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FIRE INCIDENT STUDY

NATIONAL SMOKE DETECTOR

PROJECT

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EXECUTIVE SUMMARY

The Consumer Product Safety Commission conducted the Fire Incident Study to identify why smoke detectors fail to alarm in residential fires. Data were collected from 263 fires in 15 U.S. cities between April 1992 and February 1993. Fourteen deaths, 33 injuries, and $2.7 million in property loss occurred in these fires.

The study results indicated that about 60 percent of the detectors failed to alarm because they were disconnected from their power sources. Among those that were disconnected because occupants experienced problems with them, the reasons most often cited by occupants were that it "alarms too often" or that there were unwanted alarms related to cooking activities.

Detectors that did not operate correctly after power was restored were collected for evaluation at the CPSC laboratory. In addition, some detectors that were connected but still failed to alarm in the fire were collected for laboratory testing. Laboratory tests found detectors with horns that did not operate, faulty wiring connections, excessive dirt or insects inside the detectors, and corroded or disconnected components.

The results of this study confirm the findings of a companion CPSC survey of smoke detectors in households without fires.[1] In that survey, 60 percent of detectors that did not alarm to testing were found disconnected. Both studies found that most detectors were disconnected for reasons other than problems with the detector itself. These studies indicate that in order to reduce deaths and injuries from residential fires, the number of working smoke detectors must be increased.

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[1] *Smoke Detector Operability Survey: Report on Findings*, Charles L. Smith, U.S. Consumer Product Safety Commission, as Revised, October 1994.

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I. BACKGROUND

A. Earlier Studies

Residential structure fires continue to cause almost 4,000 deaths and over 21,000 injuries annually. Although the presence of smoke detectors in households has climbed steadily since their introduction in the early 1970's, a variety of local studies have indicated that an unacceptably large proportion of installed detectors are unpowered. "Three local studies in the 1980's showed that on the order of one-fourth to one-third of detectors were non-operational."[2] Moreover, anecdotal information indicated that detectors were being disconnected from their power sources in response to nuisance alarms. A landmark study of detector operation when a fire occurred was completed in 1983 by the International Association of Fire Chiefs Foundation.[3] This was the first large-scale study of detector operation that included multiple localities and measured sensitivity of the detectors in the field. That study documented power-related problems as a major cause of failure to alarm in a fire, and included an effort to test detector sensitivity.

B. U.S. Fire Loss Estimates

Fire department incident data commonly report detector performance in attended fires. These data are captured by the U.S. Fire Administration's National Fire Incident Reporting System (NFIRS).[4]

CPSC staff estimated detector operation in U.S. fires based on NFIRS data applied to National Fire Protection Association (NFPA) aggregate estimates of residential fire losses over the 3-year period 1989-1991, using a method developed by Hall and

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[2] Hall, John R. Jr., *U.S. Experience with Smoke Detectors and Other Fire Detectors, Who Has Them? How Well Do they Work? When Don't They Work?*, National Fire Protection Association, Boston, MA , 1990.

[3]Hawkins, Raymond E., *An Evaluation of Residential Smoke Detectors Under Actual Field Conditions, Final Report*, International Association of Fire Chiefs Foundation, March 1983.

[4]NFIRS does not capture data from all U.S. fire departments, nor all states. Nevertheless, it is a very large data base consisting of more than 200,000 residential structure fire reports annually. It is the most comprehensive data available and is thought to reasonably represent U.S. fire losses.

Harwood.[5] These data indicated that detectors were present in about 52 percent of home fires (1 or 2 family, or apartments), that resulted in 40 percent of fire deaths and 56 percent of fire injuries in the home (Table 1a).

Table 1.

Detector Performance in Home Fires,
Average Annual Estimates, 1989-1991

a) Detector Presence, Excludes Incidents Where Detector Presence Was Not Reported

	Fires		Deaths		Injuries	
Presence	Estimated	Percent	Estimated	Percent	Estimated	Percent
Total	321,400	100	2,590	100	15,200	100
No Detector	152,700	48	1,550	60	6,700	44
Detector Present	168,700	52	1,040	40	8,500	56

b) Detector Operation, Excludes Incidents Where It was Likely that Smoke Did Not Reach the Detector[1]

	Fires		Deaths		Injuries	
Operation	Estimated	Percent	Estimated	Percent	Estimated	Percent
Total	83,400	100	880	100	6,500	100
Operated	57,100	68	480	55	4,200	65
Did Not Operate	26,300	32	400	45	2,300	35

[1] If the detector was in the room of origin, only incidents with smoke damage beyond part of the room were included. If the detector was outside the room of origin, only incidents with smoke damage beyond the room the origin were included.

Source: Estimates were derived by applying proportions observed in the U.S. Fire Administration's National Fire Incident Reporting System (NFIRS), to aggregate national estimates from annual surveys conducted by the National Fire Protection Association (NFPA).

However, even if a detector was present in the home, there may not have been adequate smoke at the detector to activate it. (The fire may have been small, or the smoke confined to areas away from the detector location.) To take this

[5]John R. Hall, Jr. and Beatrice Harwood, *The National Estimates Approach to U.S. Fire Statistics*, Fire Technology, May 1989, volume 25, Number 2, pages 99-113.

into account, estimation of detector performance included only the smaller number of home fires where a detector was present and the smoke damage appeared to have extended sufficiently that it may have reached the detector.[6] Among this group of fires, the detector did not alarm in an estimated 32 percent, that resulted in 45 percent of the deaths and 35 percent of the injuries (Table 1b). This performance distribution was the same for one- or two-family dwellings as for multiple-unit housing such as apartments and condominiums. Although a greater proportion of the deaths occurred in fires in which detectors operated, the death rate in fires where they operated was nearly half that of the rate in fires where they did not operate (0.8 versus 1.5 deaths per 100 fires).

NFIRS data do not distinguish between smoke and heat detectors. However, since relatively few heat detectors are present in homes, detector performance data probably reflect smoke detectors rather than heat detectors.

C. National Smoke Detector Project

In response to continuing reports of detectors failing to operate in fires, the U.S. Consumer Product Safety Commission (CPSC) initiated a National Smoke Detector Project in 1991. The project was jointly sponsored with the U.S. Fire Administration, the Congressional Fire Services Institute, and the National Fire Protection Association. Operating committees were formed to concentrate on four areas: Field Investigations, Technology, Codes and Standards, and Consumer Awareness.

The activities of the Field Investigations Committee were directed to completing two studies of smoke detector operability. One was to determine the status of smoke detector operability in households generally. The other was to determine the reasons why detectors failed to operate in fires. While different populations were surveyed, both studies used the same testing procedures to determine operability and the reasons for lack of operability.

The survey of detector operation in non-fire households was conducted over the period October - December, 1992. The final report on that survey was completed in October 1994, entitled *Smoke Detector Operability Survey, Report on Findings* by Charles L. Smith, Directorate for Economic Analysis, U.S. Consumer Product Safety Commission, as Revised. The study of smoke

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[6] If the smoke detector was in the room of origin, only incidents with smoke damage beyond part of the room were included. If the detector was outside the room of origin, only incidents with smoke damage beyond the room of origin were included. This adjustment had the effect of reducing the estimated percent of fires in which the detector did not operate, from 35 percent based solely on detector performance coding, to 32 percent adjusted for extent of smoke damage.

detector operation in fires was conducted over the period April 1992 - February 1993. This report presents the results of that fire study.

II. METHODOLOGY

A. Sample Selection

The National Smoke Detector Project Fire Incident Study collected data on smoke detector operation in fires attended by 15 fire departments over the period April 15, 1992, through February 28, 1993 (Appendix A). These cities were randomly selected from the universe of U.S. cities with a population of between 250,000 and 1 million. The sample was restricted to cities of this size so that an adequate number of in-scope fires would be expected to occur during an optimum time period, and the logistics of data collection would be feasible. Fire departments that agreed to participate donated the time needed to complete the project requirements. Manufacturers donated replacement smoke detectors, and CPSC provided all project materials.

B. Study Procedures

The study questionnaire and protocol (Appendix B) were developed by CPSC with the assistance of the National Smoke Detector Project Field Investigations Committee.[7] The questionnaire was pilot tested with the assistance of the Baltimore, MD, and Washington, DC, Fire Departments. Following the pilot test, the questionnaire was modified to improve the question wording and sequence.

Before data collection began, each of the 15 participating fire departments assigned a project coordinator who attended a CPSC-sponsored one-day training course to familiarize them with background information on detectors and project requirements. The coordinators were responsible for managing the project in the fire departments. A training video describing the project procedures also was provided to each coordinator to use in training other fire department staff. Although it was requested that each incident be investigated immediately following extinguishment of the fire, the internal procedures used to identify and follow-up on in-scope fires were modified to fit into each fire department's day-to-day operations.

The salient features of the study were as follows:

1) In-scope Criteria: A residential structure fire in which a detector failed to sound even though it was believed that there was enough smoke at the detector that it should have sounded.

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[7]Members included representatives of manufacturers, insurance companies, the public health community, and the fire prevention community.

2) Investigation Procedure: The fire service was instructed to complete the project questionnaire as soon after the fire as possible, testing up to three detectors per household.

3) On-site Detector Testing: The test procedure included spraying each detector with aerosol smoke to initiate an alarm and pressing the detector's test button (when available). Depending on the circumstances, a detector could have been sprayed with the aerosol smoke either once or twice. The test procedure generally was as follows: First the detector was sprayed with aerosol smoke. If the detector did not alarm, the detector cover was removed and power was restored, if possible. The detector then was sprayed a second time with aerosol smoke and the test button was pushed.

4) Collection of Detectors: Project guidelines called for sample collection under the following conditions: 1) a detector that did not respond to aerosol smoke when powered, 2) a detector that did not respond to the test button when powered, 3) a detector that was found disconnected from the power source and the occupant reported a problem with it, 4) a detector that was found to have a dead battery and the occupant reportedly did not hear a low-battery signal, and 5) an AC-powered detector that could not be tested but had failed to sound during the fire. Collected detectors were sent to CPSC for laboratory analysis. When a detector was removed, it was replaced with a new detector.

C. Comparison of Study Cities with National Data

An additional aspect of the study involved collection of fire incident data on all residential structure fires that occurred in each city during the study period.[8] These data were compared to 1991 NFIRS data (the most recent year available) to evaluate how well these cities reflected the larger data base.

These comparisons are presented in Figures 1 - 3. Very little difference in distribution was found among types of residential property, detector performance and extent of smoke damage. Among the grouped forms of heat, the relative proportions of fires that involved smoking materials (often resulting in smoldering fires) versus open flame were similar in the study cities and NFIRS. There were some differences: 1) a smaller proportion of fires in the study cities than in NFIRS involved fuel-fired heating equipment,[9] and 2) a larger

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[8]Ten fire departments provided data for the study period. Four departments reported data to NFIRS but could not provide data for the study period in the format requested. As a surrogate, this analysis includes their 1991 data from NFIRS. No overall fire data were available for one department.

[9]It is noted that a large proportion of fires coded "Other" in the Equipment Involved in Ignition section were fires coded "No Equipment Involved."

Figure 1: COMPARISON OF FIRE DATA FROM CITIES IN THE 1992 SMOKE DETECTOR FIRE INCIDENT STUDY WITH NATIONAL FIRE DATA

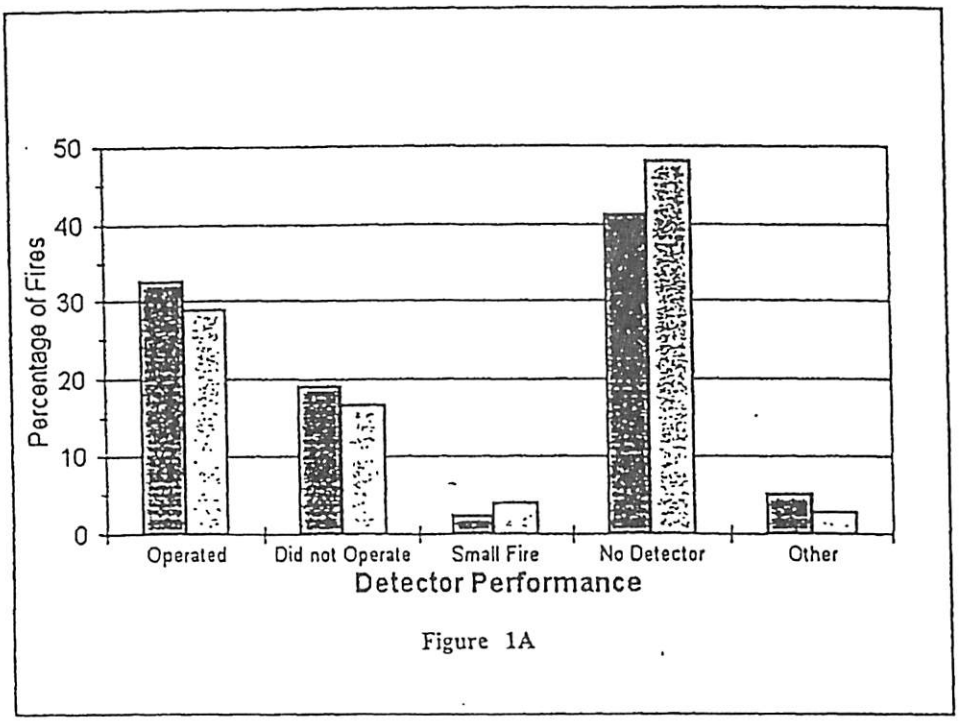

Figure 1A

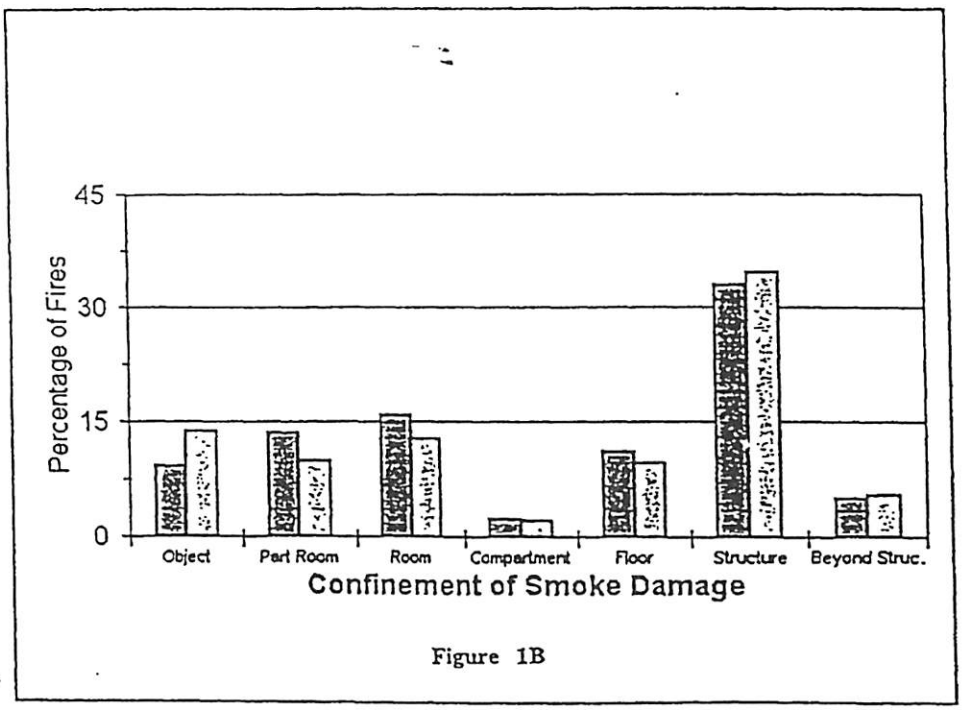

Figure 1B

Note: Includes residential structure fires only
Cities : 11 cities, 5/92 - 2/93
4 cities, 1/91 - 2/91 and 5/91 - 12/91
NFIRS : 1/91 - 3/91 and 5/91 - 12/91

CITIES NFIRS

Source: U.S. Consumer Product Safety Commission/EPHA

Figure 2: COMPARISON OF FIRE DATA FROM CITIES IN THE 1992 SMOKE DETECTOR FIRE INCIDENT STUDY WITH NATIONAL FIRE DATA

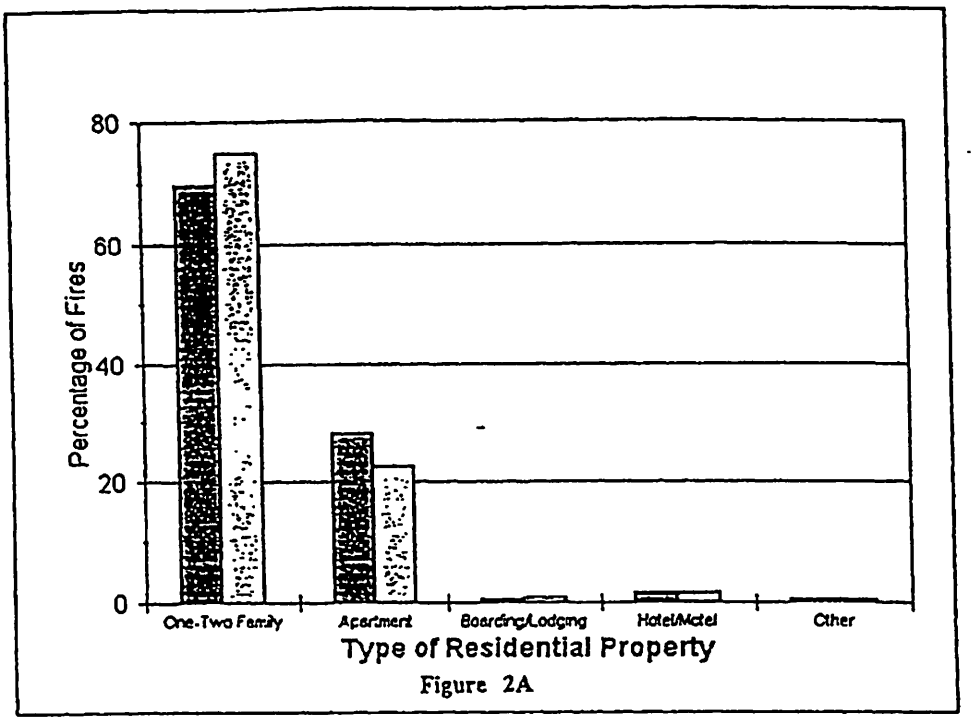

Figure 2A

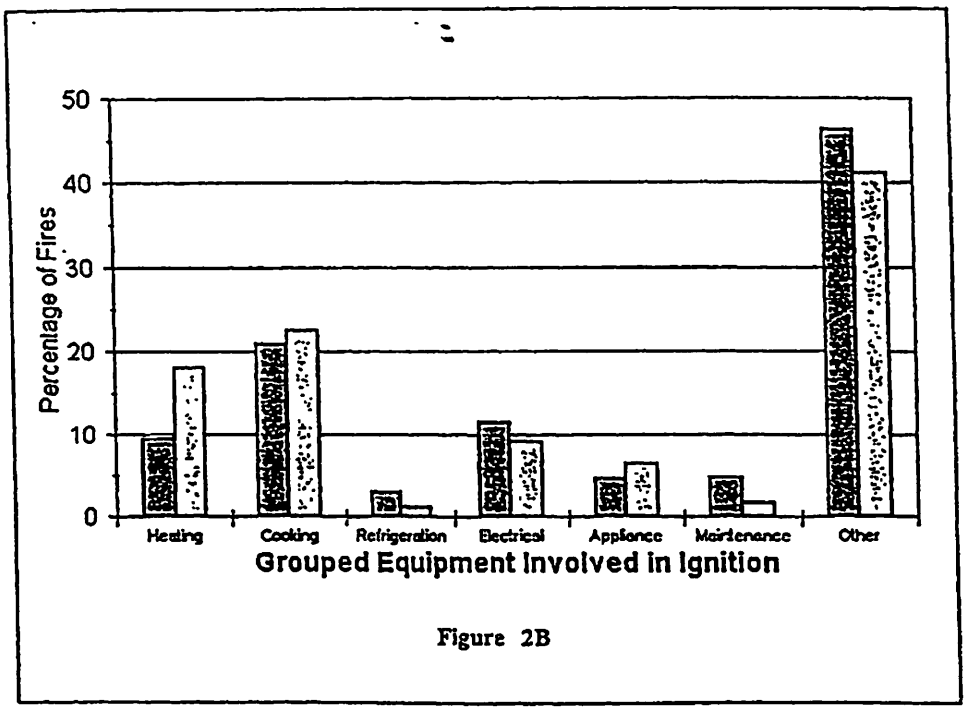

Figure 2B

Note: Includes residential structure fires only
Cities : 11 cities, 5/92 - 2/93
4 cities, 1/91 - 2/91 and 5/91 - 12/91
NFIRS : 1/91 - 3/91 and 5/91 - 12/91

CITIES NFIRS

Source: U.S. Consumer Product Safety Commission/EPHA

Figure 3: COMPARISON OF FIRE DATA FROM CITIES IN THE 1992 SMOKE DETECTOR FIRE INCIDENT STUDY WITH NATIONAL FIRE DATA

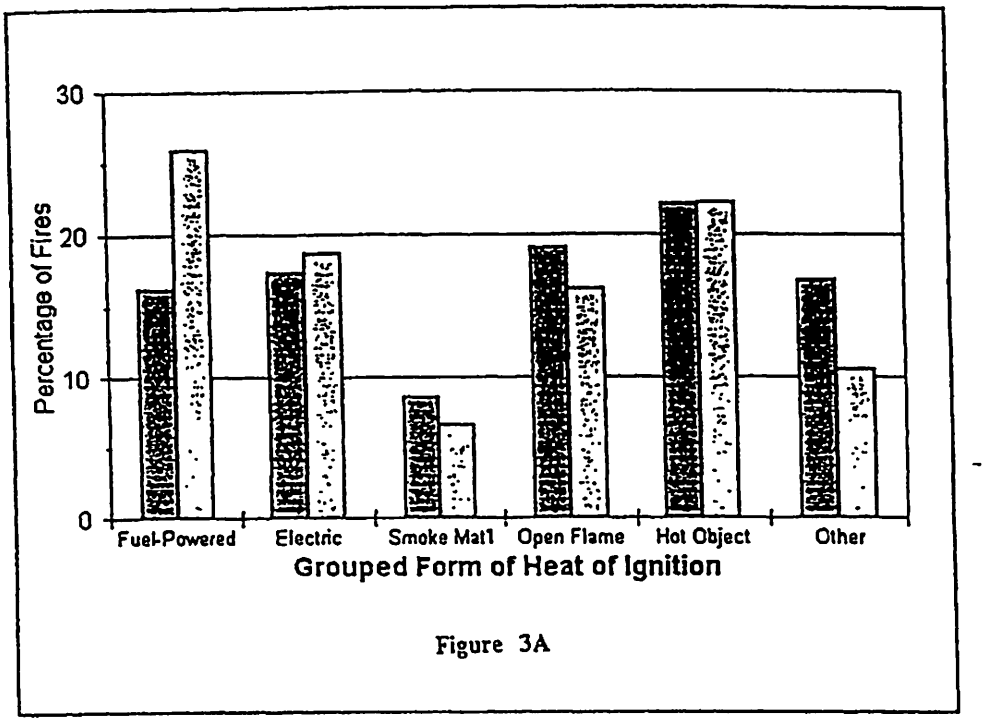

Figure 3A

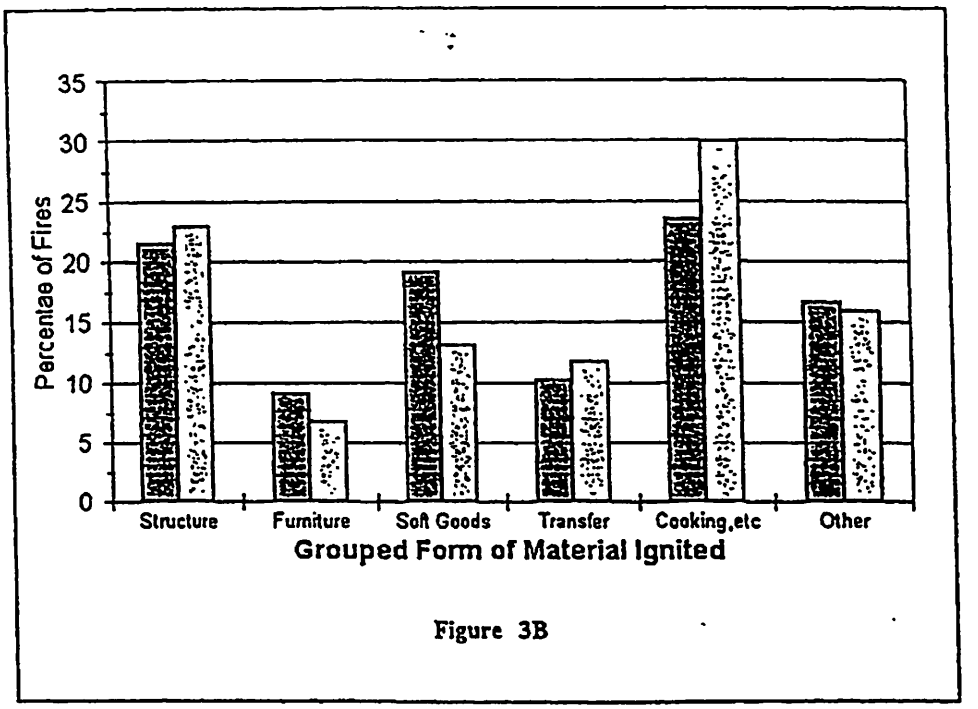

Figure 3B

Note: Includes residential structure fires only
Cities : 11 cities, 5/92 - 2/93
4 cities, 1/91 - 2/91 and 5/91 - 12/91
NFIRS : 1/91 - 3/91 and 5/91 - 12/91

CITIES NFIRS

Source: U.S. Consumer Product Safety Commission/EPHA

proportion of fires in the study cities involved soft goods such as mattresses/bedding as the form of material first ignited. The effect of these differences on the study findings is not clear. However, for the most part, it appears that residential structure fires in these cities are reasonably representative of fires nationally, as characterized by NFIRS.

D. Smoke Detector Legislation

It is noted that smoke detector legislation varied by city, which could affect the proportion of dwellings that had detectors, as well as the type of detectors in use. The details of the smoke detector legislation operable in the sample cities are summarized in Appendix C. A few general statements may be made. All of the sample cities required detectors for at least some subset of housing. Legislation in most cities became effective in the early 1980's. Few cities required detectors for all existing housing. Detectors were more often required for multiple-unit housing than one- or two-family homes. Some cities required detectors for rental housing only, particularly for housing existing when the regulations became effective (as opposed to new construction).

III. RESULTS

A. Population of Detectors and Type of Housing

1. Number of Detectors

This study included a total of 263 reports on residential structure fires in which a smoke detector failed to alarm when it should have. These fires resulted in 14 deaths, 33 injuries and $2.7 million in property loss. These 263 households contained a total of 324 detectors, a mean of 1.2 detectors per household. Most households, 81 percent, contained only one detector; 16 percent contained two (See Table 2). Thus, 97 percent of these households contained no more than two detectors. The largest number of detectors reported in a household was six.

Compared to the findings of the Smoke Detector Operability Survey, these fire households contained a smaller average number of detectors than did non-fire households. In the Smoke Detector Operability Study (of non-fire households), among households with detectors, the general population contained 1.6 detectors per household; the low income population contained 1.5 detectors per household. Also, 59 percent of the general population of households with detectors and 71 percent of the low income households with detectors contained only one detector.[10]

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[10] *Smoke Detector Operability Survey: Report on Findings*, Charles L. Smith, U.S. Consumer Product Safety Commission, as Revised, October 1994, p. 4.

2. Detector Type and Power Source

The study protocol specified that information on detector type and operation was to be collected for a maximum of three detectors per household. Information was reported for a total of 314 detectors in 263 households. (Information occasionally was not collected for all three detectors.) Of those detectors for which type was reported, most detectors, 89 percent, were ionization type (contained a warning citing radioactive materials). About 10 percent were photoelectric type (did not contain a warning citing radioactive materials). The

Table 2.

Number and Characteristics
(Power Source, Type, and Housing Type)
of Detectors, All Households

Number of Detectors per Household (n-262)	Percent of Households
1	81
2	16
3	2
4 or more	1
Power Source (n=289)	**Percent of Detectors**
Battery Only	81
Hard-Wire Only	16
Plug-In Only	2
Combination	1
Detector Type (n=246)	**Percent of Detectors**
Ionization	89
Photoelectric	10
Combination	2
Type of Housing (n=253)	**Percent of Households**
Rental	70
Owner-Occupied	30

Note: Distributions allocated households or detectors for which the variable was not reported.

Source: U.S. Consumer Product Safety Commission/EPHA
Data collected from 15 fire departments

remainder, about 2 percent, were thought to be a combination of ionization and photoelectric (had two test buttons).

Most detectors in these households, 81 percent, were solely battery-powered. About 18 percent were AC-powered; 16 percent hard-wired, and 2 percent cord-connected plug-in units. One percent were hard-wired with a battery back-up.

The most common detector was battery-operated ionization, accounting for 78 percent (191 of 245) of detectors where both type and power source were known.

Compared to the Smoke Detector Operability Survey, the Fire Incident Study included a greater proportion of ionization-type, battery-powered detectors. The Smoke Detector Operability Survey indicated that 78 percent of detectors in U.S. households were ionization type and 72 percent were solely battery-powered.

3. Type of Housing

Of the 253 fires in which renter/owner status was reported, 70 percent of the households involved were rental units, the remainder were owner-occupied. While 56 percent of the rental units were apartments, 43 percent were one- or two-family dwellings. The remainder included rooming houses or hotels.

This preponderance of rental units was not evident among the inoperable detectors identified in the Smoke Detector Operability Survey, the subset most equivalent to the fire study where failure to operate was a prerequisite for inclusion. Among detectors that failed to alarm to testing in the Operability Survey, 29 percent were in rental housing, the same percent of rental housing as in the total survey population. There is no indication, then, that rental housing is a contributing factor to detector inoperability.

B. Detectors That Should Have Alarmed

1. Characteristics

Of the 314 detectors for which information was collected, 273 detectors were believed to be in situations where the detector should have alarmed, the focal point of the study. This included all detectors for which the fire department or occupant believed that there was enough smoke at the detector that the detector should have alarmed, and the fire was not arson-related.[11] Subsequent analysis will be confined to these 273

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[11] A total of 26 fires involved arson or suspected arson. The 37 detectors in these fires have been excluded from the remainder of this analysis, due to the possibility that they may have been tampered with by the arsonist.

detectors, or appropriate subsets. Their characteristics are presented in Table 3, column 1, and are very similar to the distributions of detectors in the larger number of households (Table 2).

Table 3.

Smoke Detector Characteristics, by Selected Category

	CATEGORY					
	All Detectors that Should have Alarmed (Col. 1)	Detectors that Wouldn't Alarm to Smoke Test When Powered (Col. 2)	Detectors Found Disconnected (Col. 3)	Disconnected Detectors with a Reported Problem (Col. 4)	Detectors Found Connected (Col. 5)	Detectors that Alarmed to Smoke Test When Powered (Col. 6)
Characteristics	Percent	Percent	Percent	Percent	Percent	Percent
Power Source						
Total	100 (n=258)	100 (n=53)	100 (n=161)	100 (n=40)	100 (n=96)	100 (n=133)
Battery Only	81	72	88	82	70	96
Hard-Wire Only	16	26	9	13	27	2
Plug-In Only	2	-	2	5	2	1
Combination	1	2	1	-	1	1
Type						
Total	100 (n=223)	100 (n=50)	100 (n=140)	100 (n=37)	100 (n=83)	100 (n=116)
Ionization	88	92	88	89	88	90
Photoelectric	10	6	11	8	10	9
Combination	2	4	1	3	2	1
Housing Type						
Total	100 (n=264)	100 (n=53)	100 (n=157)	100 (n=39)	100 (n=107)	100 (n=131)
Rental	69	70	71	69	66	68
Owner-Occupied	31	30	29	31	34	32

Note: Distributions allocate detectors for which the variable was not reported.

Source: U.S. Consumer Product Safety Commission/EPHA
Data collected from 15 fire departments

2. Initial Condition Found

After the fire was extinguished, the fire department investigator sprayed the detector with aerosol smoke and pushed the test button, with some exceptions for special conditions as noted in the protocol. Following those steps, the investigator described the condition of the detector as it was found (Table 4). Among the 273 detectors in the study that ought to have alarmed but did not, 162 (59 percent) were found to be disconnected from the power source. A battery was missing in 102 detectors, and disconnected in 41 detectors. The AC power to 19 detectors was disconnected. The remaining 111 (41 percent) detectors were found to be connected to a power source.[12] We note that this does not necessarily mean that in all cases the

Table 4.

Initial Condition of the Detector
Found by the Investigator
(n=273)

Condition	No.	Percent of Detectors
Power Disconnected	**162**	**59**
Missing Battery	102	37
Disconnected Battery	41	15
Disconnected AC	19	7
Other	**180**	
Heat Deformed	41	15
Missing Cover	36	13
Clogged with dust/dirt	23	8
Insect Infestation	14	5
Failure of AC Power Supply	6	2
Located in dead air space	5	2
Other	55	20

Note: It was possible to specify multiple conditions for a detector. Therefore, number of conditions is greater than 273 and the percent of detectors adds to more than 100. The conditions cited under "Power Disconnected" do not overlap each other, but could overlap conditions in the "Other" section.

Source: U.S. Consumer Product Safety Commission/EPHA
Data from 15 fire departments

[12]This includes four detectors collected as samples that were too damaged to be sure that power was connected.

power source was functioning when smoke reached the detector during the fire. This finding of 59 percent without connected power is remarkably consistent with the findings of the Smoke Detector Operability Survey in which it was found that 60 percent of the detectors that did not alarm to the smoke test were found without a connected power source.[13]

Among the other most common conditions noted by the investigators, 15 percent were deformed by heat, 13 percent were missing a cover, 8 percent were clogged with dust/dirt, and 5 percent showed signs of insect infestation. Heat deformation was almost certainly a result of the fire. A missing cover may or may not have been a result of the fire and subsequent extinguishment. Some conditions grouped under "other" involved batteries; dead or corroded batteries, and wrong type of battery installed.

3. Test Results

Following any necessary restoration of power, a total of 136 detectors (50 percent) alarmed to the aerosol smoke test (Table 5 and Figure 4). Fifteen responded to the first smoke test, the remainder (121 of 136) responded only after a new battery had been installed or the AC power connection was

Table 5.

Aerosol Smoke Test Results

Result	Total		Initial Connection to Power Source			
			Disconnected		Connected	
	No.	Percent	No.	Percent	No.	Percent
Total	273	100	162	100	111	100
Alarmed	136	50	99	61	37	33
Did not Alarm	53	19	20	12	33	30
Not Tested When Powered	84	31	43	27	41	37

Source: U.S. Consumer Product Safety Commission/EPHA
Data from 15 fire departments

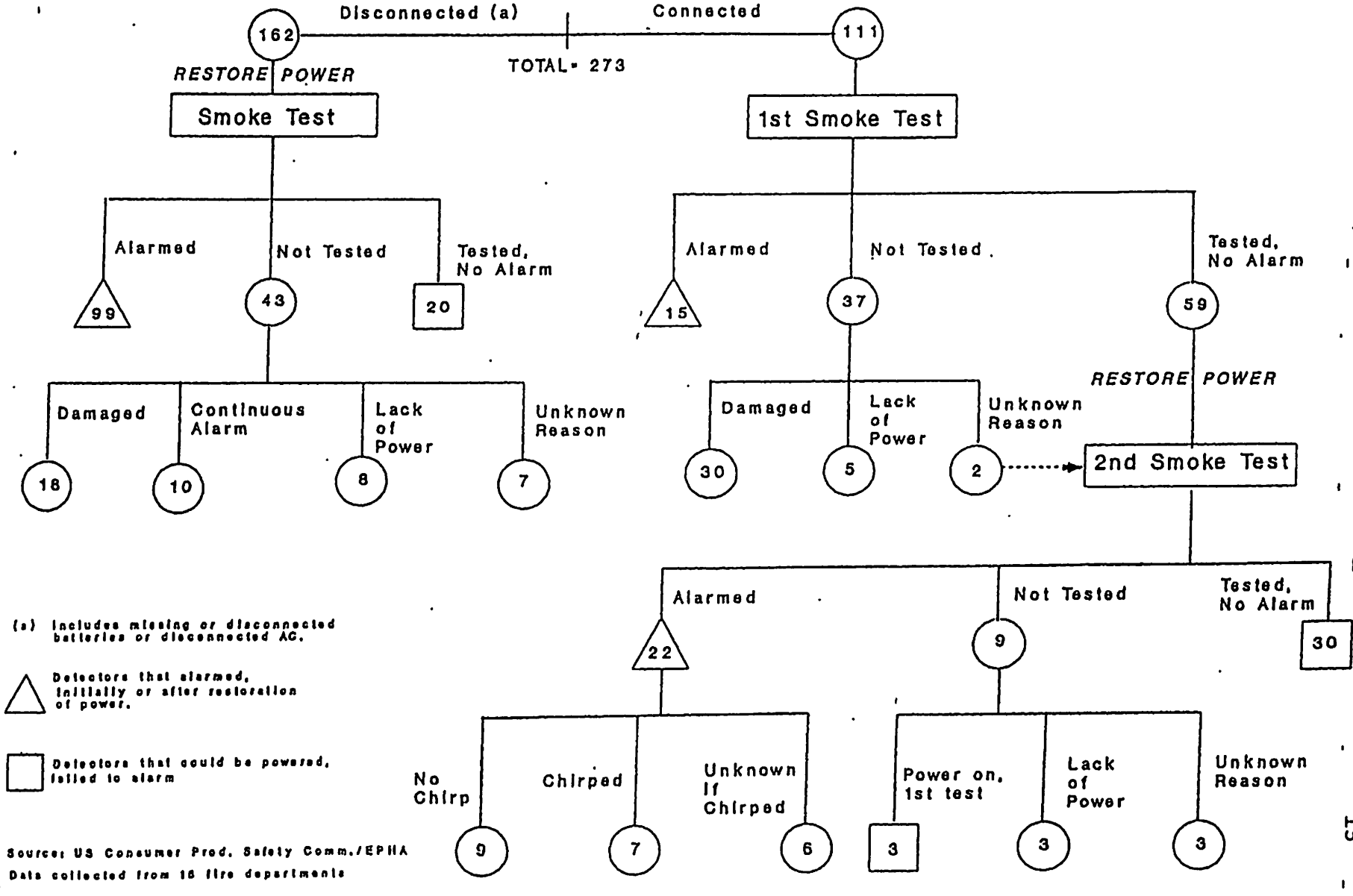
[13] *Unpublished communication from* Charles L. Smith, U.S. Consumer Product Safety Commission.

Figure 4

Fire Incident Study

Smoke Test Results

Detectors That Should Have Alarmed



restored. A total of 53 detectors (19 percent) failed to alarm to the smoke test even after power was restored. A total of 84 (31 percent) could not be tested under conditions of a connected power source, predominantly due to damage from the fire. Of these 84, 10 could not be tested because they alarmed continuously when repowered. A total of 189 detectors were tested with aerosol smoke during the testing procedure. Among those that were tested, 72 percent alarmed to the smoke test; 28 percent did not alarm.

The characteristics of the 53 detectors that failed to alarm to a smoke test when powered are shown in Table 3, column 2. They included a significantly smaller proportion (72 percent) of battery-powered detectors than detectors that could be made to alarm (96 percent) ($p < .005$) shown in Table 3, column 6. Conditions noted for these detectors included 15 that were heat deformed, 13 clogged with dirt/dust, 11 missing a cover, and 7 with insect infestation (multiple conditions could be cited for a given detector).

The test button was pushed if the detector alarmed to the aerosol smoke or, following the second aerosol smoke test, even if the detector did not alarm. Of the 136 detectors that responded at some point to the aerosol smoke, 3 (2 percent) did not respond to the test button. Conversely, 4 detectors responded to the test button that had not responded to the aerosol smoke. A total of 15 of 273 detectors (5 percent) did not have a test button. When interpreting these results, it must be kept in mind that all these detectors were in households in which a fire had occurred, and received varying amounts of damage or contamination.

4. Sample Collection and Engineering Analysis

As noted earlier, investigators collected detectors as samples in accordance with the study protocol. This included detectors that did not respond to aerosol smoke or the test button when powered, detectors that were found disconnected and the occupant reported that there was a problem, and detectors that were found with a dead battery and the occupant reportedly had not heard a low-battery signal. The study protocol also called for sample collection if the detector was an AC type without severe damage that failed to alarm in the fire but could not be repowered for testing. Some detectors continuously alarmed when repowered and could not be tested. These, also, were collected. We note that not all detectors that met the criteria for sample collection were sent to CPSC, particularly AC detectors which were more difficult to remove. Although provisions were made for occupants to send AC detectors to CPSC after they had been removed by an electrician, few did so.

A total of 114 detectors met the study criteria for sample collection and were evaluated by the CPSC Engineering Laboratory. Some detectors met multiple criteria for collection.

The number of detectors collected for specific reasons follow.

Failed to Alarm to Aerosol Smoke While Powered	49
Disconnected with Reported Problem	33
Dead Battery with No Low Battery Signal	7
Alarmed to Aerosol Smoke but Not to Test Button	3
Could Not Be Tested	42

Of the 114 detectors collected for laboratory analysis, 22 could not be subjected to testing due to extensive fire damage. Among the remaining 92 detectors that were tested, 43 passed all screening tests in the laboratory.

Among the detectors that failed the aerosol smoke test in the field, 25 passed all screening tests in the laboratory. However, examination indicated the presence of deterioration and corrosion on the horn element contacts, which can result in the horn becoming inoperative. Function may be restored by slight movement of the horn element, such as might occur during removal from the home and subsequent transport to the laboratory.

Of the 33 detectors for which problems were reported by the occupant, 22 involved nuisance alarms (alarmed to non-fire situations). Testing indicated that, on average, these 22 were more sensitive than detectors without nuisance problems that were tested in the Smoke Detector Operability Survey.

Additional findings included a variety of component failures, corroded battery clips, presence of excessive debris in the detector, and fire damage that prevented evaluation of their pre-fire condition. Additional details of sample analysis are included in Appendix D.

C. Comparison of Detectors Found With and Without an Initially Connected Power Source

1. Characteristics

As indicated earlier, 59 percent of the detectors were found disconnected from their power sources, and 41 percent were still connected. The characteristics of these two groups of detectors are included in Table 3, columns 3 and 5. The percentage of hard-wired detectors (27 percent) was significantly greater among connected detectors than among those disconnected (9 percent), $p < .005$. Put another way, solely battery-operated detectors were more often disconnected, compared to solely hard-wired

detectors. There were no significant differences in the distribution of type of detector or type of housing between the two groups.

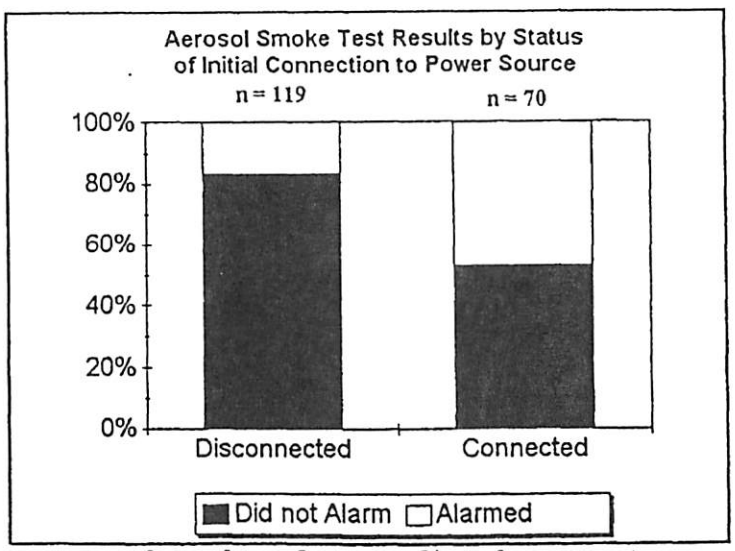
The condition of the power connection to the detector is shown below, distributed by power source (excluding combination power sources).

Condition	Battery		Hard-Wired	
	Number	Percent	Number	Percent
Total	208	100	41	100
Connected	67	32	26	63
Disconnected	141	68	15	37

2. Test Results

Results of testing in the field indicated that after power had been restored, a greater proportion of initially disconnected detectors than initially connected detectors responded to the aerosol smoke test (Figure 5). Among the initially disconnected detectors that could be tested, 99 of 119 (83 percent) responded to aerosol smoke. Among the initially connected detectors that could be tested, 37 of 70 (53 percent) responded to the aerosol smoke, a significant difference ($p < .005$).

Figure 5



Based on data from 15 fire departments

Most of the detectors that failed to respond to aerosol smoke were collected for testing; 19 of the 20 in the disconnected group, and 30 of the 33 in the connected group. Among the 43 initially disconnected detectors that were not tested under power, 10 alarmed continuously when powered which prevented testing. Seven were collected as samples. Among the detectors in the initially connected group that were not tested, it is noted that 8 were AC detectors in dwellings in which the electrical power was not functioning at the time of the investigation.

D. Possible Malfunctions

1. Detectors with Reported Problems

For the 162 detectors found without a connected power source, when occupants were available they were asked additional questions. They were asked, "Did you have any problems with this detector?" If they said "yes," the investigator was to say "Please describe the problem." Among the 115 detectors for which the occupant was available to be questioned, occupants reported that 40 detectors (35 percent) caused them problems. The detector characteristics (Table 3, column 4) were not significantly different from the disconnected detectors without problems ($p > .05$). Of these 40 detectors with problems, 33 were collected for analysis in the laboratory. Detectors with problems accounted for an estimated 21 percent of the detectors in the study, allocating incidents involving disconnected detectors for which an occupant was not available to ask about a problem.

When occupants stated that there was a problem, they were asked to describe it. Most often (16 detectors), they cited "too frequent alarms" without specifying any circumstances connected with the alarms (Table 6). Alarms to cooking were cited for 12 detectors, followed by alarms to tobacco smoke and batteries running down (4 detectors each). An alarm to steam or humidity was reported for one detector. Other situations cited as problems included continuous alarms, intermittent alarms, and low battery-associated chirps. Some occupants cited multiple problems for a detector. When a specific source of a problem was cited, investigators were asked to provide the distance of the detector from the source. A distance was provided for only 8 detectors, ranging from 6 feet to 20 feet. Results of laboratory sensitivity are discussed in Appendix D, but may not indicate the detector's prefire condition, due to smoke and water contamination suffered in the fire. It is noted that the

problems cited above also were among those cited most often by respondents in the Smoke Detector Operability Survey.[14]

Table 6.

Problems Reported for Detectors
Found With a Disconnected Power Source
(n=115)

Problem Reported	Number	Percent
Stated no problem	75	65
Stated there was a problem	40	35
Alarms too often, unspecified	(16)	-
Alarms to cooking	(12)	-
Alarms to tobacco smoke	(4)	-
Battery runs down to often	(4)	-
Other	(10)	-

Note: Occupants sometimes cited multiple problems.
Includes only detectors for which occupants were available to respond to questions.
Source: U.S. Consumer Product Safety Commission/EPHA
Data from 15 fire departments

2. Dead Batteries

Among the connected detectors that alarmed to the smoke test were 22 detectors that did not alarm until the battery was replaced. This was thought to indicate that the battery in place was dead. For these detectors, the protocol called for the occupant to be asked "Detectors usually chirp or beep to tell you that the battery is getting weak. Do you recall hearing this sound?" Of the 16 detectors for which the occupant was available and able to respond either positively or negatively, 9 indicated that they had not heard a chirp. The study protocol called for sample collection of these 9; 7 were received. These 22 detectors with likely dead batteries constituted about 8 percent of the 273 detectors in the study.

[14] *Smoke Detector Operability Survey: Report on Findings*, Charles L. Smith, U.S. Consumer Product Safety Commission, as Revised, October 1994, p.22.

IV. DISCUSSION

The purpose of this study was to identify the reasons why some smoke detectors failed to alarm in residential structure fires. To do this, it was necessary to work within the confines of the fire scene and the difficulties it entailed.

It is important to recognize a number of vital features to put the study results into proper perspective. First, the primary goal of the fire service is suppression of the fire. Although the fire service recognizes the importance of prevention and the activities needed to achieve it, those activities are usually "add-ons" to their already busy schedule. This has the effect of limiting the number of questions they realistically will be able to answer. Second, the event of the fire itself and ensuing suppression may have affected the condition of the detector as it was found. This means that its condition before the fire must be estimated to some extent, taking the effect of the fire, suppression, and clean-up into consideration. Third, questions asked of the occupant must take into account the possibility of potential liability on the part of the occupant, e.g., some jurisdictions have taken occupants to court because they allegedly removed the battery from the detector.

These factors all affected the questions asked during the study. Primarily, they had the effect of limiting the number of questions. The companion study, the Smoke Detector Operability Survey, included exploration of some issues that the Field Investigations Committee believed could not be accurately assessed after a fire. One example of this was further exploration of why detectors had been disconnected. In the Operability Survey, when a detector was found to have a disconnected power source, the respondent was asked why the battery was removed or power disconnected. While 32 percent of those respondents reported removal of power due to nuisance alarms, about 40 percent forgot to replace the batteries or did not check to see that they had power, with an additional variety of explanations such as "no batteries in the house" or "removed for other purposes."[15] Both studies indicated that while removal of power to address unwanted alarms was a major reason for disconnection, absence of power for other reasons also was common.

The finding that battery-powered detectors were more likely to be disconnected is consistent with the finding that relatively large numbers of detectors were disconnected for reasons apparently unrelated to unwanted alarms. Together, these findings lend further support to the current trend toward requiring hard-wired detectors in new construction. For the majority of households that do not have hard-wired AC detectors,

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[15] *Smoke Detector Operability Survey: Report on Findings*, Charles L. Smith, U.S. Consumer Product Safety Commission, as Revised, October 1994, p.12.

it appears that additional efforts to revise consumer messages are in order. One possibility is to increase the emphasis on keeping spare batteries in the house so that the battery can be replaced immediately when the low battery signal chirps.

Compared to detectors that were found disconnected, a greater proportion of detectors found connected did not alarm to the aerosol smoke test. To some extent, this difference probably results from the large number of detectors in the disconnected group that were unpowered for reasons apparently unrelated to performance. When these detectors were powered and tested with aerosol smoke, most were able to respond.

The study findings indicated a greater than expected presence of rental units among fire households with detectors that did not alarm. Other studies have indicated that the risk of fire is higher in households with lower income and education levels.[16] A greater proportion of renters may also occur in these households. Further research to verify the proportion of fires that occur in rental housing might help direct prevention efforts to populations at higher risk.

It is further noted that it was the intent of the study to identify the ages of the detectors involved. However, the information collected to address this issue, the Underwriters Laboratories (UL) Issue Number that is stamped on each detector, turned out not to be a reliable indicator of the actual age when compared to manufacturers' date codes. CPSC staff has not been successful in obtaining information to interpret date codes for most detectors in the study.

Finally, it is important to note that other studies have documented the prevalence of inoperable detectors in residences. In Fairfield, CT, for example, a survey of one- and two-family dwellings indicated that among over 14,000 homes surveyed, more homes were found with detectors not working (1,438) than with no detectors (765).[17] A similar finding was documented in the Smoke Detector Operability Survey. It is clear that the importance of addressing this situation is at least as important as the issue of getting detectors in every home.

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[16]Rita F. Fahy and Alison L. Norton, *How Being Poor Affects Fire Risk...*, Fire Journal, January/February 1989, pages 29 - 36.

[17]"Smoke Detector Compliance in Fairfield, Connecticut," Final Report, February 1, 1993.

V. Conclusions

U.S. fire loss data indicated that operating smoke detectors have the ability to reduce fire death rates, but also indicated that detectors did not operate in a large proportion of the fires where they should have. The results of the Fire Incident Study of detector operability indicated that the most common reason for failure to alarm in fires was that the detector was not connected to a power source at the time, 59 percent of all detectors. For detectors without a power source, an unacceptably large proportion of consumers, 35 percent, stated that there were problems with the detector, predominantly alarms to cooking activities. Results also indicated that some detectors were incapable of alarming to the aerosol smoke test when powered. Although fire damage and fire contamination limited the conclusions that could be drawn from laboratory sample analysis, laboratory findings included horns that did not sound, failure to respond in the sensitivity testing chamber, and a variety of conditions that included corroded battery clips and component failures. These results are consistent with the reasons for detector inoperability identified in the Smoke Detector Operability Survey of non-fire households.

APPENDIX A

PARTICIPATING CITIES

City	Number of Reports
Total	263
Buffalo, NY	12
Corpus Christ, TX	17
El Paso, TX	3
Ft. Worth, TX	22
Memphis, TN	55
Miami, FL	12
New Orleans, LA	4
Oklahoma City, OK	13
Phoenix, AZ	11
Portland, OR	36
Sacramento, CA	26
Seattle, WA	13
Tampa, FL	2
Tulsa, OK	18
Virginia Beach, VA	19

OMB #3041-0029

APPENDIX B

February 1992

NATIONAL SMOKE DETECTOR PROJECT

SUPPLEMENTAL REPORT FOR RESIDENTIAL FIRE INCIDENTS

INSTRUCTIONS:

Complete this report for every residential structural fire in which the detector nearest the fire failed to alarm when it should have. Attach your Fire Incident Report, and Casualty Report when applicable.

Circle appropriate responses or fill in the blanks as appropriate.

Date of Fire _____ FD Incident No._____

Address _____

Suggested Wording to Explain the Project:

(SAID TO OCCUPANT) I would appreciate your permission to test your smoke detectors as part of a national project that our fire department is supporting. This project could lead to better, more effective, smoke detectors for everyone. Our testing will not hurt your home or your detectors. In fact, if we find any dead or missing batteries, we will replace them free of charge. And if we find problems with a detector that we can't solve here, we want to collect it for further testing. We will leave battery-powered detectors free of charge to replace any that we collect. If your detectors are not battery operated, we will leave a battery-powered detector for your protection until you can arrange for proper replacement. Is it okay for us to collect this information?

_____ Yes _____ No (If No, then stop.)

(SAID TO OCCUPANT) It would help us if you would accompany us as we go through your home, so we can ask you questions about each detector as we test it.

SECTION I:

REPEAT THIS SECTION AS NECESSARY TO TEST THREE DETECTORS, INCLUDING THE ONE NEAREST THE FIRE. ANSWER QUESTIONS 1-13 FOR ONE DETECTOR BEFORE PROCEEDING TO THE NEXT. BE SURE ALL RESPONSES FOR A DETECTOR ARE IN THE SAME COLUMN OR CITE THE SAME NUMBER. WHEN ALL DETECTORS HAVE BEEN TESTED, COMPLETE SECTION II, QUESTIONS 14-19.

INSTRUCTIONS FOR SAMPLE COLLECTION:

When the questionnaire indicates that a battery-operated detector should be collected, immediately label the collected detector with the assigned detector number, (1-3), your city, and the fire department incident number before you proceed to the next detector. Mail detector to CPSC in box supplied. If you supplied a new battery while testing detector, send both the old and new batteries.

When the questionnaire states that a hard-wired detector should be collected, tell the occupant that the detector should be replaced and ask them to mail it. To remind them, put a stick-on dot on the detector on which you have written its assigned number (1-3). Leave an information sheet and a franked, addressed mailing box with enclosed ID card that you have filled out.

Leave a replacement battery-powered detector.

1. Did anyone (either the fire service or someone else) hear this detector alarm in the fire?

	Detector #		
	1	2	3
Yes	Y	Y	Y
No	N	N	N
Don't know	U	U	U

2. Based on the available knowledge of the fire, was there believed to be sufficient smoke at the detector that the detector might have been expected to alarm?

	Detector #		
	1	2	3
Yes	Y	Y	Y
No	N	N	N
Don't know	U	U	U

IF ALL DETECTORS IN THE UNIT ARE TOO SEVERELY DAMAGED TO TEST, CHECK HERE ☐ , ANSWER Q. 1-2 FOR EACH DETECTOR, THEN SKIP TO Q. 14.

IF OCCUPANT VOLUNTEERS INFORMATION THAT THIS DETECTOR DOES NOT HAVE A BATTERY IN IT, SKIP TO Q. 5.

3. Conduct an initial smoke test. Using the designated aerosol spray, point the tube at the detector and release a two-second burst of aerosol. (Count "one one thousand" to estimate one second.) If there is no response, wait 10 seconds (in case there is a time-delay feature in the detector), then spray again for one second with the tube positioned right against the detector's smoke inlets. If there is still no response, wait 10 more seconds and repeat the test a third time with a one-second spray.

   Did the detector sound in response to this test?

	Detector # 1	2	3
Yes	Y	Y	Y
No (If No, skip to Q. 5)	N	N	N
Not tested due to severe damage (Return to Q. 1 for next detector or Q. 14 if last detector)	U	U	U

4. If detector alarmed in response to smoke test, press and hold the test button(s), one at a time. Did the detector sound in response to the test button(s)?

	Detector # 1	2	3
Yes (all available buttons)	Y	Y	Y
One alarmed, the other didn't (Collect detector & continue)	M	M	M
No (Collect detector and continue)	N	N	N
No test button	U	U	U

5. What type of power supply does the detector have? (Remove detector cover, or remove from ceiling as necessary.)

	Detector # 1	2	3
a. Battery only	a	a	a
b. Hard wire only (AC)	b	b	b
c. Plug-in	c	c	c
d. Hard-wired with battery back-up	d	d	d
e. Other (specify)_____	e	e	e
f. Unknown	f	f	f

6. Does this detector indicate that it contains radioactive materials (either on the enclosure or inside)?

	Detector # 1	2	3
Yes	Y	Y	Y
No	N	N	N
Unknown	U	U	U

7. Does this detector have 2 test buttons?

	Detector # 1	2	3
Yes	Y	Y	Y
No	N	N	N
Unknown	U	U	U

8. Enter all available identifying information:

Detector #	Brand Name	Model #	UL Issue #	UL Control #
1.				
2.				
3.				

9. Circle condition of the detector <u>as you found it</u>. Circle as many as apply.

	Detector # 1	2	3
a. Missing battery	a	a	a
b. Disconnected battery	b	b	b
c. Disconnected from AC power supply	c	c	c
d. Failure of AC power supply	d	d	d
e. Missing cover	e	e	e
f. Heat deformed, soot covered	f	f	f
g. Insect infestation	g	g	g
h. Clogged with dust/dirt	h	h	h
i. Located in dead air space	i	i	i
j. Other (specify) _____	j	j	j
k. None of the above	k	k	k

IF THIS DETECTOR SOUNDED in response to smoke and button tests, replace cover and remount on ceiling or wall, then return to Q. 1 to report on next detector. If the detector is to be collected, label it, then return to Q. 1. If this is the last detector to be tested, skip to Section II, Question 14.

IF THIS DETECTOR DID NOT SOUND IN RESPONSE TO SMOKE TEST OR IF OCCUPANT VOLUNTEERED THAT THE BATTERY WAS MISSING, put in a new battery or restore AC power if appropriate, remount on ceiling or wall, and answer Q. 10. If you cannot restore power, indicate this in Q. 10.

10. Repeat the smoke test, using up to three one-second sprays, spaced 10 seconds apart. Did the detector sound in response to this smoke test?

	Detector # 1	2	3
Yes	Y	Y	Y
No (Collect detector after pressing test button, Q. 11, and continue)	N	N	N
Not retested, couldn't restore power (Collect if there was sufficient smoke in the fire that it should have operated but didn't, skip to Q. 13)	U	U	U
Not retested, AC power was on at beginning (Collect after pressing test button, Q. 11, and continue)	Z	Z	Z

11. Press the test button(s). Did the detector sound?

	Detector # 1	2	3
Yes (all available buttons)	Y	Y	Y
One alarmed, one didn't alarm (Collect detector & continue)	M	M	M
No (Collect detector and continue)	N	N	N
Not tested, no power	U	U	U
No test button	Z	Z	Z

12. Was this detector found to have a <u>dead</u> battery, that is, the old battery was <u>connected</u>, but the detector responded to aerosol smoke only <u>after</u> you replaced an old battery?

Yes (Ask Q. 12a)	Y	Y	Y
No (Skip to Q. 13)	N	N	N

a. Say to occupant, **"DETECTORS USUALLY CHIRP OR BEEP TO TELL YOU THAT THE BATTERY IS GETTING WEAK. DO YOU RECALL HEARING THIS SOUND?"**

	Detector # 1	2	3
Yes	Y	Y	Y
No (Collect detector)	N	N	N
Don't know	U	U	U
Occupant not available	Z	Z	Z

13. Was this detector found without a battery, battery disconnected, or AC disconnected (9a, 9b or 9c circled)?

Yes	(Ask Q. 13a).....	Y....	Y....	Y
No	(Skip to instructions following Q. 13c).....	N....	N....	N

a. Ask the occupant, **"HAVE YOU HAD ANY PROBLEMS WITH THIS DETECTOR?"**

	Detector # 1	2	3
Yes (Collect detector).....	Y....	Y....	Y
No.....	N....	N....	N
Occupant not available.....	Z....	Z....	Z

b. If "yes" to Q. 13a, say **"PLEASE DESCRIBE THE PROBLEM."** Don't suggest possible answers. Circle as many as apply.

		Detector # 1	2	3
a)	Alarms too often, unspecified.....	a....	a....	a
b)	Alarms to steam/humidity.....	b....	b....	b
c)	Alarms to cooking.....	c....	c....	c
d)	Alarms to tobacco smoke.....	d....	d....	d
e)	Alarms to fireplace.....	e....	e....	e
f)	Battery runs down too often.....	f....	f....	f
g)	Other (specify below).....	g....	g....	g

Detector#___Problem_____

Detector#___Problem_____

Detector#___Problem_____

c. For any detector referred to in Q. 13b whose problem may be related to location, cite detector number, source reported by occupant to have caused the problem (such as stove), and distance between the detector and source, in feet.

Detector #____ Source_____ Distance_____

Detector #____ Source_____ Distance_____

Detector #____ Source_____ Distance_____

RETURN TO QUESTION 1 AND RESPOND TO QUESTIONS 1-13 FOR NEXT DETECTOR. When you have provided information on all detectors, complete Section II, Q. 14-19.

SECTION II:

14. Summary

Briefly describe the features of the fire incident and detector usage that are relevant to understanding what happened. You need not repeat information included in accompanying documents.

_____

_____

_____

_____

_____

_____

15. Is the occupant the owner or the renter?
    a. Owner
    b. Renter
    c. Unknown

16. How many detectors are in this unit? _____

17. Which detector was closest to the fire origin?

    Assigned number (1 - 3) _____

18. Circle the assigned number of each detector that you collected as a sample. Be sure each detector is labeled with the assigned number, fire incident number and city.

    Detector # 1 2 3 none

19. Circle the assigned number of each detector that you asked the occupant to mail to CPSC. Be sure detector number, incident number, and city are entered on the card you enclose in the mailing container.

    Detector # 1 2 3 none

UNITED STATES GOVERNMENT

MEMORANDUM

U.S. CONSUMER PRODUCT
SAFETY COMMISSION
WASHINGTON,D.C. 20207

TO : Linda Smith, EPHA
THROUGH: James I. Price, Director, ESME
Margaret L. Neily, Project Manager, Smoke Detectors
FROM : Eleanor Perry, ESME EP

January 14, 1993

SUBJECT: Summary of City Code Requirements to Support the Fire Incident Study Report (EP)

The attached summary, "Provisions of City Smoke Detector Codes" was prepared from the city code information you provided. Code provisions have been separated into those for new and existing residential property for either one and two family dwellings or multiple family dwellings since these categories were treated separately in many of the codes. Under the heading for multiple family dwellings, the provisions apply to apartment houses, rooming houses, dormitories, hotels, motels and lodging houses.

PROVISIONS OF CITY SMOKE DETECTOR CODES

CITY	STATE	EFFECTIV DATE	1 & 2 FAMILY DWELLING NEW CONSTRUCTION TYPE	1 & 2 FAMILY DWELLING NEW CONSTRUCTION LOCATION/PROVISION	1 & 2 FAMILY DWELLING EXISTING CONSTRUCTION TYPE	1 & 2 FAMILY DWELLING EXISTING CONSTRUCTION LOCATION/PROVISION	MULTIPLE FAMILY DWELLINGS NEW CONSTRUCTION TYPE	MULTIPLE FAMILY DWELLINGS NEW CONSTRUCTION LOCATION/PROVISIONS	MULTIPLE FAMILY DWELLINGS EXISTING CONSTRUCTION TYPE	MULTIPLE FAMILY DWELLINGS EXISTING CONSTRUCTION LOCATION/PROVISIONS
Phoenix	Arizona	State - 7/27/83	Hard wired	Every dwelling unit shall have detectors installed outside each sleeping area in the immediate vacinity of the bedrooms & on each story including basements. Detectors on stories without sleeping areas shall be installed close to the stairway to the floor above. Additional installation & location details shall be in accord with the manufacturer's instructions. The detector's alarm shall be clearly audible in the sleeping area its protecting.	Hard wired or battery	When a permit is required for repairs alterations, or additions valued over $1000 every dwelling unit shall have detectors installed outside each sleeping area in the immediate vacinity of the bedrooms & on each story including basements Detectors on stories without sleeping areas shall be installed close to the stairway leading to the floor above. Additional installation & location details shall be in accord with the manufacturer's instructions. The detector's alarm shall be clearly audible in the sleeping area its protecting.	Hard wired	Every dwelling unit shall have detectors installed outside each sleeping area in the immediate vacinity of the bedrooms & on each story including basements. Detectors on stories without sleeping areas shall be installed close to the stairway leading to the floor above. Additional installation and location details shall be in accord with the manufacturer's instructions. Every dwelling unit for sleeping in hotels, motels & dormitories shall have a detector. Detectors shall be centrally located on the ceiling of a hotel room or the main room in efficiency dwelling units, hotel sleeping rooms, & hotel suits. Its alarm shall be clearly audible in the sleeping area its protecting.	Hard wired or battery	When a permit is required for repairs, alterations, or additions valued over $1000, every dwelling unit shall have detectors installed outside each sleeping area in the immediate vacinity of the bedrooms & on each story including basements. Detectors on stories without sleeping areas shall be installed close to the stairway leading to the floor above. Additional installation and location details shall be in accord with the manufacturer's instructions. Every dwelling unit for sleeping in hotels, motels & dormitories shall have a detector. Detectors shall be centrally located on the ceiling of a hotel room or the main room in efficiency dwelling units, hotel sleeping rooms, & hotel suits. Its alarm shall be clearly audible in the sleeping area its protecting.
Sacramento	California	3/1/84			Hard wired except with State Fire Marshal approval	New owners of residential buildings constructed before 1/1/76 must install detectors within 30 days of acquiring the building. The installation & location shall be in accord with the latest version of the Uniform Building code adopted by Sacramento.	Hard wired or by exception battery with State Fire Marshal approval	Buildings used as hotels, motels lodging or apartment houses must have smoke detectors that have been approved by the State Fire Marshall after 3/1/84. The installation and location shall be in accord with the latest version of the Uniform Building code adopted by Sacramento.	Hard wired or by exception battery with State Fire Marshal approval	New owners of residential buildings constructed before 1/1/76 must install detectors within 30 days of acquiring the building. The installation & location shall be in accord with the latest version of the Uniform Building code adopted by Sacramento. Buildings used as hotels, motels lodging or apartment houses must have smoke detectors that have been approved by the State Fire Marshall after 3/1/84. The installation and location shall be in accord with the latest version of the Uniform Building code adopted by Sacramento.
Miami (NFPA 101 Life Safety Cod 1985 Edition Sec. 19-3.4.4)	Florida								Approved hard wired single or multi - station	Every living unit in the apt. must have a detector (does not include common use areas like corridors, lobbies & basements). Activated alarms shall be audible in sleeping rooms of that unit. Buildings equipped with total automatic smoke detection systems throughout are . exempt . Bldgs using option 2 must have an automatic fire detection system with detectors interlinked to activate alarms & other automatic fire protection devices.
New Orleans	Louisiana	8/78	Hard wired	All residential structures built after 8/78 shall have hard wired smoke detectors.	Hard wired	All residential structures built after 8/78 shall have hard wired smoke detectors	Hard wired	All residential structures built after 8/78 shall have hard wired smoke detectors	Hard wired	All residential structures built after 8/78 shall have hard wired smoke detectors.

CITY	STATE	EFFECTIV DATE	1 & 2 FAMILY DWELLING NEW CONSTRUCTION TYPE	NEW CONSTRUCTION LOCATION/PROVISION	EXISTING CONSTRUCTION TYPE	EXISTING CONSTRUCTION LOCATION/PROVISION	MULTIPLE FAMILY DWELLINGS NEW CONSTRUCTION TYPE	NEW CONSTRUCTION LOCATION/PROVISIONS	EXISTING CONSTRUCTION TYPE	EXISTING CONSTRUCTION LOCATION/PROVISIONS
Buffalo	New York	1/1/84	Hard wired	There shall be one detector in each sleeping area with an alarm clearly audible in adjoining sleeping spaces with intervening doors closed. There shall be one detector at the head of each stairway to an occupied living area placed so that rising smoke is not obstructed from reaching the detector & so that the smoke is intercepted before it reaches the sleeping area.	Hard wired, monitored battery, plug-in with restrainer	There shall be one detector in each sleeping area with an alarm clearly audible in adjoining sleeping spaces with intervening doors closed. There shall be one detector at the head of each stairway to an occupied living area placed so that rising smoke is not obstructed from reaching the detector & so that the smoke is intercepted before it reaches the sleeping area	Hard wired	There shall be one detector in each dwelling unit & one to protect each sleeping area with an alarm that is clearly audible in adjoining sleeping spaces with intervening doors closed. In units not applicable to section 61 of chapter XII, a Buffalo fire department approved smoke detector system shall be installed in public halls & stairways & be connected to an alarm clearly audible through out the building.	Hard wired, monitored battery, plug-in with restrainer	There shall be one detector in each dwelling unit & one to protect each sleeping area with an alarm that is clearly audible in adjoining sleeping spaces with intervening doors closed. In units not applicable to article 26 of chapter 93, a Buffalo fire department approved smoke detector system shall be installed in public halls & stairways & be connected to an alarm clearly audible through out the building.
Oklahoma City	Oklahoma	6/29/82		Section 1216 BOCA Basic Building Code 1978.				All occupied structures except R-3, detached 1 & 2 family dwelling residential & temporary and miscellaneous (BOCA classification) shall be fitted with smoke detectors according to manufacturer's specifications. They shall be located and in sufficient number to insure that the alarm is audible in all parts of the structure.		All occupied structures except R-3, detached 1 & 2 family dwelling residential & temporary and miscellaneous (BOCA classification) shall be fitted with smoke detectors according to manufacturer's specifications They shall be located and in sufficient number to insure that the alarm is audible in all parts of the structure.
		2/3/82				Smoke detectors installed in a manner & location to qualify for a new construction building permit shall be installed when alterations requiring a building permit or valued in excess of $1000 are made or when 1 or more sleeping rooms are added.				All hotels/motels & residential structures constructed before new construction required smoke detectors shall have at least 1 approved detector installed in a manner and location that would qualify it for a current building permit for new construction
Tulsa	Oklahoma	City - 1973 new construction State - 1987 new & exising construction City - 1991 existing 1 & 2 family dwellings		At least 1 single or multiple station detector shall be installed in the immediate vicinity of the bedrooms & on each floor including basements. A detector on the upper level of a split level not more than 1 full level above the lower level without an intervening door is sufficient. Detectors shall be installed according to NFPA 74. When actuated, the alarm shall be suitable to warn the occupants in the dwelling unit.		At least 1 single or multiple station detector shall be installed in the immediate vicinity of the bedrooms & on each floor including basements. A detector on the upper level of a split level not more than 1 full level above the lower level without an intervening door is sufficient. Detectors shall be installed according to NFPA 74. When actuated, the alarm shall be suitable to warn the occupants in the dwelling unit		At least 1 single or multiple station detector shall be installed in each guestroom, suite or sleeping area in buildings of groups R-1 & I-1 Detectors shall be installed according to Nfipa 74. When actuated, the alarm shall be suitable to warn occupants in the room or dwelling unit.		At least 1 single or multiple station detector shall be installed in each guestroom, suite or sleeping area in buildings of groups R-1 & I-1 Detectors shall be installed according to Nfipa 74. When actuated, the alarm shall be suitable to warn occupants in the room or dwelling unit.
Portland	Oregon	1977		Every dwelling unit occupied by a tenent shall have an approved & properly functioning detector installed according to the rules of the State Fire Marshall. The owner of a rental dwelling unit is to supply & install the detector & provide instructions for testing it. The tenent is responsible for testing the detector & notifying the owner of deficiencies in writing. Dwelling units shall not be transferred without having a properly installed, approved detector.		Every dwelling unit occupied by a tenent shall have an approved & properly functioning detector installed according to the rules of the State Fire Marshall The owner of a rental dwelling unit is to supply & install the detector & provide instructions for testing it. The tenent is responsible for testing the detector & notifying the owner of deficiencies in writing. Dwelling units shall not be transferred without having a properly installed, approved detector.		Every lodging house & hotel guest room shall have an approved & properly working detector installed according to the State Fire Marshall's rules. A hotel shall provide 1 detector for hearing impaired & 1 door knock device for each 75 rooms or fraction of rooms. These shall be provided when requested. They may be protable or permanently installed. Dwelling units shall not be transferred without having a properly installed, approved detector.		Every lodging house & hotel guest room shall have an approved & properly working detector installed according to the State Fire Marshall's rules. A hotel shall provide 1 detector for hearing impaired & 1 door knock device for each 75 rooms or fraction of rooms. These shall be provided when requested They may be protable or permanently installed. Dwelling units shall not be transferred without having a properly installed, approved detector.

CITY	STATE	EFFECTIV DATE	1 & 2 FAMILY DWELLING NEW CONSTRUCTION TYPE	NEW CONSTRUCTION LOCATION/PROVISION	EXISTING CONSTRUCTION TYPE	EXISTING CONSTRUCTION LOCATION/PROVISION	MULTIPLE FAMILY DWELLINGS NEW CONSTRUCTION TYPE	NEW CONSTRUCTION LOCATION/PROVISIONS	EXISTING CONSTRUCTION TYPE	EXISTING CONSTRUCTION LOCATION/PROVISIONS
Memphus	Tennessee	Multifamily-several yrs. 7/1/90 state law 1 & 2 family rentals		Rental units must have smoke detectors. Fire dept. gives free detectors to single family residences.		Rental units must have smoke detectors. Fire dept. gives free detectors to single family residences.		Multiple family dwellings must have smoke detectors.		Multiple family dwellings must have smoke detectors.
Corpus Christe	Texas	9/1/81	Hard wired, battery or other power source	Rented units must have at least 1 detector in the vicinity of each bedroom. In units having a single room used for dinning, living & sleeping, the detector must be inside the room. When bedrooms have the same corridor, at least 1 detector is to be in the corridor in the immediated vacinity of the bedrooms. If a bedroom is above the level of the living & cooking area, the detector for the bedrooms must be in the center of the ceiling directly above the top of the stairway. Detectors must be installed according to manufacturer's instruction of the ceiling no closer than 6" to the wall or on the wall within 12" of the ceiling or as approved by local ordinance or local or state Fire Marshal. The landlord is to test & assure the detector is in good working order when installed & inspect and repair on tenant notification.	Hard wired, battery, or other power source	Rental units occupied or having a bldg. permit issued before 9/1/81 must by 9/1/81 have at least 1 detector in the vacinity of each bedroom In units having a single room used for dinning, living & sleeping, the detector must be inside the room When bedrooms have the same corridor, at least 1 detector is to be in the corridor in the immediated vacinity of the bedrooms. If a bedroom is above the level of the living & cooking area, the detector for the bedrooms must be in the center of the ceiling directly above the top of the stairway. Detectors must be installed according to manufacturer's instruction of the ceiling no closer than 6" to the wall or on the wall within 12" of the ceiling or as approved by local ordinance or local or state Fire Marshal. The landlord is to test & assure the detector is in good working order when installed & inspect and repair on tenant notification.	Hard wired, battery or other power source	Rented units must have at least 1 detector in the vicinity of each bedroom. In units having a single room used for dinning, living & sleeping, the detector must be inside the room. When bedrooms have the same corridor, at least 1 detector is to be in the corridor in the immediated vacinity of the bedrooms. If a bedroom is above the level of the living & cooking area, the detector for the bedrooms must be in the center of the ceiling directly above the top of the stairway. Detectors must be installed according to manufacturer's instruction of the ceiling no closer than 6" to the wall or on the wall within 12" of the ceiling or as approved by local ordinance or local or state Fire Marshal. The landlord is to test & assure the detector is in good working order when installed & inspect and repair on tenant notification.	Hard wired, battery or other power source	Rental units occupied or having a bldg. permit issued before 9/1/81 must by 9/1/81 have at least 1 detector in the vacinity of each bedroom. In units having a single room used for dinning, living & sleeping, the detector must be inside the room. When bedrooms have the same corridor, at least 1 detector is to be in the corridor in the immediated vacinity of the bedrooms. If a bedroom is above the level of the living & cooking area, the detector for the bedrooms must be in the center of the ceiling directly above the top of the stairway. Detectors must be installed according to manufacturer's instruction of the ceiling no closer than 6" to the wall or on the wall within 12" of the ceiling or as approved by local ordinance or local or state Fire Marshal. The landlord is to test & assure the detector is in good working order when installed & inspect and repair on tenant notification.
El Paso	Texas	9/1/81	Hard wired or battery	There shall be one detector in rental units constructed on or before 9/1/81 in the immediate vicinity of the bedroom. Efficiency units shall have 1 detector inside the room. When bedrooms have a common corridor, 1 detector shall be in the corridor in the vacinity of the bedrooms When bedrooms are on a level above a cooking & living area, place the detector at the center of the ceiling directly above the top of the stairway. Place detectors on the ceiling at least 6" away form the wall. Place the detectors on the wall 6" to 12" from the ceiling., Detectors may also be located elsewhere if permitted by local ordinance or by the Local, City, County or State Fire Marshal. The landlord is to test & assure the detector is in good working order when installed & inspect & repair on tenant notification.	Hard wired, or battery	There shall be one detector in rental units constructed on or before 9/1/81 in the immediate vicinity of the bedroom Efficiency units shall have 1 detector inside the room. When bedrooms have a common corridor, 1 detector shall be in the corridor in the vacinity of the bedrooms When bedrooms are on a level above a cooking & living area, place the detector at the center of the ceiling directly above the top of the stairway. Place detectors on the ceiling at least 6" away form the wall Place the detectors on the wall 6" to 12" from the ceiling , Detectors may also be located elsewhere if permitted by local ordinance or by the Local, City, County or State Fire Marshal. The landlord is to test & assure the detector is in good working order when installed & inspect & repair on tenant notification.	Hard wired or battery	There shall be one detector in rental units constructed on or before 9/1/81 in the immediate vicinity of the bedroom. Efficiency units shall have 1 detector inside the room. When bedrooms have a common corridor, 1 detector shall be in the corridor in the vacinity of the bedrooms. When bedrooms are on a level above a cooking & living area, place the detector at the center of the ceiling directly above the top of the stairway. Place detectors on the ceiling at least 6" away form the wall. Place the detectors on the wall 6" to 12" from the ceiling., Detectors may also be located elsewhere if permitted by local ordinance or by the Local, City, County or State Fire Marshal. The landlord is to test & assure the detector is in good working order when installed & inspect & repair on tenant notification.	Hard wired or battery	There shall be one detector in rental units constructed on or before 9/1/81 in the immediate vicinity of the bedroom. Efficiency units shall have 1 detector inside the room. When bedrooms have a common corridor, 1 detector shall be in the corridor in the vacinity of the bedrooms. When bedrooms are on a level above a cooking & living area, place the detector at the center of the ceiling directly above the top of the stairway. Place detectors on the ceiling at least 6" away form the wall. Place the detectors on the wall 6" to 12" from the ceiling., Detectors may also be located elsewhere if permitted by local ordinance or by the Local, City, County or State Fire Marshal. The landlord is to test & assure the detector is in good working order when installed & inspect & repair on tenant notification.

CITY	STATE	EFFECTIV DATE	1 & 2 FAMILY DWELLING NEW CONSTRUCTION TYPE	NEW CONSTRUCTION LOCATION/PROVISION	EXISTING CONSTRUCTION TYPE	EXISTING CONSTRUCTION LOCATION/PROVISION	MULTIPLE FAMILY DWELLINGS NEW CONSTRUCTION TYPE	NEW CONSTRUCTION LOCATION/PROVISIONS	EXISTING CONSTRUCTION TYPE	EXISTING CONSTRUCTION LOCATION/PROVISIONS
Fort Worth	Texas	2/10/85	Hard wired	Group R residences shall have single station detectors to protect each sleeping area System detectors connected to an approved automatic fire alarm system capable of alerting all occupants shall be installed to protect each sleeping area if the occupancy is used by more than 6 persons, 3 of which are under 18 years old and not related by blood or marriage.		Group R residences shall have single station detectors to protect each sleeping area System detectors connected to an approved automatic fire alarm system capable of alerting all occupants shall be installed to protect each sleeping area if the occupancy is used by more than 6 persons, 3 of which are under 18 years old and not related by blood or marriage.		Buildings 3 or more stories high having 15 dwelling units in an apt. house or dormitory or 20 or more hotel guest rooms must have an approved fire alarm system. Actuation of an alarm shall cause all alarms to sound until the signal zone is identified & it is manually reset. 1 & 2 story apt. houses with 1 hour fire resistive construction & 1 hr. occupancy separations between dwelling units & an exit directly to a public way, exit court or yard, exterior stairway or exterior exit balcony or having less than 15 dwelling units between area separation walls are exempt. Buildings less than 75 feet tall that are protected by an approved fire sprinkler system conforming to the building code & having an approved local alarm are exempt. Detectors for occupancies having common interior exit corridors or lobbies shall have an approved & listed system-type detector installed according to UFC 10-2 & listed space limitations in the corridor or lobby. Detectors near a front desk that's manned 24 hrs. a day may be omitted from the immediate desk area when approved by the chief. Approved & listed system type automatic rate of rise detectors shall be installed on the wall or ceiling of common areas (eg. laundry) & on the ceiling of the main living area of each unit according to manufacturer's instructions. Alarms shall be audible throughout the building. Alarm indicating devices shall be located in each sleeping room & in other locations to be audible throughout the building. Group R occupancies shall have single station detectors protecting each sleeping area. Hotels shall provide hearing impaired detectors according to Texas law.		Buildings 3 or more stories high having 15 dwelling units in an apt. house or dormitory or 20 or more hotel guest rooms must have an approved fire alarm system. Actuation of an alarm shall cause all alarms to sound until the signal zone is identified & it is manually reset. 1 & 2 story apt. houses with 1 hour fire resistive construction & 1 hr. occupancy separations between dwelling units & an exit directly to a public way, exit court or yard, exterior stairway or exterior exit balcony or having less than 15 dwelling units between area separation walls are exempt. Buildings less than 75 feet tall that are protected by an approved fire sprinkler system conforming to the building code & having an approved local alarm are exempt. Detectors for occupancies having common interior exit corridors or lobbies shall have an approved & listed system-type detector installed according to UFC 10-2 & listed space limitations in the corridor or lobby. Detectors near a front desk that's manned 24 hrs. a day may be omitted from the immediate desk area when approved by the chief. Approved & listed system type automatic rate of rise detectors shall be installed on the wall or ceiling of common areas (eg. laundry) & on the ceiling of the main living area of each unit according to manufacturer's instructions. Alarms shall be audible throughout the building. Alarm indicating devices shall be located in each sleeping room & in other locations to be audible throughout the building. Group R occupancies shall have single station detectors protecting each sleeping area. Hotels shall provide hearing impaired detectors according to Texas law
Seattle	Washington	12/31/80 12/31/81	Hard wired or battery	Smoke detectors shall be installed inside all dwelling units built or manufactured after 12/31/80. Smoke detectors shall be installed in all dwelling units occupied by persons other than the owner. The detector shall be designed, manufactured & installed to conform with Nationally accepted standards & the administrative procedure act, chapter 34 05 RCW promulgated by the director of community development through the director of fire protection. The owner shall assure that the detector is operating properly before a new tenent moves in. The tenent is responsible for maintaining the detector.	Hard wired or battery	Smoke detectors shall be installed in all dwelling units occupied by persons other than the owner. The detector shall be designed, manufactured & installed to conform with Nationally accepted standards & the administrative procedure act, chapter 34 05 RCW promulgated by the director of community development through the director of fire protection. The owner shall assure that the detector is operating properly before a new tenent moves in The tenent is responsible for maintaining the detector.	Hard wired or battery	Smoke detectors shall be installed inside all dwelling units built or manufactured after 12/31/80 Smoke detectors shall be installed in all dwelling units occupied by persons other than the owner. The detector shall be designed, manufactured & installed to conform with Nationally accepted standards & the administrative procedure act, chapter 34.05 RCW promulgated by the director of community development through the director of fire protection. The owner shall assure that the detector is operating properly before a new tenent moves in. The tenent is responsible for maintaining the detector.	Hard wired or battery	Smoke detectors shall be installed in all dwelling units occupied by persons other than the owner. The detector shall be designed, manufactured & installed to conform with Nationally accepted standards & the administrative procedure act, chapter 34.05 RCW promulgated by the director of community development through the director of fire protection. The owner shall assure that the detector is operating properly before a new tenent moves in. The tenent is responsible for maintaining the detector.

CITY	STATE	EFFECTIV DATE	1 & 2 FAMILY DWELLING				MULTIPLE FAMILY DWELLINGS			
			NEW CONSTRUCTION		EXISTING CONSTRUCTION		NEW CONSTRUCTION		EXISTING CONSTRUCTION	
			TYPE	LOCATION/PROVISION	TYPE	LOCATION/PROVISION	TYPE	LOCATION/PROVISIONS	TYPE	LOCATION/PROVISIONS
Virginia Beach	Virginia	3/1/91	Hard wired unless no comm. power	Smoke detectors shall be installed outside each sleeping area in the immediate vicinity of the bedrooms, on each Story & in the basement. In split levels, detectors must be installed on the upper levels unless there is a door, then they must be installed on both levels. Detectors shall be connected to give an alarm audible in all sleeping areas.	Hard wired or battery	Smoke detectors shall be installed outside each sleeping area in the immediate vicinity of the bedrooms, on each Story & in the basement. In split levels, detectors must be installed on the upper levels unless there is a door, then they must be installed on both levels. Detectors shall be connected to give an alarm audible in all sleeping areas When building alterations, repairs or additions requiring a permit are done, detector laws for new dwellings shall be followed.	Hard wired unless no comm. power	Detectors shall be installed in any building having 1 or more dwelling units, hotels or motels having overnight sleeping accomodations, rooming houses, group houses, domotories & other public lodgings used to provide overnight sleeping accomodations. Alarms shall be audible in individual dwelling units. Installation shall be according to the VA Uniform Building Code. Owners of buildings with 1 or more units shall provide & maintain detectors in hallways, stairwells & other common areas The owner of a leased dwelling unit shall provide a tenant at the beginning of tenancy & annually a written certification that the detectors are present, have been inspected and are working well The tenant is responsible for interim testing, battery replacement & notifying the owner in writing of needed repair. The owner is to provide the tenant notification of his responsibilities & duties	Hard wired or battery	Detectors shall be installed in any building having 1 or more dwelling units, hotels or motels having overnight sleeping accomodations, rooming houses, group houses, domotories & other public lodgings used to provide overnight sleeping accomodations. Alarms shall be audible in individual dwelling units. Installation shall be according to the VA Uniform Building Code. Owners of buildings with 1 or more units shall provide & maintain detectors in hallways, stairwells & other common areas. The owner of a leased dwelling unit shall provide a tenant at the beginning of tenancy & annually a written certification that the detectors are present, have been inspected and are working well. The tenant is responsible for interim testing, battery replacement & notifying the owner in writing of needed repair. The owner is to provide the tenant notification of his responsibilities & duties

Fire Incident Study
Sample Analysis

January 1995

Julie I. Shapiro
U.S. Consumer Product Safety Commission
Directorate for Engineering Sciences
Division of Engineering Laboratory

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The author acknowledges the efforts of Underwriters Laboratories Inc. (UL) for their cooperation and support in developing a proper testing chamber by allowing CPSC laboratory personnel to visit their smoke detector testing laboratory in Northbrook, Illinois. UL continued support by supplying issue number information and technical assistance throughout the project.

Additional gratitude is extended to the CPSC Engineering Laboratory staff for their technical expertise and continued support throughout the smoke detector examinations.

Table of Contents

Executive Summary

The Division of Engineering Laboratory evaluated 114 smoke detectors collected during the Fire Incident Study to determine why the detector did not sound in residential fires. Tests performed at the laboratory were limited; only five performance tests were executed. The current UL Standard for smoke detectors [3] requires over 40 performance tests to be performed on new smoke detectors.

In 78 out of 114 cases evaluated by the laboratory, the battery or AC power supply was found by fire department personnel disconnected from the smoke detector. After restoring the power to the smoke detectors in the laboratory, 48% that could be tested (33 out of 68) passed the laboratory testing protocol. The remaining samples had a variety of problems, some resulting from the fire damage.

Problems were reported by consumers in 33 of the 78 smoke detectors with removed power sources. These included: nuisance alarms, continuous alarms, repetitive chirping, and battery related problems. Nuisance alarms were associated with two-thirds of the reported problems. Testing the sensitivity of these smoke detectors found that they were more sensitive, on the average, then detectors tested during the Smoke Detector Operability Survey [1] without nuisance problems. However, elements from a fire (soot, water, and heat) can adversely affect the sensitivity of the detector.

Thirty-two out of 114 detectors were found with a connected power source by fire department personnel, but no one heard the alarm during the fire. A variety of problems that may have inhibited the detectors from sounding were found in the laboratory in over 50% of the units that could be tested (13 out of 24). These included: not responding with high levels of smoke, corroded battery clips, component failures, and intermittent response. The remaining 11 detectors were able to pass all screening tests in the laboratory. In one quarter of these, soot patterns suggest that the detector may have actually sounded [2].

Twenty-two of the detectors collected in the study could not be analyzed due to extensive damage from the fire. An additional nine detectors had fire-related damage that adversely affected the detector performance. Soot and other fire-related debris may have caused an additional six smoke detectors to sound continuously in the laboratory.

Introduction

The Engineering Laboratory, as part of the National Smoke Detector Project, performed a preliminary evaluation of the smoke detectors collected in the Fire Incident Study. The primary goal of the study was to determine the reason for malfunction.

This report describes the visual observations and test data recorded by the Engineering Laboratory personnel during the preliminary analysis of samples collected in the study. Based upon this report and the results of the Smoke Detector Operability Survey [1], recommendations will be made to increase the reliability of smoke detectors in consumers' homes.

Smoke detectors that residents stated did not respond in an actual fire were collected from homes in 15 mid-size cities across the United States. In most situations, fire department personnel tested the units and answered survey questions concerning the condition of the smoke detector. One-hundred fourteen samples were collected as "in scope" samples, and were sent to the Engineering Laboratory to be analyzed for any of the following conditions:

- "Smoke" generated by UL Listed aerosol smoke detector test spray failed to activate the alarm.
- Pressing and holding the test button failed to activate the alarm.
- Unit sounded continuously when powered.
- Consumer reported that the smoke detector had problems and the power to the detector was found disconnected.
- Unit had a dead battery and consumer did not hear the low battery alarm.
- Unit could not be tested in the field due to fire damage.

Each smoke detector was present during a fire. This makes analysis of the units more difficult because some aspects of the condition before the fire are unknown. Evaluating the inoperable and troublesome detectors in the laboratory can be misleading since some aspects of the fire and the fire fighting mission have an adverse effect on the units.

Laboratory Test Procedure

Each sample underwent a visual examination at the Laboratory prior to any testing. After visual examination, the samples were energized and subjected to five tests, as shown in Table 1. All observations were recorded on examination sheets and visible conditions adversely affecting the performance of the detector were electronically photographed and permanently stored on magnetic media.

Test	Test Procedure	Pass Criteria
Gross Smoke Test	Large quantity of smoke generated from cotton wick.	Sounding Alarm
Test Button Test (if appropriate)	Press and hold the test button for maximum of one minute.	Sounding Alarm
Sound Level Test	Measure the sound pressure level with sound level meter.	Sound pressure level greater than 85 dB at 10 ft (3.05 m)
Low Battery Test (if appropriate)	Simulate a low battery using 300Ω resistor in series with a 9-volt battery.	Unit chirps at specified intervals
Sensitivity Test	UL 217 Sensitivity Test at 32 fpm (0.16 m/s) [3]	0.5 to 4.0% obscuration/foot(ob/ft) (1.6 to 13.0% ob/m)

Table 1. Description of Laboratory tests used to evaluate smoke detectors.

Detectors that did not initially pass the Gross Smoke Test or the Test Button Test were repaired when possible to determine the cause of the failure. This included replacing components in the detector with comparable parts (some were damaged in the fire), as well as cleaning and mechanically correcting deficiencies in the smoke detector. Tests were repeated following any repairs and the results and repairs necessary were recorded on the examination sheet.

The Engineering Laboratory conducted only the tests shown in Table 1. Further assistance from the manufacturers and private consultants in the fire protection arena will be necessary for exact determination of failure in some samples.

Power State of Detectors

Smoke detectors that did not respond in a fire situation were collected by the participating fire departments. If possible, the fire department tested the smoke detector and collected units that conformed with specific collection criteria. The Engineering Laboratory received 114 samples from 15 selected cities.

There were 92 battery powered smoke detectors and 22 AC powered smoke detectors collected in the study. These 114 samples were sent to the Engineering Laboratory for investigation of the failure.

The results of the laboratory testing are divided by the detector's power state: units that were found disconnected after the fire, units that were found still connected after the fire, and units for which the power state at the time of the fire could not be determined. These categories are displayed in Figure 1.

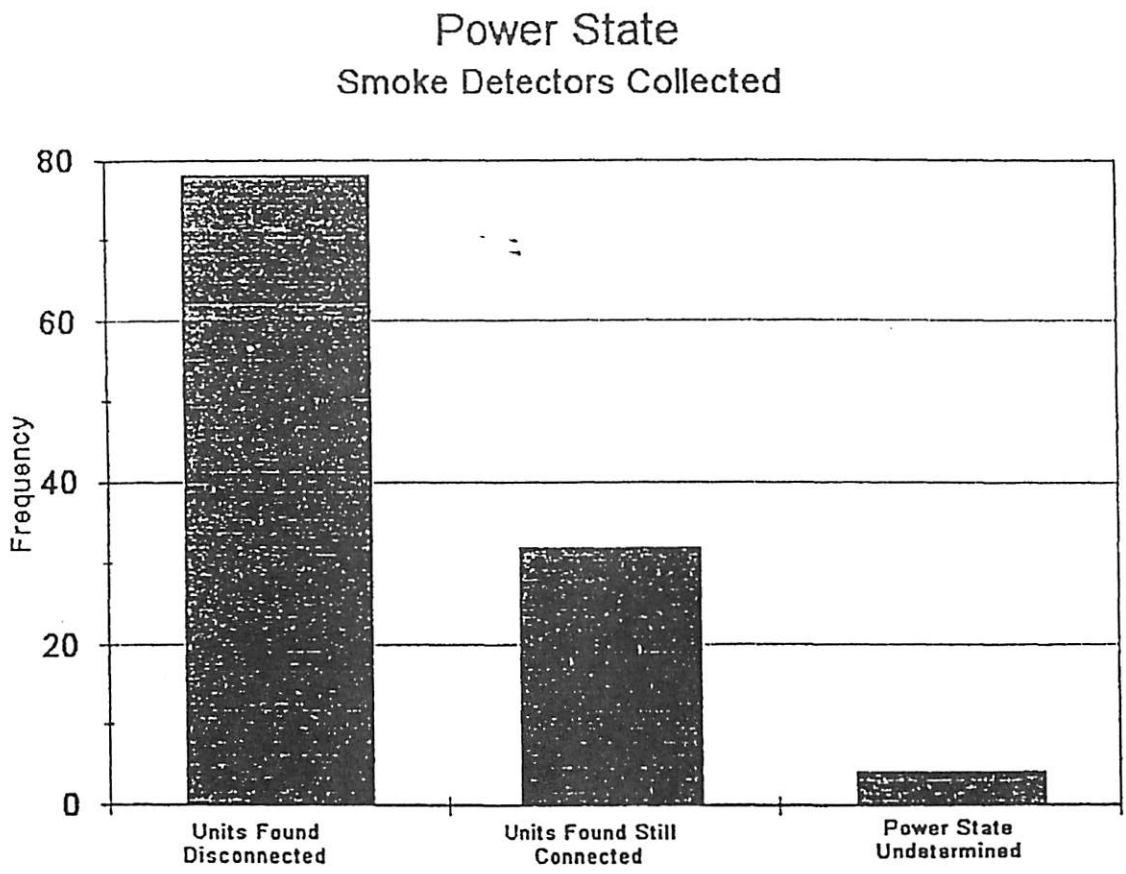

Figure 1. Power state of smoke detectors.

Laboratory Analysis

The smoke detectors vary in damage; some units could not be tested in the field or in the laboratory because of the damage. Those that could be tested or repaired in the laboratory underwent the testing procedure outlined in Table 1.

Units Found Disconnected After the Fire

Seventy-eight smoke detectors collected by fire personnel were found disconnected after the fire. Ten of these units had extensive fire damage, and no further testing was performed by the Engineering Laboratory. The remaining 68 detectors were examined, and the results are shown in Figure 2.

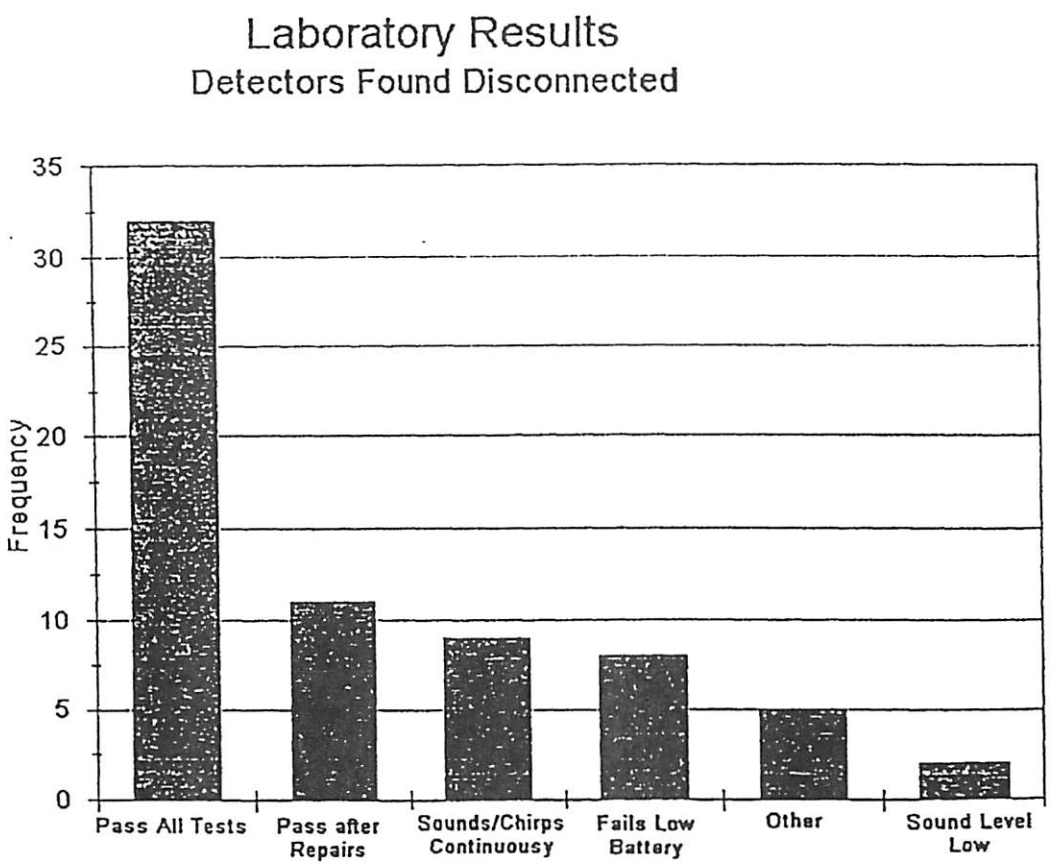

Figure 2. Laboratory results of detectors found disconnected after the fire.

Thirty-three of the units passed all screening tests satisfactorily in the Engineering Laboratory. An additional 11 units were repaired in the laboratory and passed all retests satisfactorily. These repairs included:

- Seven of these units required that the piezo-electric horn be replaced in the detector. In four of the units, excessive heat caused damage to the horn housings causing them to be non-functional. Horns in the other three units did not operate and there were no signs of damage.
- Two smoke detectors failed only the Test Button Test. Cleaning the contact area of the test button switch restored the unit.
- Two other units required that wires be reconnected. In one unit, the AC input wires were purposely cut; in the second unit, the battery terminal wire was damaged in the fire and required replacement.

After power was restored to the smoke detectors in the laboratory, eight detectors sounded continuously and one chirped at one-minute intervals. All of the detectors were thoroughly cleaned, and five functioned properly following the procedure. Three detectors continued to sound and one chirped at repetitive intervals, but could respond to other tests. No further testing was performed on the continuous sounding samples.

Eight additional units failed only the Low Battery Test. Each of these smoke detectors uses older horn technology consisting of an electromagnetic horn. The test used to simulate a low battery in the laboratory placed a 300 ohm resistor in series with a 9-volt battery. The electromagnetic horn does not respond to this test because of the internal resistance of the smoke detector. Appropriate adjustments were made to the Low Battery Test for these horns by directly decreasing the voltage from a power supply. With the modified test, the electromagnetic horn generated a low battery alarm signal.

A variety of problems encompass the five detectors classified in the "Other" category. These included:

- A heat damaged unit that could not be repaired because replacement parts were not available at the laboratory;
- Two smoke detectors responded intermittently during testing;
- One unit that failed the Test Button Test depending on the orientation of the detector; and
- One detector that did not respond during the Sensitivity Test with smoke obscuration over 4.0% obscuration/foot.

An additional two detectors failed the Sound Level Test in the laboratory. Both detectors' sound level was intermittent, at times dropping below 70 dB. The detectors passed all other tests in the laboratory.

Units Found Connected After the Fire

Thirty-two units were found with power connected after the fire; however, no one heard the alarm sound during the fire. Laboratory testing could not be performed on eight of the units received due to extensive fire damage. Test results for the remaining 24 units are summarized in the five categories below.

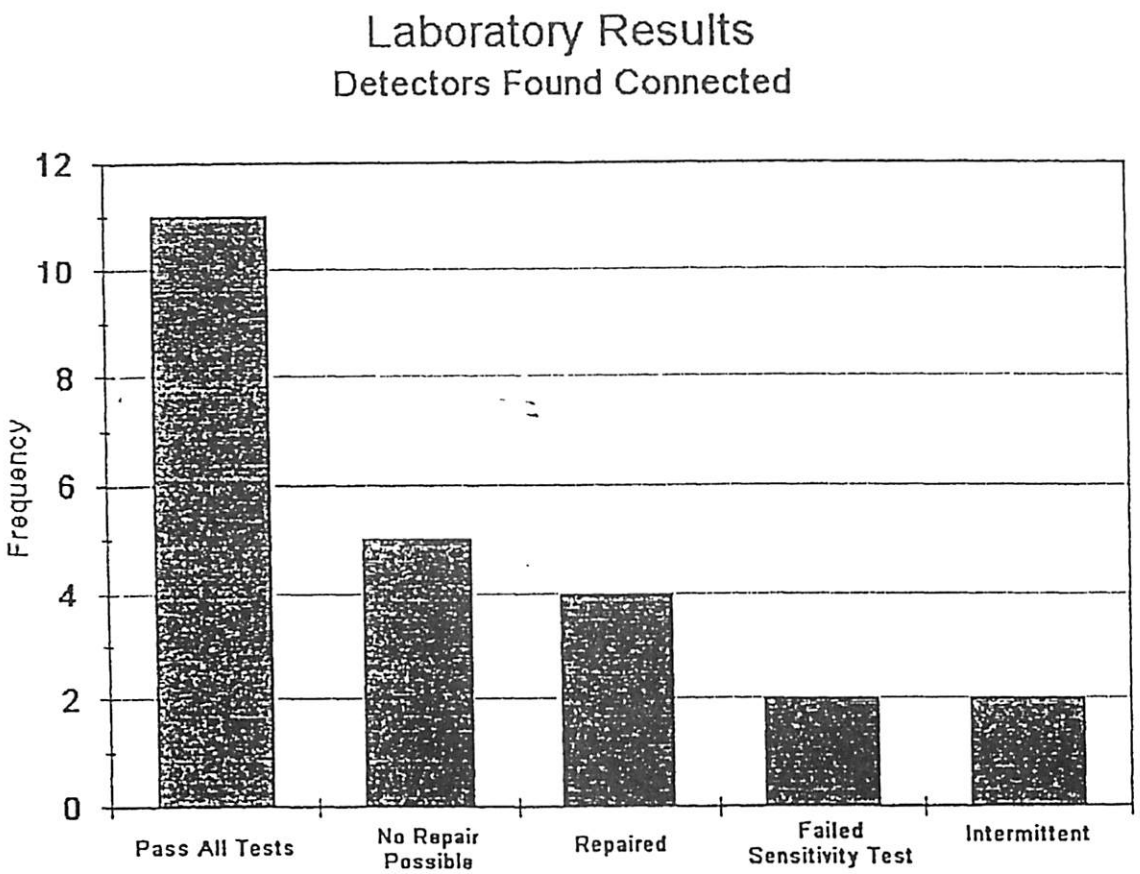

Figure 3. Laboratory results for smoke detectors found connected after the fire.

Ten smoke detectors passed all the tests outlined in Table 1 in the laboratory; an additional unit passed the testing protocol after handling. Handling the smoke detector in the laboratory may have restored continuity to a contact in the unit, resulting in a functional detector.

In five other units, repairs could not be successfully made. The exact reason for the detector malfunction could not be determined.

Repairs were successful in four units. Each detector passed the testing protocol after the following repairs:

- reconnecting a 'plug-in' horn in the smoke detector;
- re-soldering a cold solder joint on one connection of the horn;
- replacing a corroded battery clip on the smoke detector; and
- replacing the entire horn housing, which was damaged in the fire.

In two units, there was not a response during the sensitivity tests with smoke obscuration levels over 4% obscuration of smoke per foot. In two additional units the smoke detector sounded intermittently for unknown reasons.

Among the 32 units for which the fire department reported that no one heard the alarm, laboratory analysis revealed that three of these units responded at some point during the fire. Soot patterns on the smoke detector [2] suggest that the detector alarmed during the fire.

Unknown if Powered at Time of Fire

The power state of four detectors at the time of the fire could not be determined. Each of these detectors had extensive fire damage. No testing of these units was performed in the laboratory because of the damage.

Laboratory Results of Detectors Collected for Failing Field Tests

Forty-nine smoke detectors were collected for failing the smoke test in the field after power was restored to the unit. The results are summarized in the Figure 4.

Twenty-five of these units were able to pass the testing protocol in the

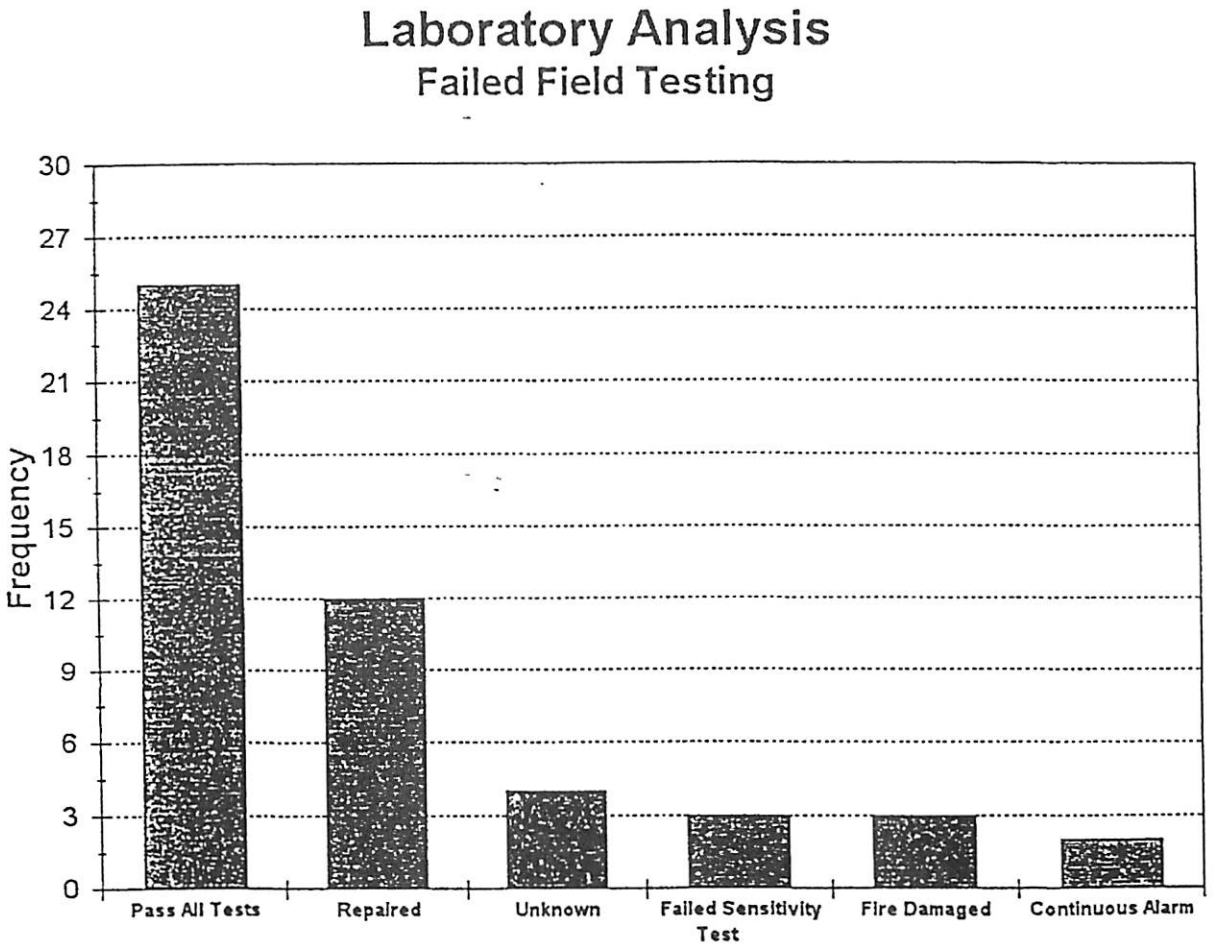

Figure 4. Laboratory results for smoke detectors collected for failing field testing.

laboratory without any repairs. One possible reason other than excessive debris in the detector and the uncertainty of the power state of the detector is horn corrosion. Horn corrosion has been shown to account for detector failure [1]. The suspected detectors use a piezoelectric disk with three plated areas, typically made of silver, for the horn. Laboratory examination showed visible deterioration and corrosion on each of the horn contacts. Over time, the detector may become inoperative because the plated area in the horn element corrodes in the household environment. With corrosion and deterioration, the normally low electrical resistance of the pressure contact becomes higher until the horn can not sound an alarm signal.

Continuity can be restored to the deteriorated electrical contacts by slight movement of the horn element. Removing the malfunctioning detector from the consumer's home, packing the unit and transporting it to the Laboratory can have a significant consequence. During transportation and handling, the contact continuity can be restored with the result that the previously malfunctioning sample will pass the Gross Smoke Test and Test Button Test upon arrival at the Laboratory.

Twelve additional detectors could pass the testing protocol after repairs were made to the detector. These repairs included replacing components deformed in the fire, corroded components, and others.

The reason for failure could not be determined for four detectors collected. Three other detectors did not respond to the sensitivity test, and an additional three detectors could not be tested due to extensive fire damage. Two detectors sounded continuously when powered and could not be tested.

Smoke Detectors Collected for Complaints

If the smoke detector had a disconnected power source, fire department personnel asked the consumer if they had a problem with the detector. Thirty-three smoke detectors were collected because of complaints, which are displayed in Figure 5.

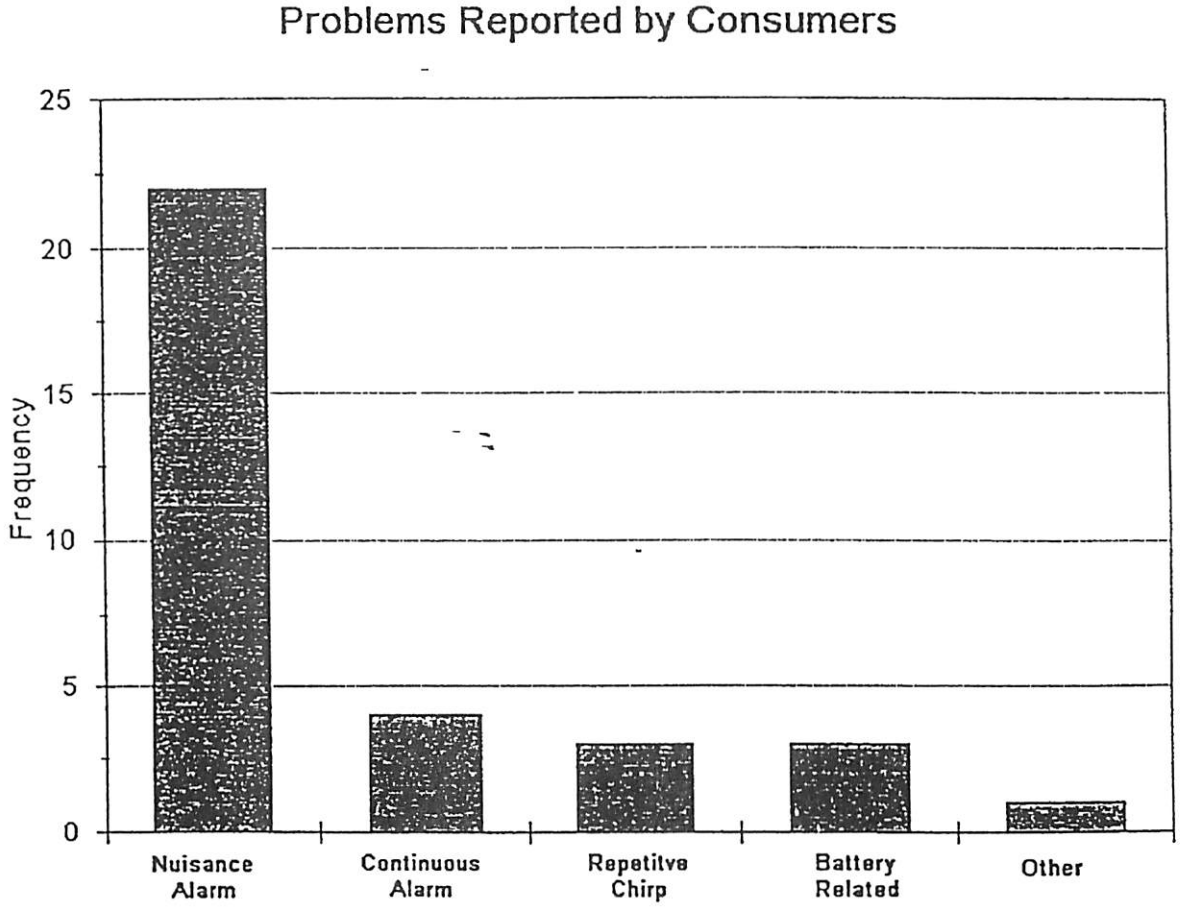

Figure 5. Problems with detector reported by consumers.

Nuisance Alarms

Consumers reported nuisance alarm problems with 22 smoke detectors. Three major reasons can cause nuisance alarms: the sensitivity of the unit, the location of the unit, and the technology the smoke detector uses to detect smoke.

Sensitivity

The sensitivity of the smoke detector determines at what concentration of smoke the detector will respond. Smoke concentration is measured by its "obscuration rate," which relates the percentage of light beam intensity lost per foot (or meter) of smoke that it passes through. A smoke detector with a higher sensitivity will respond to a lower smoke concentration.

Sixteen smoke detectors were tested in the sensitivity chamber at the Engineering Laboratory. The values of sensitivity ranged from 0.5% to 1.7% obscuration of smoke/foot. A lower value signifies a higher sensitivity. In the Smoke Detector Operability Survey [1], the sensitivity values for detectors collected because of nuisance alarms ranged from 0.6% to 2.0% obscuration of smoke/foot. The sensitivity values from both studies are shown in Figure 6.

On average, the smoke detectors collected because of nuisance alarms have a greater sensitivity when compared to units collected without complaints of nuisance alarms. The average sensitivity of detectors collected because of nuisance alarms in the Smoke Detector Operability Survey is 1.16% obscuration of smoke/foot, compared to the Fire Incident Study of 1.03% obscuration of smoke/foot. Smoke Detector Operability Survey detectors that did not have nuisance alarm complaints had sensitivity averaging 1.32% obscuration of smoke/foot.

Excessive dirt, dust and insect infestation can alter the sensitivity of the detector, causing an unusual number of nuisance alarms. The additional elements from the fire (e.g. soot, heat, and water) can adversely affect the detector's sensitivity. Thus, limited conclusions can be drawn from the information. An accurate assessment of the sensitivity values for detectors collected in the Fire Incident Study cannot be made since the condition of the unit before the fire is unknown.

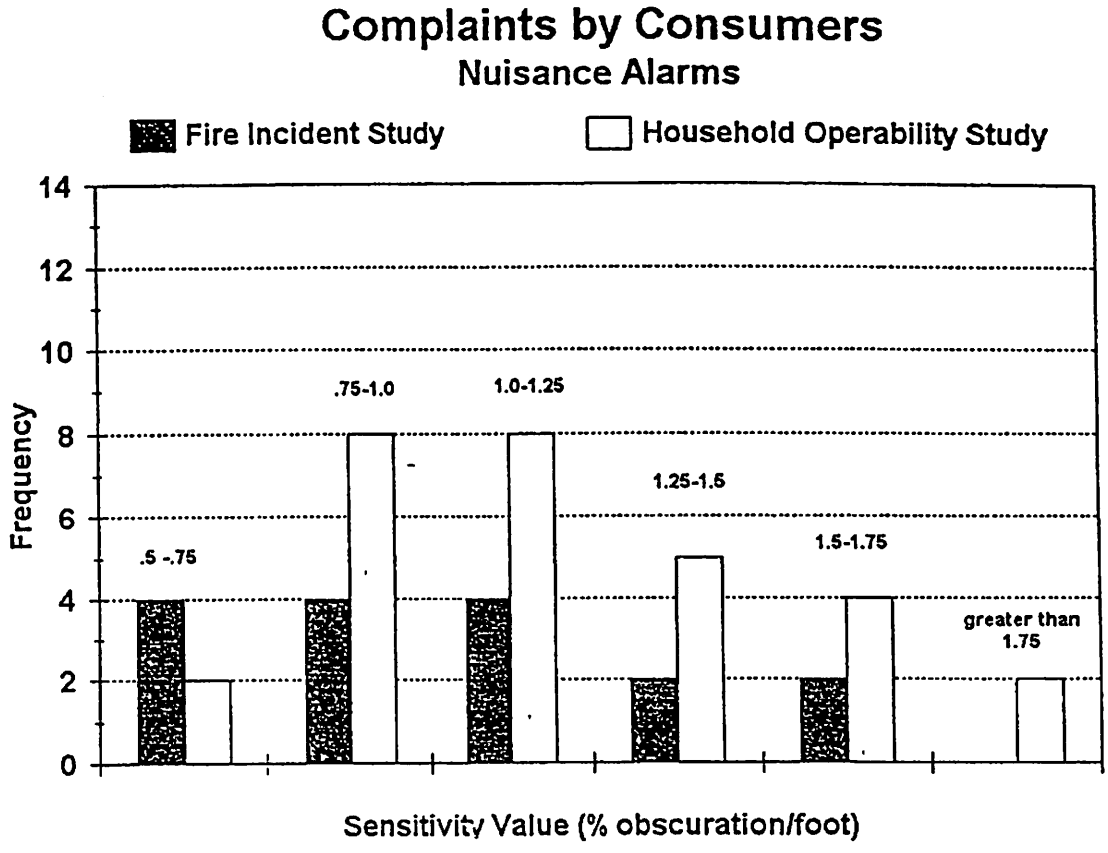

Figure 6. Sensitivity values of smoke detectors collected with which consumers complained of nuisance alarm problems.

Location

Poor location of the detector can contribute to nuisance alarms. In the Smoke Detector Operability Survey, more than one-third of the detectors collected for nuisance alarms were placed less than five feet from the source of smoke. This information was not collected adequately in the Fire Incident Study to make a statement. Out of the 22 complaints of nuisance alarms, distance from the source was reported in less than half of the cases.

Technology Used in the Smoke Detector

Currently, two types of technology are used in residential smoke detectors, ionization and photoelectric. However, the nuisance complaints from consumers in the Fire Incident Study were from only ionization type smoke detectors.

Ionization detectors use a small amount of radioactive material (Americium 241) which makes the air in the sensing chamber between two electrodes conductive [4]. When particles enter the chamber, the current is reduced, thus triggering a control circuit and sounding the alarm. The ionization detector reacts to particle sizes less than one micron. Particles of this size can occur from cooking in kitchens where fast burning fires are created, exhaust gases from automobiles, and cigarette smoking. Placing an ionization detector close to these sources may result in nuisance alarms [5].

The photoelectric detector utilizes a light scattering design that incorporates a light source and a photocell. Smoke particles greater than one micron enter the detector and deflect the light source to the photocell, which sounds the alarm. No photoelectric smoke detectors were collected with complaints of nuisance alarms. However, the Smoke Detector Operability Survey [1] indicated that photoelectric detectors account for approximately 11% of detectors in residences, and the ionization detector accounts for 76 % of detectors in use (13% of detector types undetermined).

Continuous Alarms

Four consumers complained of continuous alarms when asked if they had experienced any problems with their detector. In the laboratory, cleaning the ionization chamber with compressed air stopped the alarming in one sample, but did not correct the problem in a second sample. In another sample, the battery supplied with the smoke detector caused the unit to sound continuously. In some smoke detectors, an extremely low voltage will cause the unit to go into continuous alarm; the battery voltage measured 5.5-volts for this particular sample. Connecting a new battery,measuring 9 volts, to the unit did not produce a continuous alarm, and the unit was able to pass all tests satisfactorily. For the last unit, the circuit board was not properly attached in the detector, which forced the test button contact closed causing a

continuous alarm. Placing the circuit board in the detector properly corrected the continuous alarming problem, and the unit passed the testing protocol.

Battery Related

Another category of complaints by consumers was that "the battery ran down too often." No evidence of this was shown with the three detectors collected. Battery voltages were measured in the laboratory each month for eight months. The measured voltages were appropriate and the detectors functioned properly.

Repetitive Chirp

Three consumers complained that the smoke detector continually chirped. In the laboratory, two units showed no signs of this and functioned properly. The third unit produced a low battery alarm at one-minute intervals with a new battery. This sample is being analyzed by the manufacturer for an exact reason.

Other

One consumer complained that the problem with the detector was that it was defective. In the questionnaire, the consumer did not give a reason or description of the defect in the smoke detector. In the laboratory, the unit passed the testing protocol after the test button contact was cleaned.

No Low Battery Alarm

If the detector was found with a dead battery in the unit when tested by fire department personnel, the consumer was asked if they had ever heard the low battery alarm. If the respondent answered that they had not, the detector was collected for this reason.

Consequently, seven units were collected. Five of the units used electromagnetic horns, which failed the Low Battery Test in the laboratory using the protocol outlined in Table 1. The test procedure was modified for these horns, and the units were able to sound a low battery alarm signal. The two units that use the piezo-electric horn passed the Low Battery Test in Table 1. There is no indication from the laboratory testing that the low battery alarm did not sound in the consumer's home.

Conclusion

The Engineering Laboratory performed limited testing on the 114 smoke detector samples received to determine why they did not respond in a fire. In 68% of the units collected, the detector was found with a disconnected power source after the fire.

Nuisance alarms and other problems were reported in 42% of the cases with removed power. These detectors were more sensitive (lower sensitivity values) when compared to smoke detectors collected that did not have nuisance alarm problems. However, the fire-related debris in the detector can alter the sensitivity. Location of the detectors may contribute to nuisance alarms. Unfortunately, the distance from the detector to the sources of smoke were not collected by the fire department personnel in most cases.

Twenty eight percent of the detectors were found with power connected after the fire. In the laboratory, a variety of problems were found with the units that inhibited them from sounding. Two detectors did not respond in the sensitivity chamber even with high levels of smoke. Additional problems were found with internal components of the detectors .

Twenty percent of the units collected could not be tested in the laboratory because of damage from the fire. Additional units required repairs because of the excessive heat during the fire. Smoke detectors are placed on the ceiling or the upper part of the wall in a home. Heat rises creating high temperatures at the ceiling. Critical elements in the smoke detector can be damaged with levels of heat in the excess of 150 degree Celsius. Additional recommendations to the voluntary standard may include a survivability test to insure detectors can properly function for an extended period of time in a fire.

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