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Full-Scale Fire Tests with Automatic Sprinklers in a Patient Room

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

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U.S. DEPARTMENT OF COMMERCE, Juanita M. Kreps, *Secretary*
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FULL-SCALE FIRE TESTS WITH AUTOMATIC SPRINKLERS IN A PATIENT ROOM

John G. O'Neill and Warren D. Hayes, Jr.

Abstract

The Center for Fire Research is conducting a research program to examine the use of automatic sprinklers in patient rooms of health care facilities. This is an interim report of eight full-scale fire tests in which the effectiveness of automatic sprinklers was measured in terms of fire control and overall life safety. These fire tests simulated the scenario in which mattresses with bedding constituted the burning items.

Analysis of test results indicate that prior to sprinkler operation, smoke obscuration reached critical levels in the burn room doorway and adjacent corridor such that rescue of patients in the burn room and the use of the corridor as an exit way would have been seriously impeded. Immediately following sprinkler operation, there was total obscuration from floor to ceiling throughout the corridor and lobby area.

For several tests, a privacy curtain was installed between the sprinkler head and the bed. The shielding action delayed extinguishment and the carbon monoxide concentrations increased significantly. In these cases it was estimated that the carboxyhemoglobin level for a patient in an adjacent bed would reach levels considered hazardous. In other tests where the privacy curtain was not installed and this shielding did not occur, the estimated hazardous threshold was not reached.

Key words: Health care facilities; hospitals; mattresses; smoke movement; sprinkler systems.

1. INTRODUCTION

The Center for Fire Research (CFR) and the Department of Health, Education and Welfare (HEW) are jointly conducting a five year life safety/fire safety research program. The program, which began in 1975, consists of projects in the following areas: decision analysis; fire and smoke detection systems; smoke movement and control; automatic extinguishment; and the behavior of institutionalized populations in fire situations.

This interim report presents the results of the first phase of full-scale fire tests conducted during the period from August to November 1977. These tests were designed to study automatic sprinkler performance in simulated patient rooms. A second series of tests began in January 1979.

Automatic sprinklers have proven to be very reliable in controlling fires in buildings. The National Fire Protection Association's (NFPA) fire record statistics indicate that automatic sprinklers have been approximately

95% successful in controlling or extinguishing fires in the United States [1][1]. In addition, a study based on the Australian Fire Protection Association fire records indicates that, excluding closed or inoperative valves, an even higher performance success rate of 99.8% was achieved for automatic sprinklers in controlling or extinguishing fires. This study is based on the most complete record available and includes every fire which occurred in New Zealand and Australia during the period from 1886 to 1968 in which sprinklers were present [2].

Sprinklers have been used to only a limited extent when the primary purpose is to prevent life loss or injury. Until recently the use of automatic sprinklers has been primarily directed at industrial, storage and mercantile occupancies where the fuel loads and the potential for large monetary losses are high. Insurance companies considered the reliability of sprinkler systems to prevent large monetary losses in the event of fire in these types of occupancy to be quite high, and offered substantial premium reductions if automatic sprinklers were installed. The savings in insurance premiums and reduction in the risks of a severe business interruption have motivated the investment in these systems throughout industrial and warehouse facilities.

More recently the use of automatic sprinklers has been considered for buildings primarily to provide life safety rather than property protection. This has evolved to a large extent as a result of the concern by building code and standards making groups that fires in certain types of facilities pose a significant risk to life safety. Therefore, requirements have been established for installation of sprinklers in these buildings.

One particular type of facility where this concern for life safety has warranted such requirements is the health care facility, i.e. hospitals and nursing homes. The Life Safety Code of the NFPA requires automatic extinguishing systems in all new and existing health care facilities except those in fire resistive buildings or in one-story buildings of noncombustible construction [3]. An added impetus to this expanded use of sprinkler systems was the introduction of a bill into the United States House of Representatives in late 1977 "To amend the Social Security Act to require automatic sprinklers in all nursing facilities certified for participation in the Medicare or Medicaid program, and to provide for direct low-interest Federal loans to assist such facilities in constructing or purchasing and installing the automatic sprinkler systems" [4]. Although this bill has not become law, there is continuing interest in mandating the installation of sprinklers in all skilled nursing facilities and intermediate care facilities participating in Medicare and Medicaid [5].

As previously mentioned, the use of automatic sprinklers has historically been applied to reduction of property losses in industrial, warehouse and merchantile buildings. Most of the research and development in automatic sprinklers, therefore, has been directed toward effective extinguishment of such fires with little work being done addressing the use of sprinklers for life safety, especially in health care facilities. In an effort to partially fill this gap, the CFR is conducting a research project to develop test information concerning the effectiveness of automatic sprinklers on overall life safety in health care facilities. Engineering design information for automatic sprinklers in these facilities will also be developed from this project.

2. SCOPE OF WORK

The first series of full-scale tests was based on fire scenarios involving flaming ignitions of bedding, and mattresses, which represent typical contents in a patient room. The sprinkler systems used in this test

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

series were designed primarily in accordance with currently established standards [6] and use sprinkler heads which meet the current UL Standard 199 [10]. Although water flows were reduced in some tests below that required in the current standard, the scope of this project does not include the use of spray nozzles which do not meet the UL standard.

To assess the effects of adverse conditions on a patient in the bed which served as the burning item, a complex arrangement of instrumentation would have been necessary. In addition, the analysis of data from this instrumentation would, at best, provide limited information. Therefore, the scenario for this test series is based on the assumption that the patient in the bed which serves as the burning item either removed himself from the bed or was rescued. Analysis of the test results for life safety will be considered in terms of a patient in an adjoining bed as well as for patients and staff exiting in the corridor adjacent to the room.

It is assumed that the door between the burn room and the corridor would remain open during the fire, i.e., the door has not been closed by actions of the staff nor by means of an automatic closing device. It is further assumed in the analysis of the data that the patient in the adjoining bed has not escaped nor been removed during the time of the fire test (approximately 30 minutes from ignition).

3. OBJECTIVE

The primary objective of this project is to provide engineering design information on the use of automatic sprinklers to minimize life loss and injury in the event of fire in health care facilities. The effectiveness of sprinklers is being measured in terms of:

- Overall fire control
- Time available for evacuation of patients in the fire area
- Maintaining tolerable environmental conditions for patients who cannot be evacuated

To this end, current design criteria for sprinklers contained in NFPA 13 [6] and fire safety requirements in the NFPA Life Safety Code 101 are specifically examined to determine if these criteria can be improved, based on both life safety and cost efficiency of system designs.

4. REVIEW OF PREVIOUS WORK

Two previous studies of some significance were identified regarding the use of automatic sprinklers in health care facilities. First, fire tests were conducted by Southwest Research Institute (SwRI) for the Des Moines (Iowa) Hospital Council in 1971 [7]. The SwRI report gave the results of two tests in which sprinklers were installed in a patient room. The burning items in the tests included foam rubber mattresses and bedding materials reportedly of the type used in health care facilities. The test procedure and analysis of results addressed relative response time of detection devices and sprinklers and some measure of the potential burn injuries to patients in the bed used as the burning item. Various smoke detectors and an infrared flame detector, as well as 71°C (160°F) automatic sprinklers, were placed at the ceiling in the patient room. A mannequin was placed in the bed used as the fuel source. The report concluded that response by staff to a smoke detector alarm (under ideal conditions) would be faster than the response time and extinguishing action of the sprinkler. It was also concluded from an examination of the mannequin after one test that a patient in the bed may have suffered 2nd and 3rd degree burns to 35% of the body before the sprinkler activated. No information was provided concerning the impact of heat flux or carbon monoxide on other patients in the burn room or adjacent areas.

More recent fire tests were conducted by the Illinois Institute of Technology Research Institute (IITRI) with automatic sprinklers in simulated patient rooms [8]. The report prepared by the American Health Care Association included the results of four full-scale tests using ceiling mounted and sidewall sprinklers in the patient room, and ceiling sprinklers only in the corridor. The test procedures included a flaming ignition of combustible materials in a wooden wardrobe in the patient room. Sprinkler flow rates ranged from 83.3 ℓ/min (22 gal/min) to 174 ℓ/min (46 gal/min) in one of the tests when two sprinklers activated. The system in the test facility was hydraulically designed for an average density[2] of 4.07 ℓ/min/m^2 (0.10 gal/min/ft^2). The actual flow density in the patient room during the fire tests ranged from 5.7 to 10.6 ℓ/min/m^2 (0.14 to 0.26 gal/min/ft^2).

The wardrobe with contents was selected as the burning item since it was judged that it would result in a relatively high rate of fire growth as compared to fires involving other items in a patient room. The reported results indicated that sprinklers in the patient room prevented the fires from extending beyond the wardrobe to the Class C[3] interior wall and ceiling finishes. In the test where sprinklers were placed only in the corridor, flashover was not observed, but the upper part of the wall surfaces around the bed was charred and the ceiling surfaces were scorched. Maximum ceiling temperatures reached 760°C (1400°F) in the room.

Carbon monoxide was measured 1.5 m (5 ft) above the floor in several locations, including the patient room and the adjacent corridor. Carboxyhemoglobin (COHb) percentages were calculated from these CO measurements and were based on a slightly accelerated breathing rate to reflect simultaneous exposure to higher CO_2 and depleted O_2 in the fire area. Maximum COHb levels were estimated to be in the range of 17.3 to 28.8% in the tests where sprinklers were placed in the room. These levels occurred after 16 to 18 minutes from ignition. However, COHb percentages in the test where sprinklers were placed only in the corridor exceeded 60% in the patient room at 15 minutes from time of ignition. A COHb level of 30% was considered in the report as a debilitation level for occupants or rescuers without breathing apparatus. The peak levels of COHb in excess of 60%, which were reached in the corridor only sprinkler test, were considered to result in at least unconsciousness and in probable death after continued exposure. Although the 30% COHb was established as a level which would prevent an individual from effectively escaping, the 26 to 28% levels calculated from measurements made in the tests with sprinklers in the room were not considered to be significant. The report also concluded that the combustible interior finishes (Class C) did not play any role in the fire development when sprinklers were installed in the room (either pendant ceiling mounted or sidewall sprinklers). It was noted, however, that the fire continued to burn inside the wardrobes as the sprinklers operated due to the shielding action of the partially closed wardrobe doors.

In addition to these two studies, an extensive fire research program was conducted by the CFR to determine relative hazards of various mattresses used in institutional occupancies [9]. The program was prompted by investigations of actual hospital and prison fires where multiple losses of life occurred. The severity of these fires was attributed mainly to mattresses which became involved in the early stages of the fires.

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[2]Sprinkler density is defined as average water flow per unit area protected by sprinkler(s).

[3]Class C interior finish has a flame spread rate ranging from 76-200 based on the American Society for Testing and Materials ASTM E 84 Tunnel Test.

The mattresses tested were evaluated in terms of time to reach critical thresholds for human tenability and fire growth. Specific elements of environmental conditions examined in this study included toxic gases (CO and CO_2), O_2 depletion, high temperatures and heat fluxes, and smoke obscuration. The fire growth hazard was measured in terms of elapsed time to flashover in the room of origin and critical levels of heat flux corresponding to the point in fire development when fire could spread to other areas. The results of the test program indicated that a latex foam rubber mattress and a solid polyurethane foam mattress (both designed for use in health care facilities) generated critical levels in all categories of hazards considered. Both mattresses resulted in flashover of the room with no other furnishings present. Levels of CO, CO_2, radiant heat flux and smoke obscuration in excess of the thresholds established for human safety were reached. A polyurethane innerspring mattress specified for use in health care facilities, while not resulting in flashover, did reach the other critical levels sooner than the latex foam rubber and solid polyurethane mattresses. Tests with two cotton padded innerspring mattresses did not result in the attainment of the threshold levels for fire spread potential or for human safety.

Although the test program did not include automatic sprinkler tests, it was conducted in a similar facility to the tests conducted in this study. The results are important to this project because:

a. Many of the same testing procedures are being followed in the sprinklered patient room tests that were used in this previous study (e.g. room size, exposure fire, measurements).

b. The same rationale for analysis of the hazards to humans resulting from the development of a fire is used in this study.

c. Analysis of full-scale fire tests in patient rooms can be made based on exposure fires both with and without automatic sprinklers.

5. EXPERIMENTAL DETAILS

5.1. Test Area

The fire test area consisted of a simulated patient room, corridor, and lobby located in a former barracks building. Figures 1 thru 5 in the back of the report provide detailed dimensions, as well as the instrumentation and sprinkler system plans.

The room where test fires were initiated, the "burn room," was lined with 13 mm (1/2 in) cement asbestos board screwed to steel studs and channels over 13 mm (1/2 in) vinyl covered gypsum board. For the series of tests included in this interim report, the walls surrounding the bed were covered with prefinished lauan plywood paneling, 4 mm (5/32 in) thick, fastened to nominally sized 1 x 2 in furring strips. The paneling had a nominal flame-spread index of 200 (ASTM E 84). The flooring throughout the test area was asphalt tile. The room opened into a 2.4 m (8 ft) wide corridor with walls and ceiling lined with 13 mm (1/2 in) cement asbestos board over 13 mm (1/2 in) vinyl covered gypsum board as in the burn room.

All of the tests except one were conducted in a closed "nonventilated" condition. That is, all outside doors and entrance doors into the area were closed prior to ignition and no mechanical ventilation was provided. No allowance was made for window opening or breakage. Incidental air movement occurred due to leakage around doors. This nonventilated mode simulates a common situation in health care facilities where, upon detection of a fire, the air handling systems are automatically shut down.

In one test an exhaust system was in operation in the burn room. A moderate flow rate of 1.2 m^3/min (42 ft^3/min) was established providing two air changes per hour in the burn room. This is the minimum rate required by JCAH criteria [11]. Make up air came from exterior air infiltration into the lobby and corridor.

5.2. Automatic Sprinkler System

The layout of the automatic sprinkler system is shown in figure 5. The steel piping extended above the fire resistive ceiling and was supplied through a fire hose connection on the building exterior. The water supply was provided through 15 m (50 ft) of fire hose connected to a 1892 ℓ/min (500 gal/min) pump which was interconnected with a pressure tank to maintain a residual pressure between 414 and 621 kPa (60 and 90 psi). A gate valve and flow meter at the fire hose connection permitted regulation of flow to the sprinkler system. Prior to each test the flow rate was calibrated through the open orifice of the same type of sprinkler head to be used in the fire tests.

For the tests reported here the outlets in the corridor piping system were plugged. An initial flow for the patient room was established at 102 ℓ/min (27 gal/min) to provide the equivalent specified minimum flow resulting from one sprinkler head operating if the system is hydraulically designed in accordance with NFPA Standard No. 13. The standard requires a minimum average density of 4.1 ℓ/min/m^2 (0.10 gal/min/ft^2) for this type of occupancy. The standard, however, states that for this type of room arrangement the system must be designed to provide this density with the sprinkler in the burn room plus two operating outside the room. Since the required average density is 4.1 ℓ/min/m^2 (0.10 gal/min/ft^2) for all three sprinklers operating, the actual density in the burn room with the single sprinkler operating will be more than the 4.1 ℓ/min/m^2 (0.10 gal/min/ft^2). For the system calculated for the test area, the actual flow in the burn room with only that sprinkler operating was 102 ℓ/min (27 gal/min), resulting in an average 6.9 ℓ/min/m^2 (0.17 gal/min/ft^2) density in the burn room.

This initial part of the test series was set up to reflect the current "state of the art". Therefore, a standard pendant sprinkler of a single manufacturer with a 13 mm (1/2 in) orifice and a 74°C (165°F) temperature rated link and lever fusible element was used in the fire tests. In one test, however, as will be described later, a lower flow rate was desired, and a 10 mm (3/8 in) orifice pendant sprinkler with a 71°C (160°F) link and lever fusible element was chosen.

The range of temperatures for fusible elements allowed in a health care facility (low hazard occupancy) is 135° to 165°F [10]. The intent was to use a typical fusible element, operating in the higher part of the allowable range of temperatures, and not specifically designed for rapid response.

In addition to the "wet" sprinkler head, three other "tell-tale" sprinkler heads were also placed at the center of the burn room ceiling. The purpose was to obtain data on response times of other types of sprinkler heads in the full-scale fire tests. The tell-tale sprinkler heads were pressurized by nitrogen which was pumped through copper tubing placed above the fire resistive ceiling. A pressure switch was connected into the tubing to each sprinkler head and, when the sprinkler operated, the pressure switch activated a relay which stopped a clock. Thus, response times were automatically recorded from time of ignition. Tell-tale sprinkler heads included the following fusible elements:

Rapid-response 135°F (57°C)
Fusible bulb 165°F (74°C)
Link lever 165°F (74°C) duplicate of wet sprinkler head

The response times of these sprinklers will be included in another report.

5.3. Instrumentation

The instrumentation used in the test series is shown in figures 1 thru 4 and is listed in table 1. Various heat and smoke detectors were placed in the burn room and in the corridor. A record of their operation is not reported here. All tests were recorded on video tape with separate coverage of the burn room and down the length of the corridor. All instrumentation channels were recorded at 10-second intervals on a magnetic tape data acquisition system.

Thermocouples measured gas and surface temperatures throughout the test area and locations are shown in figures 1 thru 4. Thermocouples were chromel-alumel type, 0.25 mm (30 gauge).

Calibrated, water cooled heat flux meters measured total heat flux at the adjacent patient level and across the corridor from the burn room.

The patient bed and the trash container which served as the initiating fire source were placed on a steel plate (see figure 6). The plate was suspended from a load cell mounted above the ceiling to monitor weight loss rate during each test.

The velocity of air and gases entering and leaving the burn room and moving along the corridor were measured with directional low velocity probes placed in the doorway and corridor. This type of probe was developed by Heskestad [12], and the description and construction details of these devices are provided in the reference. The differential pressure was measured with a calibrated diaphragm-type pressure transducer. Calibration techniques are provided by McCaffrey and Heskestad [13]. The equation for velocity is:

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

ΔP = measured differential pressure
ρ = gas density (calculated from temperature of thermocouple next to probe)
μ = gas velocity
$C(Re)$ = constant dependent on Reynolds number
$C = 1.08$ according to McCaffrey and Heskestad.

Continuous gas measurements included CO, CO_2 and O_2. Sampling tubes were located at the adjacent patient level, and in the doorway at .05 mm (2 in) and 1.5 m (5 ft) above the floor. In addition, CO was measured in the lobby at the 1.5 m (5 ft) level. CO and CO_2 in the burn room and doorway were measured with non-dispersive, infrared analyzers. Gases were pumped through cold traps to remove condensable vapors before the analysis. Electrolytic oxygen cells were used to measure O_2 concentrations.

Smoke meters developed by Bukowski [14] were used to measure light obscuration in the doorway to the burn room and in the corridor and lobby. Locations are shown in figures 2 thru 4. This type of smoke meter is essentially an extinction beam consisting of a collimated light source and a detector separated by a one-meter long path through the smoke. The obscuration is measured by the magnitude of attenuation of the light seen by the detector.

5.4. Test Program

The program for the initial automatic sprinkler tests reported here addressed these specific areas:

a. Determine the response and effectiveness of automatic sprinklers on fires involving beds in patient rooms for health care facilities. Two specific types of mattresses with bedding were examined, representing a wide range of performance in the earlier mattress flammability study [9].

b. Determine the effect of combustible interior walls on the fire development in the sprinklered room.

c. Determine the effect of a privacy curtain placed between the sprinkler and the bed on the response and extinguishing performance of the sprinkler.

The approach used in the project was to select one mattress which did not exceed any of the critical fire spread or human safety thresholds in previous studies and one which exeeded all of the limiting thresholds. The rationale in using a low hazard mattress was to determine if the action of the sprinkler might result in reaching or exceeding any of the limiting thresholds for human safety; in particular, smoke obscuration. The test schedule is listed in table 2.

5.5. Test Procedure

The test procedure followed closely that of the previous mattress flammability test program. Since the procedure was designed to provide an analysis of data from tests with and without sprinklers, it was essential to repeat the same sequence of initial flame transfer from the trash container to the bedding and mattress. A small polyethylene container containing 443 g (0.97 lb) of combustibles for each test was placed next to the bed adjacent to the wall. Table 3 lists the contents of the container. The container was placed in contact with the bedspread, with the top of the container 0.2 m (8 in) from the top of the bed. Each test began at the time the contents were ignited with a paper match[4].

Prior to test N-22 thru N-34 the burn room was conditioned to a relative humidity (RH) of 40 to 60%, and an ambient temperature range of 18 to 27°C (65 to 80°F). The moisture content of the paneling was within the range of 5 to 8%. For tests N-20 and N-21 no particular attempt was made to condition the burn room prior to tests, and ambient conditions for these two tests were approximately 27°C (80°F) and 80% RH. All of the bedding and waste container items were kept in a 50% RH conditioning room at a temperature of 21°C (70°F) for at least 24 hours prior to each test to maintain a consistent moisture content of these items from test to test.

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[4] Reference 9 reported good repeatability using this ignition sequence.

5.6. Automatic Sprinklers

Prior to each test the desired water flow was established by flowing water through the orifice of an open sprinkler (deflector removed) of the same manufacturer and model as that planned for the fire test. A gate valve was operated in coordination with a flow meter until the desired flow was obtained. At that point a quarter turn valve in series with the gate valve was closed to shut off the system. While the calibration flows were made the water pump for the site was kept continuously in operation. After the valve was closed, the automatic sprinkler for the next test was installed, and the quarter turn valve was then opened. During the fire tests the water pump was kept in operation to maintain the same residual pressure on the automatic sprinkler system. During the sprinkler operations in the fire tests the flow meter was monitored to insure that the desired flow was maintained during the test.

5.7. Privacy Curtains

Two types of privacy curtains were examined in the full-scale fire tests; one was a solid cotton, fire-retardant treated curtain and the second was a cotton, fire-retardant treated curtain with a nylon mesh top. Details of curtain construction and sizes are provided in table 4. Figures 1 and 8 indicate the position of the curtain around the bed. Each curtain was suspended by nylon glides which slid in a steel track fastened to the ceiling. A drawing including key dimensions of the curtain suspension is provided in figure 7. Following the tests of the two types of curtains which were suspended with nylon glides, another test was conducted with a solid curtain suspended from steel glides. The reason for this variation will be discussed in the results.

5.8. Test Mattresses and Bedding

As previously mentioned two mattresses identical to ones examined in the previous mattress fire test program served as the mattress fuel items.

The mattress chosen from those which were found to result in the least severe fire in terms of fire growth and the attainment of limiting conditions (i.e. the established criteria were not exceeded), was an innerspring hospital mattress constructed with fire retardant treated cotton felt padding, a nonretardant polypropylene interfacing fabric and a retardant treated polyvinylchloride ticking (outermost layer)[5]. This mattress was chosen since it was specified for hospitals.

In the previous study, two mattresses exceeded critical levels of fire growth and the established thresholds for limiting conditions for life safety. One was constructed of latex foam rubber and the other of polyurethane foam used without innerspring. Since the latex foam rubber mattress is no longer manufactured in this country, it was decided to use the polyurethane slab mattress[6]. As with the more moderate burning innerspring mattress described above, it was designed for hospital use.

Following the initial test (test N-21) which will be described later, it was discovered that the polyurethane mattress had only one-half the density of the M-01 mattress tested in the previous series. Although the

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[5]This mattress is coded as M-03 to correspond to the previous work.

[6]This mattress is coded as M-01 to also correspond to the previous work.

newer mattress had been ordered from the same manufacturer, and under the same model number, it was apparent that the foam construction was substantially different from the previous mattress. An inquiry to the manufacturer did not result in anything conclusive about a change in product, except that they apparently no longer manufactured a mattress identical to the M-01 of the previous test series.

It was still considered essential to use mattresses identical to those in the previous program. The polyurethane innerspring mattress (M-02) was selected to represent the more severe exposure fire for the sprinkler tests. While flashover had not been exceeded in the previous tests, the limiting conditions for life safety were exceeded earlier when testing this mattress than with any other mattress tested. Details of these test mattresses are provided in table 5.

Each mattress was tested with bedding which was obtained from a commercial hospital supplier and intended for use in health care facilities. The bedding consisted of a cotton water repellant drawsheet, two cotton/polyester sheets, a cotton/polyester bedspread, a cotton/polyester pillowcase and a pillow which consisted of shredded polyurethane foam filling in a cotton cover. The properties of these items are provided in table 5.

6. HAZARD ANALYSIS

Consistent with specific objectives mentioned in section 3, the test results were measured in terms of the following:

- Fire spread
- Heat flux
- Toxic gases
- Smoke obscuration

6.1. Fire Spread

The automatic sprinkler system in this first series was evaluated to determine its performance in controlling and extinguishing fires involving institutional type mattresses and bedding. The impact of the privacy curtain between the bed and the sprinkler was specifically examined. It was difficult to determine accurately the extinguishing performance of the sprinkler systems. Since the water spray and water absorption of the mattresses following sprinkler operation complicated the weight loss measurements from the load cell instrumentation, visual examinations of the burned mattress were made after each test to determine the approximate consumption.

In addition, the wall finishes near the bed were examined to determine the extent to which they had become involved in the fire. Average ceiling temperature data were examined to determine the relative capabilities of the sprinkler systems to reduce ceiling gas temperatures, based on the sprinkler flow rate and the type of privacy curtain.

6.2. Heat Flux

Any consideration of limiting conditions adverse to human safety in a health care facility must include the potential hazard of burn injuries. In the fire scenario selected for these tests, the patient in an adjacent bed would be in the most immediate danger. A critical level of heat flux for human exposure is a function of time since a sustained exposure to a lower flux can result in a burn injury equivalent to that of a short exposure at higher flux. The operating automatic sprinkler could be expected to reduce rapidly the heat flux imposed at the adjacent level. A value of 2.5 kW/m^2 radiant flux was selected as the upper limit prior to one feeling pain. This value is based on information provided by Dinman [15] and Parker and West [16].

6.3. Smoke Levels

Limiting levels of smoke obscuration for human safety were determined for two separate hazards in this fire test scenario. The first concerned rescue of a patient in the adjacent bed in the room of fire origin. The second involved the use of the corridor and lobby adjacent to the room of origin as an exit way. Two critical levels of obscuration were considered, one measured at the doorway to the patient room and the other in the corridor and lobby. Critical levels selected for each location were based on investigations by Jin [17,18].

The critical level of smoke obscuration was selected as an optical density per meter (OD/m) = 0.5 m^{-1} in the doorway to the patient room. This level was measured horizontally at 0.3 m (1 ft) from the top of the doorway. The critical level for the corridor and lobby was selected as OD/m = 0.25 m^{-1} as measured horizontally, 1.5 m (5 ft) from the floor.

6.4. Gas Concentration

Concentrations of CO and CO_2 were measured as well as O_2 depletion. It should not be inferred that CO and CO_2 are the only toxic gases that are significant in terms of having adverse effects on humans in fires. These were the only two measured, however, because of experimental uncertainties in measuring and evaluating the toxic effects of other gases. It is known, in any case, that CO and CO_2 are always generated in building fires.

Critical limits or thresholds were selected for CO, CO_2 and O_2 depletion based on previous studies which examined the adverse effects on humans. Specific limitations for this study were based on quantities which resulted in incipient incapacitation of healthy persons. Incipient incapacitation for this analysis can be considered the point at which environmental conditions could have an adverse effect on a person to function reliably. The critical levels or thresholds should not be interpreted as precise boundaries but rather as an approximation, based on the literature and unique characteristics of the occupancy type being assessed, of the levels which would result in adverse effects. In health care facilities occupants in varying states of health may be more severely affected at the critical levels established here than in occupancies where most persons are not physically impaired. It would be impossible to determine every critical level which may adversely affect patients with varying physiological problems. Therefore, by practical necessity, the criteria established here are based on the incipient incapacitation of healthy persons, and can serve as upper boundaries for health care occupancies.

A critical level of 8% CO_2 was established for this program based on tabulations by Kimmerle [19]. A minimum oxygen concentration of 14% was selected based on Pryor and Yuill's study [20]. However, determining critical levels of CO is a much more complex issue. What makes CO toxic is that it reduces the oxygen carrying capacity of the blood. CO forms COHb in the blood and, therefore, the percent COHb is the more precise measure of CO toxicity. The CFR has tentatively established a methodology for determining a critical level of COHb from CO concentrations based on previous studies by others. Stewart derived an equation of COHb from experiments with human volunteers [21]. The volunteers were subjected to very high concentrations and their COHb levels were then measured. CO uptake is directly proportional to the breathing rate which is approximately 6.5 ℓ/min for an individual at rest. The breathing rate increases with activity and also from exposure to CO_2. A 4% concentration of CO_2 will more than double the breathing rate [22]. Since both of these factors must be considered in a fire situation, a breathing rate was established as 18 ℓ/min. The equation for determining COHb% 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 0.75% was established from information provided by Alarie and Zullo [23]. A 25% COHb was established in this study as the level of COHb at which incipient incapacitation may occur [19].

In addition to the threshold for time-rated accumulation, another limit must be selected for CO exposure. Instantaneous doses of high levels of CO must also be considered due to the physiological effects such as cardiac arrythmia [24] which can occur independently of the effects of increased COHb. Claudy [25] reported on the effects of exposure to high concentrations of CO. The results of his work indicate that incipient incapacitation may occur with only a few short breaths at an exposure level of 10,000 ppm CO. And, at a slightly higher concentration of 12,800 ppm Claudy reported that unconsciousness could occur in 2 to 3 breaths, followed by death in 1-3 minutes. Based on this an instantaneous threshold of 10,000 ppm (1.0% by Vol) CO was selected as a criterion in addition to the time integrated exposure resulting in COHb level of 25%.

7. TEST RESULTS AND DISCUSSION

Eight full-scale fire tests were conducted in this initial phase of the project (see table 2). Using the small waste container described earlier in the tests was particularly useful since it resulted in a realistic energy source strong enough to consistently ignite the mattress but not strong enough to operate the sprinklers before the mattress became the dominant burning item. The ignition transfer sequence was very consistent with the exception of test N-21. In this test, at 420 seconds, the contents of the waste container had to be reignited. Generally, in the other tests, the fire extended to the bedding in 15 to 30 seconds. The fire involvement of the mattresses was observed to be very consistent throughout the tests. After the bedding on the side next to the waste container became involved, the fire spread along the side of the bed facing the container, and within four minutes, the mattress became involved. The fire generally spread along the edge of and into the side of the mattress, to the corner of the pillow, and into the pillow fill prior to sprinkler operation. Figure 9 shows the consistent rate of temperature rise measured above the waste container plume for the tests involving the M-02 mattresses. This fire development sequence proved to be a useful repeatable fire with which to measure the desired parameters in the study.

Since the fire test involving the cotton innerspring mattress was unique with respect to the remaining tests, the results of that particular test are discussed separately. The results of the other tests are discussed together, based on the hazard analysis established for this project.

7.1. Cotton Innerspring Mattress

The fire (test N-20) involving the cotton innerspring mattress did not activate the sprinkler system. At 906 seconds the quick operating 57°C (135°F) tell-tale sprinkler did activate. After the contents of the waste container were consumed, the fire burned in a smoldering mode along the edge of the mattress facing the container. At 30 minutes the test was terminated; the mattress was taken outside and extinguished with a hose. Figure 10 shows the average ceiling gas temperatures. There was no damage to the plywood wall finish.

The limiting levels established for smoke obscuration as described in 6.3, were exceeded at the patient room doorway (860 sec) and in the corridor (370 sec). CO and CO_2 concentrations were minimal; maximum CO levels reached only .03% (300 ppm) and CO_2 levels reached .75% at the 1.5 m (5 ft) height in the doorway.

7.2. Fire Growth

The automatic sprinkler in the room operated in all of the tests involving the solid polyurethane and polyurethane innerspring mattresses. Sprinkler response times ranged from 345 to 388 seconds. In tests N-22 and N-23 it was observed that some of the nylon glides and nylon mesh failed from exposure to the heat of the fire before sprinkler operation. The failures resulted in approximately 1 to 1.5 m (3 to 5 ft) lengths of the curtains measured from the wall at the head of the bed to drop from the ceiling track. This reduced the shielding effect of the curtain and allowed the sprinkler spray to fall directly on the end toward the head of the bed. Following these two tests it was decided to fabricate steel glides to suspend a solid curtain, the same type used in N-22. The steel guides were used in test N-33 and the curtain stayed in placed throughout the test. As a result the curtain did shield most of the sprinkler spray and, significantly reduced the impact of the sprinkler in extinguishing the fire. As shown in figure 11, overall ceiling temperatures, although limited by the sprinkler, were higher following sprinkler operation than in tests N-22 and N-23, and in test N-25 (see figure 12), where no privacy curtain was installed. In test N-33 the mattress continued to burn and it was almost totally consumed by the end of the test. While the bed was shielded from the sprinkler spray, there was wetting of the wall at the head of the bed. The wall was scorched in several places, but there was no sign of sustained burning.

In test N-32, the introduction of the modest ventilation, 3.9 m^3/min (42 ft^3/min) exhaust from the room did not significantly influence the rate of the fire growth nor the response time and performance of the sprinkler.

The reduced flow rate using the 10 mm (3/8 in) nominally sized orifice sprinkler head flowing at 64 ℓ/min (17 gal/min) resulted in fire control and extinguishment equivalent to the flow rate of 102 ℓ/min (27 gal/min) from the 13 mm (1/2 in) orifice sprinkler. In reducing the flow rate, the use of the 10 mm (3/8 in) orifice sprinkler was selected to obtain a nozzle pressure (131 kPa (19 psi)) approximately the same as the 13 mm (1/2 in) orifice (159 kPa (23 psi)) sprinkler. See figure 12 for the average ceiling gas temperatures.

As previously detailed in section 5.2, design criterion for this type of sprinkler installation requires the system to provide an average density of 4.1 ℓ/min/m^2 (0.10 gal/min/ft^2) with the sprinkler head in the room plus two in the corridor operating. Corridor ceiling gas temperatures (5 in from the ceiling) recorded from these tests indicate that a sprinkler head with the same thermal response properties as the sprinkler in the room would not have operated. A maximum temperature of 78°C (178°F) was recorded at the corridor ceiling in test N-33. This was an instantaneous reading and generally the temperatures stayed well below 70°C (158°F).

7.3. Heat Flux

Total heat flux measured at the adjacent patient level was negligible in all tests. Maximum levels measured prior to sprinkler operation were around 2.05 kW/m^2 (.18 BTU/ft^2-sec).

7.4. Smoke Obscuration

In all the tests, the limiting level for smoke obscuration was exceeded at the doorway and in the corridor, and in some tests also in the lobby before the sprinklers operated. See table 6 for maximum obscuration prior to automatic sprinkler operations and times to reach limiting levels for the doorway (0.5 OD/m) and for the corridor and lobby (0.25 OD/m). Although the limiting level adverse to human safety had been exceeded 1.5 m (5 ft) above the floor in the corridor, observations and video recordings indicated that the visibility was clear up to 1.2 m (4 ft) from the floor prior to sprinkler operation. Within one minute after sprinkler operation, however, there was nearly total obscuration throughout the corridor and lobby. See figures 13 and 14 for results of test N-34 which was typical of all tests where sprinklers operated.

Gas velocity measurements in the doorway to the burn room indicated an almost complete reversal of gas flow after sprinkler operation when compared to pre-sprinkler conditions. Generally the result was that smoke and gaseous combustion products accumulating in the upper portions of the corridor outside the burn room were drawn back into the room, cooled, and pushed back out at the bottom into the corridor. See figure 15 for the net gas velocity profiles at the burn room doorway prior to and after sprinkler operation.

In test N-34, where an exhaust system was installed in the room, critical obscuration levels measured in the doorway and in the corridor occurred in less time than in other tests; however, the total obscuration measured prior to sprinkler actuation was approximately the same as the other tests.

7.5. Toxic Gases

After the sprinklers operated the carbon monoxide concentrations changed significantly. Just prior to sprinkler operation the highest concentrations were measured at the 1.5 m (5 ft) level in the doorway. Concentrations at the adjacent patient level and at the bottom of the doorway were negligible. Following sprinkler operation, the distribution of CO concentrations changed significantly. The concentrations recorded at 1.5 m (5 ft) in the doorway were reduced temporarily and the concentrations recorded near the floor and at the adjacent patient level increased rapidly. Figures 16 and 17 illustrate this shift in the CO distribution for tests N-25 and N-33. The same type of shifts in concentrations was noted for all tests where sprinklers operated. The concentrations in general did not reach what were considered hazardous thresholds except in the tests where the privacy curtain stayed in place. In test N-33 where the privacy curtain tended to shield the sprinkler spray as described earlier, carbon monoxide concentrations increased significantly as compared to test N-25 where there was no privacy curtain installed. (In test N-25 the sprinkler flow and the quiescent test conditions were equivalent to test N-33). Figures 18 through 20 illustrate the differences in CO concentrations at various locations. In test N-33 estimated carboxyhemoglobin levels exceeded a hazardous threshold (25%) at the adjacent patient level at approximately 20 minutes after ignition. In test N-23 where the mesh topped curtain was installed, the curtain partially shielded the sprinkler spray, estimated carboxyhemoglobin levels exceeded the 25% level at approximately 26 minutes after ignition. Although the CO concentrations recorded in the lobby (1.5 m or 5 ft) were higher for test N-33 as shown in figure 19, hazardous thresholds were not reached.

The instantaneous hazardous threshold for CO (10,000 ppm) was not reached in any of the tests (see table 7).

In the previous mattress fire test series, two tests were conducted in the same facility using the M-02 mattress as the burning item [9]. (These tests were conducted with a noncombustible interior finish in the burn room.) Maximum COHb levels for the two tests measured at the adjacent patient level were recorded as 14.2% at 1200 seconds and 5.2% at 1800 seconds respectively. In those tests the critical gas concentration failures were due to O_2 depletion. Times to reach 14% O_2 were 350 and 340 seconds.

The CO_2 and O_2 depletion in the sprinkler series never reached critical levels in any of the tests. See tables 8 and 9 for maximum CO_2 and minimum O_2 concentrations.

8. SUMMARY AND CONCLUSIONS

For the given room arrangement, fire scenario, and test conditions selected, and the limited tests conducted to date, the following summary and conclusions appear justified:

a. Critical levels for smoke obscuration were reached prior to sprinkler operation, potentially impeding the rescue of the patient in the adjacent bed and use of the corridor as an exit way. Following sprinkler operation, total obscuration (>.9 OD/m) occurred from floor to ceiling throughout the test area.

b. The presence of the privacy curtain interfered with extinguishing performance of the sprinkler.

c. The distribution of CO concentrations shifted after sprinkler actuation and concentrations were the highest at the floor level after sprinklers operated. Prior to sprinkler operation the highest concentrations were recorded at the highest measuring point, 1.5 m (5 ft) level in the doorway.

d. The CO concentrations in general did not reach what were considered hazardous thresholds except in tests where the privacy curtain stayed in place. The presence of the privacy curtain and the delayed extinguishment of the fire resulted in significantly higher concentrations of CO. Calculated COHb eventually exceeded a critical level of 25% at the adjacent patient level. A more optimum location of the sprinkler with respect to the curtain or the use of privacy curtains which do not extend to the ceiling may enhance the extinguishing action of the sprinkler and reduce the CO concentration.

e. Fire tests conducted thus far in this project indicate that flow rates lower than that required in established criteria achieved equivalent fire control.

f. The presence of the Class C wall finish did not play a role in the fire development or affect the fire control of the sprinkler.

g. Neither the presence of the privacy curtain nor the operation of the exhaust system in the room influenced sprinkler response time.

9. FUTURE EXPERIMENTS

In the next series of tests a more comprehensive approach will be used to quantify the smoke obscuration in the corridor occurring after sprinkler operation. Smoke meters will be arranged to record a profile of smoke obscuration at several levels from floor to ceiling in the corridor.

The next phase will also include:

a. A fire involving a patient room clothing wardrobe.

b. The use of a horizontal sidewall sprinkler in the patient room.

c. A simulated rapid response sprinkler keyed to the activation time of a fusible element heat detector.

d. A smoldering ignition of bedding.

e. A ventilated patient room using a fan coil unit, a make up air supply, and an exhaust system.

f. Measurements of sprinkler spray distribution will be made using collection pans in an attempt to quantify the shielding of the privacy curtain on the sprinkler spray.

10. ACKNOWLEDGEMENTS

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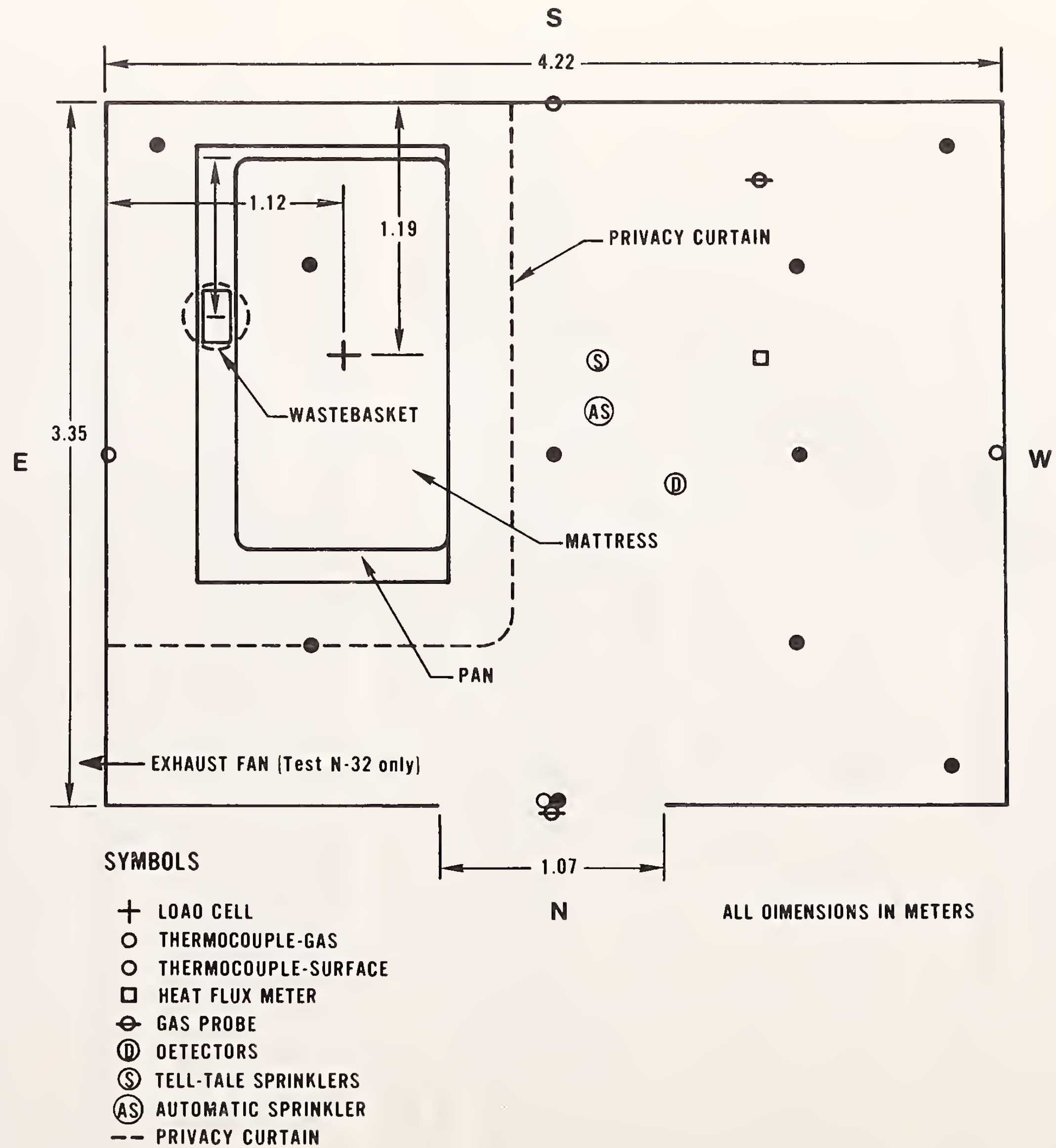


Figure 1. Burn room plan view

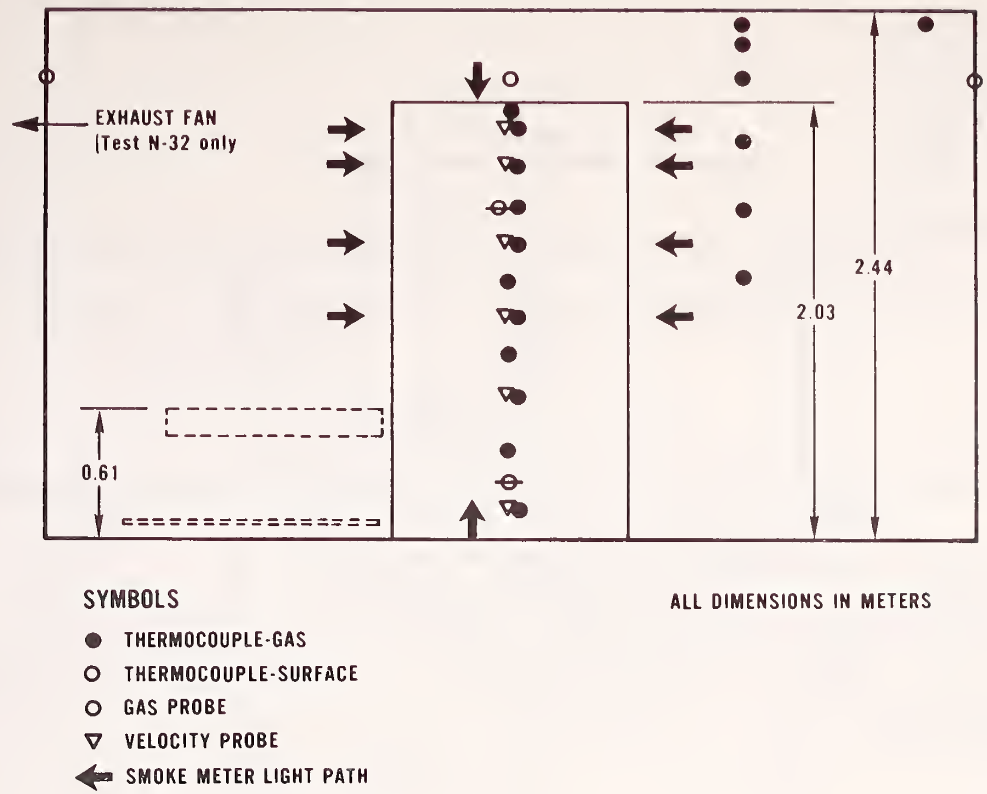


Figure 2. Burn room - doorway elevation

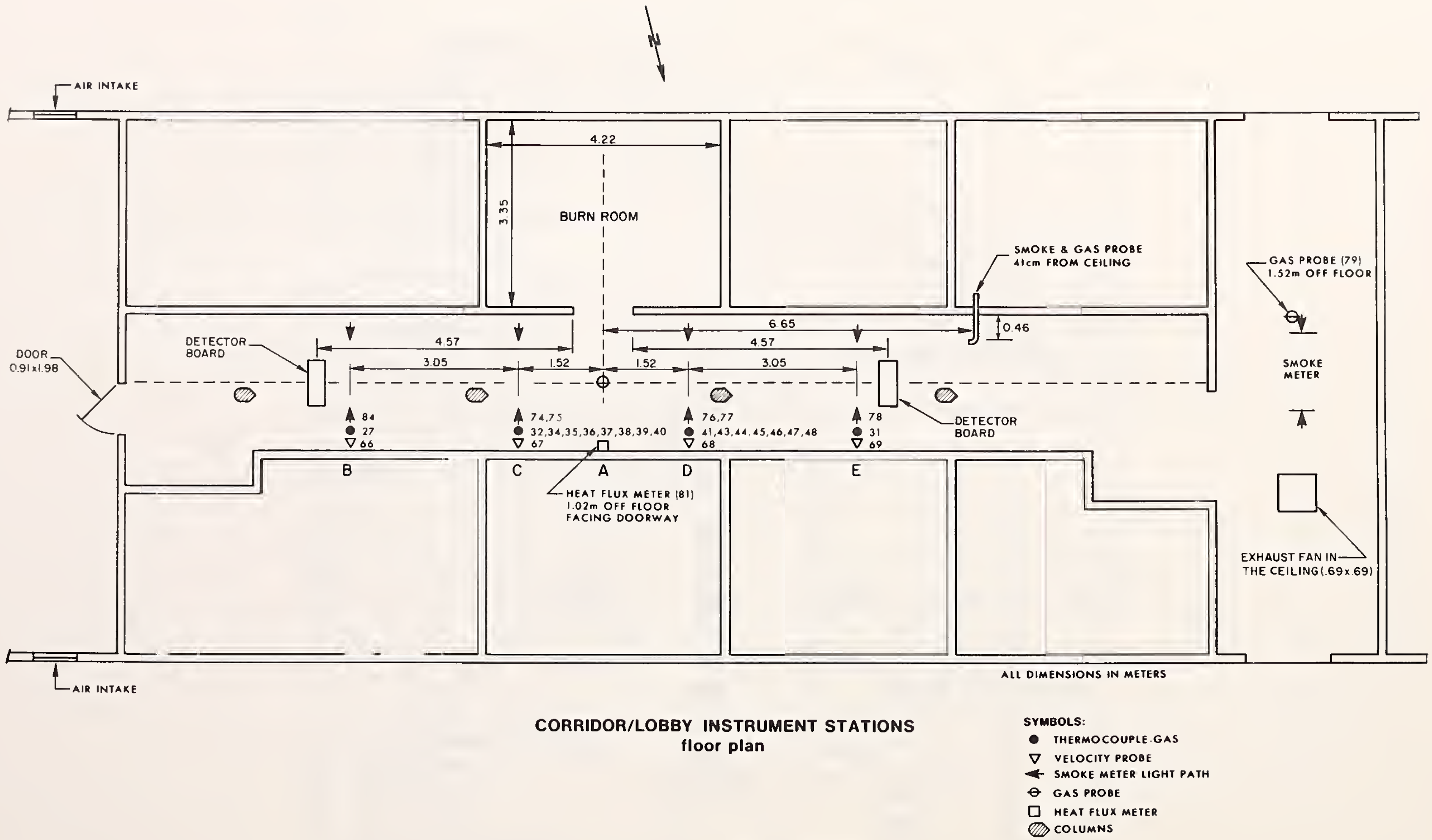


Figure 3. Corridor/lobby instrument stations floor plan

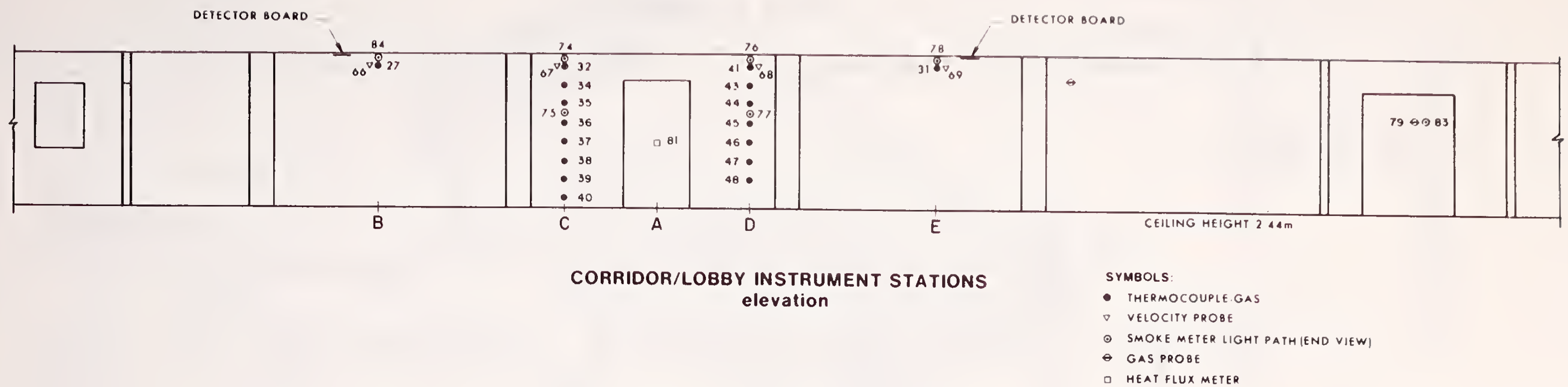


Figure 4. Corridor/lobby instrument stations elevation

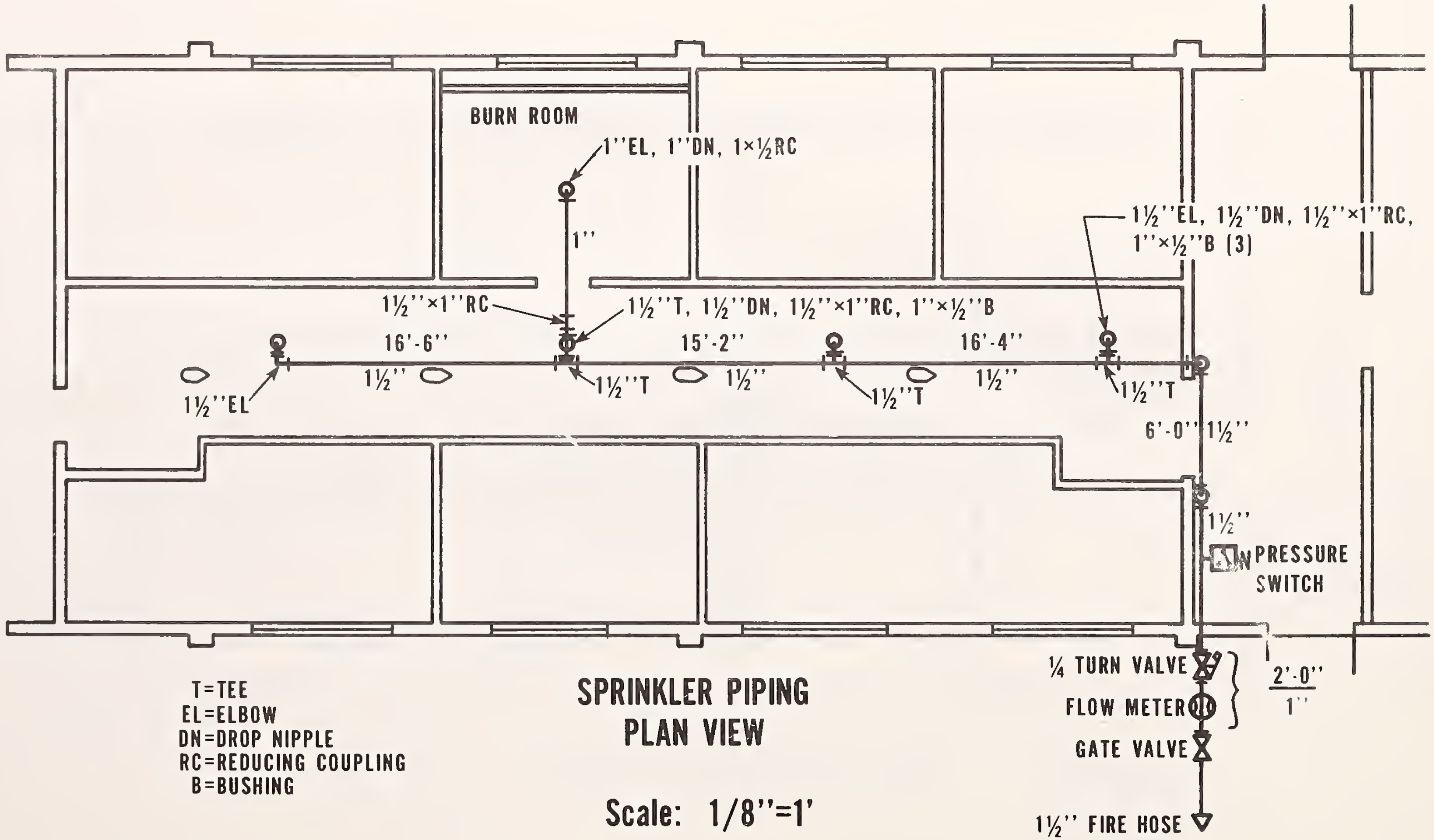


Figure 5. Sprinkler piping plan view

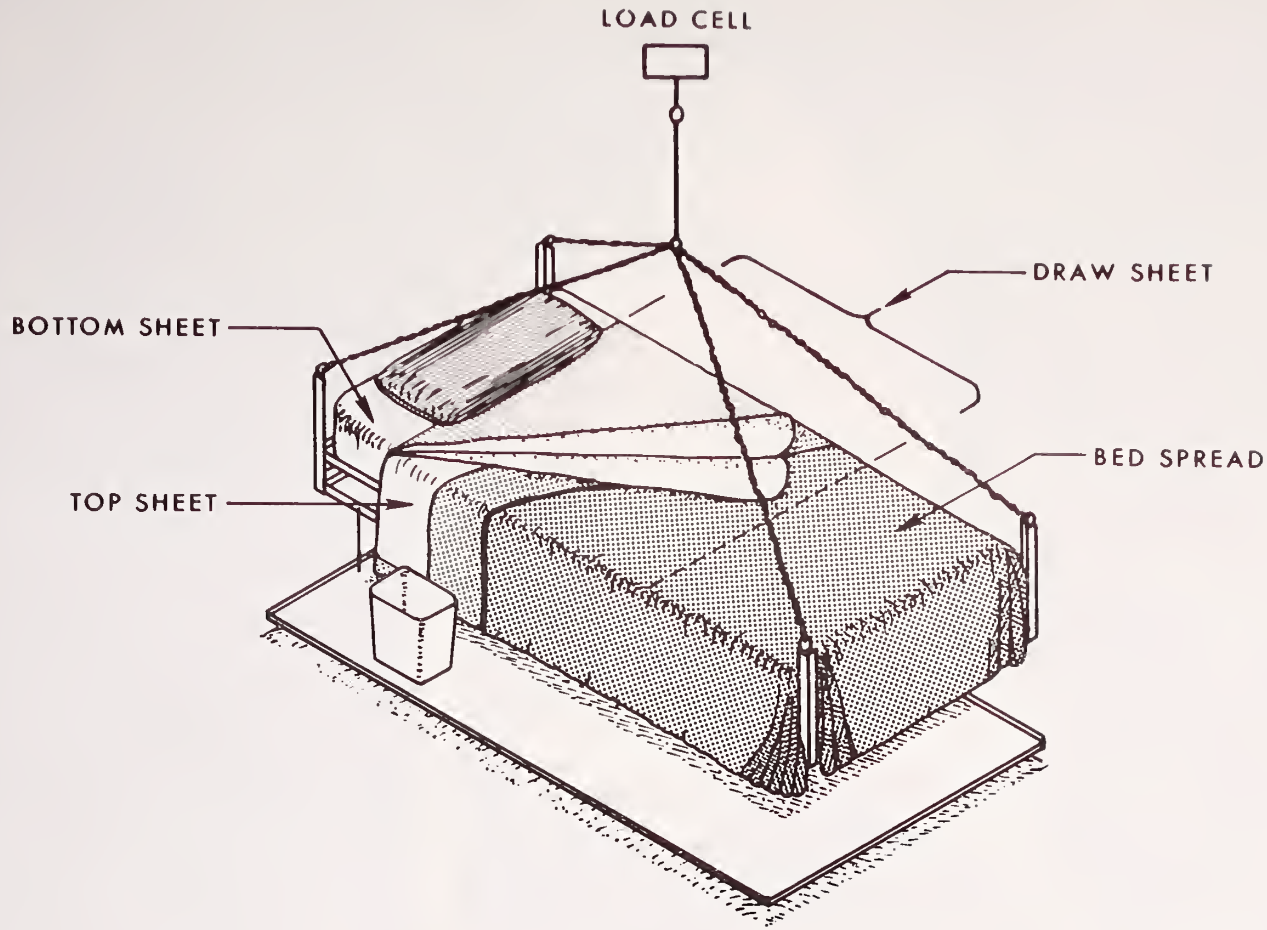


Figure 6. Load cell suspension for mattress and bedding

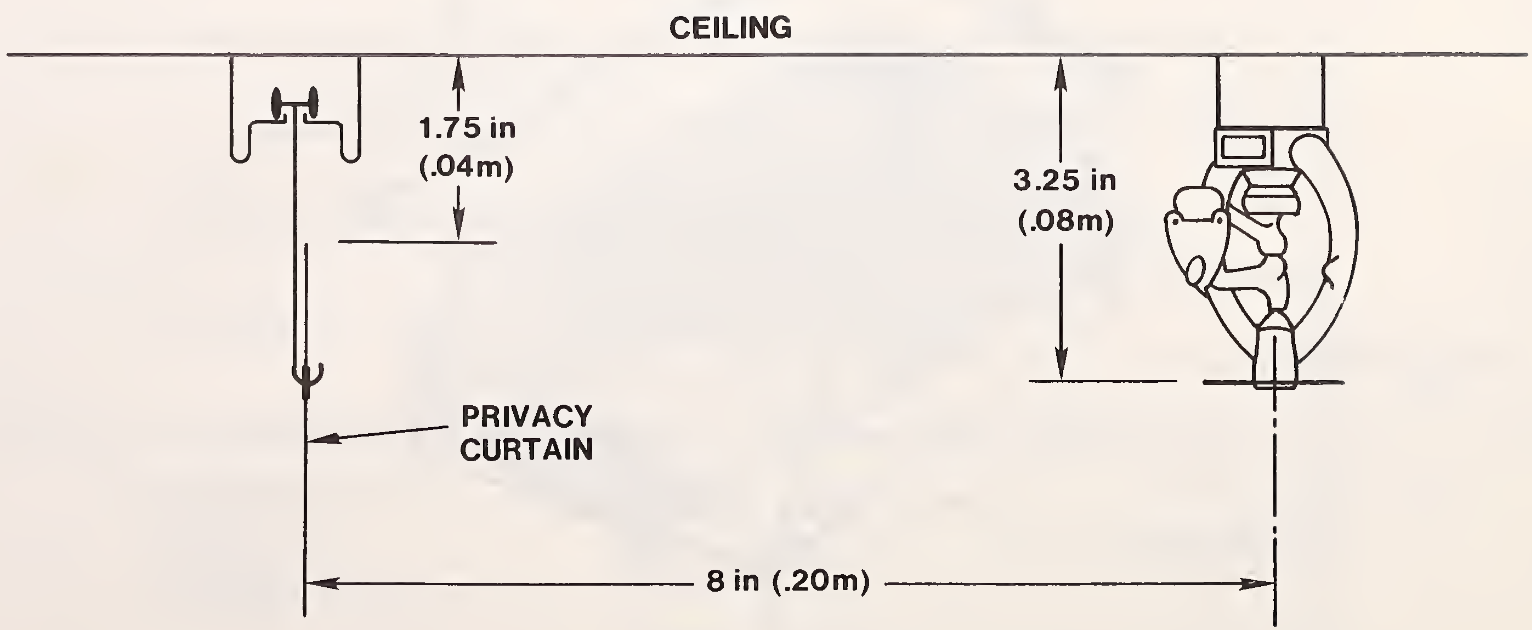


Figure 7. Privacy curtain details

Figure 8. Privacy curtain placed around bed before test

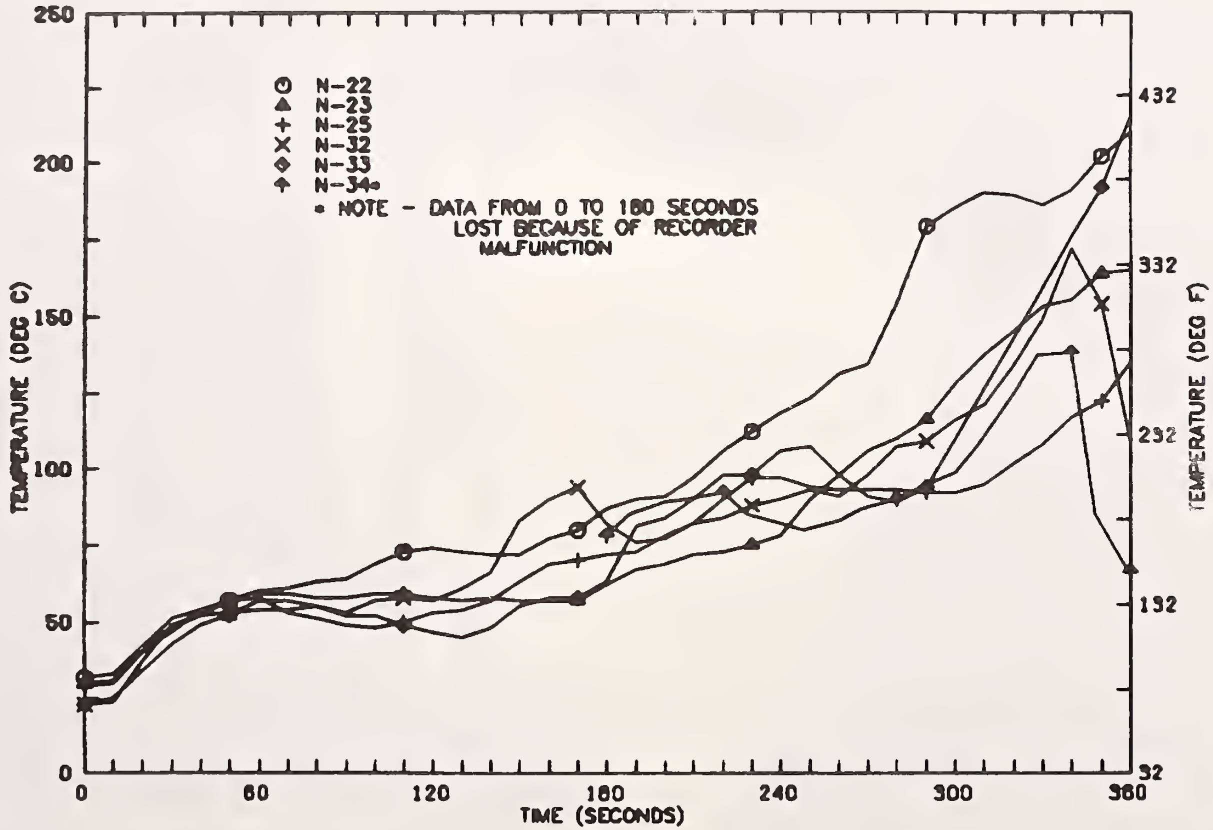


Figure 9. Average gas temperature - wastebasket plume

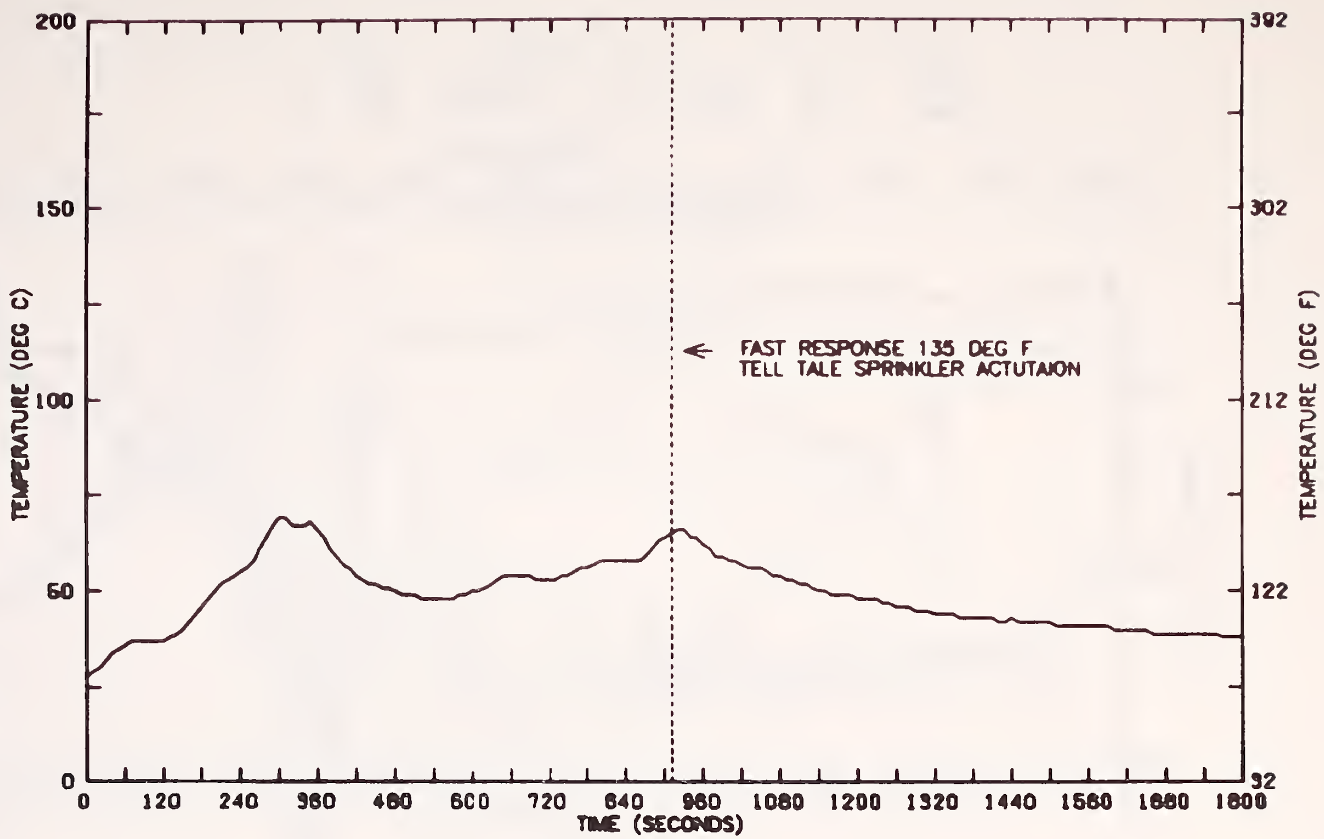


Figure 10. Average ceiling temperature - test N-20 cotton innerspring mattress (M-03)

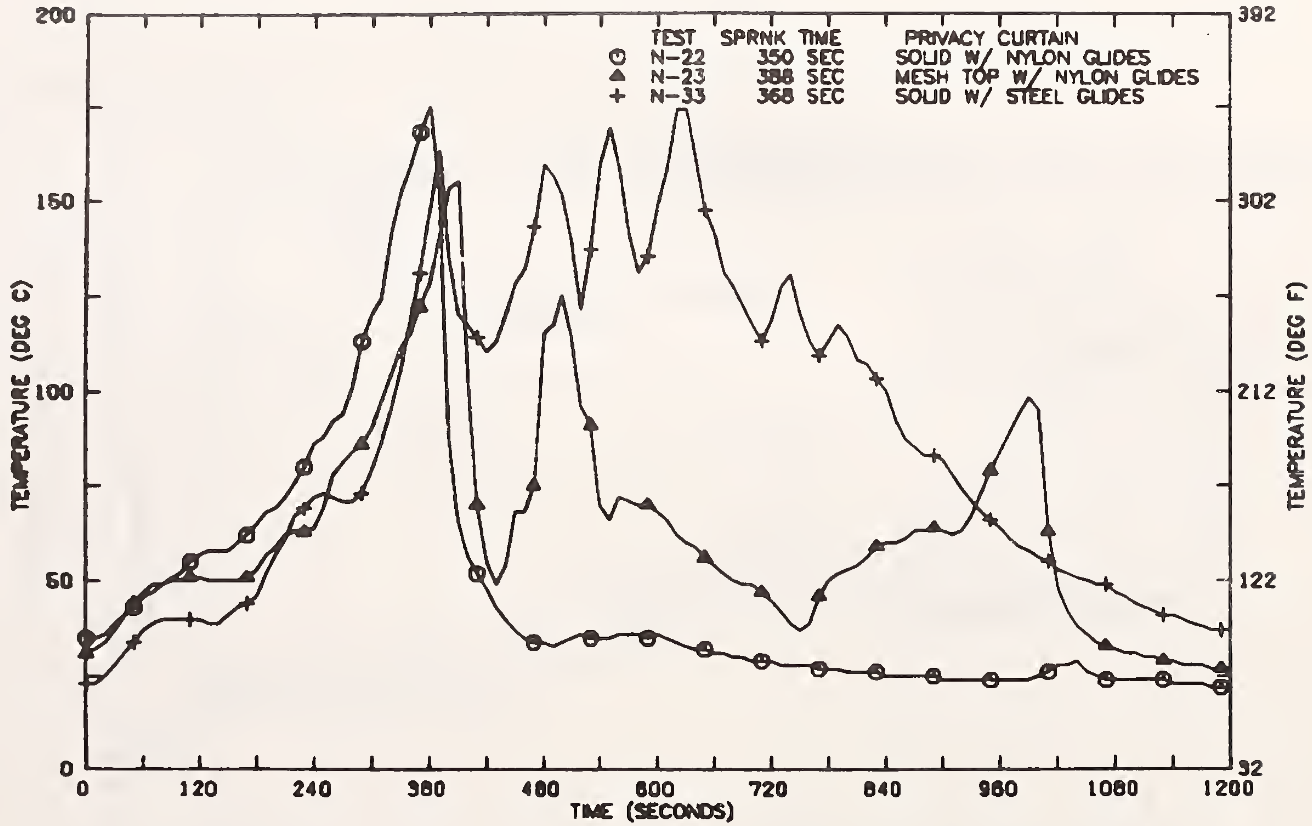


Figure 11. Average ceiling gas temperature for tests with privacy curtains

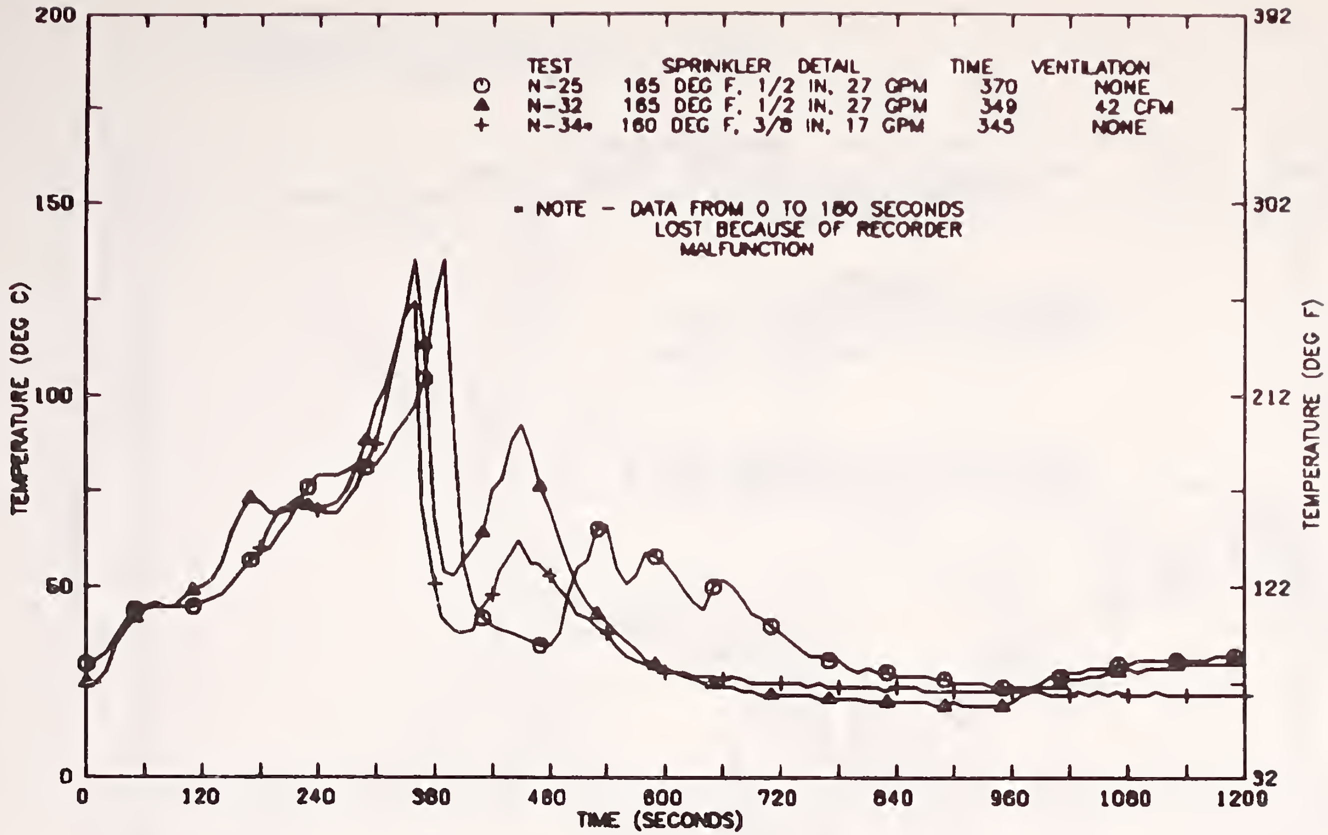


Figure 12. Average ceiling gas temperature for tests without privacy curtains

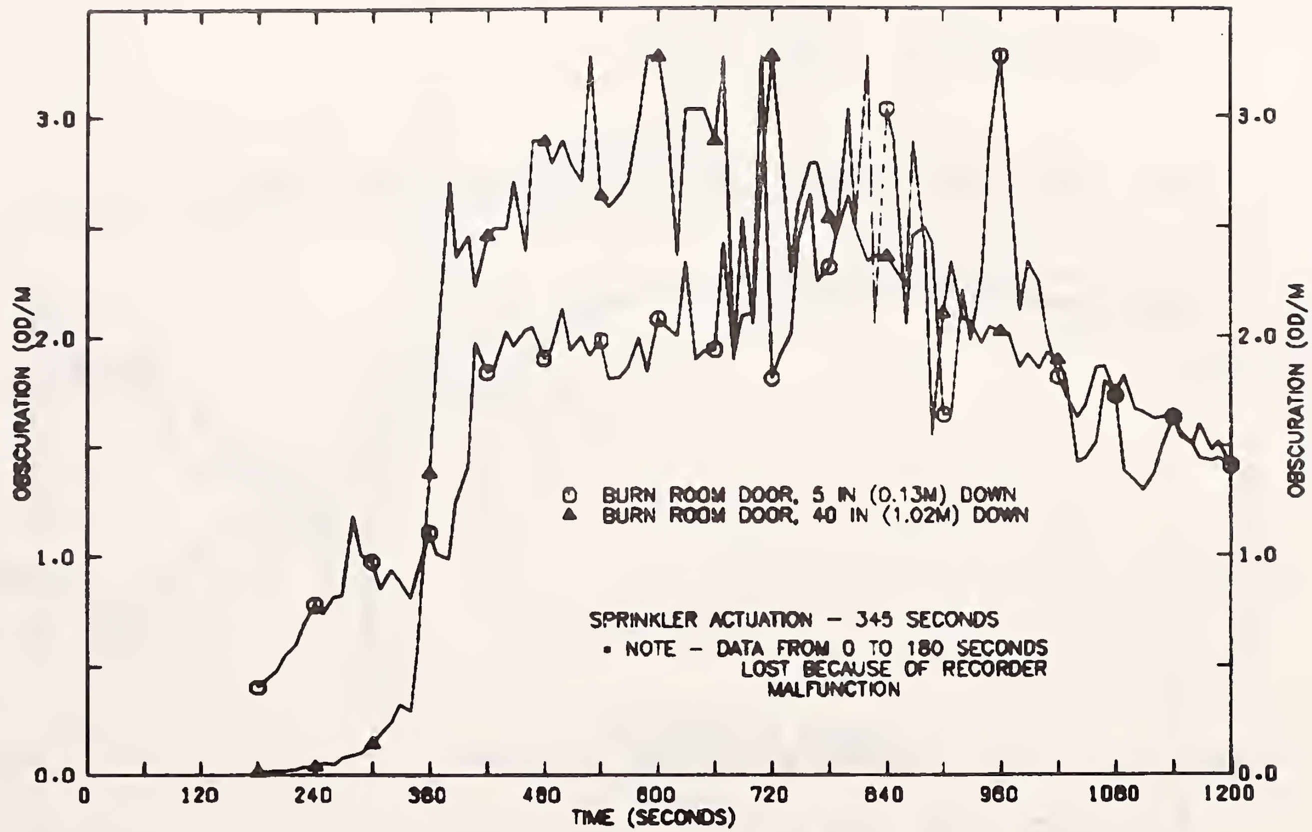


Figure 13. Smoke obscuration in burn room doorway - test N-34

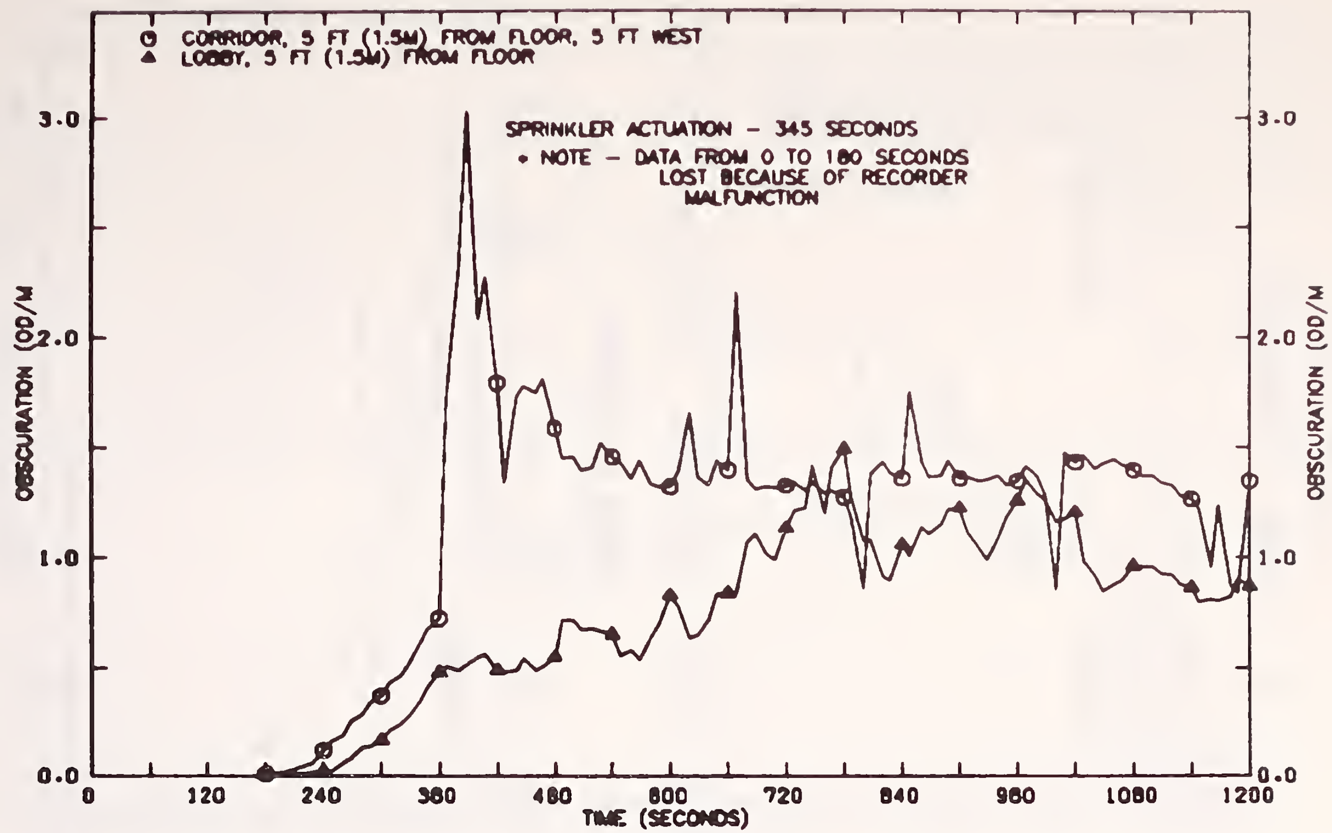
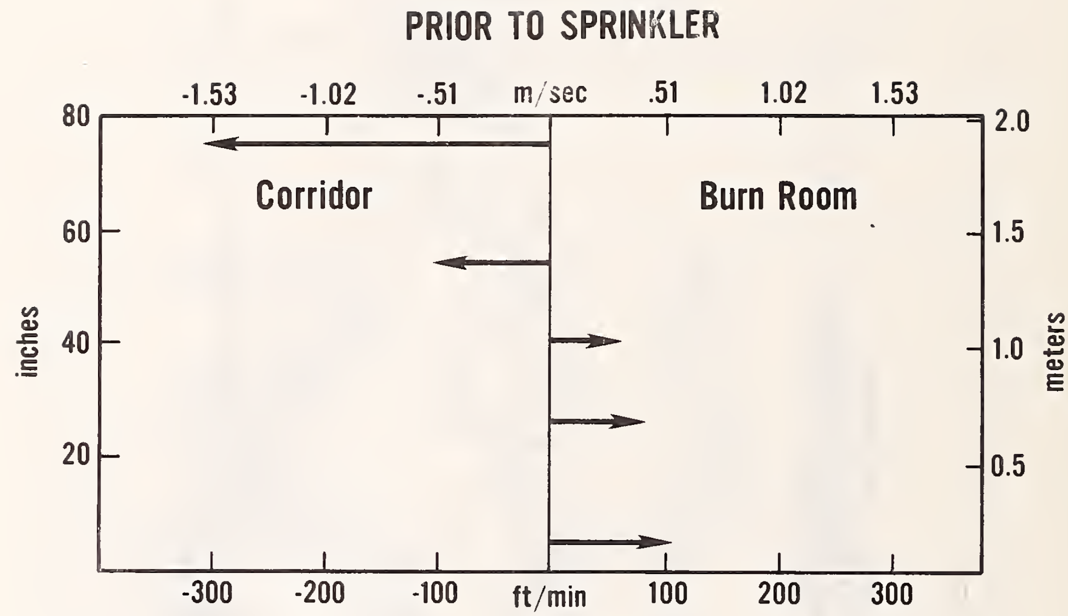


Figure 14. Smoke obscuration test N-34 corridor and lobby



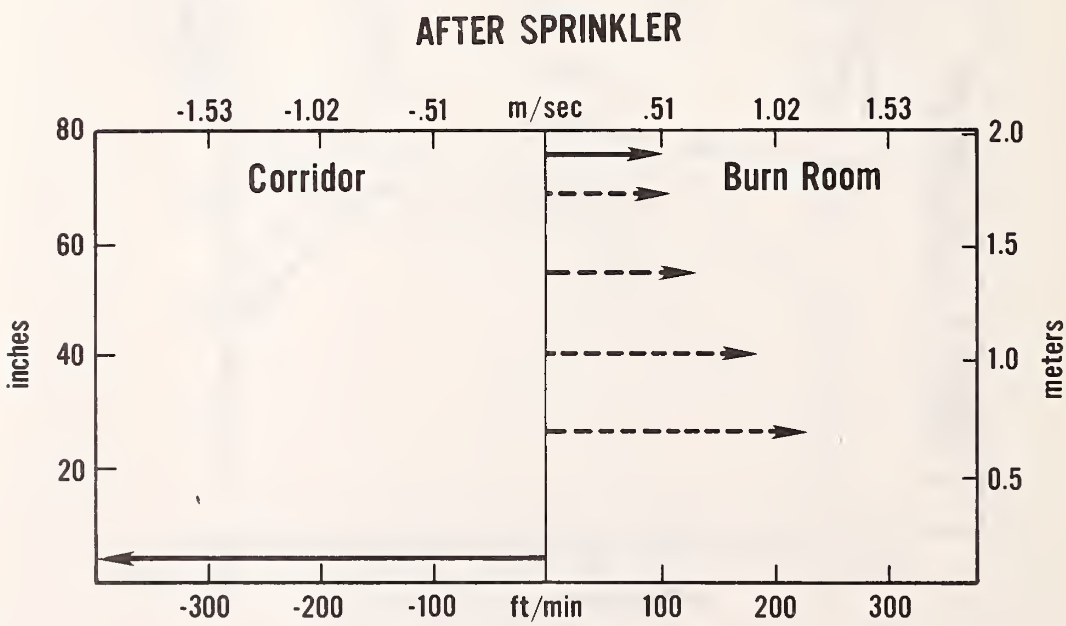


Figure 15. Net gas velocities at burn room doorway

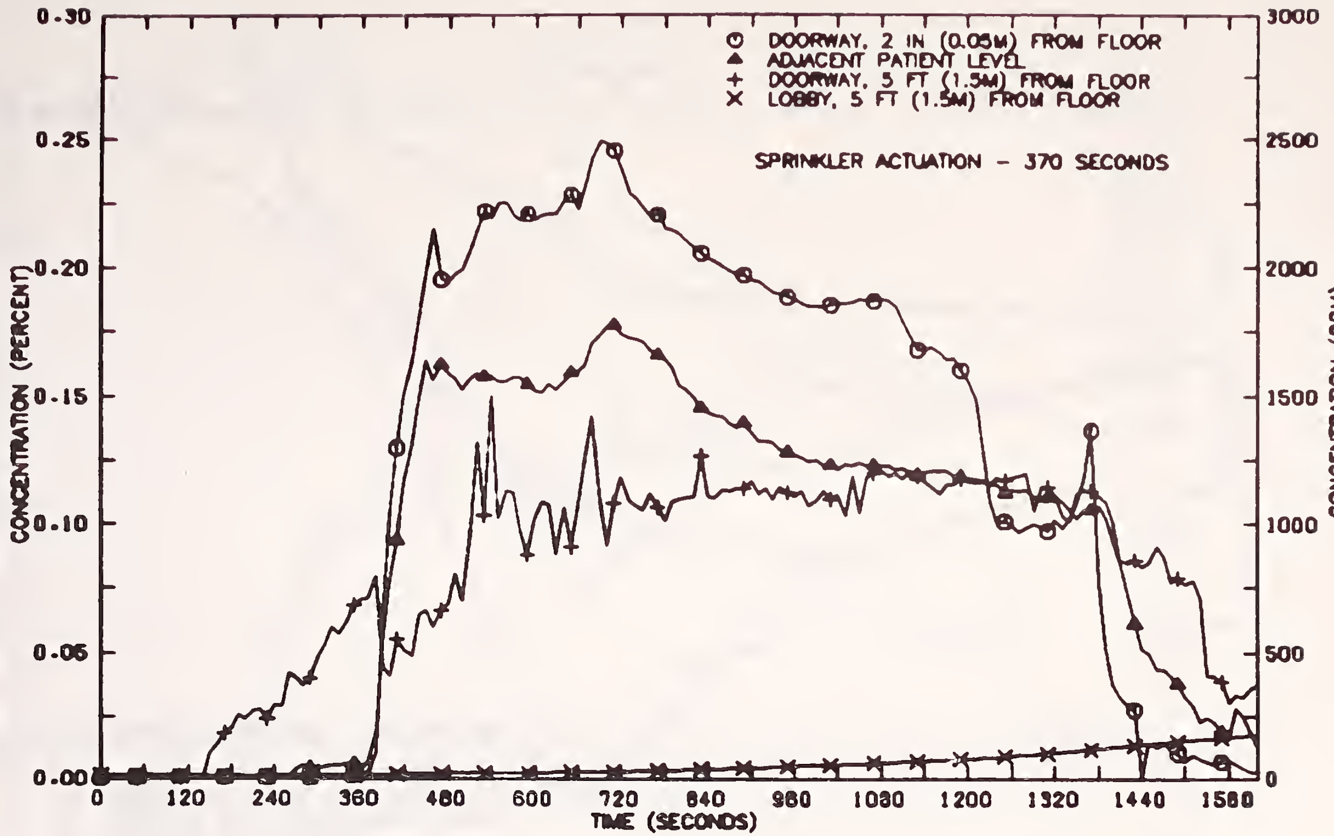


Figure 16. Carbon monoxide concentrations; test N-25

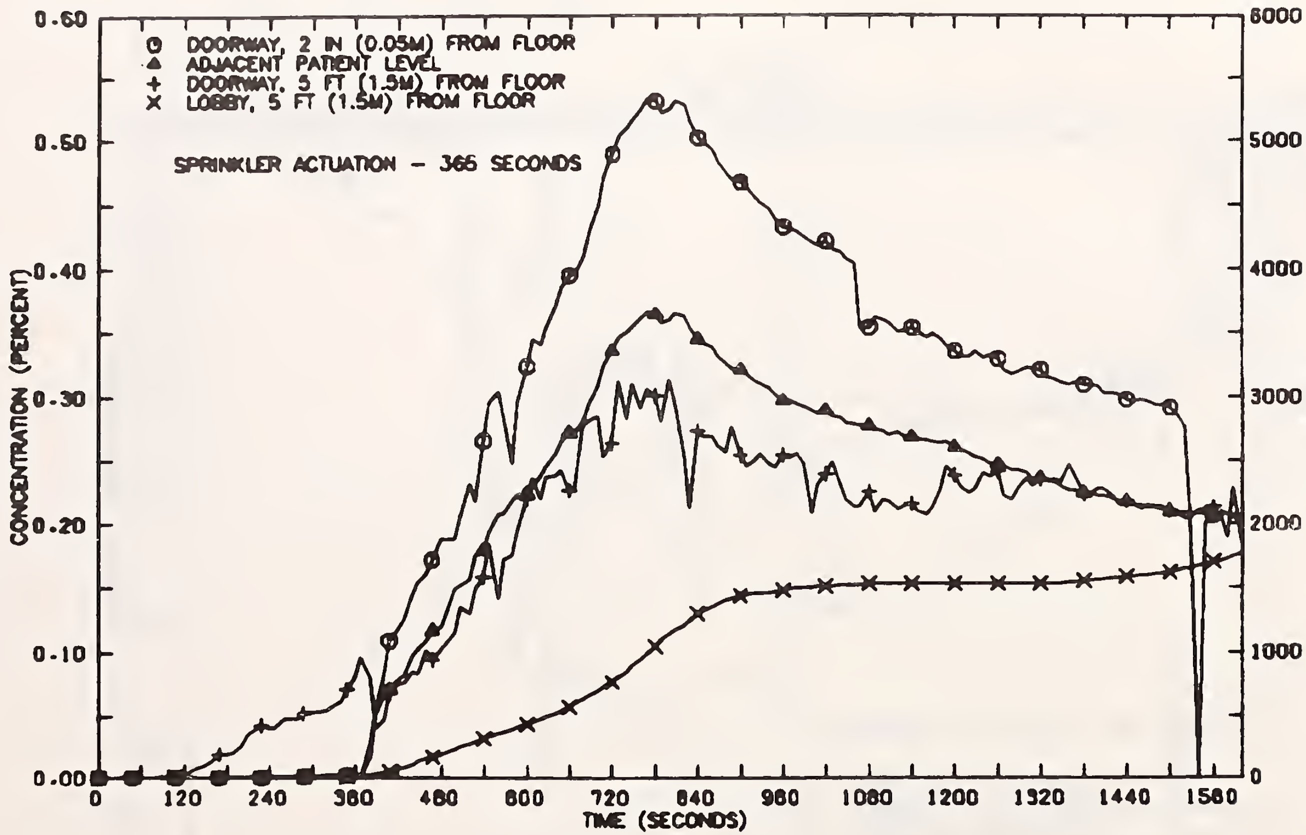


Figure 17. Carbon monoxide concentrations; test N-33

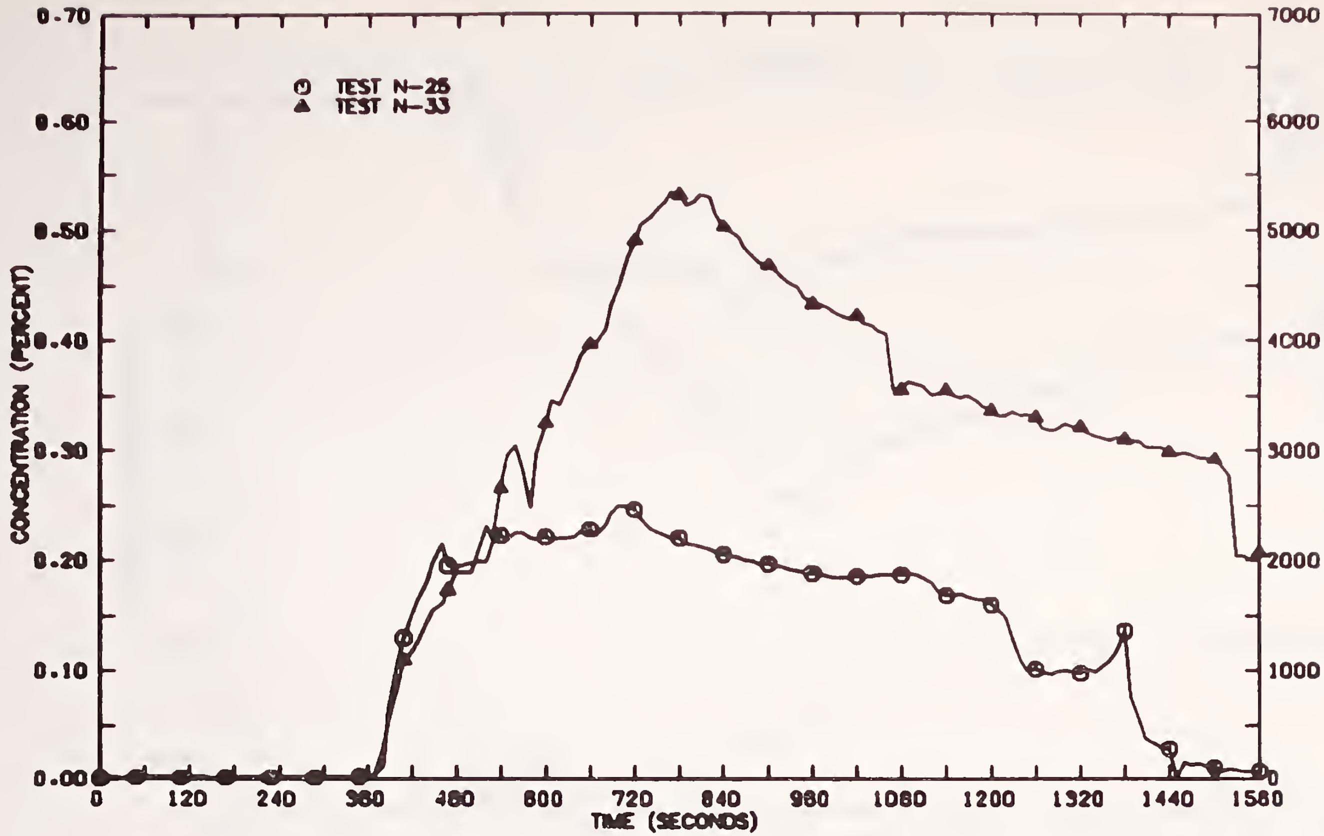


Figure 18. Carbon monoxide concentrations at doorway, .05 mm (2 in) from floor

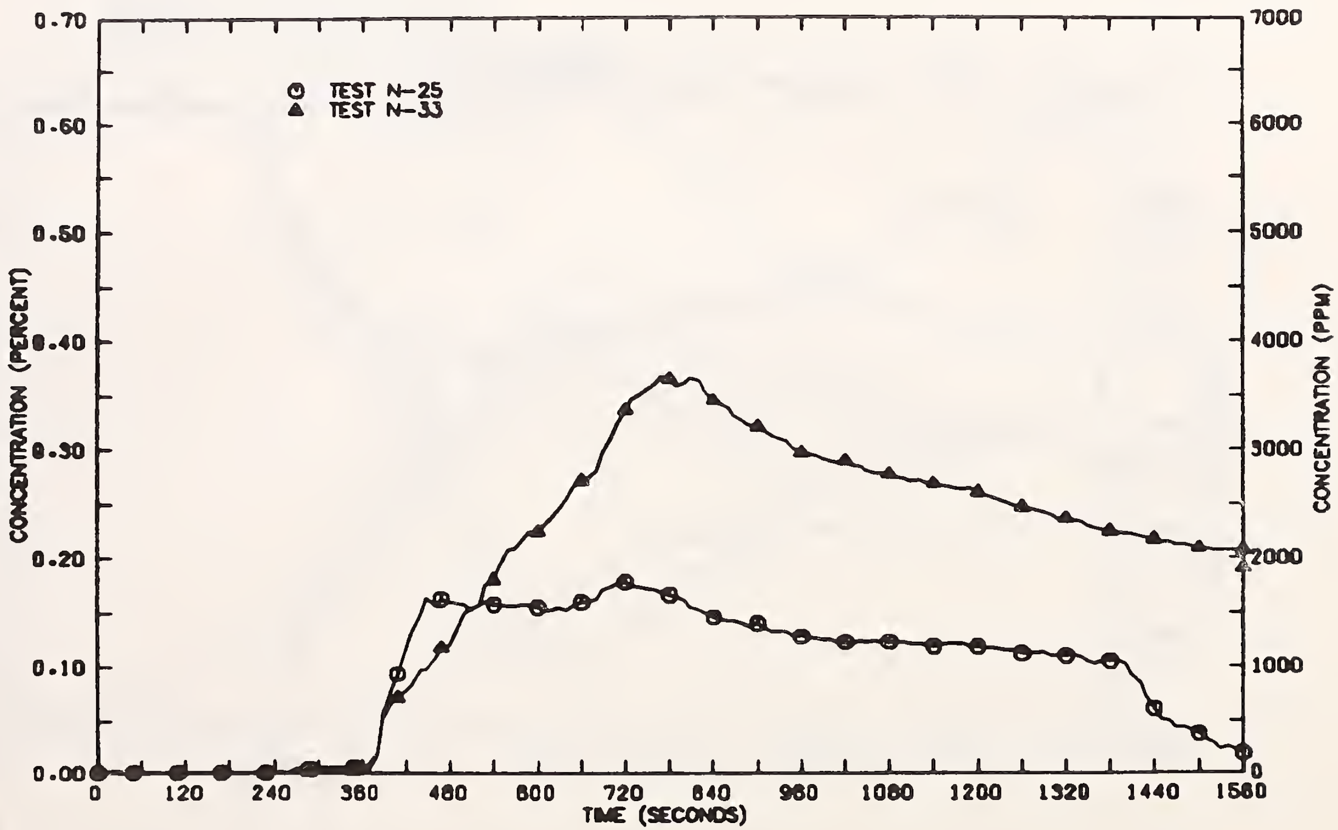


Figure 19. Carbon monoxide concentrations at adjacent patient level

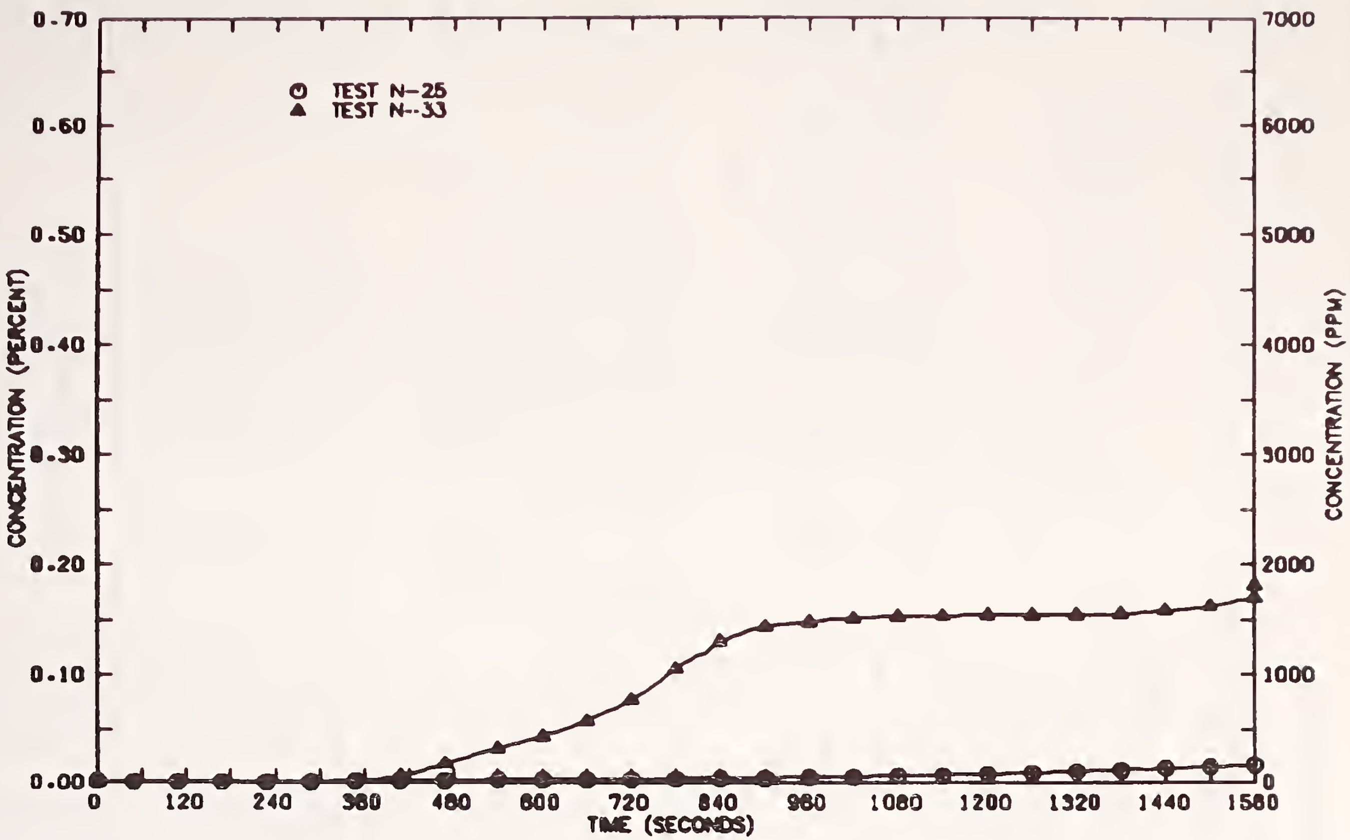


Figure 20. Carbon monoxide concentrations in lobby, 1.5 m (5 ft) above floor

Table 1

List of instrumentation

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 - 500 lb.

Table 1 (continued)

Number	Gas Concentration Probes
51	Carbon monoxide, at doorway centerline, 1.95 m below top. Analyzer Range: 0 to 0.2% (±0.02%)
52	Carbon dioxide, at doorway centerline, 1.95 m below top. Analyzer Range: 0 to 5% (±0.5%)
53	Carbon monoxide, 1.12 m from W wall, 0.36 m from S wall, 0.89 m from floor. Analyzer Range: 0 to 1% (±0.1%)
54	Carbon dioxide, 1.12 m from W wall, 0.36 m from S wall, 0.89 m from floor. Analyzer Range: 0 to 20% (±2%)
55	Carbon monoxide at doorway centerline, 0.51 m below top. Analyzer Range: 0 to 5% (±0.5%)
56	Carbon dioxide, at doorway centerline, 0.51 m below top. Analyzer Range: 0 to 20% (±2%)
57	Oxygen, at doorway centerline, 1.95 m below top. Analyzer Range: 0 to 21% (±2%)
58	Oxygen, 1.12 m from W wall, 0.36 m from S wall, 0.89 m from from floor. Analyzer Range: 0 to 21% (±2%)
59	Oxygen, at doorway centerline, 0.51 m below top. Analyzer Range: 0 to 21% (±2%)
79	Carbon monoxide, lobby, 1.55 m from E wall, 3.58 m from S wall. Analyzer Range: 0 to 1% (±0.1%)
	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)

Table 1 (continued)

Number	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; range to 20 BTU/ft^2/sec (23 W/cm^2)
81	Total heat flux meter, facing horizontally toward burn-room, on doorway centerline, 2.44 m N from doorway, 1.02 m from floor; range to 5 BTU/ft^2/sec (5.7 W/cm^2)
	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 2. Test schedule

Test No.	Burning Item*	Wall	Privacy Curtain	Sprinkler	Flow gal/min (ℓ/min)	Ventilated
N-20	M-03	FS-200	No	165°F - 1/2 in SSP (73.9°C - .013 m)	27 (102)	No
N-21	M-01	FS-200	No	165°F - 1/2 in SSP (73.9°C - .013 m)	27 (102)	No
N-22	M-02	FS-200	Solid	165°F - 1/2 in SSP (73.9°C - .013 m)	27 (102)	No
N-23	M-02	FS-200	Mesh Top	165°F - 1/2 in SSP (73.9°C - .013 m)	27 (102)	No
N-25	M-02	FS-200	No	165°F - 1/2 in SSP (73.9°C - .013 m)	27 (102)	No
N-32	M-02	FS-200	No	165°F - 1/2 in SSP (73.9°C - .013 m)	27 (102)	Yes 42 ft^3/min
N-33	M-02	FS-200	Solid 1/	165°F - 1/2 in SSP (73.9°C - .013 m)	27 (102)	No
N-34	M-02	FS-200	No	160°F - 3/8 in SSP (71.1°C - .01 m)	17 (64.4)	No

* Coded according to previous mattress test series [8].

SSP - Standard sprinkler pendant, ref - Underwriters Laboratories Standard #199, Automatic Sprinklers for Fire Protection Service [9].
M-01 - Untreated polyurethane slab mattress, PVC ticking.
M-02 - Untreated polyurethane padded innerspring mattress, PVC ticking.
M-03 - Cotton innerspring mattress, FR cotton felt padding, PVC ticking.
FS-200 - 4 mm (5/32 in) thick prefinished Lauan plywood; nominal flame spread classification 200 (Class C) in accordance with ASTM E 84 Tunnel Test.

1/ Steel glides instead of nylon

Table 3. Ignition source

Wastebasket -- polyethylene wastebasket

Size: 248 mm x 178 mm x 254 mm high
Weight: 282 g (.6 lb)

Trash contents, in order of stacking

1 -- Polyethylene liner
16 -- Sheets of newspaper
1 -- Paper cup, 3 oz. (85 g), crumpled
2 -- Sheets of writing paper
3 -- Tissues, paper handkerchief, crumpled
1 -- Cigarette pack, crumpled
1 -- Milk carton, 8 oz. (227 g)
2 -- Paper cup, 3 oz. (85 g), crumpled
1 -- Cigarette pack, crumpled
1 -- Sheet of writing paper, crumpled
2 -- Tissues, paper handkerchief, crumpled

Total weight of contents: 443 g (.97 lb)

Combined weight, wastebasket and contents: 725 g (1.6 lb)

Table 4. Privacy curtain details

Test	Material	Size
N-22	Fire retardant treated cotton, 5.28 oz/yd ($1.79\ g/cm^2$)	16 ft length x 6 ft high (4.9 x 1.8 m)
N-23	Same as above except with 22 in (.56 mm) nylon mesh at top	Same as N-22
N-33	Same as N-22	Same as N-22

Table 5. Mattress and bedding technical data

Mattress	Code	Size Width	Size Length	Size Thickness	Total Weight (kg)	Weight Combustibles (kg)	Weight Innerspring (kg)
Solid Polyurethane	-	39 in (0.89 m)	75 in (2.03 m)	7 in (0.17 m)	6.3	6.3	-
Polyurethane Innerspring	M-02	39 in (0.89 m)	75 in (2.03 m)	7 in (0.17 m)	15	6	9
Cotton Innerspring	M-03	39 in (0.89 m)	75 in (2.03 m)	7 in (0.17 m)	20	11	9

Bedding Item	Length & Width (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	0.180	0.90
Pillow Case	0.53 x 0.91	50% Cotton,	0.21	595	0.125	0.60

Table 6. Smoke obscuration data

Location	Maximum Levels Prior to Automatic Sprinkler (OD/m)						
	Test Time to AS in (sec)						
	N-21 (817)*	N-22 (350)	N-23 (388)	N-25 (370)	N-32 (349)	N-33 (365)	N-34 (345)
Room doorway-5 ft 8 in (1.7 m) from floor	1.5	1.5	1.5	1.3	1.2	1.6	.90
Corridor-5 ft (1.5 m) east of room, 5 ft from floor	.82	-	.98	.98	-	.62	.71
Corridor-5 ft (1.5 m) west of room, 5 ft from floor	.47	-	.73	.73	.80	.60	.67
Lobby-5 ft (1.5 m) from floor	.24	-	.34	.46	.40	.19	.40

* Reignition at 420 sec.
Note: Blank space indicate data unreliable due to instrumentation problems.

Location	Critical Level OD/m	Time to Critical Obscuration Levels (sec)								Previous M-02 Mattress Tests [8]	
		N-20	N-21	N-22	N-23	N-25	N-32	N-33	N-34	N-5	N-9
Room doorway 5 ft 8 in (1.7 m) from floor	.5	860	690	250	250	230	148	220	220	200	300
Corridor-5 ft (1.5 m) east of room, 5 ft from floor	.25	370	610	-	280	250	-	320	248	NA	NA
Corridor-5 ft (1.5 m) west of room, 5 ft from floor	.25	420	650	-	300	280	240	330	280	NA	NA
Lobby-5 ft (1.5 m) from floor	.25	520	800	-	360	330	320	380	328	NA	NA

NA - Not available

Table 7. CO data and calculated COHb

Test	Adjacent Patient Level		Calculated COHb at Adjacent Patient Level			Doorway 2 in (.05 m)*		Doorway 5 ft (1.5 m)*		Lobby 5 ft (1.5 m)*	
	Peak (ppm)	Time (s)	Time to 25% (s)	Peak (%)	Time (s)	Peak (ppm)	Time (s)	Peak (ppm)	Time (s)	Peak (ppm)	Time (s)
N-20	365	1500	NA	NA	NA	440	1430	602	1090	NA	NA
N-21	1018	1150	NA	NA	NA	1438	1200	1366	1260	NA	NA
N-22	1340	810	NR	13.5	1800	-	-	1120	350	NA	NA
N-23	2740	620	1550	28	1800	3170	600	2650	620	593	1800
N-25	1760	700	NR	17	1600	2490	690	1270	830	176	1600
N-32	1620	490	NR	15	1600	1990	480	1690	500	216	1290
N-33	3660	780	1190	40	1800	5400	770	3100	730	1860	1650
N-34	1635	520	NR	17	1800	2500	520	1520	510	620	1480

*Distance from floor
NA: Not available
NR: Never reached

Table 8. Maximum CO_2 concentrations

Test	Adjacent Patient Level		Doorway 2 in (.05 m)*		Doorway 5 ft (1.5 m)	
	Peak (%)	Time (s)	Peak (%)	Time (s)	Peak (%)	Time (s)
N-20	.33	1470	.34	1430	.78	970
N-21	.58	1040	.90	1190	1.10	1280
N-22	1.70	750	NA	-	NA	-
N-23	2.74	520	1.82	600	2.08	560
N-25	1.61	680	1.52	690	1.34	680
N-32	1.86	480	1.64	468	1.20	500
N-33	2.99	740	2.91	760	1.86	800
N-34	1.84	510	1.71	510	1.86	510

*Distance from floor
NA - Not available

Table 9. Minimum O_2 concentrations

Test	Adjacent Patient Level		Doorway 2 in (.05 m)*		Doorway 5 ft (1.5 m)	
	Peak (%)	Time (s)	Peak (%)	Time (s)	Peak (%)	Time (s)
N-20	19.61	1500	19.97	1430	19.19	1550
N-21	17.89	1050	19.15	1180	18.44	1280
N-22	19.08	650	NA	-	19.03	850
N-23	17.08	620	18.25	600	17.39	620
N-25	18.00	710	18.58	690	18.40	680
N-32	17.28	500	18.59	460	18.16	500
N-33	15.00	768	16.68	820	16.84	800
N-34	18.68	510	18.43	510	19.19	510

* Distance from floor
NA: Not available

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15. SUPPLEMENTARY NOTES

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

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

The Center for Fire Research is conducting a research program to examine the use of automatic sprinklers in patient rooms of health care facilities. This is an interim report of eight full-scale fire tests in which the effectiveness of automatic sprinklers was measured in terms of fire control and overall life safety. These fire tests simulated the scenario in which mattresses with bedding constituted the burning items.

Analysis of test results indicate that prior to sprinkler operation, smoke obscuration reached critical levels in the burn room doorway and adjacent corridor such that rescue of patients in the burn room and the use of the corridor as an exit way would have been seriously impeded. Immediately following sprinkler operation, there was total obscuration from floor to ceiling throughout the corridor and lobby area.

For several tests, a privacy curtain was installed between the sprinkler head and the bed. The shielding action delayed extinguishment and the carbon monoxide concentrations increased significantly. In these cases it was estimated that the carboxyhemoglobin level for a patient in an adjacent bed would reach levels considered hazardous. In other tests where the privacy curtain was not installed and this shielding did not occur, the estimated hazardous threshold was not reached.

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)*

Health care facilities; hospitals; mattresses; smoke movement; sprinkler systems.

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