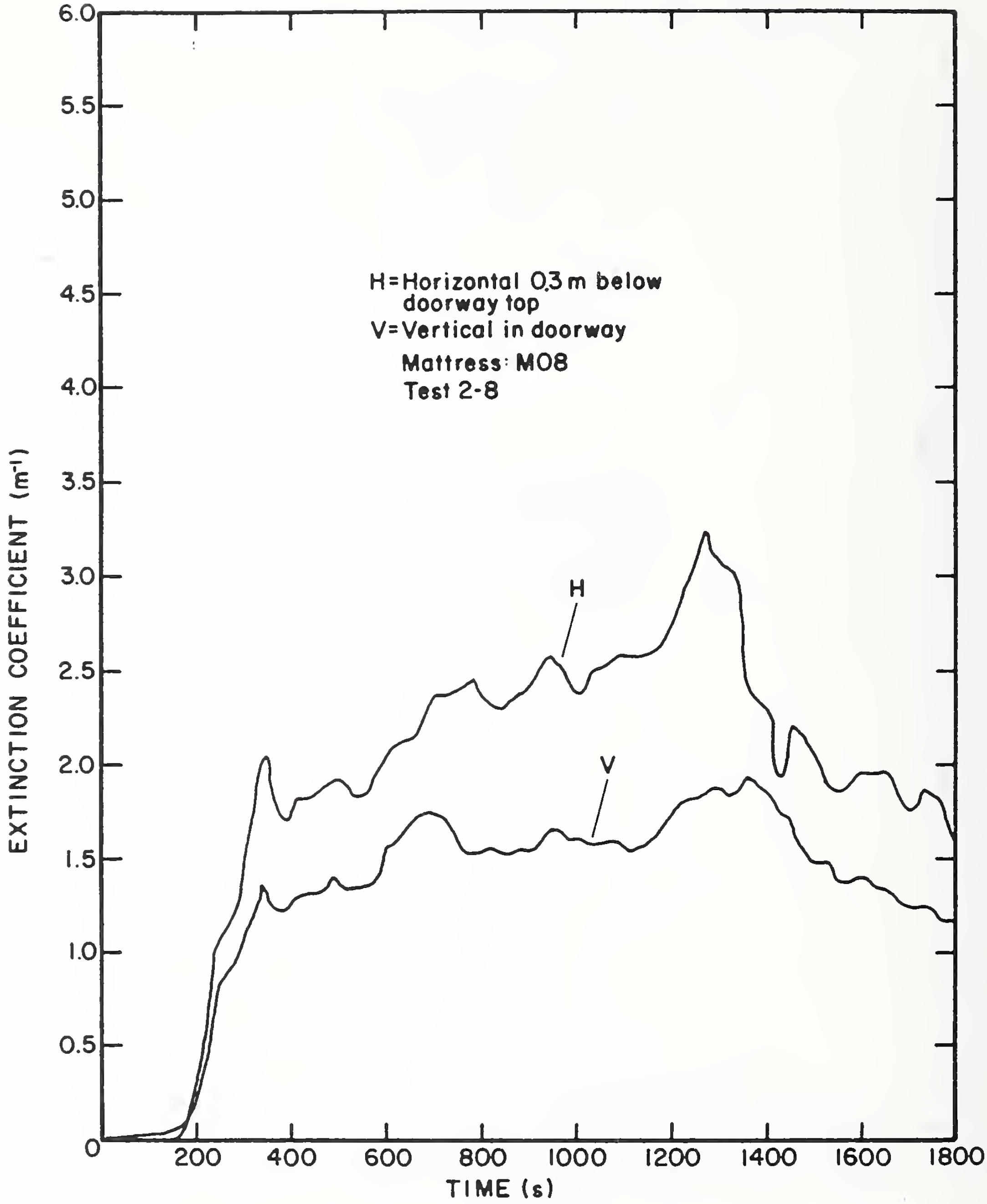


Figure 57. Smoke Levels for Mattress M08

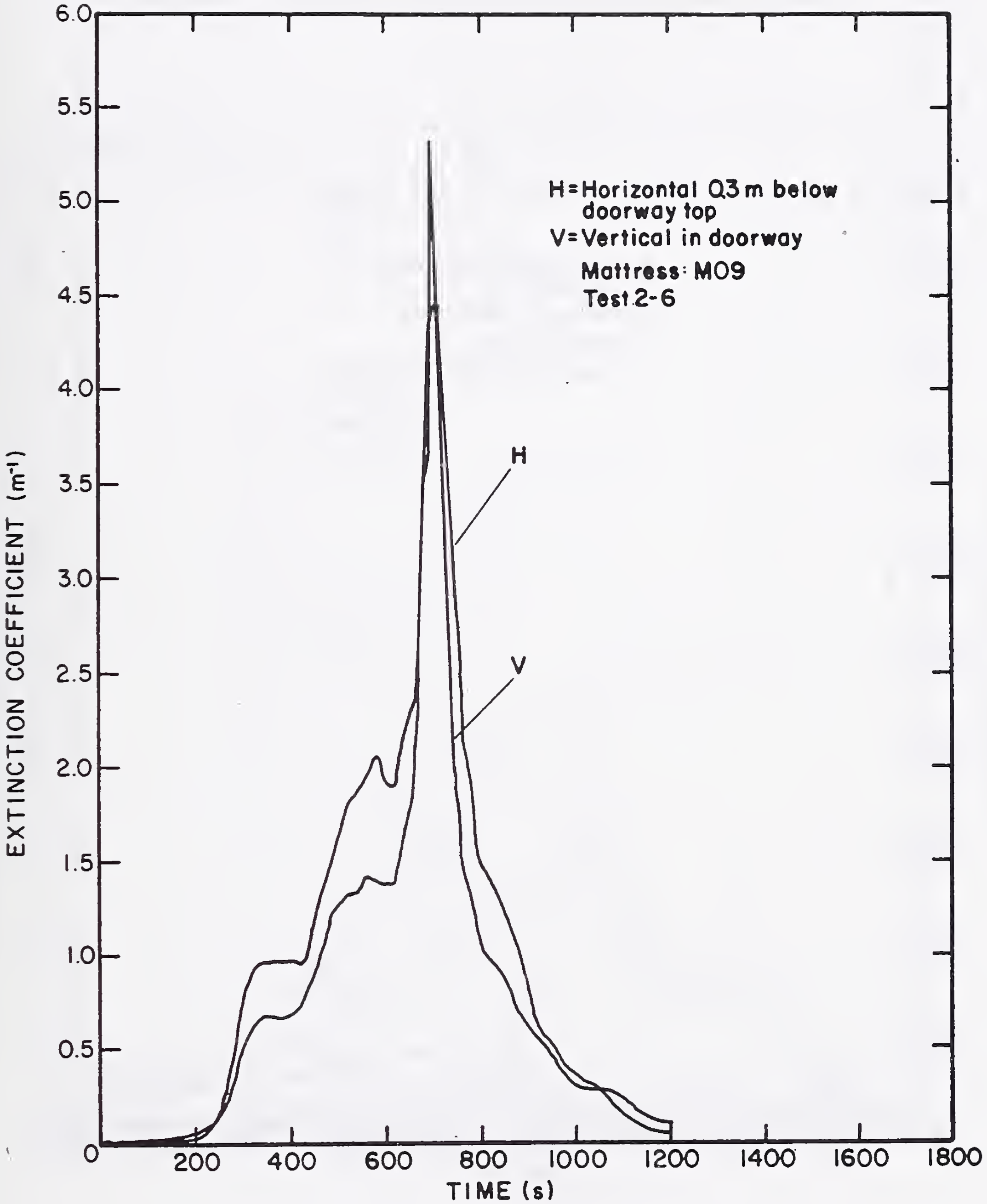


Figure 58. Smoke Levels for Mattress M09

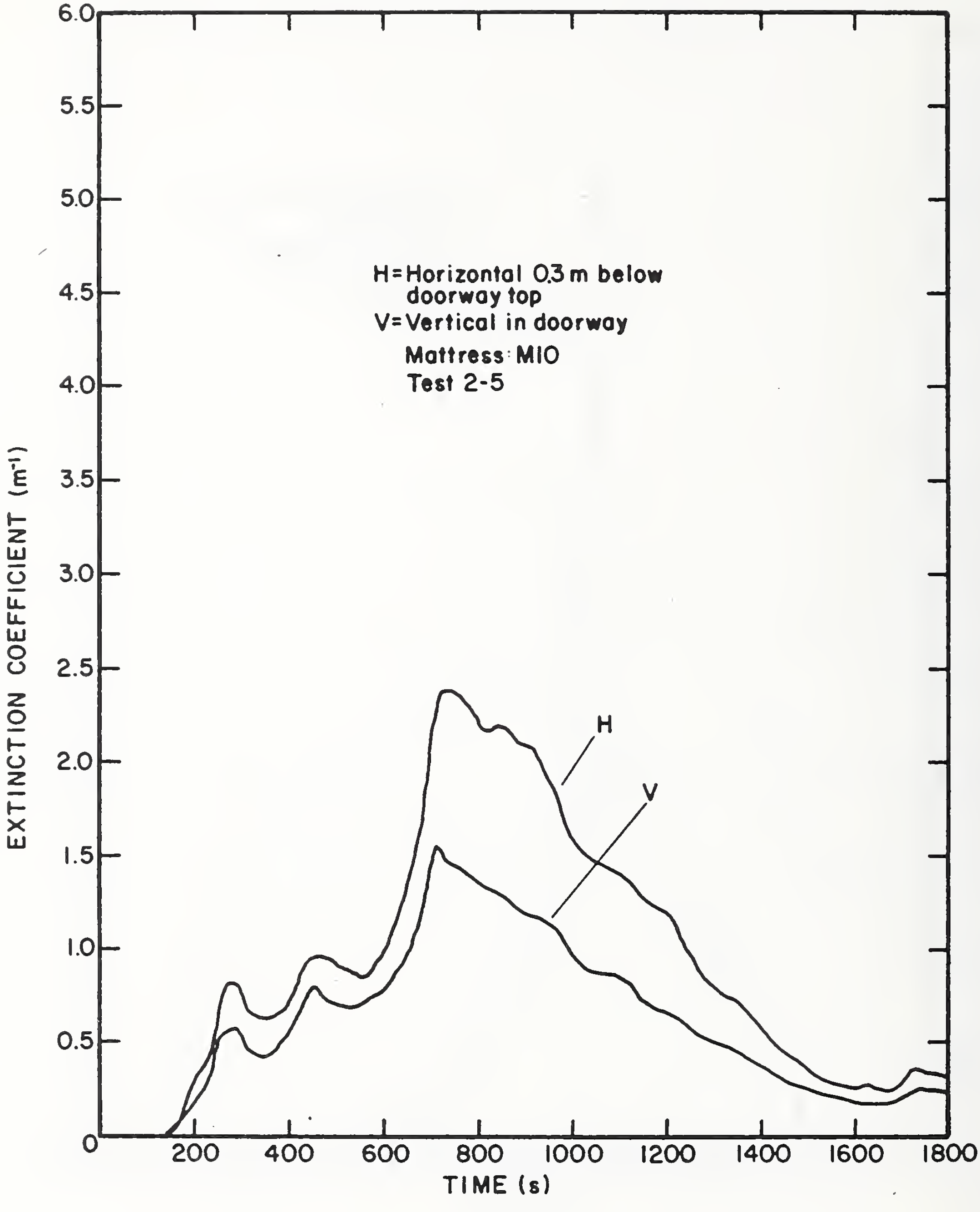


Figure 59. Smoke Levels for Mattress M10

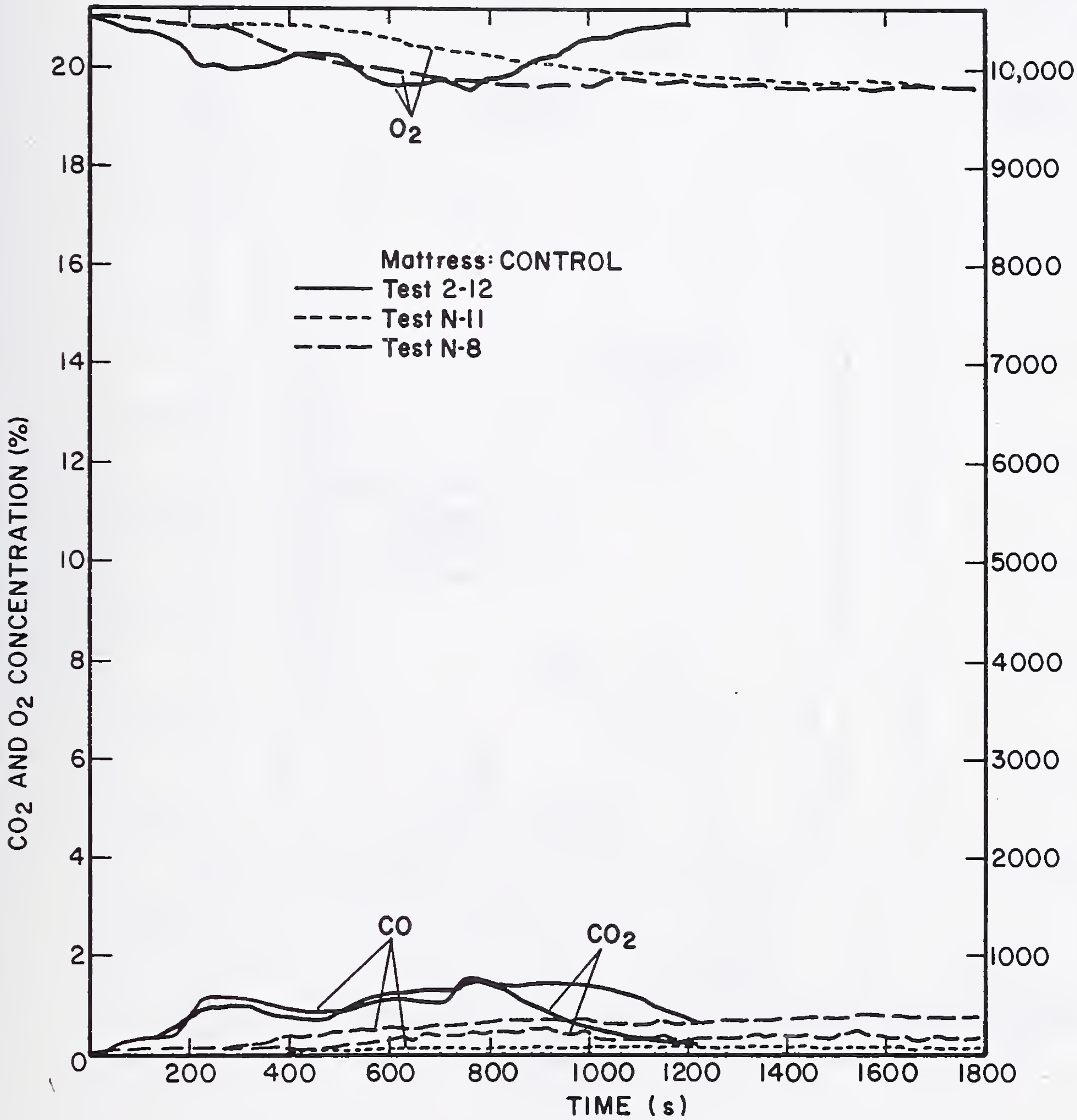


Figure 60. Gas Concentrations for Control Mattress

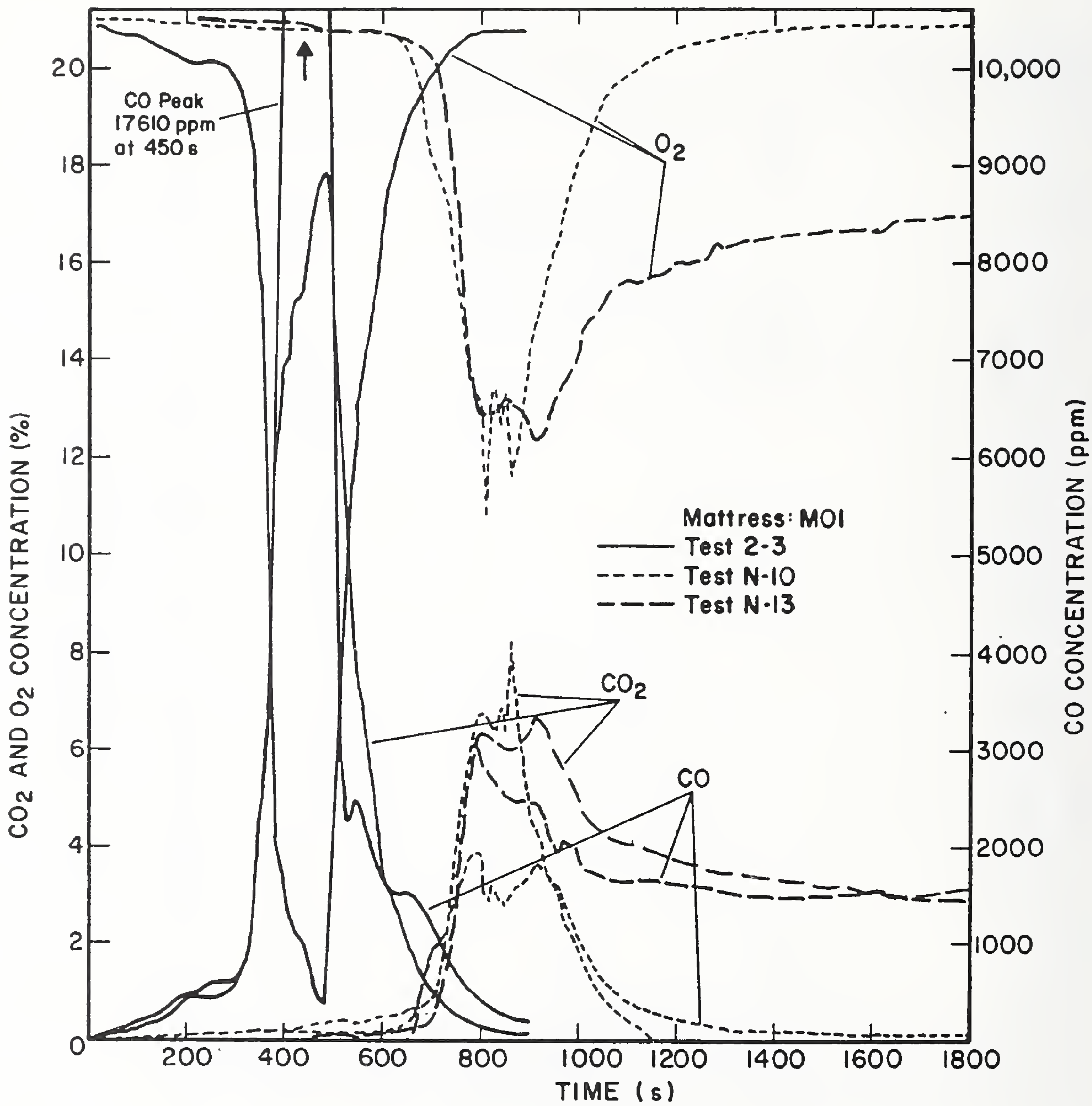


Figure 61. Gas Concentrations for Mattress M01

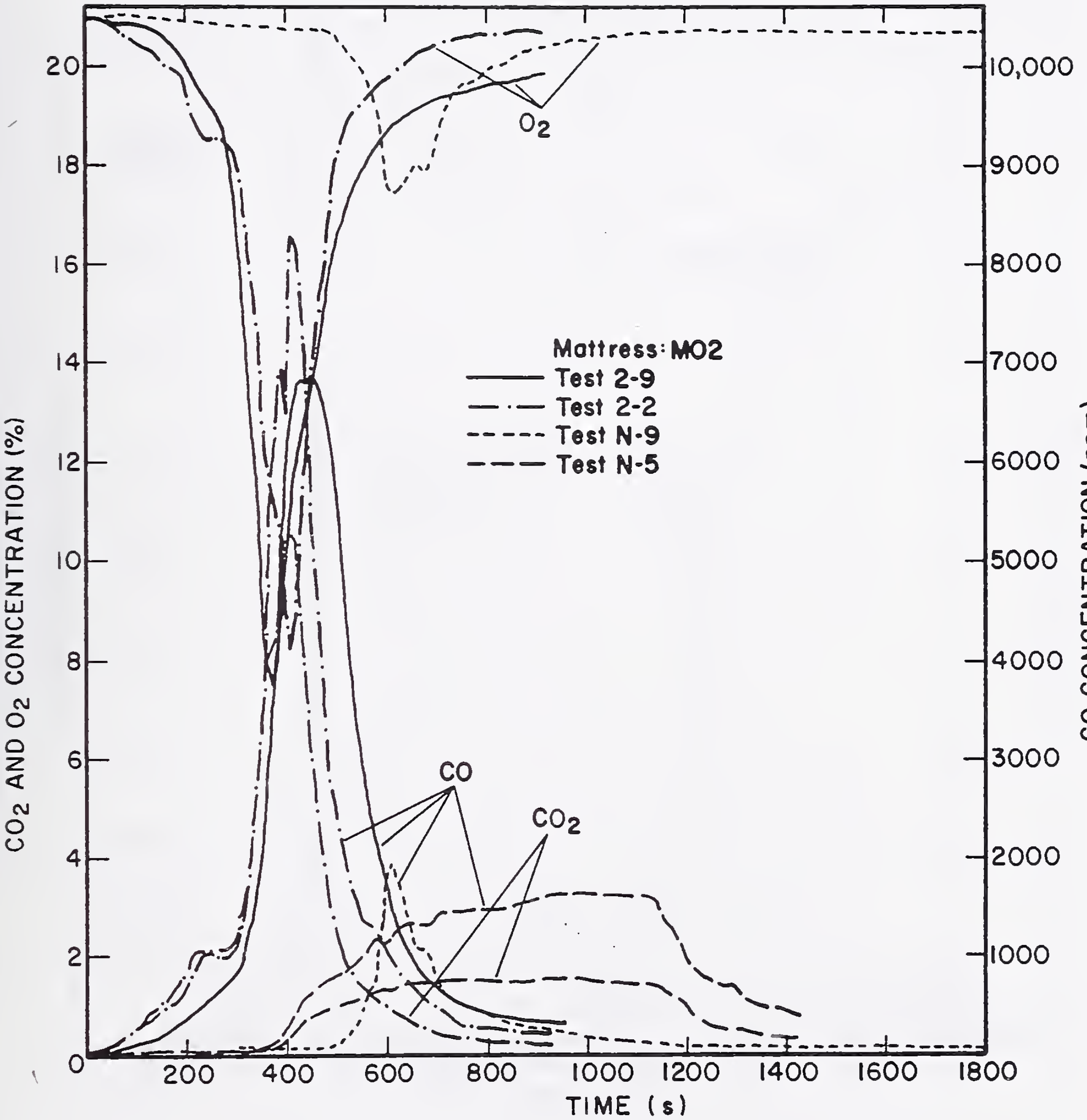


Figure 62. Gas Concentrations for Mattress M02

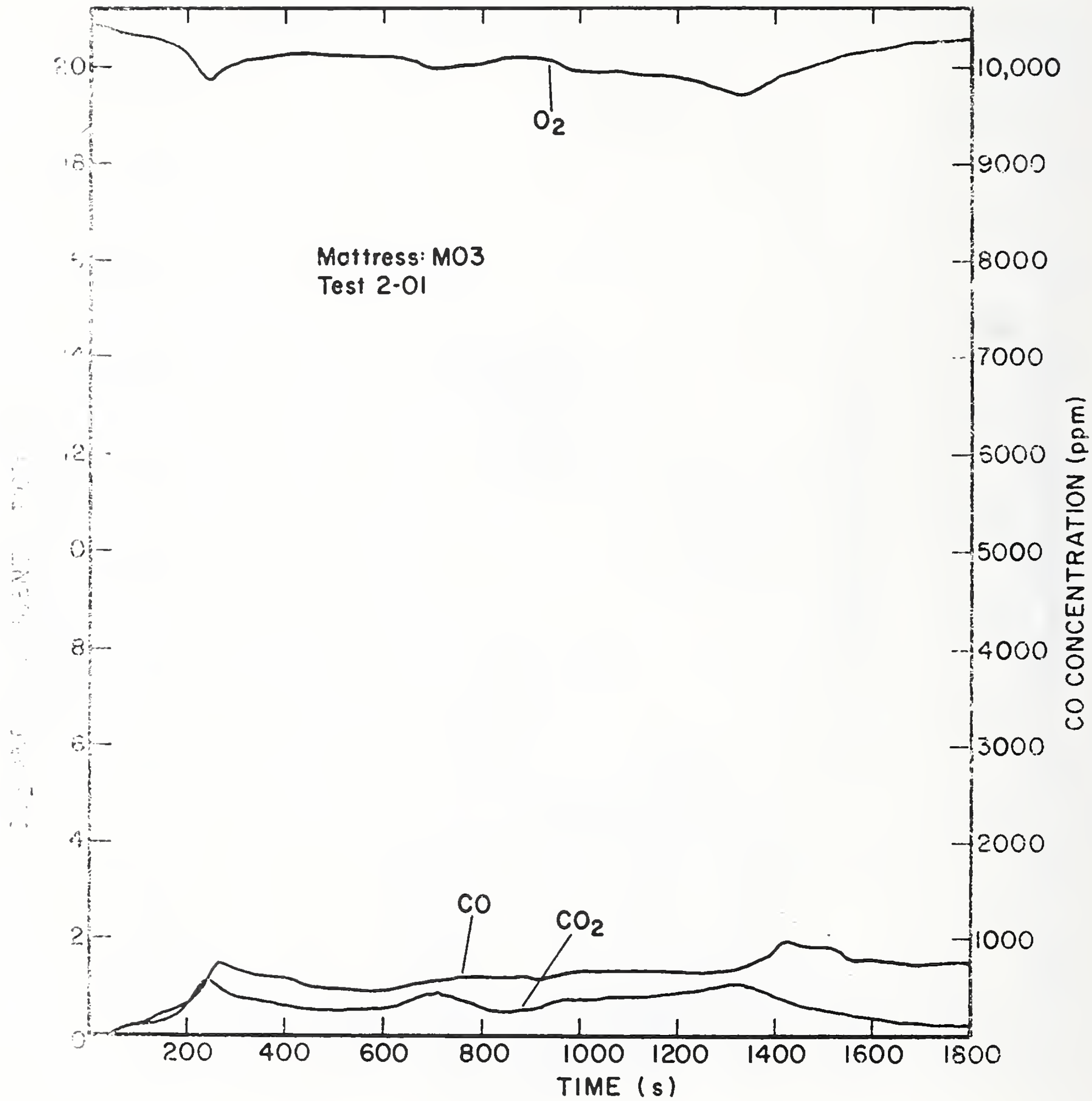


Figure 63. Gas Concentrations for Mattress M03

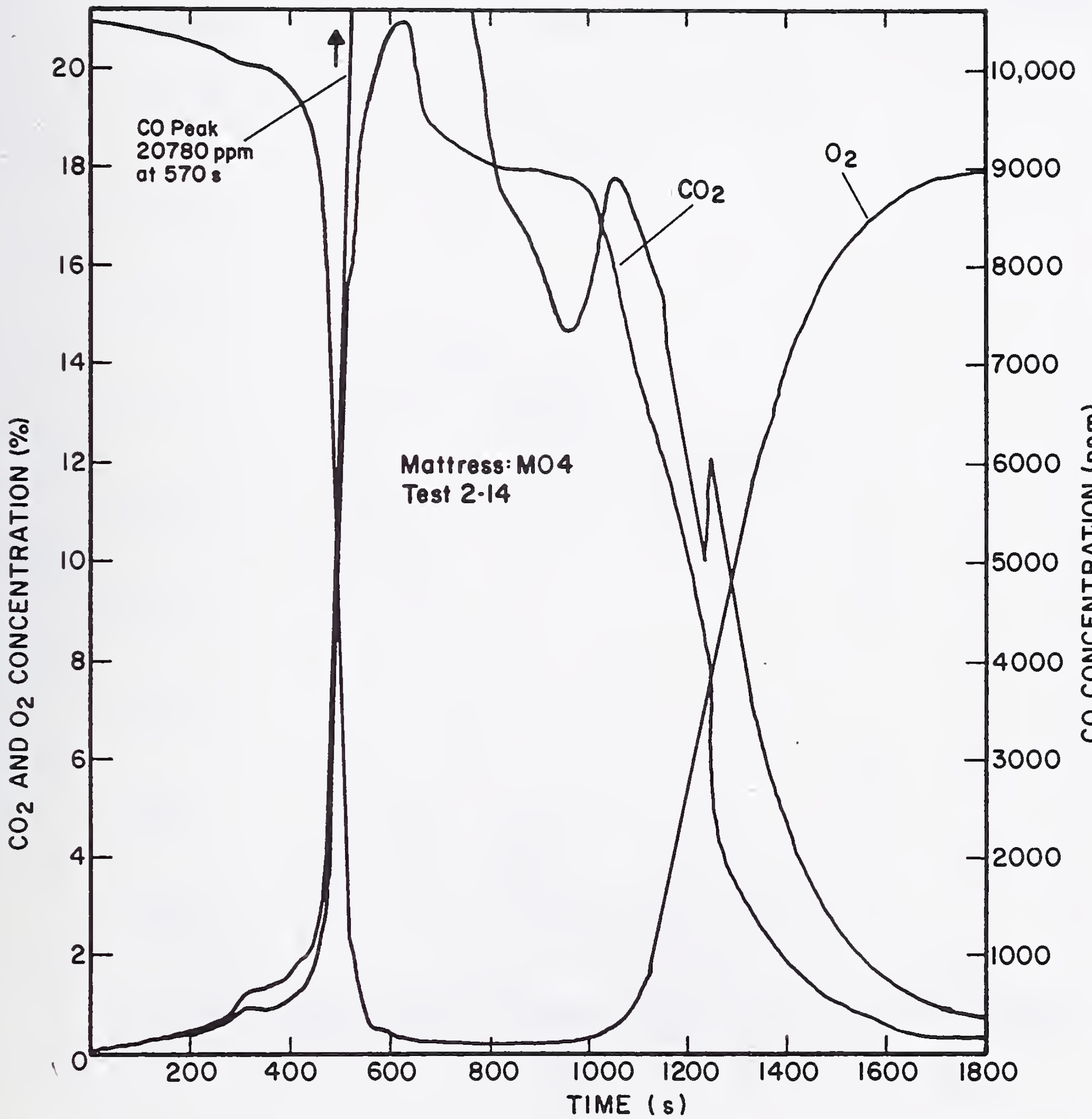


Figure 64. Gas Concentrations for Mattress M04

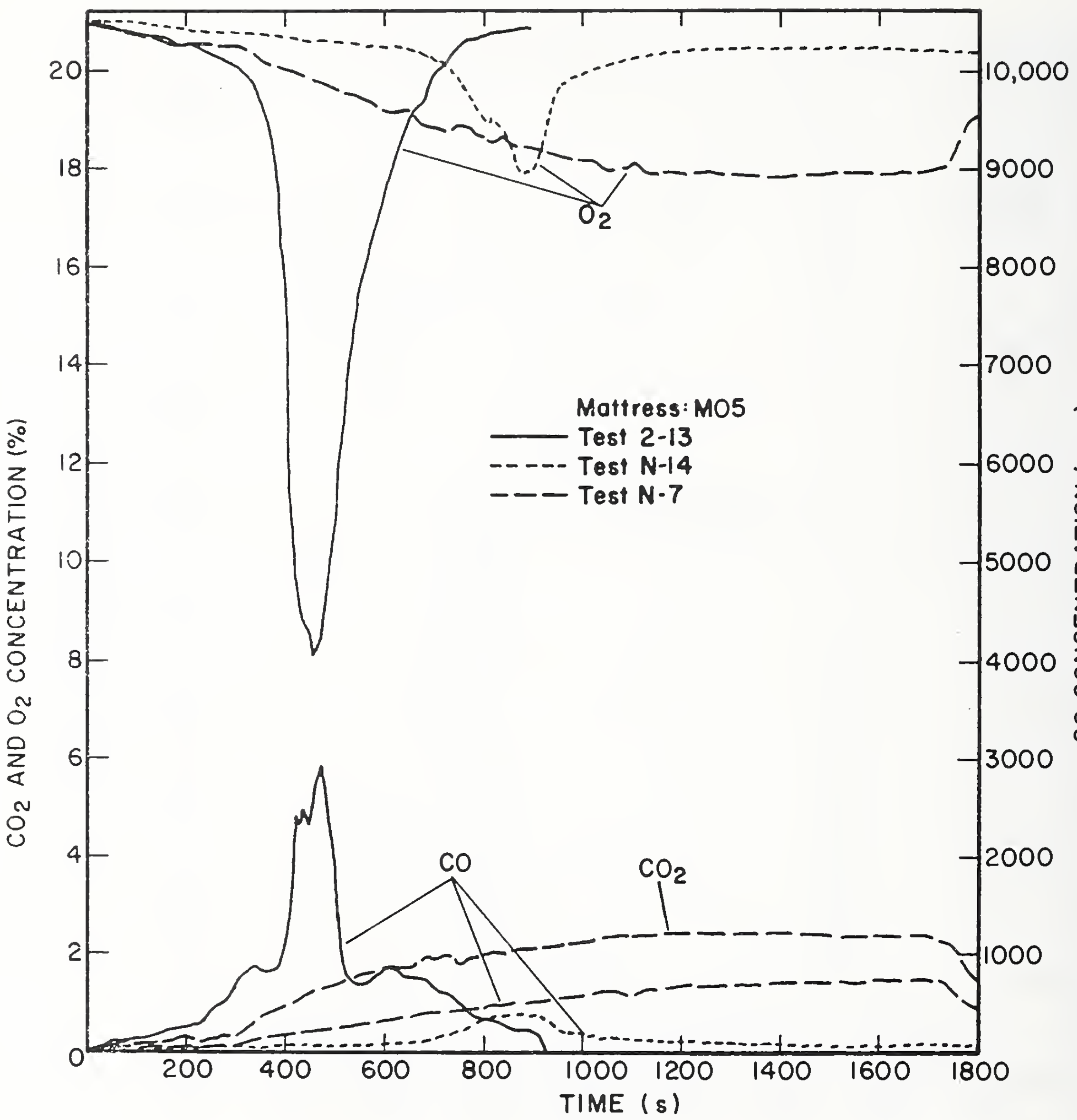


Figure 65. Gas Concentrations for Mattress M05

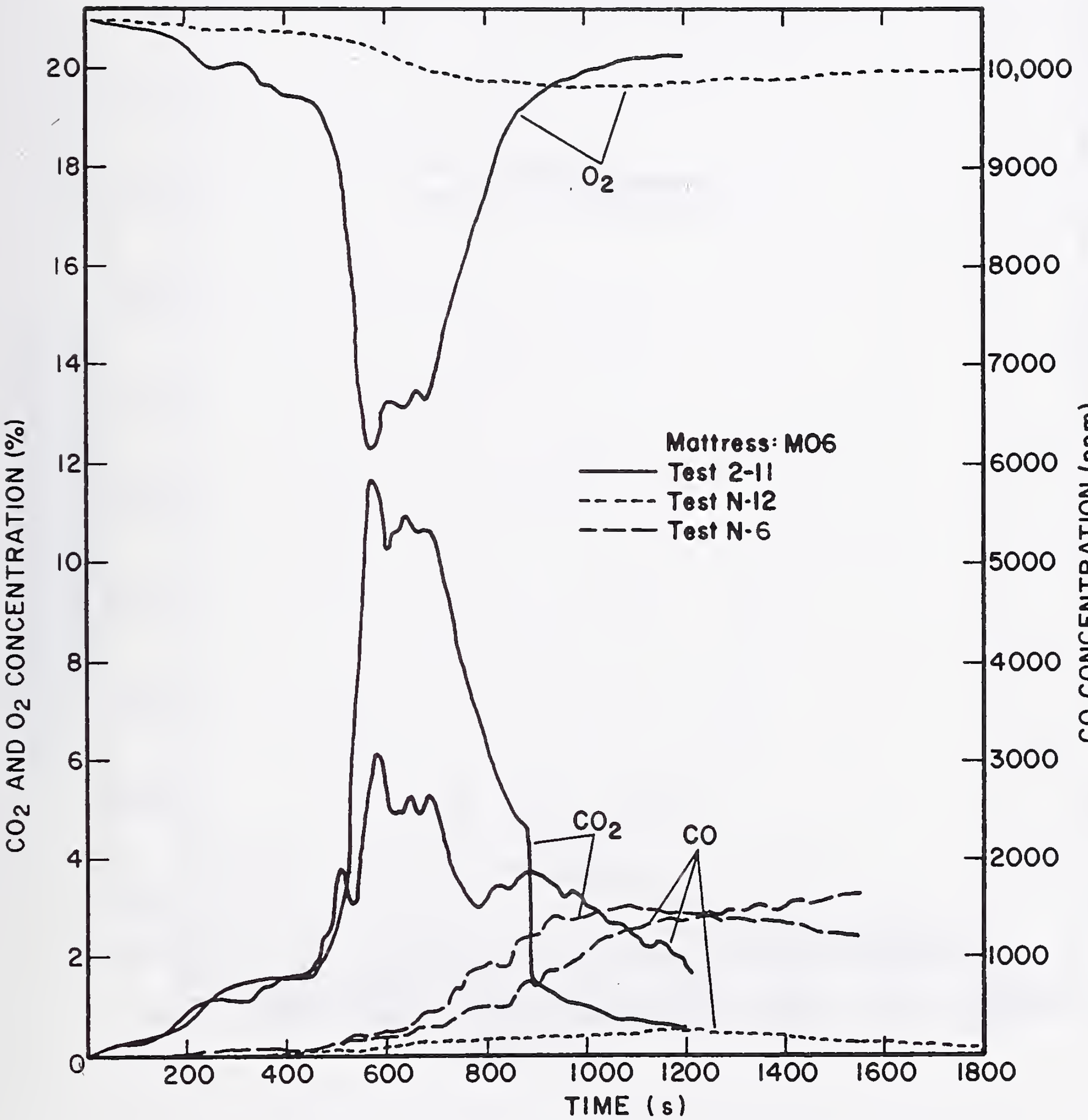


Figure 66. Gas Concentrations for Mattress M06

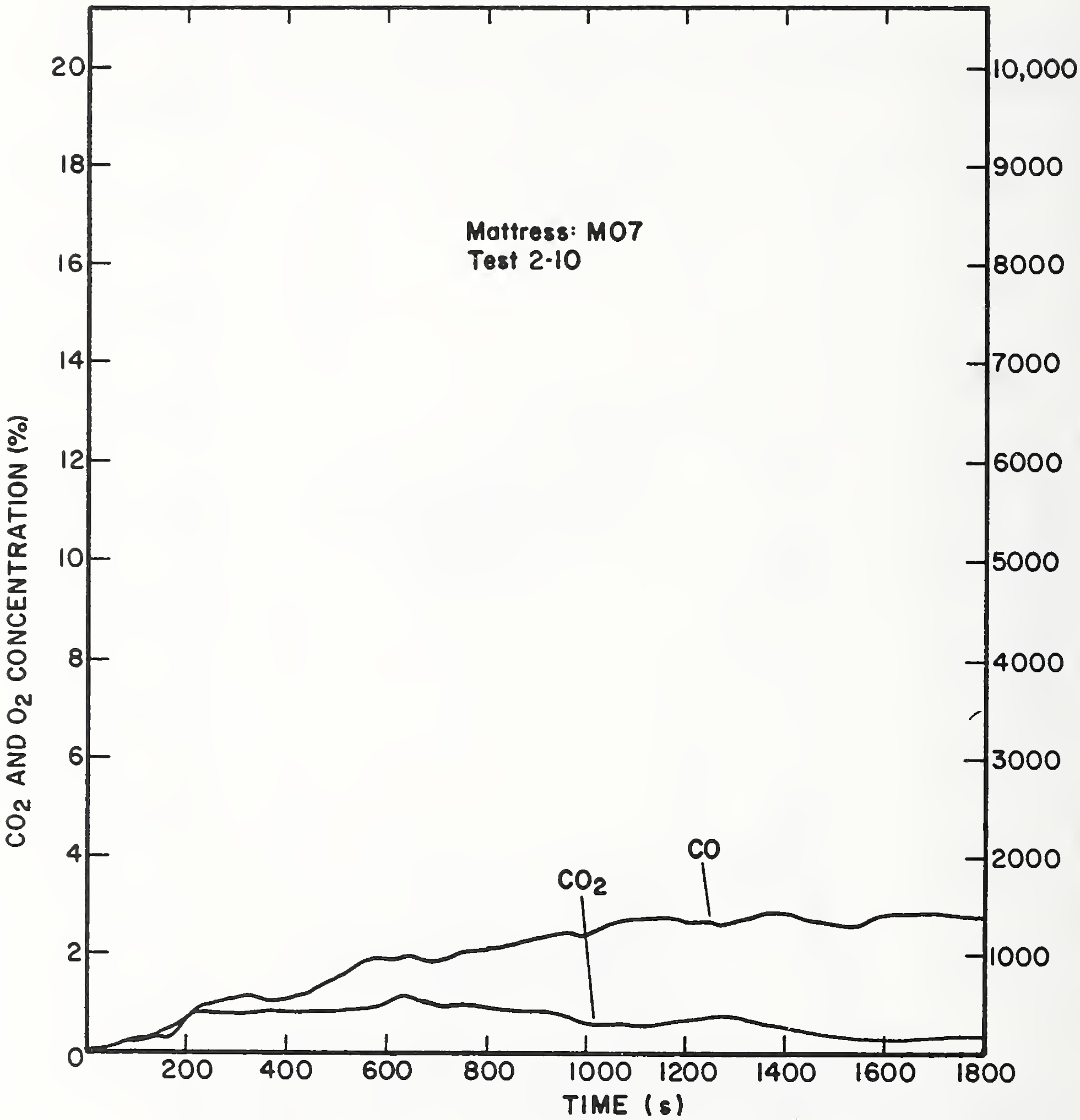


Figure 67. Gas Concentrations for Mattress M07

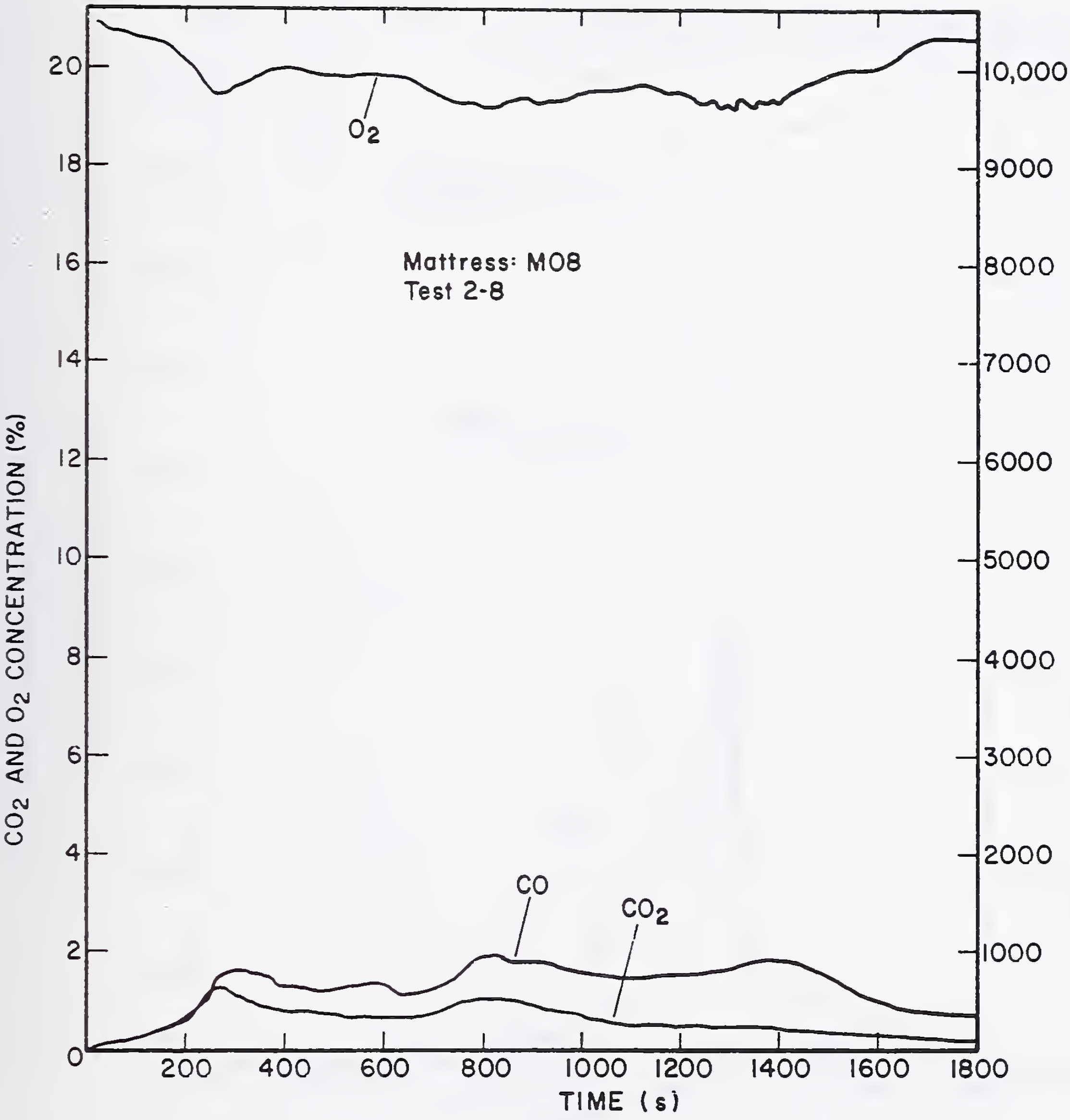


Figure 68. Gas Concentrations for Mattress M08

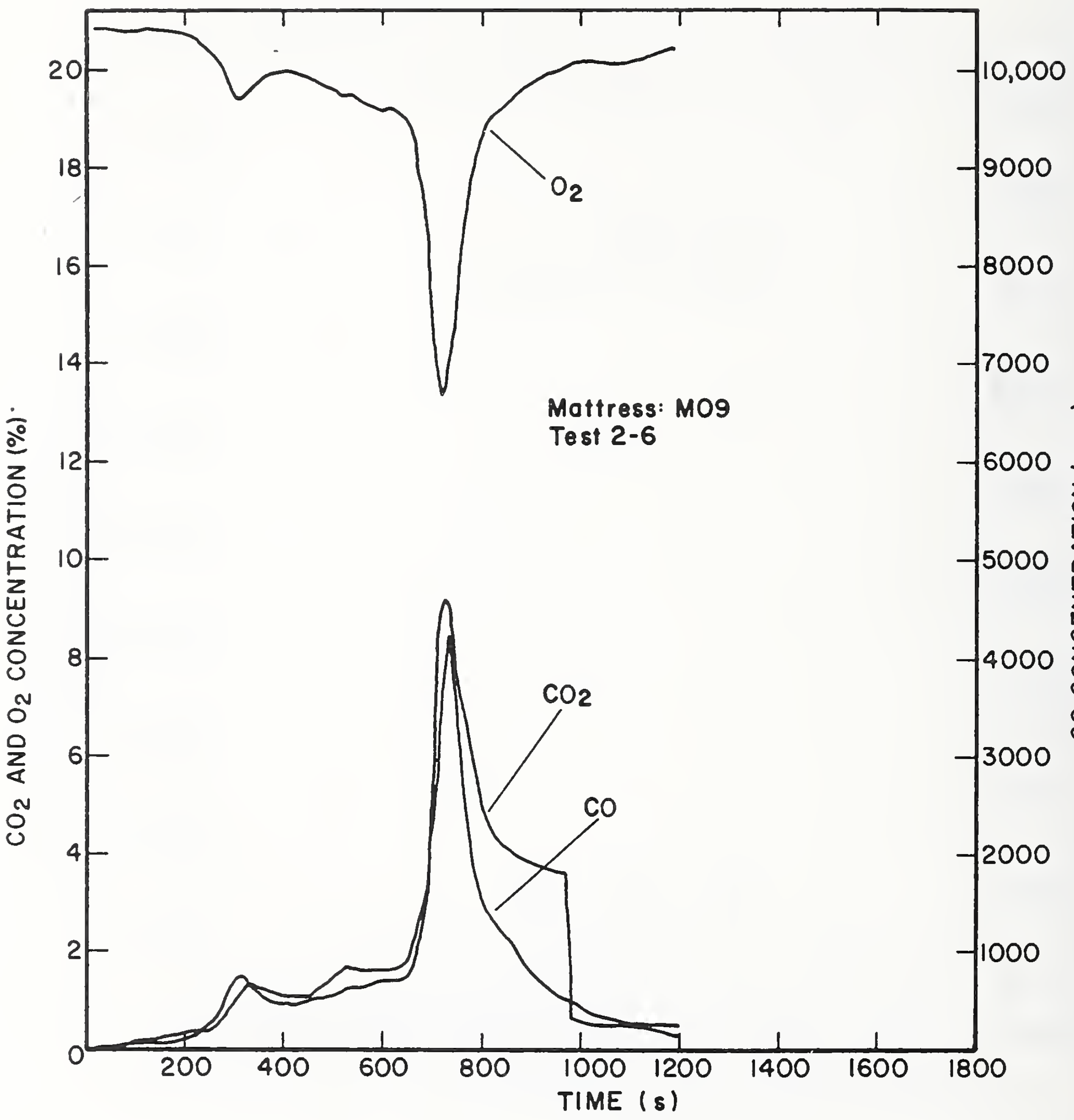


Figure 69. Gas Concentrations for Mattress M09

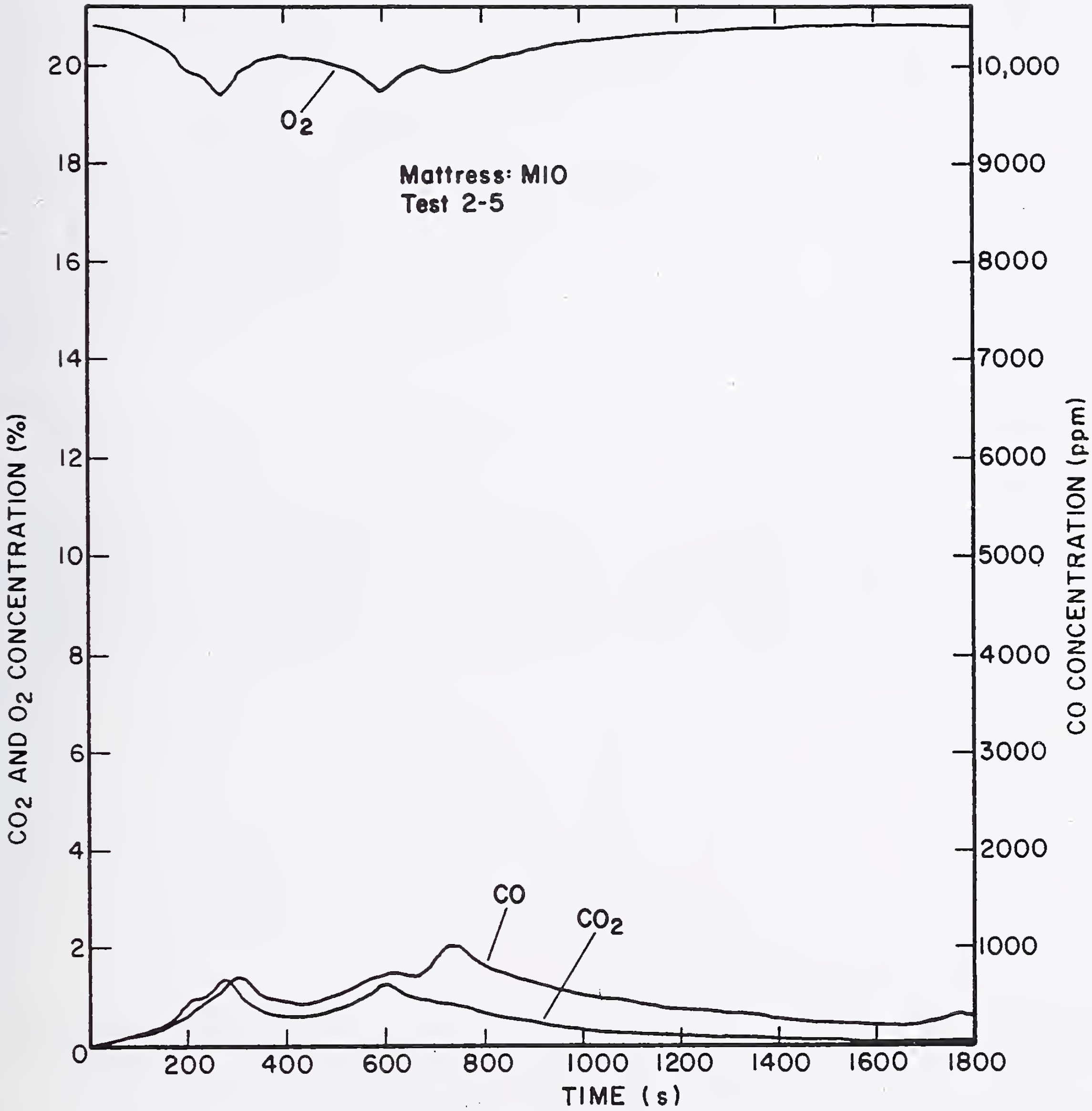


Figure 70. Gas Concentrations for Mattress M10

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

A test program was conducted to assess the hazards of institutional mattresses when subjected to a sustained flaming ignition source. This report gives results on full-scale room burns of ten different mattress types under several ventilation conditions. Tenability and rapid flame spread potential criteria were applied in a hazard assessment which showed a wide range of behavior among mattresses now being used in institutions. An extensive review of previous fire tests involving mattresses is included.

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)* Bedding; beds; compartment fires; firesafety engineering; fire tests; health care facilities; hospitals; mattresses; prisons.

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