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Tests on the Performance of Automatic Fire Detectors in Health Care Occupancies - A Preliminary Report

Richard W. Bukowski

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

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Abstract

The paper reports the results of the first series of eight full-scale fire tests to evaluate the response of automatic fire detectors in health care occupancies to flaming ignition mattress fires. Comparisons were made between three types of detectors (ionization, photoelectric, and heat) installed in the patient room versus in the corridors.

For the fire scenario selected (flaming ignition of bedding and mattress), the results indicated that the ionization-type detectors in the patient room provided the maximum time for escape. The maximum time period available for either rescue of a non-ambulatory patient in the room of origin or for use of the corridor past the room of origin as a means of escape averaged only about five minutes. The times available for escape or rescue were based on the time provided between detector alarm and the time that one of several criteria selected for occupant tenability was exceeded.

Key words: Corridors; escape; fire detectors; full-scale tests; heat detectors; hospitals; ionization detectors; mattresses; nursing homes; photoelectric detectors.

1. INTRODUCTION

The National Bureau of Standards (NBS), Center for Fire Research (CFR) is currently engaged in a five year experimental program sponsored by the U.S. Department of Health, Education and Welfare (HEW) to study fire protection techniques for health care facilities. One of the major segments of this program includes the conduct of full-scale experiments to obtain data on the response of automatic detection and suppression systems to fires in a patient room. This is a report of the results of the first group of eight tests in this series as pertains to the response of selected detectors to these fires. It should be emphasized that this is only a report on the results of the first eight experiments of a larger test program. Further reports on other groups of experiments on detectors and sprinkler systems will be issued separately. This report summarizes the response of detectors representative of current technology to flaming ignition bedding and mattress fires with detection principle and installation location as key parameters.

2. DESCRIPTION OF FULL-SCALE FACILITY

Full-scale experiments were conducted in one wing of a building formerly used as a military barracks. The building corridor was widened to 2.44 m (8 ft) and the burn room and corridor were fire hardened by lining them with cement asbestos board over 1.3 cm (1/2 in) gypsum board. The burn room and corridor were instrumented for temperature, smoke, air velocity, gas, and heat flux at various locations. Detailed drawings giving dimensions and instrument locations are shown in figures 1 thru 4.

The burn room was laid out to represent a small two-bed hospital room. The test fires were initiated in a trash-filled plastic wastebasket adjacent to a bed frame and

mattress. The bed was mounted on a steel platform suspended on a high temperature strain gage load cell to measure weight loss during the test. No second bed was used, but the second bed location was instrumented to give data on conditions at the adjacent patient location. Flaming fires were selected for the test scenario since Veterans Administration records [1][1] indicate that this is the highest life hazard type of fire in their health care occupancies.

Figure 5 shows the experimental arrangement of the test bed. For all tests, bedding materials including 50/50 cotton/polyester sheets and pillow case and a cotton-covered shredded urethane foam pillow were used to provide a typical bed arrangement. A cotton/polyester bedspread was also used for the experiments. Prior to ignition, the sheet and bedspread were folded back as shown in figure 5.

A more complete description of the facility and instrumentation is contained in a separate report [2].

3. EXPERIMENTAL PROCEDURE

The first group of experiments was primarily designed to identify the most and least severe fire which might occur from the exposure of four mattresses representative of types commonly used in health care facilities to a fire in a waste container. Descriptions of these four mattress types are given in table 1.

Identical tests were conducted with each mattress type in ventilated and unventilated conditions. For the ventilated condition, the exhaust fan shown in the ceiling of

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

the lobby area was operated continuously during the test. For the unventilated condition, the exhaust was not operated and the fan opening was closed by a set of metal louvers. It should be understood that these represent only two ventilation conditions and are not representative of all the different ventilation conditions which might occur. Such other conditions could have a significant effect on the detection system performance. For example, if the patient room pressure is positive with respect to the corridor the performance of the corridor detectors could be enhanced. Conversely, if the room is negative with respect to the corridor (as is done in hospitals for infection control) the performance of the corridor detectors could be delayed. It is hoped that these effects can be studied in future tests in this series.

For this first series of tests, none of the fires were extinguished until temperatures had peaked and subsided to low, steady state values. Dry sprinkler heads (tell-tale sprinklers) were installed in the burn room and were monitored for their actuation time only. A report on sprinkler operation is being prepared separately. As explained, the intent was to determine which of the mattresses provided the most severe fire. Once this mattress was identified, it would then be the only mattress type used in the next series of experiments to determine the effectiveness of an automatic sprinkler system in control or extinguishment of the fire.

3.1 Automatic Fire Detection System

Three sets of automatic fire detectors were installed in the facility. Each set of detectors included three smoke detectors and two heat detectors. Two of the smoke detectors used the photoelectric principle and one the ionization principle. The two heat detectors used at each location

consisted of one 57° C (135° F) fixed-temperature heat detector with a UL 15 m (50 ft) space rating and one 60° C (140° F) rate-compensation type heat detector with a UL 15 m (50 ft) space rating. The heat and smoke detectors used were of the commercial type normally used in health care facilities and were selected as a representative of current detector technology. Table 2 gives the types and sensitivities of the detectors used by location.

One detector board was installed in the center of the burn room ceiling and the other two detector boards were installed 4.6 m (15 ft) either side of the leading edge of the burn room doorway on the corridor ceiling. This was done to provide comparative data on the performance of detectors installed in each patient room versus detectors installed on 10 m (30 ft) nominal (33 foot actual separation for these tests) spacings in the corridors. These are the two installation schemes most often encountered in health care occupancies [3]. Figures 1 and 3 show the detector board locations.

In addition, one ionization type door closer detector and one photoelectric type door closer detector were mounted at the inside top of the burn room door for one experiment. Since the first series of experiments did not include automatic suppression, extremely high temperatures were reached during the course of the tests. The detector board on the ceiling of the burn room was arranged such that, after all the detectors had alarmed, the board could be physically lowered to the floor to minimize damage to the detectors. Since this was not possible with the door closer detectors, they were destroyed by the test fire.

Since this gave only one data point, no conclusions were drawn about the performance of door closer detectors in the patient room. Although the corridor detectors were 4.6 m (15 ft) down the hall from the burn room door, these detectors were also damaged by some test fires and had to be replaced periodically. When replaced, every attempt was made to replace the detector with one of equivalent sensitivity. Table 3 gives the sensitivities of replacement detectors and the times they were replaced.

3.2 Evaluation Criteria

The performance of the detection systems was evaluated for two situations. The first was the amount of time which would be available to staff or firefighters to rescue a patient in the adjacent bed of the room of origin. Since this patient is located in the room of origin, it must be assumed that he would rescue himself if he were ambulatory. Therefore for the purposes of this analysis, it was assumed that this patient was not ambulatory and would require assistance in leaving the fire area.

This "patient rescue time" was estimated by determining the time period from alarm of the detector by class and location to the time at which a patient in the adjacent bed would be physically incapacitated by the fire. Physical incapacitation of the patient was considered to be the time at which the patient had been exposed to a time-rated concentration of CO sufficient to result in a calculated 25% carboxyhemoglobin blood concentration, instantaneous 0.25 watts per square centimeter radiant flux on the adjacent bed, or 0.5 optical density (OD) per meter smoke level in the upper portion of the burn room. (Data taken from smoke meter on instrument channel 71 - see figure 4.) The 0.5 OD per meter value was selected as a level at which rescuers

wearing self-contained breathing apparatus (fire department personnel) would no longer be able to see far enough to locate the patient. A discussion of these three limits is contained in reference [2].

The second situation considered in assessing detector performance was the determination of the amount of time available after detector alarm for staff or patients to use the corridor past the burn room as a means of egress. For this portion of the analysis, the limits for incapacitation were set at 0.25 optical density per meter smoke level at the five foot level or 0.25 watts per square centimeter radiant flux coming out of the burn room door (1 m (3 ft) from floor). The 0.25 OD/m^{-1} value used here was based on a value used by the author and others [4,5,6] as the point where some psychological apprehension might be encountered in individuals moving down a corridor through the smoke. Table 4 lists the time to reach each critical tenability value for the room and corridor for each test.

4. RESULTS

Table 5 gives the device response times for each test. These times and the tenability times from table 4 were used to prepare figures 6, 7 and 8.

The range of elapsed times for detector alarm for the first series of tests are shown in figure 6. The alarm points are given by detector class and location. The dots are the numerical average of the response times of either:

-- The one ionization smoke detector in the room array.

-- The two photoelectric smoke detectors in the room array.

-- The two heat detectors in the room array.

-- The two ionization smoke detectors in the corridor - one in the east array and one in the west array,

or

-- One each of identical model photoelectric smoke detectors in the corridor - one in the east array and one in the west array. (The second photoelectric model pair was not present in all tests.)

The bars indicate the range of values for all of the tests conducted in phase 1. As can be seen in figure 6, the ionization detector in the burn room alarmed the fastest for all tests. The response of the photoelectric detector in the burn room was essentially equivalent to that of the ionization detectors in the corridor with the photoelectric detectors in the corridor alarming later. The heat detectors in the burn room alarmed last. The heat detectors in the corridors are not shown in figure 6 since the heat detectors in the corridor did not alarm for a number of tests.

Figure 7 shows the available rescue times for patients by detector class and location. The maximum rescue time was provided by the ionization detector in the patient room, averaging just less than five minutes and ranging from a little more than two and a half minutes to more than nine minutes. The heat detectors in the patient room gave the least rescue time, averaging a little over one minute and actually ranging negative; indicating that the heat detectors operated after conditions had been reached which would likely prohibit rescue of the patient. As was seen with the alarm time data, the ionization detectors in the corridor were essentially equivalent to the photoelectric detectors in the patient rooms.

When examining the results in figure 8 for the time available to use the corridor as an escape route the same order of rank holds. The ionization detectors in the patient room again provided an average of somewhat less than five minutes of tenability time ranging from about three and a half minutes to almost seven minutes. Again, the ionization detectors in the corridor demonstrated essentially equivalent performance to the photoelectric detectors in the room and the heat detectors in the burn room provided the least time.

5. DISCUSSION

The results of the phase 1 experiments indicated that, with a flaming fire involving a bed in the patient room, the maximum time for escape and rescue was obtained with the ionization-type detector installed in the patient room. The performance of ionization detectors in the corridor and photoelectric detectors in the patient rooms was essentially equivalent, but would provide nearly one minute less time. However, a more fundamental point derived from this series of tests is that maximum time provided was an average of slightly less than five minutes of escape or rescue time. Given the likely typical reaction time of the staff to a fire situation, this time seems quite short. This would suggest the need to use other approaches to increase the amount of time available for escape and rescue or to better manage the time available through preplanning and training.

To the extent that additional time could not be provided, some consideration should be given to decreasing staff reaction time or to better direct their rescue and other fire safety activities to make optimum use of the time available. Conceptually, one method of doing this would be to connect the detectors in the patient room to the nurse

call system in addition to the fire alarm system. It is reasonable to assume that after the initial alarm, as much as 30 seconds or more might be lost to the staff trying to remember the appropriate procedures to be followed in case of fire. If, however, the fire detector were connected to the nurse call system such that an emergency mode nurse call was generated with the detector alarm, the instinctive nurse reaction would be to proceed immediately to that room. After the patients in the room of origin were rescued, one need only glance at the nurse call master station to determine the subsequent rooms for rescue or evacuation as those would be in the emergency signaling mode when the detectors in these rooms operated. Therefore, this interconnection would graphically indicate the fire spread or smoke contamination in each individual room in the wing. This cross connection is attractive primarily since most newer hospitals have this type of nurse call system already installed and the connection into the nurse call system from the detector could be easily done using the detector supplementary alarm contacts connected into the bedside station or bathroom call button. This would typically require no additional equipment other than the length of wire connecting the systems within the patient room. Also, since this would be a supplementary signaling feature, its implementation would not require any changes to current installation or approval laboratory standards [7,8].

6. FUTURE WORK

In the next series of tests, only the worst case mattress (M-02, polyurethane innerspring) determined from the first series will be used. The 74° C (165° F), 1.27 cm (1/2 in) sprinkler will be connected to a water supply sufficient to flow 102 ℓpm (27 gpm). Tests will include

three types of privacy curtains around the bed of origin. These are mesh top, solid top with plastic hangers, and solid top with metal hangers.

Future tests will investigate the effects of room ventilation in the burn room, smoldering ignition of the bedding, and fires in free standing wardrobes.

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[7] Standard for local protective signaling systems - 72A, article 270, National Fire Protection Association, Boston, MA (1975).

[8] Standard for control units for fire protective signaling systems - UL 864, paragraph 27.2D, Underwriters Laboratories Inc., Northbrook, IL (1975).

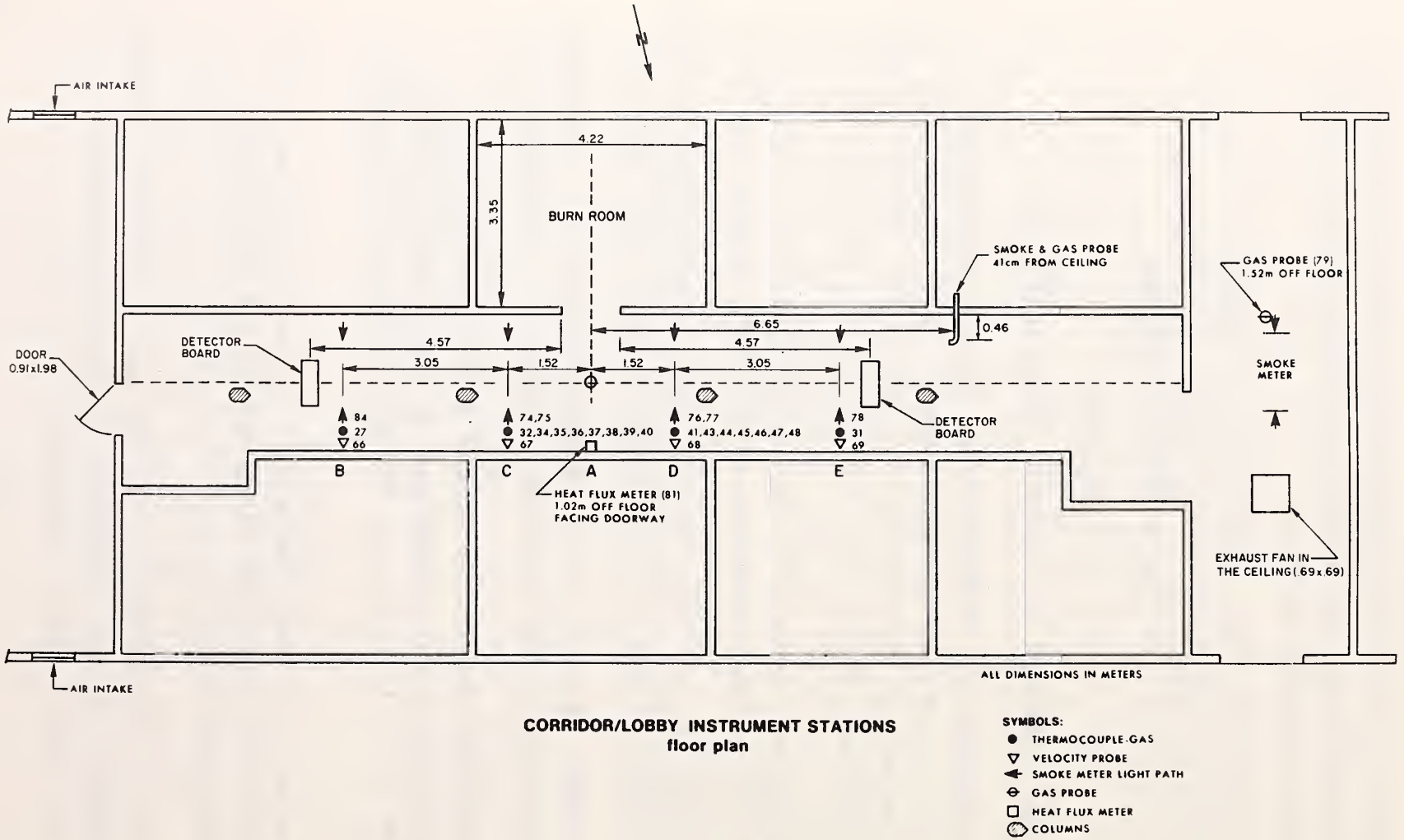

Figure 1. Corridor/lobby instrument stations floor plan

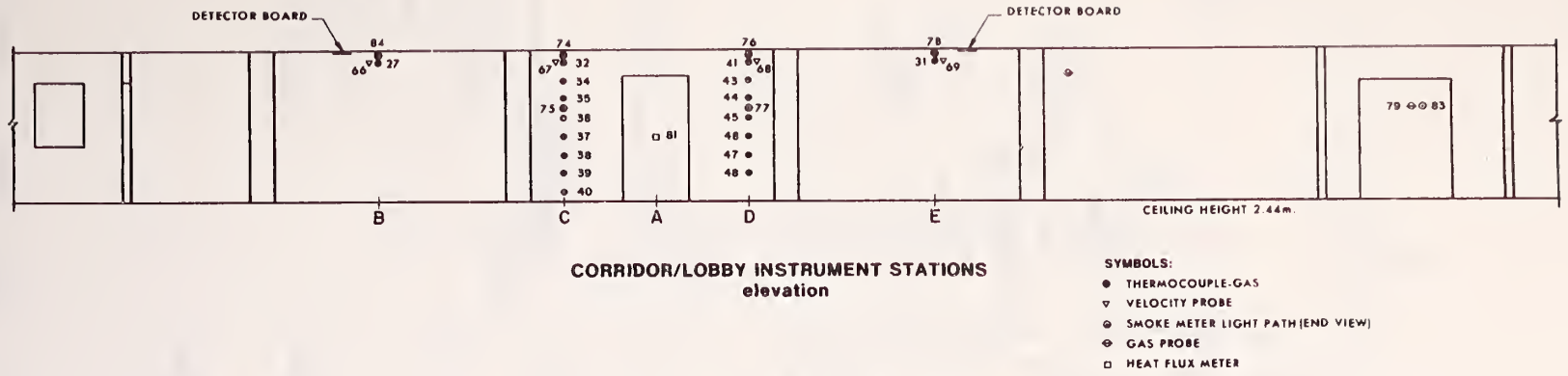

Figure 2. Corridor/lobby instrument stations elevation

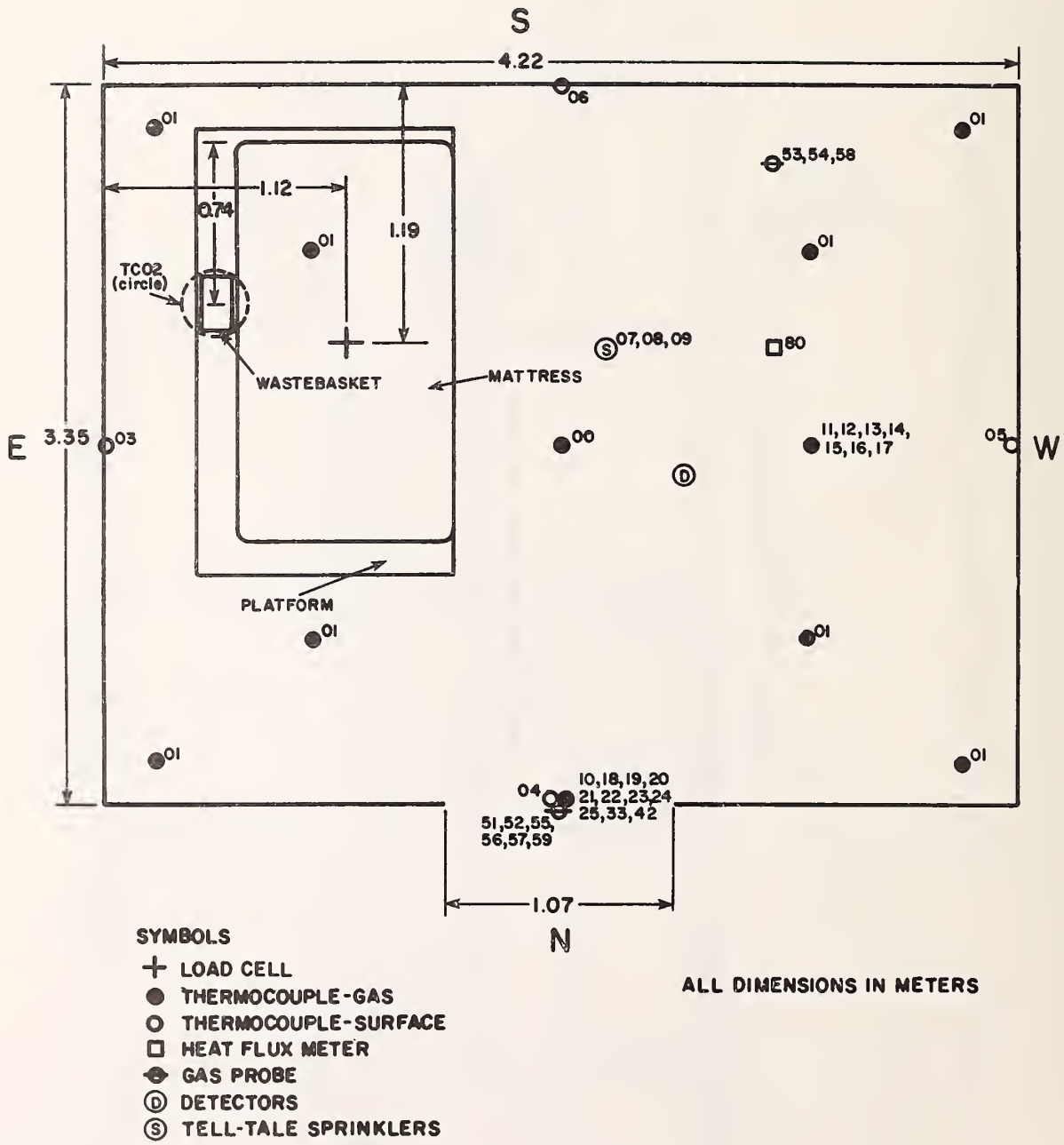

Figure 3. Burn room - plan

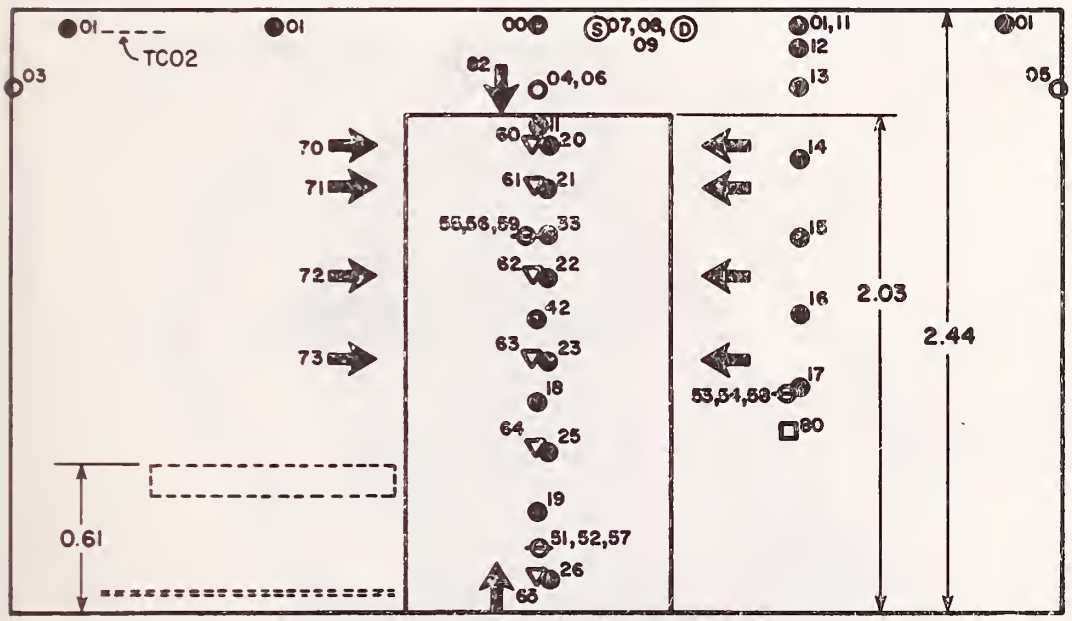

Figure 4. Burn room - elevation

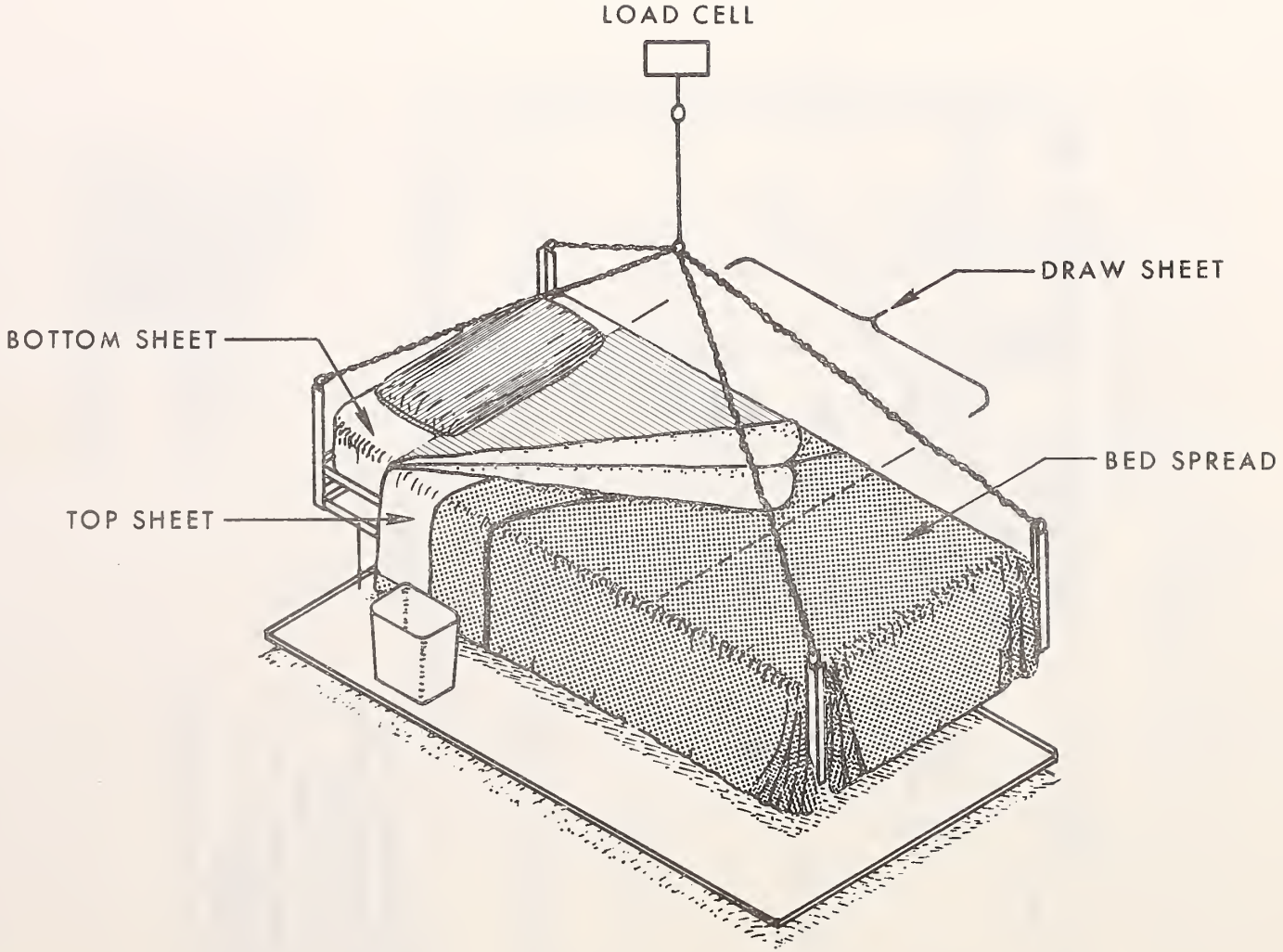

Figure 5. Experimental arrangement

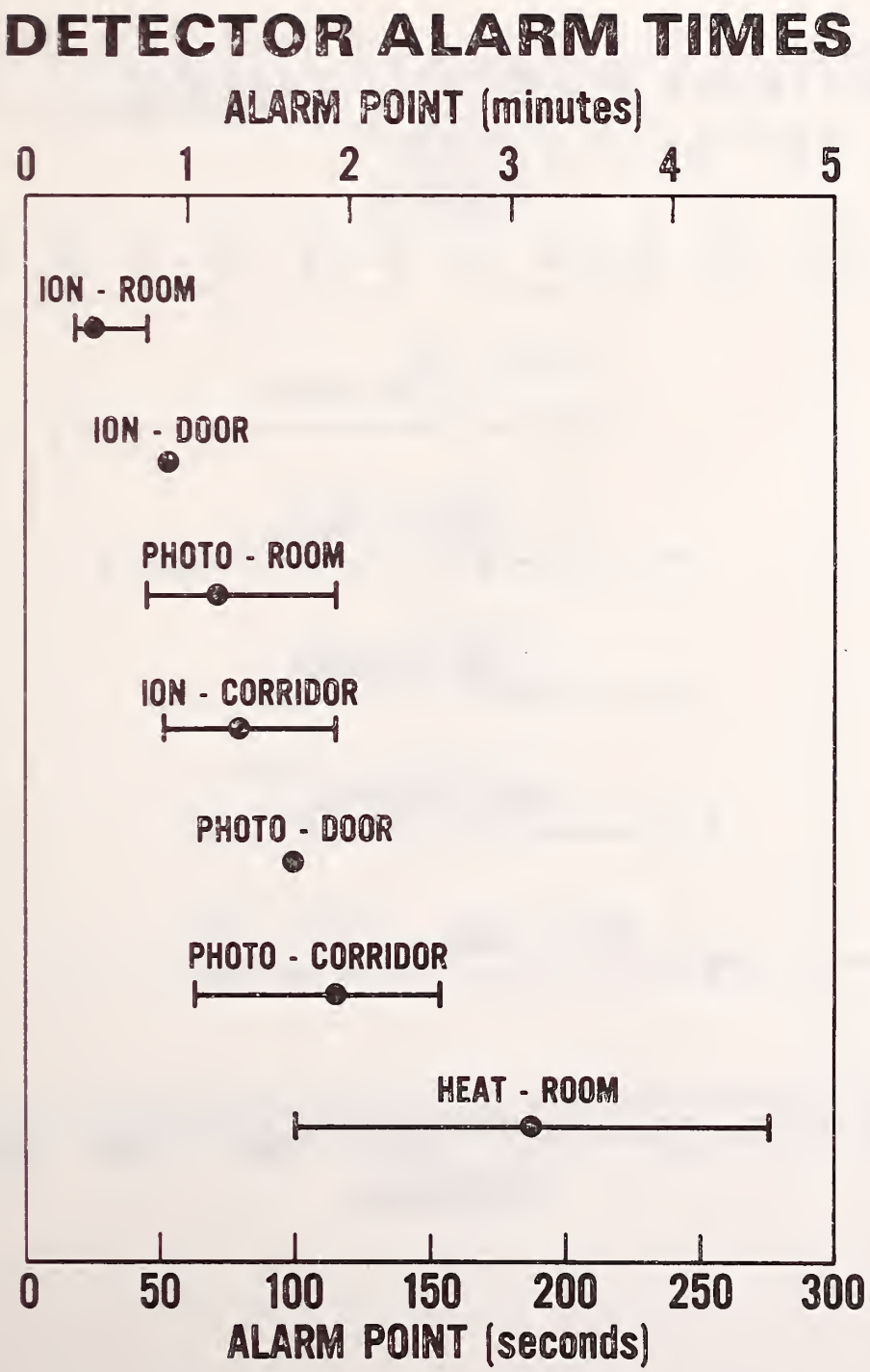

Figure 6. Detector alarm times

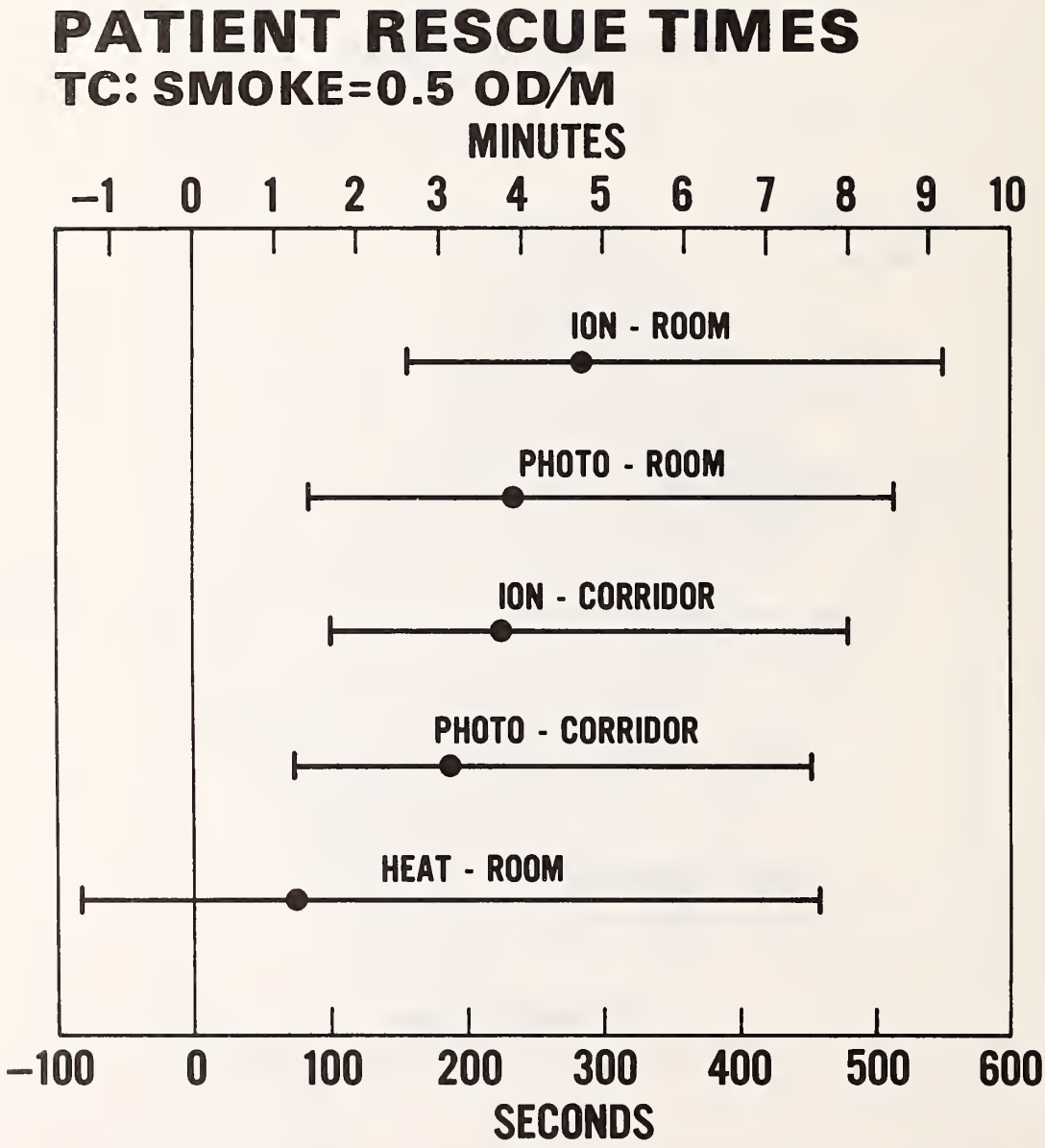

Figure 7. Patient rescue times

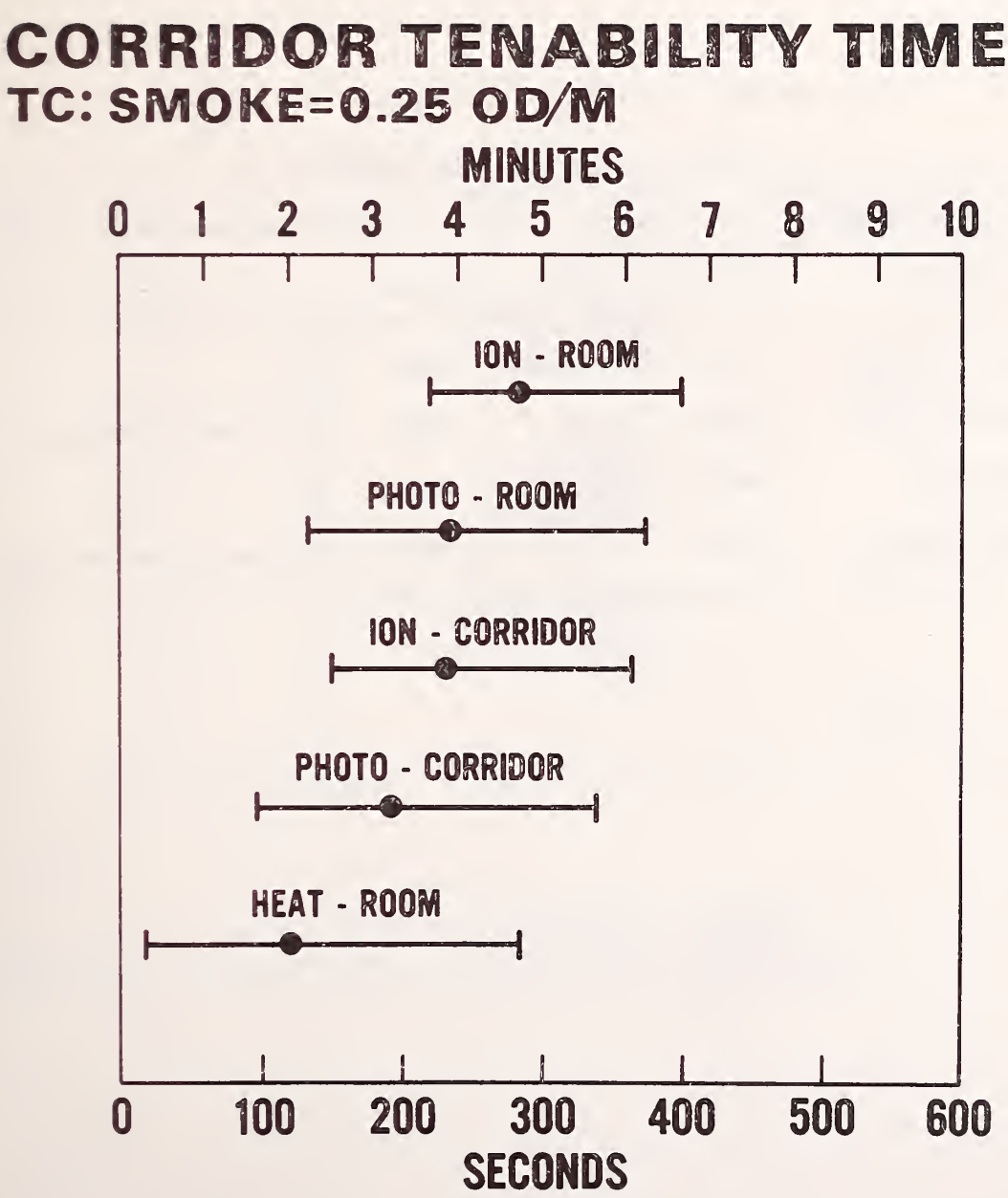

Figure 8. Corridor tenability times

Table 1. Mattress details

Type	Mattress No.	Test No.	Ticking	Core
Institutional	MO-1	10,13	PVC	PU
Institutional	MO-2	3,5	PVC	PU over springs
Commercial	MO-5	7,14	Rayon	PU
Commercial	MO-6	6,12	Polyester	Cotton over springs

Table 2. Detector type and sensitivity

Type	Clock	Location	Smoke Detector Sensitivity	Heat Detector Sensitivity
P	1	B	0.016 OD/m	
P	2	B	0.033 OD/m	
I	3	B	0.026 OD/m	
H	4	B		60° C
H	5	B		57° C
P	6	E	0.037*OD/m	
P	7	E	0.040 OD/m	
I	8	E	0.022 OD/m	
H	9	E		60° C
H	10	E		57° C
P	11	W	0.043*OD/m	
P	12	W	0.033*OD/m	
I	13	W	0.023 OD/m	
H	14	W		60° C
H	15	W		57° C

* Not used in all tests.

Legend:

Type - P-photoelectric, I-ionization, H-heat.
Location - B-burn room, E-east hall, W-west hall

Table 3. Detector replacements

Clock Asn.	Type	Replaced After Test No.	New Type	New Sensitivity
1	P	4	P	0.030 OD/m
6	P	4	P	0.033 OD/m
11	P	4	P	0.025 OD/m
11	P	9	P	0.013 OD/m
6	P	10	I	0.048 OD/m
11	P	10	I	0.035 OD/m
7	P	10	P	0.044 OD/m
12	P	10	I	0.026 OD/m
5	H	10	H	57° C
10	H	10	H	57° C
15	H	10	H	57° C
4	H	13	H	60° C

Table 4. Times to untenable conditions

Test	0.5 OD/m	0.25 W/cm^2	25% COHb
Time (seconds) to untenable conditions - adjacent patient			
N3	570	NA	870
N5	200	350	1430
N6	180	570	1550
N7	300	NR	NR
N10	230	660	1860
N12	360	NR	NR
N13	250	670	1740
N14	390	NR	NR

Test	0.25 OD/m	0.25 W/cm^2
Time (seconds) to untenable conditions - corridor		
N3	240	360
N5	250	1430
N6	250	1550
N7	290	NR
N10	330	740
N12	390	NR
N13	260	730
N14	420	NR

NR - Not reached during test

Table 5. Device response times (sec)

Clock no. \ Test	3	5	6	7	10	12	13	14
1	59	113	43	61	90	54	69	81
2	54	116	38	56	97	50	65	45
3	20	30	23	19	24	18	23	20
4	113	170	186	100	277	346	407	297
5	110	179	194	102	310	172	226	134
6	106	154	105	103	152	89	147	81
7	106	153	109	94	151	88	154	80
8	90	103	78	74	82	62	84	60
9	266	282	494	298	580	455	613	420
10	257	283	482	298	577	469	609	426
11	108	295	135	126	123	115	177	98
12	104	152	111	94	142	63	81	60
13	89	95	70	71	68	57	76	52
14	237	259	453	277	528	444	596	429
15	247	271	478	293	552	445	590	394
Ion Door Closer	53							
Photo Door Closer	100							

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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 paper reports the results of the first series of eight full-scale fire tests to evaluate the response of automatic fire detectors in health care occupancies to flaming ignition mattress fires. Comparisons were made between three types of detectors (ionization, photoelectric, and heat) installed in the patient room versus in the corridors.

For the fire scenario selected (flaming ignition of bedding and mattress), the results indicated that the ionization-type detectors in the patient room provided the maximum time for escape. The maximum time period available for either rescue of a non-ambulatory patient in the room of origin or for use of the corridor past the room of origin as a means of escape averaged only about five minutes. The times available for escape or rescue were based on the time provided between detector alarm and the time that one of several criteria selected for occupant tenability was exceeded.

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)*

Corridors; escape; fire detectors; full-scale tests; heat detectors; hospitals; ionization detectors; mattresses; nursing homes; photoelectric detectors.

18. AVAILABILITY

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