Smoke Detector Operability Survey

Engineering Laboratory Analysis

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REVISED

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

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Executive Summary

The Smoke Detector Operability Survey collected 155 smoke detector samples from the field for at least one of the following reasons: failing a simulated smoke test (73 Units), failing the test button test (63 Units), complaints of nuisance alarms (33 Units), complaints of continuous alarms (32 Units), and battery related problems (17 Units). The Division of Engineering Laboratory evaluated the detectors to determine the reason for malfunction. The Engineering Laboratory discovered four major reasons that detectors were inoperable in residences.

Horn corrosion and deterioration caused at least six of the 73 units collected for failing a simulated smoke test to fail in the Laboratory. It is suspected that an additional 24 of these smoke detectors failed to respond to the smoke test in the field because of horn deterioration, although they functioned properly when received by the Laboratory. Each of these smoke detectors have similarities in horn design and have visible deterioration on each of the horn contacts. Shipping and handling of the smoke detectors may have restored temporary continuity to the smoke detector's horn and resulted in a functional unit.

The second problem is that frequent nuisance alarms cause homeowners to disable their detector. Various reasons for the excessive alarms include location, type of detector, lack of maintenance causing excessive debris and insects to accumulate in the detector, and high sensitivity levels. Dust, cooking contaminants, high humidity, debris, and insects in the sensing chamber can increase the sensitivity level of the detector, which leads to excessive nuisance alarms. Educating consumers on how smoke detectors work and how to keep them in proper condition may solve some of these problems.

The third major problem discovered during the Engineering Laboratory evaluation is that some smoke detectors sound continuously or chirp at periodic intervals. The Engineering Laboratory was unable to determine the exact defects in the smoke detector. Members of the Technology Committee have agreed to examine selected samples to help determine the exact causes of malfunction.

The fourth problem encompasses a variety of complications with batteries and defective mechanical and electrical elements.

Laboratory analysis of inoperable and troublesome detectors collected by the Survey provided invaluable information regarding the technical reasons for smoke detector failures and operating problems. Effectively addressing each of these areas has the potential to increase the number of working smoke detectors in residences.

Introduction

The Engineering Laboratory, as part of the National Smoke Detector Project, performed a preliminary evaluation of the smoke detectors collected in the Smoke Detector Operability Survey during the Fall of 1992. The primary goals of the Survey are to determine the number of non-functioning detectors in the general population and the reason for any malfunction.

This report describes the visual observations and test data recorded by Engineering Laboratory personnel during the limited analysis of samples collected during the Survey. A discussion of the laboratory results highlights the critical and potentially dangerous malfunctions associated with smoke detectors that were collected by field interviewers.

Field interviewers conducted 1,012 in-person interviews and preliminary assessments to determine if smoke detectors properly functioned in the field. Field interviewers tested smoke detectors with a simulated smoke spray without removing the units from their installed locations. If there was no response from the smoke detector, the test was repeated after power was restored to the smoke detector by replacing the battery or re-connecting AC power. A Test Button Test was performed on the unit after the smoke test. Smoke detectors that did not respond properly to either of the two tests or exhibited other possible malfunctions during field testing were collected and shipped to the CPSC Engineering Laboratory for preliminary analysis.

One-hundred fifty-nine samples were collected during the Survey for at least one of the following inadequacies:

- Simulated (uncontrolled, excessive quantity) smoke generated by UL Listed aerosol smoke detector test spray failed to activate alarm.
- Pressing and holding the test button failed to operate the alarm.
- Consumer complained of nuisance or continuous alarms.
- Unit sounded continuously when powered.
- Unit had problems related to the battery.

Four samples did not fit in the necessary profile and were excluded from the analysis, bringing the total number of samples for evaluation to 155. In Figure 1, the various reasons for sample collection are shown. Units collected during the field assessment for more than one reason are tallied in multiple categories. For instance, if the smoke detector failed the Simulated Smoke Test and the Test Button Test in the field, and the consumer complained of excess nuisance alarms, the detector would appear in three different categories in Figure 1.

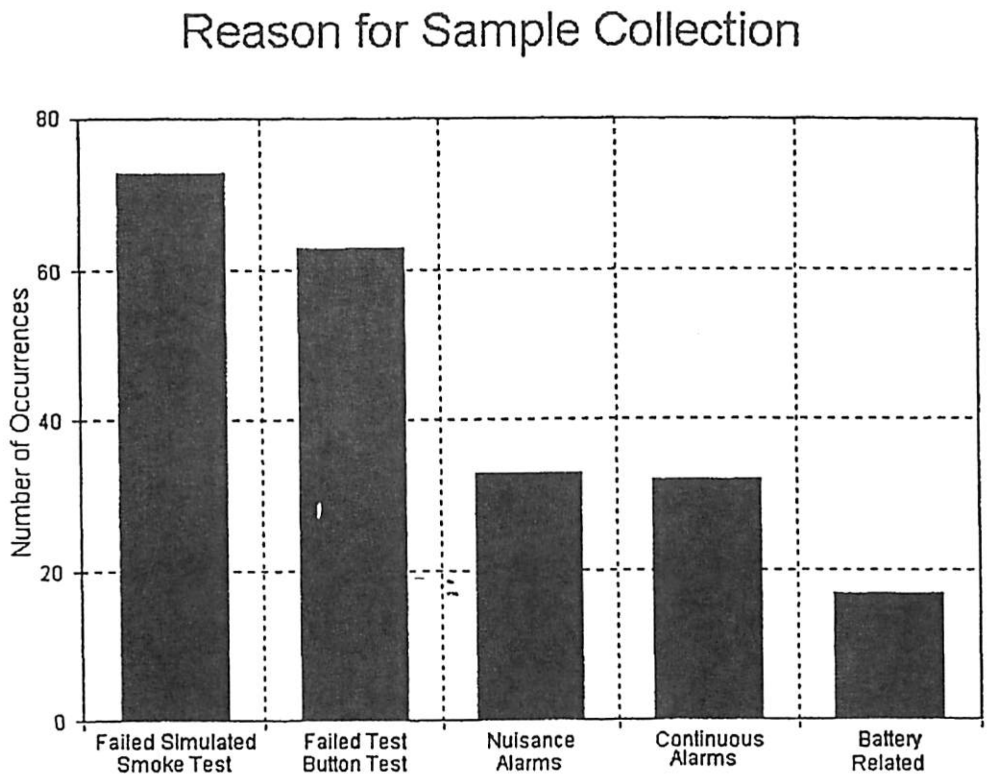

Figure 1. The Reasons for Sample Collection by the Field Interviewer (n=155). (Smoke Detectors were collected for multiple reasons causing the total to be greater than 155.)

The most prevalent reason for sample collection is failure of a properly powered smoke detector to respond to smoke. This report will determine the cause of this and other potentially hazardous conditions with smoke detectors. The Laboratory Analysis Section will evaluate each of the five categories in Figure 1.

Test Procedure

Each sample underwent a visual examination at the Laboratory prior to any testing. Afterwards, the samples were energized and subjected to five tests, as shown in Table 1. All observations were recorded on examination sheets (see Appendix A) 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) [1]	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. This included replacing components in the detector with comparable parts, as well as cleaning, and mechanically correcting deficiencies in the smoke detector. Tests were repeated following any repairs and the results and necessary repairs were recorded on the examination sheet.

The Engineering Laboratory conducted only the tests shown in Table 1. Assistance from the manufacturing community and private consultants in the fire protection arena will be necessary for exact determination of failure in some samples. Members of the Technology Committee agreed to analyze selected samples collected from the Survey.

Laboratory Analysis

The Laboratory Analysis Section examines each smoke detector collected in the survey by determining the reason for malfunction during field testing. Each of the five reasons, which include Simulated Smoke Test Failure, Test Button Test Failure, Nuisance Alarming, Continuous Alarming, and Low-Battery Alarm Failure (shown in Figure 1) are discussed below.

Failed Simulated Smoke Tests

In consumers' homes, interviewers used an aerosol spray with a three-foot wand extension to spray a two second burst of artificial smoke into the detector. If there was no response, additional bursts followed. If there was still no response, the process was repeated after the batteries were replaced, or AC power was restored. A total of 73 units (51 battery-powered and 22 AC-powered) were collected for failing the Simulated Smoke Test.

<u>Battery Powered Detectors</u>

Twenty-two battery-powered detectors that failed the Simulated Smoke Test in the field, arrived at the Engineering Laboratory in working order and were able to pass the testing program listed in Table 1 with satisfactory results. It is noted that an additional 13 smoke detectors passed all tests in the Laboratory, but excessive dirt, dust or insects were present in the unit. The possible reasons for the malfunction in the field, and the smoke detector's functionality after arriving at the Engineering Laboratory are discussed in the "Discussion" section of this report. The remaining 16 samples had three principal reasons for failing the Simulated Smoke Test during field testing and the Laboratory Gross Smoke Test, which included:

- deteriorated electrical horn contacts,
- component problems, or
- defective units.

Six nonfunctional units arrived at the laboratory because of horn contact corrosion. In these detectors, the horn element is a piezoelectric disk with three plated surface pads, typically made of silver, incased in a plastic housing. Three flexible metal arms create a pressure contact onto each plated pad. The horn element's housing allows the low-energy, low-voltage electrical pressure contacts to be exposed to the normal household environment, making them susceptible to contaminants from cooking such as hydrogen sulfide from eggs, and cleaning fumes such as ammonium hydroxide. These contaminants and many others in the residential environment may result in corrosion and deterioration of the contact surfaces.

In the Laboratory, powering the six detectors and introducing smoke to the units resulted in a flashing light emitting diode (LED) or a constantly lit LED in the units (the circuit's visible response to sufficient smoke), but no sound was emitted from the horn. Removing the horn element from the circuit board revealed discoloration of the three exposed horn surface contacts in each sample. Also noted was that each detector's contact metal arm used a bifurcated construction. The laboratory analyst measured the contact resistance of the horn from the contact arm to the plated pad on the piezoelectric disk. One measurement was made on each of the three plated pads. The laboratory analyst found an infinite resistance on at least one of the three measurements on each horn. The high resistance causes the horn not to function.

A second class of problems that contributed to failure of the Gross Smoke Test was component problems. Component complications caused failure in two battery powered detectors. One failed the Gross Smoke Test because of complication related to the battery terminal on the detector (see "Battery Related Problems"), and the other failed because the horn was detached from the circuit board. This detector had fallen from the ceiling in the consumer's home and on impact the horn separated from the circuit board. Testing was not performed on this detector because repairs were not possible.

Defects in the detector caused failure for eight battery powered detectors sent to the Laboratory for failed Simulated Smoke Test. The units sounded continuously or sporadically when power was restored in the Laboratory. The exact reason is unknown, but it is possibly due to a defective or failed integrated circuit (IC) device in the detector. Members of the Technology Committee agreed to examine the units to determine the exact cause of failure. Results of the research are not included in this report, but will be available as soon as the work is complete.

<u>AC Powered Detectors</u>

For AC powered detectors, if the detector did not respond to the Simulated Smoke Test or Test Button Test in the field, interviewers attempted to restore intentionally disconnected AC power to the detectors to retest the unit. If the detector did not respond following a second test, a licensed electrician removed and collected the AC powered detectors at a later date from the consumers' homes. Twenty-two AC powered detectors were collected that failed the Simulated Smoke Test. An additional 35 boxes were left with consumers to send the malfunctioning detector, but the Engineering Laboratory never received these units. Five of the 22 AC powered units received by the Laboratory functioned properly and passed all tests satisfactorily. The remaining 17 detectors are discussed below.

The reasons for Gross Smoke Test failure (see Figure 2) discovered by the Engineering Laboratory are:

- Three units were missing covers, which made them inoperative because of an interlock switch that activated the detector when its cover was in place.
  In the laboratory, using the appropriate covers, one detector was operable and two sounded continuously. After a thorough cleaning of the detectors that sound continuously, one behaved appropriately, and one continued to alarm. Further investigation of the latter sample is required.

- Two units' AC input terminals were intentionally detached from the circuit board.
  Both detectors functioned properly and passed all tests satisfactorily after reconnecting the input wires.

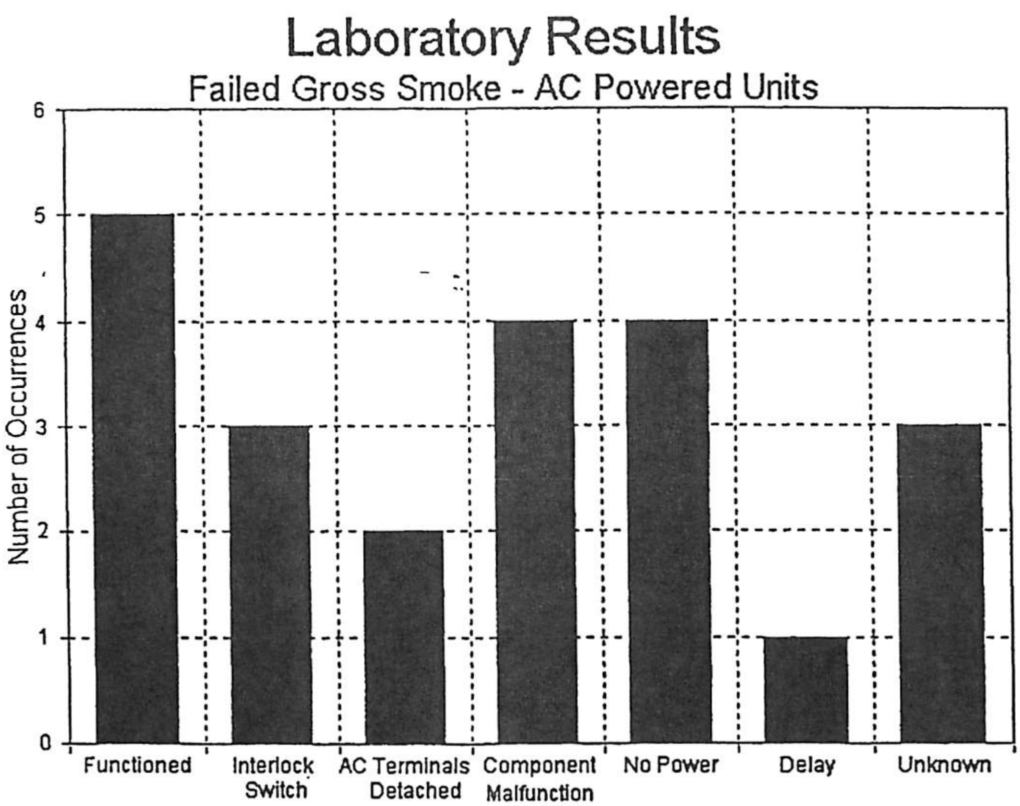

Figure 2. Laboratory Results for AC Powered Detectors Collected for Simulated Smoke Test Failure (n=22).

- Four units had defective components.
  In one unit, the photoelectric light source was burned out. After replacing the light source with an equivalent model, the detector responded to the Gross Smoke Test, but did not respond during the Sensitivity Test with the lower UL 217 limit of 4.0% ob/ft level (12.5% ob/m).

  In another smoke detector, the power dropping resistor failed and overheated. The heat generated by the resistor melted the solder connection for the resistor and it became detached from the circuit board causing the unit to fail the Gross Smoke Test.

  Figure 3 shows a side view of where the ionization chamber punctured through the circuit board, destroying an electrical trace in the third smoke detector. The circuit trace on the circuit board of the detector could not be repaired, so no testing was possible.

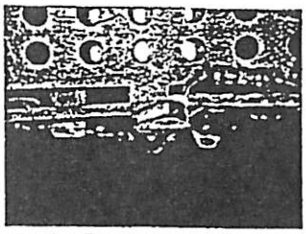

Figure 3. Destroyed circuit trace.

  The capacitor in the fourth sample failed, inhibiting power to the unit. The detector was not repaired and consequently could not be retested.

- Four detectors did not have AC power in the field. Each passed the test protocol in the laboratory when AC power was restored to the unit.

- One photoelectric detector was found to be slow to respond to the Gross Smoke Test and to the Test Button Test. The field interviewer may not have waited an appropriate amount of time before deciding that this unit was inoperative.

- Further examination is required on the other three detectors to determine the exact causes of failure. Components were replaced in the detectors, but none of the units responded to any tests. Manufacturers will assist the Laboratory in future examinations.

Failed Test Button Test in Field

Sixty-three smoke detectors were collected for failing the Test Button Test in field testing. Three detectors did not have a test button and were improperly collected for failing the Test Button Test. Twenty-nine of the 60 smoke detectors evaluated for failing the Test Button Test functioned properly when tested in the Engineering Laboratory. Ten smoke detectors that functioned properly in the Laboratory had insects and debris in the unit and the sensing chamber of the smoke detector that may have caused failure during field testing. Debris, which may have caused failure in the field, could have been dislodged during shipment, resulting in a fully functional test button.

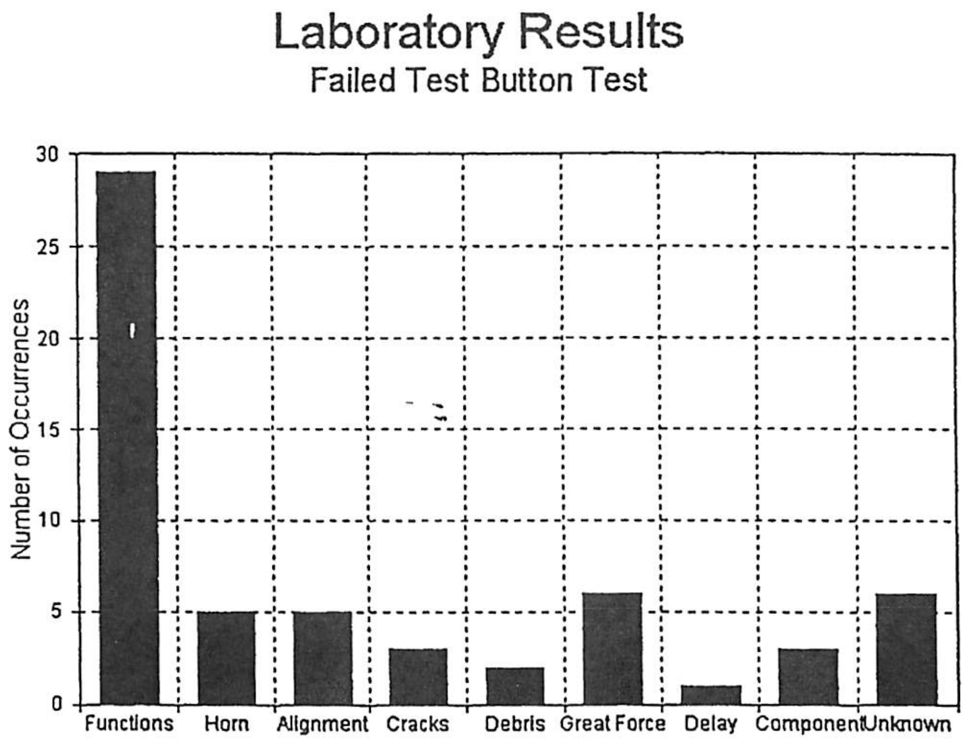

Figure 4. Laboratory Results for Detectors Collected for Test Button Test Failure (n=60).

The remaining 31 cases divide into eight categories involving horn contact deterioration, electrical component failure, physical flaws, test button contact difficulty, and other complications. The reasons for failure of the Test Button Test are summarized in Figure 4 and described below.

- Five detectors had extensive horn corrosion that inhibited them from working.
  Horn corrosion caused five detectors' horns not to respond to the Test Button Test. (These detectors also failed the Gross Smoke Test in the Laboratory.) Replacing the horn element in the detector resulted in a fully functional smoke detector.

- Five detectors' test buttons contact did not align correctly.
  In three of these detectors, the design of the test button does not make contact with the switch in the detector to sound the horn. However, all three detectors passed the Gross Smoke Test in the Laboratory.

  In two detectors, the test button arm was bent causing misalignment at the contact mechanism. Both detectors were repaired in the Laboratory and their test buttons functioned properly after realignment of the contact points.

- Three detectors' test buttons were cracked inhibiting contact and making the test button inoperative.
  Repair was possible in one detector. All three detectors successfully passed the Gross Smoke Test in the field and in the Laboratory.

- Two detectors' test button contacts were extremely dirty.
  Corrosion and dirt at the contact surfaces prevented the test button mechanism from making adequate electrical contact. Cleaning the contact points in both detectors resulted in fully functional test buttons.

- Six detectors required unusual force to operate the test button mechanism.
  In five of these six detectors, the test button was designed to press the middle of a metal strip so that it touches two metal contacts, thus sounding the alarm. This mechanism requires great force to bend the metal strip sufficiently to make contact. The test button in the sixth detector only sounded when pressed at certain angles and pressures.

- One detector sounded after a 20-second delay, which is significantly longer than most. In this case, the test button might not have been pressed for an adequate duration to sound the alarm during field testing.

- Three detectors had defective components that caused failure of both the Gross Smoke Test and the Test Button Test.
  These include capacitor failure, horn detaching from unit when dropped from ceiling, and battery terminal related problems.

- Six detectors did not function properly and could not be tested.
  Four of these detectors sounded continuously or sporadically when power was restored to the units in the Laboratory. Members of the Technology Committee agreed to examine the units to determine the exact cause of failure at some time in the future.

  Testing was not possible in two additional units that did not respond to any tests. Further examination of these units is required to determine the source of failure.

Nuisance Alarms

The Smoke Detector Operability Survey showed that many of the detectors in consumers' homes sounded due to cooking smoke, bathroom water vapors, tobacco smoke and other non-threatening sources of air-suspended particulate. Thirty-three detectors were collected and sent to the Laboratory for examination because the consumer believed there was a problem with the detector. In 32 of the detectors collected, the power had been disconnected by the consumer because of nuisance alarms. Figure 5 shows a breakdown of the sources of nuisance in the respondents' homes.

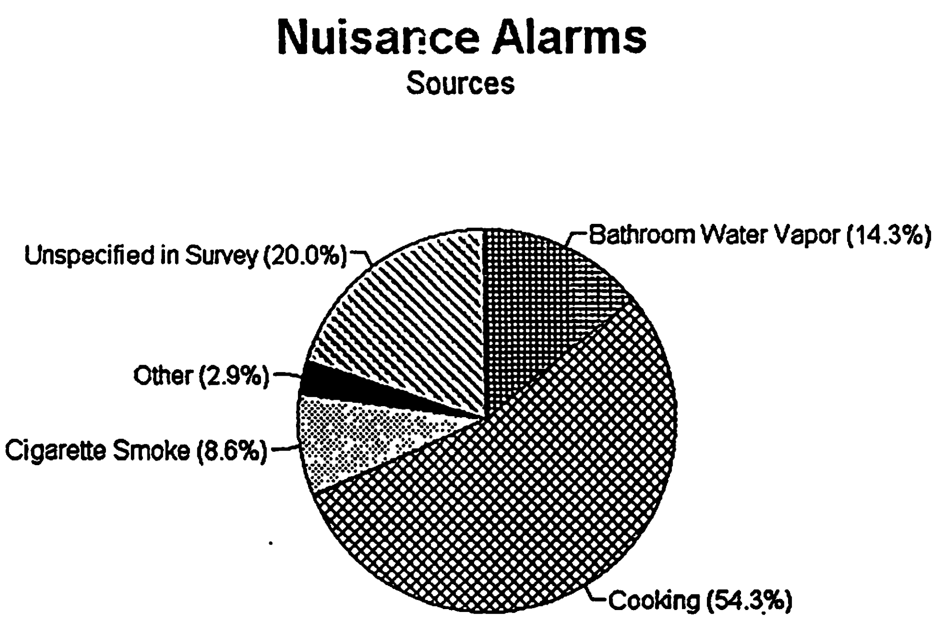

Figure 5. Sources of Nuisance Alarms from Collected Samples (n=33).

In Figure 6, the causes for frequent nuisance alarming were divided into categories determined by evaluating the smoke detectors in the Laboratory. The evaluation included reviewing the questionnaire survey responses, making visual observations of the units and testing the smoke detectors in the UL 217 Sensitivity Testing Chamber. Some units fell into more than one category. For example, one detector in which the "toaster set it off every morning," was located in the kitchen three feet from the toaster. The Sensitivity Test showed that this detector was highly sensitive, 0.66% ob/ft (2.15% ob/m). A combination of the location and the extreme sensitivity of the detector contributed to the frequent occurrence of nuisance alarms.

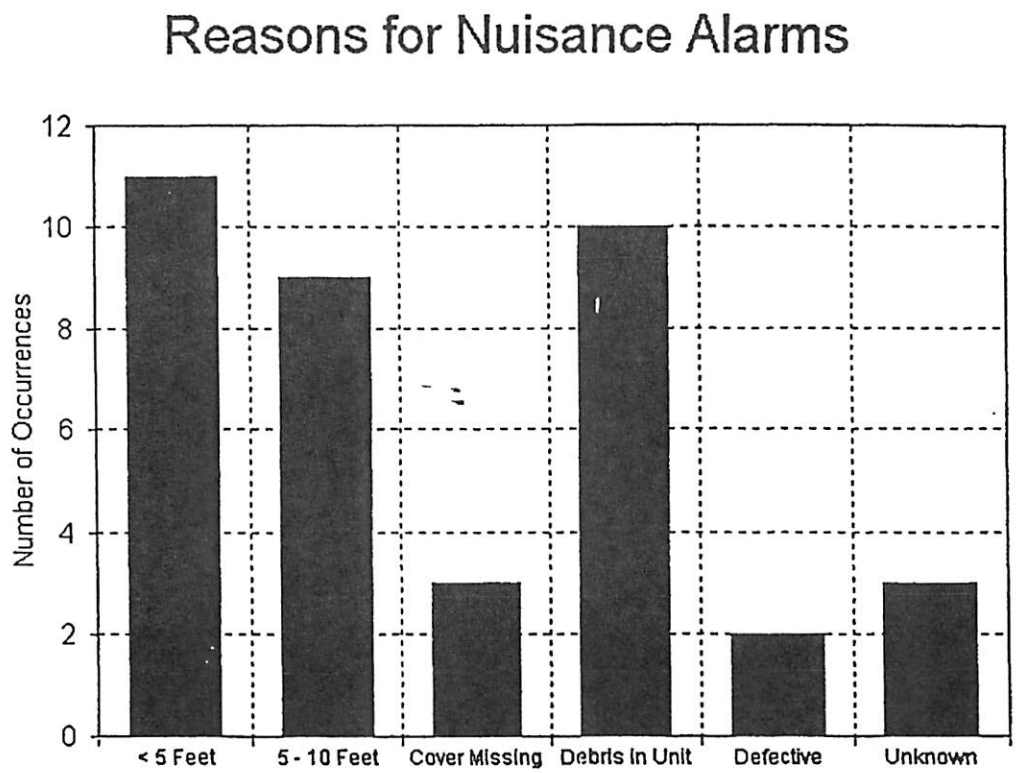

Figure 6. Reasons for Nuisance Alarms for Samples Collected (n=33).
(Smoke Detectors were collected for multiple reasons causing the total to be greater than 33.)

The proper installation of the detector is important and can affect the sensitivity of the detector. In this Survey, questions about the placement of detectors were answered. Many of the collected detectors were in poorly chosen locations near kitchens, bathrooms and air ducts. Eleven of the 33 detectors were placed less than five feet from the nuisance source. Nine more were placed between five and ten feet from the source. Nuisance alarms can often be reduced by relocating the unit. In two interviews, consumers explained to the field interviewers that they solved previous nuisance alarms by relocating the detector away from the source.

Broken or missing covers can increase the sensitivity by allowing smoke to enter the sensing chamber with greater ease. Three detectors collected for nuisance alarms had broken or missing covers. An increase in sensitivity can cause the detector to be more prone to nuisance alarms.

Excessive dirt, dust and insect infestation can also alter the sensitivity of the detector, causing an unusual number of nuisance alarms. Almost one-third of the samples collected for nuisance alarms were noted to have significant accumulations of debris. Figure 7 shows a detector with extreme insect infestation. Small insects were able to enter the sensing chamber of the ionization detector and alter the ionization current thus triggering an alarm. Cleaning and proper maintenance is vital for proper functioning of smoke detectors.

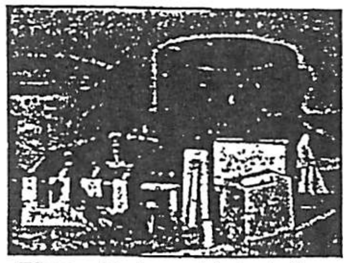

Figure 7. Insect infestation resulting in nuisance alarms.

In two detectors, the Engineering Laboratory was unable to determine the cause of nuisance alarming. One unit did not respond to the Gross Smoke Test or the Test Button Test, and the other operated erratically. Further testing on these detectors was not performed.

In the remaining three detectors, the high occurrence of nuisance alarms could not be determined by examinations of the detectors or analysis of the Survey questionnaire.

The detectors collected in the Survey were placed in the UL 217 Sensitivity Test Chamber to determine at what smoke obscuration level the detector responded. Three units collected for excessive nuisance alarming could not be tested in the UL 217 Sensitivity Test Chamber because of various malfunctions in the detector. The remaining 30 smoke detectors' sensitivity values are displayed in Figure 8. Further discussion on the sensitivity issue appears in the "Discussion" section of this report.

Sensitivity Levels

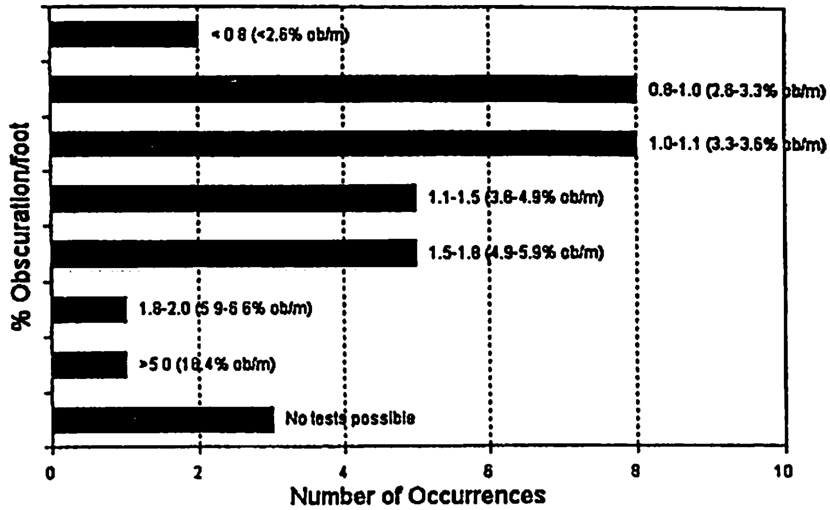

Figure 8. Sensitivity Levels of Smoke Detectors collected for Nuisance Alarming (n=33).

Continuous Alarms

Of the 155 evaluated samples, 32 detectors were collected because the detector alarmed continuously or the detector sounded with periodic chirps. When power was restored to units by field interviewers, 22 of these samples alarmed continuously and four chirped at periodic intervals similar to the low battery alarm. No further testing of these detectors was possible in the field. The remaining six samples passed tests in the field, but were collected because the consumer complained of problems relating to the alarming.

During examination in the Engineering Laboratory, 10 of the 22 detectors collected because of continuous alarms passed all tests. One of the four detectors that chirped at periodic intervals in the field functioned properly in the laboratory. Four of the six detectors collected because of consumer complaints functioned properly at the Engineering Laboratory. (Fifteen units that functioned properly are being continually monitored for any changes in behavior.) The remaining 17 samples can be divided into four categories:

- Five additional detectors passed all tests satisfactorily, but excessive dirt, improper battery installation and defective test button may have caused malfunction in the field.

  Dirt and insects in the sensing chamber can cause the detector to produce continuous alarms. Three detectors that sounded continuously in the field did not sound continuously when powered at the laboratory. Excessive dirt and insects were present in the detectors.

  The field interviewer reported that in one detector collected, the battery did not "fit tightly" into the detector. Improper battery installation caused the detector to sound continuously during the field assessment. The detector worked appropriately in the laboratory when the battery was correctly installed.

  One detector's test button remains depressed when the Test Button Test is performed. This detector was collected for continuously alarming because of this flaw.

- Six detectors that sounded continuously in the field also sounded continuously when initially powered in the laboratory.

  After being cleaned, one functioned properly and passed all tests.

  Three detectors sounded continuously for no apparent reason and could not be repaired or restored to proper operation.

  In the remaining two detectors, tests were possible, but the smoke detectors alarmed intermittently at times for no apparent cause.

- Four detectors chirped at one-minute intervals when proper power was restored to the unit. Three of these smoke detectors were collected because of chirping in the field, the fourth detector was collected because of continuous alarming in the field.

  In one unit, the A/C power terminals had been broken off the detector and the unit was being powered only by the back-up battery. The consumer was unaware of this situation.

  In the other three units, the reason for the periodic chirps could not be determined. The periodic chirps are very similar to a low-battery signal but each detector was powered with a new battery.

- Two units collected because the consumer complained of chirps exhibited malfunctions in the laboratory.

  Both detectors sounded continuously when power was restored to the units in the laboratory. No observations that would cause this condition were noted for the samples.

Continuous alarms and chirping can result from defective components in the smoke detector and for other reasons including powering the unit with a battery below 5 volts. However, the Engineering Laboratory was unable to determine the exact defects in the components and further investigation is required. Members of the Technology Committee have agreed to examine selected samples to help to determine exact causes of malfunction in the smoke detectors.

Battery Related Problems

Seventeen detectors were collected for problems associated with the battery. The reasons for collection were:

- Batteries available to field interviewers were not appropriate for testing in the field (12 detectors).
- Battery terminal had missing/loose connections (3 detectors).
- Batteries reportedly discharged too quickly (2 detectors).

The 9 volt alkaline battery has emerged as the predominant battery used in smoke detectors. In 12 samples, two types of batteries other than the common 9 volt were required, neither of which was carried by field interviewers. Nine of the 12 detectors used a 12.6 volt mercury battery. These batteries are expensive and difficult to obtain. The battery costs $20.58 at one national vendor and must be specially ordered. Eight of these detectors were not powered in consumers' homes, possibly due to battery unavailability and cost. When power was restored to these units in the Laboratory, the eight detectors passed the testing protocol.

Three other detectors collected because the battery was unavailable to the field interviewer each required six 1.5 volt batteries. In one detector, the batteries were not installed properly. Upon proper installation of the batteries at the Laboratory, this detector produced a "thunking" sound at periodic intervals. No further testing of this unit was possible. The second detector was missing the batteries. It functioned properly at the laboratory when power was restored except that it failed the Low-Battery Alarm Test. The batteries in the third detector were dead. When new batteries were installed in the detector at the Laboratory, they were drained of their charge overnight. No tests were possible on this detector and further examination is required. All of the detectors requiring 1.5 volt batteries were manufactured in the early 1980s by the same company.

Units were also collected for missing or loose battery terminal connections. In two samples, the negative battery clip on the smoke detector battery terminal had broken off. After replacing the terminal at the laboratory, both units functioned properly, except one failure of the Low-Battery Alarm Test. In another sample, the battery was reported loose by the field interviewer when he attempted to install the battery into the detector. At the Laboratory, it was found that the battery had not been properly installed in the consumer's home by field interviewers.

Two detectors were collected because the consumer claimed the battery ran down quickly. In the Laboratory, batteries were placed in the detectors, and battery voltage has been checked monthly. Neither of these detectors show any signs of unusual battery decay rate.

In addition to those listed above, several other battery related problems surfaced during testing of samples collected for other reasons. None of these involved the actual battery, but rather the battery terminal on the smoke detector.

In three detectors, battery terminal contacts were loose. Two of these detectors failed the Low-Battery Alarm Test, but otherwise they functioned properly. In two additional detectors, corrosion was found on the battery terminals. One of these detectors failed the Low-Battery Alarm Test. The other functioned properly. Another detector did not originally respond because the negative battery terminal (see Figure 9) had a cold solder joint to the battery connector that came loose. The unit functioned properly after repair.

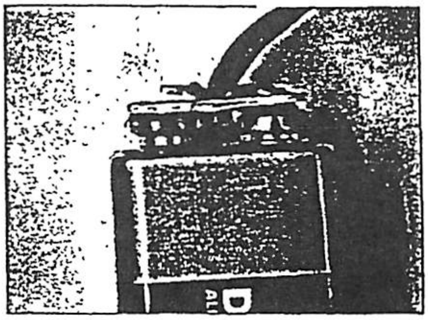

Figure 9. Cold solder joint.

The final class of problems related to the battery is a large number of Low-Battery Alarm Test failures. The Low-Battery Alarm Test was conducted by placing a 300 ohm resistor in series with the battery to simulate the internal resistance of a partially discharged battery. With this resistance, the detector should go into a low-battery alarm. Twenty-three of the collected detectors failed the Low-Battery Alarm Test. Nineteen of the 23 detectors had an electromagnetic horn element. The electromagnetic horn element is no longer used in the design of smoke detectors; the piezoelectric horn element has replaced the electromagnetic horn element. The Engineering Laboratory could not determine the reason for failure in the other four detectors that failed the Low-Battery Alarm Test.

The electromagnetic horn element 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.

Discussion

There are an estimated 3,600 fire related deaths each year and nearly 22,000 fire injuries in the United States [2]. The numbers of incidents can be reduced by increasing the number of working smoke detectors in household residences, which will give an early warning signal to occupants to protect themselves from the dangers of smoke and fire.

Installing smoke detectors in residences is not the major difficulty in increasing the number of working smoke detectors. Numerous give-away and educational programs have been attempted to place detectors in homes of varying socioeconomic conditions with some success. The fundamental problem is keeping the detectors in working order once they are installed in the residence. In Dallas, Texas, for instance, Jernigan [3] explains that over 12,000 detectors were given away or installed in residences of selected socioeconomic communities between 1983 and 1986. In addition, a bilingual detector maintenance guide was sent to participants. Surveying recipients at the end of the program found that only 66.4% of the detectors were still in operational condition. The reasons given varied from nuisance alarms, to defective units, to not replacing the battery.

In the Smoke Detector Operability Survey, an estimated 12% of households do not have any smoke detectors and an additional 17% of households do not have any operational smoke detectors [4]. The major reasons, outlined in the "Laboratory Analysis" section, for non-functional units are malfunctioning components in the smoke detector, detectors that are purposely disabled by the consumer because of nuisance alarms or continuous alarms, debris in the unit, and battery-related problems. To increase the number of working smoke detectors in homes, these areas must be addressed in detail.

Smoke Detectors Not Responding to the Simulated Smoke Test

Forty out of the 73 smoke detectors collected for failing the Simulated Smoke Test functioned normally when received at the Engineering Laboratory. This raises the question of why such a high percentage of detectors failed field operability testing and performed appropriately in the Engineering Laboratory. Failure of the detector to respond to the Simulated Smoke Test and the Test Button Test is unlikely to result from improper testing by the interviewer. Field interviewers were provided with an elaborate instruction manual explaining the testing procedure and participated in a full day of training. Training of the field interviewers included mock interviews to help conduct the Survey and extensive practice of the Simulated Smoke Test and Test Button Test using various types and models of smoke detectors. If the tests were performed appropriately, why is there such a high percentage of failures?

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 accounted for six of the 73 smoke detector's failure of the Gross Smoke Test. Each of these detectors uses the current horn technology of a piezoelectric disk with three plated areas, typically made of silver. Twenty-four smoke detectors that failed the Simulated Smoke Tests in the field and arrived at the Laboratory in working order are suspected of failing because of horn corrosion. Each of these units uses the current horn technology. Furthermore, during the Laboratory examination, deterioration and corrosion was visible 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.

Manufacturers claim [5] that testing the detector on a regular basis performs a "self-wiping" action on the plated contact areas in the horn element, which will keep the horn element in working order. In the Survey questionnaire, consumers were asked how often they tested their smoke detectors. Consumers' responses for the detectors with failed horn elements range from testing in the past month (1 response), to in the last six months (3 responses), to testing within the last year (1 response), to never testing the detector (1 response). This varied response cannot confirm or refute the "self-wiping" claim since at least one detector was tested in the manufacturer-recommended time frame.

Since corrosion is partly a function of time, it is helpful to know when the units with horn failures were manufactured. Information was obtained from Underwriters Laboratories Inc. (UL) concerning the age of the detector. The UL Release Date is the time in which the labels were given to the manufacturers to use on their product. Depending on the production schedule, the actual manufacturing date can vary up to one year. The six units with horn corrosion that failed the Gross Smoke Test and the Test Button Test during field testing all had UL Release Dates prior to 1986. Four of the six units' UL Release Dates were more than 10 years old, the recommended replacement interval by the major manufacturers. The other units suspected of possible horn failure all had UL Release Dates earlier than 1987.

The Engineering Laboratory is not certain how big a role time plays in the deterioration of horn contacts. An outside contract to address the issue was released in October 1993, which focuses on the reliability problem with the piezoelectric disk that is used in all current manufacturing of smoke detectors. The contractor is being asked to carefully examine and define the horn contact problem and to determine various solutions to deal with this potentially dangerous condition, including changes in manufacturing practices and changes in present standards.

Nuisance Alarms

Nuisance alarming is one of the major complaints consumers have about smoke detectors. Disabling the detector because of the frequent alarming creates a dangerous situation in the dwelling. There are several potential solutions to address the problem.

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 each foot (or meter) of smoke it passes through. A smoke detector with a higher sensitivity will respond to a lower smoke obscuration rate.

Ionization detectors accounted for 32 of the 33 samples collected for nuisance alarms in the Smoke Detector Operability Survey. This is a larger proportion than their share of all detectors in the surveyed houses (32/33 = 97%). In the consumers' homes, ionization detectors accounted for 87% of all detectors that could be classified as to type by field interviewers (76% ionization, 11% photoelectric, and 13% unknown) [4].

For the ionization detectors collected for nuisance alarms, the average obscuration rate at which the detector alarmed was 1.16% ob/ft (3.8% ob/m). Eighteen of the samples collected for nuisance alarms had values less than 1.1% ob/ft (3.6% ob/m). Their sensitivity was great enough to be expected to lead to nuisance alarm problems. This value is lower than for the entire set of ionization detectors collected in the Survey. For the 125 ionization detectors in which sensitivity data could be measured in the survey, the average value is 1.32% ob/ft (4.3% ob/m).

Desensitizing the units proves to be an effective way to reduce the number of nuisance alarms. In Breen's study [6] of college dormitories with histories of false alarms, desensitizing the smoke detectors significantly reduced the number of nuisance alarms. The sensitivity value was altered by circuitry changes from 1.5% ob/ft (4.9% ob/m) to either 2.2 or 2.5% ob/ft (7.2 or 8.2% ob/m). The altered values of sensitivity remain within the Standard for Single Station and Multiple Station Smoke Detectors (UL 217) limits of the smoke box standard. However, it is unclear whether these altered smoke detectors would meet all the performance requirements imposed by UL 217. By desensitizing the smoke detectors, nuisance alarms decreased 80% when compared to the nine months prior, and 69% when compared to the same calendar months after the alteration.

By decreasing the sensitivity of smoke detectors, nuisance alarms can be reduced. However, we do not know the effectiveness of the altered smoke detector in protecting against the dangers of fire.

Location

Another potential solution to nuisance alarming is using the appropriate detector in the proper location. In the Survey, 11 out of 33 of the detectors collected for nuisance alarming were placed less than five feet from the source of the smoke, steam, or moisture. All of these were ionization type detectors.

Ionization detectors use a small amount of radioactive material (Americium 241) which makes the air in the sensing chamber between two electrodes conductive [7]. When particles enter the chamber, it reduces the current in the sensing chamber, 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 [8].

An alternative to ionization detectors used near particulate sources of less than one micron, is the photoelectric detector. 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. Photoelectric smoke detectors accounted for only one of the samples collected for nuisance alarms.

The most common cause of nuisance alarm, over 50% of the samples, resulted from cooking, which typically produces particles less than one micron. Photoelectric detectors require larger particles to scatter light and are typically insensitive to particle sizes less than one micron. Sub-micron particles from cooking may prematurely trigger the ionization detector.

The photoelectric smoke detector has a lower sensitivity (usually above 2.0% ob/ft or 6.6% ob/m) than the ionization smoke detector. However, dust and dirt in the unit may contribute to the obscuration, effectively increasing sensitivity and causing a higher number of alarms. The one photoelectric smoke detector collected for nuisance alarms had extensive dirt and dust. Cleaning the unit in the Laboratory changed the detector from sounding continuously to a sensitivity of 1.9% ob/ft (6.23% ob/m). Since debris affects the detector, the photoelectric detector is not appropriate where large quantities of dirt and dust are present [8] because the particles are typically greater than one micron and can cause the detector to malfunction.

Maintenance

To help reduce the number of nuisance alarms, it is important to perform routine maintenance on the detector. Many manufacturers recommend cleaning the detector a least once a year by vacuuming. In case of nuisance alarms, cleaning is recommended additional times during the year.

Cleaning has proven to be effective in reducing the sensitivity of the smoke detector. In Dubivsky's study [9] of false alarms in the Veteran Affairs Medical Center, the sensitivity of smoke detectors was decreased by 55% with vacuuming, blowing and washing the units. However, these detectors are commercial type detectors that tend to be maintained by building maintenance personnel. Commercial detector maintenance guidelines differ significantly from residential guidelines. Recommendations for commercial detectors include cleaning with a high power vacuum, removing unit and washing, testing the sensitivity for changing over 0.25 % ob/ft, and replacing the unit if it is out of calibration [10]. The consumer does not have the capability to perform this type of maintenance and only limited cleaning is recommended by the manufacturer on residential smoke detectors.

It has been suggested by members of the Technology Committee of the National Smoke Detector Project [5] that residential smoke detectors can not be effectively cleaned by consumers. When nuisance alarm problems occur from debris in the detector, the members suggest purchase of a new detector. Although detector replacement is possible, it is not as easy as the manufacturing community has indicated. Current residential smoke detectors do not have a universal mounting base. In addition, different manufacturers use different plugs for AC powered detectors. Manufacturers could make it easy for consumers to replace smoke detectors by creating a uniform mounting base and using standard wiring configuration.

New Technology

Nuisance alarms occur because the detector responds to particles of dirt, dust, humidity, steam and insects that enter the sensing chamber in the same manner as smoke. Thus, nuisance alarms can occur for many reasons including improper location and the environmental conditions of the home. In order to solve the nuisance alarm problem, a new technology must be developed that is not affected by these contaminants. Recent patents [11] involving fire detection using CO_2 monitors may lead into a new age of early warning devices for fire detection. However, prototype testing is in progress to develop a proper fire scenario profile.

Age of Smoke Detectors

UL provided the release date for the issue numbers on each of the detectors collected in the Survey. Depending on the production schedule of the individual manufacturer, discrepancies between release date and the actual manufacturing date can exist up to a few years. For the purpose of this Survey, the age of the smoke detectors was only obtained in this manner. An alternative method to acquire age information would have been to use the date code on each detector. Although this second method can give an exact day of production, the method was not chosen because of the large number of manufacturer's detectors collected in the Survey. Many of these manufacturers do not currently produce smoke detectors, and obtaining date code information was not possible.

Figure 10 shows that detectors collected in the Survey have UL Release Dates prior to 1987. This information suggests that newly manufactured smoke detectors are much less likely to malfunction or have excessive nuisance alarms. Over time the detector's components can malfunction and their sensitivity can be altered by the household environment.

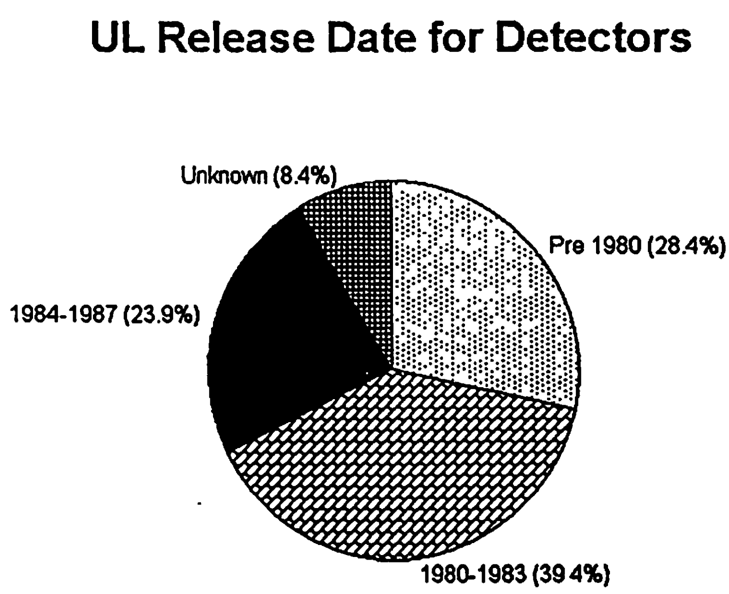

Figure 10. UL Release Date of Detectors Collected as Inoperable (n=155).

Conclusion

The Division of Engineering Laboratory performed narrowly limited testing on the units collected during the Survey. A number of significant failure mechanisms were identified during this work. It is anticipated that sophisticated analytical techniques in future work may reveal additional failure mechanisms.

Four major problems were revealed by work at the Engineering Laboratory. The most significant discovery is that deterioration and corrosion of the horn element in the smoke detector caused six units (of the 73 units that did not respond during simulated smoke testing in the field) not to respond in Laboratory testing. An additional 24 detectors that failed the field smoke test, but passed the Gross Smoke Test in the Laboratory are suspected to have failed because of horn deterioration and corrosion. Shipping and handling the detectors may have restored them to functionality. All currently manufactured smoke detectors are using the piezoelectric disks that have been shown to fail to sound the horn element in the field and the Laboratory. Further research and analytical work will address the issues of separable contact failure and look for solutions to make smoke detectors more reliable.

A second category of problems identified was nuisance alarms. Nuisance alarms occurred for a variety of reasons including: sensitivity of the detector, condition of the detector, and location of the detector. The 33 units collected because of complaints of nuisance alarms had greater average sensitivity then the 155 units collected in the Survey. In addition, one-third of the samples were noted to have significant accumulations of internal debris. Also, more than one-third of the detectors collected for this problem were placed in poorly chosen locations, often less than five feet from a particle source.

Other areas identified in the Engineering Laboratory are from continuously alarming samples. Samples arrived at the Laboratory that sounded continuously or chirped at periodic intervals. Cleaning the detectors restored some units to working order. However, other units continued to sound continuosly. The exact cause of malfunction in the smoke detector samples could not be determined by the Engineering Laboratory. Assistance is necessary from the manufacturing community to address these unknowns. Contact has been made with the manufacturers of these detectors to jointly address the reasons for malfunction.

The last category of problems discovered by the Laboratory encompass a variety of problems. Complications include battery related problems, defective electrical elements, and defective mechanical mechanisms. By effectively addressing the four major areas discovered at the Laboratory, an increase in the reliability of residential smoke detectors and their use is possible.

References

[1] UL Standard 217, "Single and multiple station smoke detectors," fourth edition, May 1993.

[2] National Fire Protection Association estimates for 1991.

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[4] Smith, Charles, "Smoke detector operability survey: Report on findings", October 1994 (Revised).

[5] Smoke Detector Manufacturer, National Smoke Detector Project -- Joint Technology and Investigations Committee, May 11, 1993.

[6] Breen, David E., "Toward more reliable residential smoke detection systems," *Journal of Fire Protection Engineers,* vol. 2, pp. 1-10, 1990.

[7] Bernigau, Norbert, Luck, Heinz, "The principle of the ionization chamber in aerosol measurement techniques - A Review," *Journal of Aerosol Science*, vol.17, pp. 511-515, 1986.

[8] Kitchenham, Christopher, "Controiling nuisance alarms," *Consulting/Specifying Engineer*, vol. sup, pp. 11-14, 1990.

[9] Dubivsky, P.M., Bukowski, R.W., "False alarm study of smoke detectors in Department of Veterans Affairs Medical Center," US Department of Commerce, May 1989.

[10] National Electrical Manufacturers Association, "Guide for proper use of system smoke detectors," April 1992.

[11] Wong, Jacob, United States Patent Number 5,053,754, Oct. 1991.

Appendix A

IDI Number: Sample Number:

LABORATORY EXAMINATION OF SMOKE DETECTOR

U. S. CONSUMER PRODUCT SAFETY COMMISSION
ENGINEERING SCIENCES DIRECTORATE
ENGINEERING LABORATORY
GAITHERSBURG, MD 20878

PROBLEM: [ ] No Alarm in Fire [ ] Nuisance Alarm [ ] No Low-battery Alarm [ ] Other:

Manufacturer:
Model #:
Issue #:
Control #:
Date Code:
Actual date:

[ ] AC Powered:
[ ] Battery backup
[ ] Interconnected type
[ ] Battery Powered
[ ] Silence Feature
[ ] Light Feature

TYPE:
[ ] Ionization
[ ] Photoelectric
[ ] Combination

SOURCE:

OBSERVED DEFECTS: [ ] None [ ] Extensive Fire Damage [ ] Minor Fire Damage

[ ] Cracked Circuit Board
[ ] Bugs or Dirt in Ionization Chamber
[ ] Bad Electrical Contacts:
 [ ] Horn
 [ ] Battery
 [ ] Ion Chamber
 [ ] Other:
[ ] Other Comments:

DEFECTIVE COMPONENTS:
[ ] Integrated Circuit
[ ] MOV
[ ] Resistor
[ ] Capacitor
[ ] Diode
[ ] LED
[ ] Battery
[ ] Other:

REPAIRED: [ ] N/A [ ] Yes [ ] Not Possible [ ] Further Examination Required

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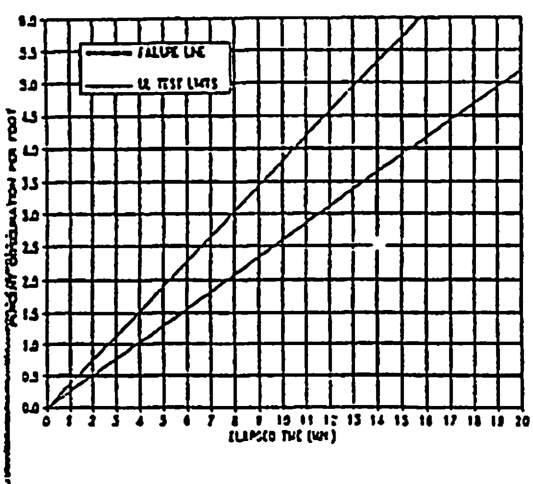
LOW-BATTERY ALARM TEST: [ ] N/A [ ] Pass [ ] Fail (Tested with R=300 Ohms at 9.28 Volts)
SOUND LEVEL TEST: [ ] N/A [ ] Pass [ ] Fail (Measured: dBA at 10 feet)
TEST BUTTON TEST: [ ] N/A [ ] Pass [ ] Fail (After second(s) delay)

SMOKE TESTS: GROSS SMOKE TEST: [ ] Pass [ ] Fail Using: [ ] Smoke [ ] SDT Spray
Sensitivity Test (Gray Smoke, per UL 217 par. 36.1 @ 30 CFM, 124 VAC or 9.0 VDC, Temp: °F RH: % BP: mBar):



TEST NUMBER:	1	2	3
SENSITIVITY:			
Lightbeam: (% Obscuration/ft)	____	____	____
Ionization: (Picoamperes)	____	____	____
AFTER	____	____	____

PERFORMED BY:____________________DATE:

REVIEWED BY:____________________DATE:

ATTACHMENTS: [ ] YES [ ] NONE [ ] PHOTOS

OTHER COMMENTS:

Appendix B.

Engineering Analysis Report

Appendix C.

Summary of Smoke Detector Code Provisions for Localities Surveyed

United States
CONSUMER PRODUCT SAFETY COMMISSION
Washington, D.C. 20207

MEMORANDUM

DATE: March 29, 1994

TO : Margaret Neily
Project Manager, Smoke Detectors
Directorate For Engineering Science

Through: James I. Price
Director, Division of Mechanical Engineering
Directorate for Engineering Science

FROM : Eleanor Perry
Physical Scientist
Directorate For Engineering Science

SUBJECT: Summary of Smoke Detector Code Provisions for Cities Used in "The Smoke Detector Operability Survey"

The attached summary, "City Smoke Detector Codes" examines the provisions for smoke detectors in city codes provided by officials of the forty cities included in the "Smoke Detector Operability Survey". When contacted by field investigators, three cities reported that they did not have codes. The remaining thirty seven cities either provided copies of local codes, state codes or model codes as follows:

- Fourteen cities sent a city code.
- Eight cities indicated formal adoption of the provisions of the model code having jurisdiction in their area.
- Ten cities reported using the provisions of the model code having jurisdiction in their area. Two of these cities reported using a combination of the model code and the state code.
- Eight cities reported using the state code and one of these cities overlapped with having a city code and two overlapped with those that "used" the model code reported above.

Coverage in most of the codes was similar. The scope of most of the codes included new and existing residential properties. Two codes, however, only pertained to new properties, one code covered rental properties, one code covered multifamily properties and one code covered both new properties and rental properties.

Fifteen of the codes required a detector in the bedroom but four of these do not include one and two family dwellings. One code required a detector in or adjacent to bedrooms and one specified ceiling height criteria.

Thirty six of the codes required a detector in the vicinity of the bedrooms.

Thirty three codes required a detector on each floor and in the basement.

The treatment for split levels was generally a detector on the upper level if there was no door and one on both levels if there was an intervening door. Eight of the codes required a detector on both levels when there was a sleeping room on the lower level. Eleven of the codes did not have a provision for split levels.

Generally, newly constructed and substantially renovated properties must have directly wired detectors. Eight codes had no provisions and five either did not apply to one and two family dwellings or made exceptions for them. Seventeen of the codes that required some direct wiring also required some interconnection. Eleven codes that required direct wiring also required battery backup for these detectors.

The code for the state of Illinois was provided and is included in the listing as an example of a state code.

Attachment(s)

CITY SMOKE DETECTOR CODES

STATE	CITY	CODE EXISTS	SCOPE	IN BEDROOMS	VICINITY OF BEDROOMS	EACH STORY & BASEMENT	SPLIT LEVEL WITH A DOOR	SPLIT LEVEL NO DOOR	DIRECT WIRED (AC) REQUIRED	INTERCONNECTION REQUIRED	BATTERY BACKUP (DC) REQUIRED	COMMENTS (*)
Alabama	Tuskegee	Adopted SFPC & NFPA 101*	New and existing 1& 2 family, multifamily & residential rental		Centrally located in the area giving access to sleeping rooms.	Yes	One on each level	Upper level if the lower level is less than one story below	New construction	When AC		Tuskegee does not have a Smoke Detector code. The city adopted the content of the Standard Fire Prevention Code and NFPA 101.
Arkansas	Fort Smith	Uses AFPC, ASFC & SBC*	New and existing* 1& 2 family, multifamily & residential rental		Centrally located in the area giving access to sleeping rooms.	Yes	One on each level	Upper level if the lower level is less than one story below	New construction & existing if detector is not installed by 7/1/92		Yes, when AC is required	There is no local code. The city uses the Arkansas Fire Prevention Code and the Arkansas State Fire Code. Section 903.2 of the Standard Building Code (SBC) was also sent. Only the SBC applies to existing 1&2 family construction.
California	Arroyo Grande	Adopted 1991 UBC*	New and existing 1& 2 family, multifamily & residential rental	Yes	Centrally located in the area giving access to sleeping rooms.	Yes		Upper level or both levels if a sleeping room on is on the lower level	New construction & $1000+ alteration needing a permit		Yes, when AC is required	The city uses the 1991 Uniform Building Code plus an addition that states that smoke detectors must be approved by the California State Fire Marshall.
California	Canoga Park	Yes, Los Angeles*	New and existing 1& 2 family, multifamily & residential rental	Yes	Centrally located in the area of sleeping rooms & on the ceiling close to the stairway when bedrooms are on the upper level	New	New		New			The city of Canoga Park is incorporated under the City of Los Angeles. The Los Angeles Fire code (1989 used) requires detectors in residential occupancies that provide an alarm in the dwelling room or guest room in accord with Chapter 9 of the Los Angeles Municipal Code (B).
California	Napa	Uses 1991 UBC, UFC & ammend.*	New and existing 1& 2 family, multifamily & residential rental	Yes	Centrally located in the area of sleeping rooms & on the ceiling close to the stairway when bedrooms are on the upper level	Yes		Upper level or both levels if a sleeping room on is on the lower level	New construction & $1000+ alteration needing a permit		Yes, when AC is required	Napa uses the 1991 Uniform Building Code and Uniform Fire Code. The ammendment provides for a manual and an automatic alarm system in 3 or more story or 16 or more unit apt. houses, 3 or more story or 20 unit hotels, 3 or more story or 20 or more occupant bed & breakfasts and 2 or more story lodging houses.
California	Palm Desert	Adopted 1991 UBC*	New and existing 1& 2 family, multifamily & residential rental	Yes	Centrally located in the area giving access to sleeping rooms.	Yes		Upper level or both levels if a sleeping room on is on the lower level	New construction & $1000+ alteration needing a permit		Yes, when AC is required	The city uses the 1991 Uniform Building Code. Additionally, ordinance 666 approved 1/23/92 requires buildings constructed with 3000' of gross floor space to have a sprinkler system.
California	Vacaville	Uses 1991 UBC & UFC*	New 1&2 family & multifamily	Yes	Centrally located in the area of sleeping rooms & on the ceiling close to the stairway when bedrooms are on the upper level	New or $1000 renovation	One on each level	Upper level or both levels if a sleeping room on is on the lower level	New construction & $1000+ alteration needing a permit		Yes, when AC is required	The Vacerville Code only applies to new construction and renovations costing $1000 or more. The codes used are the 1991 Uniform Building Code and Fire Code.
Colorado	Arvanda	Uses 1991 UBC for new*	New 1&2 family multifamily & residential rental	Yes	Centrally located in the area giving access to sleeping rooms.	Yes		Upper level or both levels if a sleeping room on is on the lower level	New construction		Yes, when AC is required	The city does not have a local code, it uses the 1991 Uniform Building Code for new construction.

STATE	CITY	CODE EXISTS	SCOPE	IN BEDROOMS	VICINITY OF BEDROOMS	EACH STORY & BASEMENT	SPLIT LEVEL WITH A DOOR	SPLIT LEVEL NO DOOR	DIRECT WIRED (AC) REQUIRED	INTERCONNECTION REQUIRED	BATTERY BACKUP (DC) REQUIRED	COMMENTS (*)
Indiana	Hammond	Yes	Rentals		On the ceiling or wall 6" to 12" from the ceiling, located within 15' of sleeping rooms not more than 15' apart in common halls							The code applies to rental dwelling and mobile home units. The owner is responsible for installation, repair and maintainence of detectors in common areas.
Maryland	Baltimore	Yes*	New and existing 1& 2 family, multifamily & residential rental		A detector is required in the sleeping area. A light signal is required for the hearing impaired.	Yes	One on each level	One on each level	Yes, if constructed after 7/1/75. Other power is allowed if approved by the Fire Prevention Commission.	Yes	Yes, when a building permit is issued for new construction after 7/1/90	An approved (Fire Prevention Commission) automatic fire sprinkler system can be installed instead of a smoke detection system. Manufacturers must get approval from the State Fire Marshal to sell smoke detection systems in the State. This code (Fire laws of Maryland) was effective 7/1/82.
Massachussetts	Boston	Yes	New and existing 1& 2 family, multifamily & residential rental		Outside each separate sleeping area	Yes*	One on each level	One on each level	Common areas for 3 or more units, outside sleeping area for 6 or more units	Yes, where AC	Yes, 6 or more units	Battery powered detectors are required on the ceiling at the base of each stairway leading to the floor above in 1 & 2 family dwellings.
Michigan	Detroit	Yes*	New and existing 1& 2 family, multifamily & residential rental		On the ceiling at least 6" from the wall or on the wall 6" to 12" from the ceiling within 15' of sleeping rooms	Yes*	One on each level	Detector on the upper level	New construction	Yes, new construction		The Detriot code applies to 1 to 4 family units sold, transferred or repaired for more than $3000. NFPA 74 is incorporated by reference for installation and maintenance. Detectors are to be installed at the top of each stairwell to an occupied area and on the first floor of each dwelling unit. Buildings having sprinkler systems in accord with NFPA 13 are exempt.
Minnesota	Minneapolis	Yes*	New and existing 1& 2 family, multifamily & residential rental		6" from the wall on the ceiling or 12" from the ceiling on the wall & 2" from intersecting walls and over stairs when bedrooms are on the upper level				Rented dwelling units, hotels and motels			Smoke detectors sold in the city must meet UL 167, 168 or 217. The code was effective 1/1/80.
Missouri	Belton	Uses 1985 UBC*	New and existing 1& 2 family, multifamily & residential rental		On the ceiling in the area giving access to bedrooms in dwellings and above the stairway when bedrooms are on the upper level On the main room ceiling in efficiencies, hotel rooms and suites	In the basement when stairs open into it			New, bedroom addition & $1000+ renovation			The city uses the 1985 Uniform Building Code. Detectors installed in the basement must be connected to a sounding device or other detector to give an alarm audible in the sleeping area.
Missouri	Lamar	Uses 1993 BOCA*	New and existing 1& 2 family, multifamily & residential rental	Yes, except with sprinkler system	In the immediate vicinity of bedrooms	Yes	One on each level	Upper level if the lower level is less than one story below	Yes	Yes	Yes, unless there is a sprinkler system	Lamar uses the 1993 BOCA Code.

STATE	CITY	CODE EXISTS	SCOPE	IN BEDROOMS	VICINITY OF BEDROOMS	EACH STORY & BASEMENT	SPLIT LEVEL WITH A DOOR	SPLIT LEVEL NO DOOR	DIRECT WIRED (AC) REQUIRED	INTERCONNECTION REQUIRED	BATTERY BACKUP (DC) REQUIRED	COMMENTS (*)
New Jersey	Edison	Uses NJUFC*	New and existing 1& 2 family, multifamily & residential rental		Outside each separate 1&2 family sleeping area in close proximity to sleeping areas in multifamily buildings	Yes	One on each level	One on each level	Hotels & multifamily*	Yes, hotels & multifamily*		The city uses the Uniform Fire Code administered by the New Jersey Bureau of Fire Safety. Battery powered detectors are allowed in hotels and multifamily when the building owner or his representative inspects it upon occupant change and cleans it and replaces the batteries when needed. 1&2 family detectors are placed according to NFPA 74. There must be a certificate of compliance on occupancy change.
New Jersey	Jersey City	Uses NJUFC*	New and existing 1& 2 family, multifamily & residential rental		Outside each separate 1&2 family sleeping area in close proximity to sleeping areas in multifamily buildings	Yes	One on each level	One on each level	Hotels & multifamily	Yes, hotels & multifamily*		The city uses the Uniform Fire Code administered by the New Jersey Bureau of Fire Safety. Battery powered detectors are allowed in hotels and multifamily when the building owner or his representative inspects it upon occupant change and cleans it and replaces the batteries when needed. 1&2 family detectors are placed according to NFPA 74. There must be a certificate of compliance on occupancy change
New York	Medford	Brookhaven County*	New and existing 1& 2 family, multifamily & residential rental	In or adjacent to bedrooms	In or adjacent to sleeping accomondations							Brookhaven Code # 30-32. Smoke detectors states that an approved automatic smoke detection and alarm device should be either in or adjacent to sleeping quarters or where otherwise specified by the chief fire marshall
New York	New York	Yes	New and existing 1& 2 family, multifamily & residential rental						New and substantially altered* after 1/1/82			This code requires installation but does not specify location in residential dwellings. Substantially altered is $150 improvement or improvements on hotels, motels, or multifamily where 50% of units or square feet of structure is altered and the cost exceeds $15,000 per unit. The code was effective 1/1/82.
New York	Rodman	Jeff County*	New and existing 1& 2 family, multifamily & residential rental		Ajacent to sleeping spaces on each floor level on or near the ceiling				Yes, but DC allowed in 1&2 family			Jeff County Code provided - Detectors must have a visible indication that the alarm is energized.
North Carolina	Charlotte	Yes*	New and existing multifamily & residential rental		On the ceiling or wall at a centrally located point giving access to sleeping rooms	Yes	One on each level	Upper level if the lower level is less than one story below		Yes,split level with a door and some multi unit buildings		The City code requires an operable detector in every dwelling unit. Other requirements are from the 1988 Southern Building Code Congress International Code with North Carolina amendments to form the 1991 North Carolina State Building Code.
North Carolina	Cordova	NCSBC*	New and existing 1& 2 family, multifamily & residential rental	Yes, hotels, motels & dorms	Centrally located on the ceiling in the area giving access to sleeping rooms	Yes	One on each level	Upper level if the lower level is less than one story below		Yes, split level with a door and some multi unit buildings		Cordova does not have a code it uses the North Carolina State Building Code.

STATE	CITY	CODE EXISTS	SCOPE	IN BEDROOMS	VICINITY OF BEDROOMS	EACH STORY & BASEMENT	SPLIT LEVEL WITH A DOOR	SPLIT LEVEL NO DOOR	DIRECT WIRED (AC) REQUIRED	INTERCONNECTION REQUIRED	BATTERY BACKUP (DC) REQUIRED	COMMENTS (*)
Ohio	Columbus	Yes	New 1&2 family, multifamily & residential rental	Suggested not required	On the ceiling or wall 4 to 12" below the ceiling & 4" from the ceiling or corner of the wall in each sleeping area in the immediate vicinity of the bedrooms	Yes	One on each level	Upper level if the lower level is less than one story below	Construction after 4/26/78 & alteration requiring a permit			The code pertains to new construction after 4/26/78 unless there is an alteration, repair or addition requiring a permit. Detectors are to be positioned relative to stairways or in the center of the room ceiling The code was effective 4/26/78.
Ohio	Lodi	No										Lodi has 3000 residents and no code
Oklahoma	Chicasha	Adpt. 1990 BOCAFPC & 1988 NFPA 101*	New and existing 1&2 family, multifamily & residential rental	Yes, hotels, motels, dorms	In the immediate vicinity of 1&2 family bedrooms. In all sleeping areas in motels and hotels.	Yes	One on each level	Upper level if the lower level is less than one story below	Yes, new	Yes, new		The city adopted the 1990 BOCA National Fire Prevention Code and the 1988 NFPA 101 Code with exceptions that do not deal with smoke detectors. The code was effective 10/24/91.
Oregon	Salem	Enforces OSS, ORS & OAR*	New and existing 1& 2 family, multifamily & residential rental	Yes	Centrally located in the area of bed rooms and on the ceiling close to the stairway when bedroooms are on the upper level	Yes	One on each level	Upper level or both levels if sleeping room is on the lower level	New construction & $1000+ alterations requiring a permit		Yes, when AC is required	The city enforces the Oregon Structural Speciality Code (based on the 1991 UBC), Oregon Revised Statutes and Oregon Administrative Rules. Smoke detectors must be installed at conveyance. The code was effective 1/1/93.
Pennsylvania	Dixon City	Uses PCFAPR & 1990 BOCAFPC*	New and existing 1& 2 family, multifamily & residential rental		Outside each separate sleeping area	Yes	One on each level	Upper level	New construction	New construction		The Pensylvania Code Fire & Panic regs 4/27/27, revised 8/79 (not provided) and 1990 BOCA Fire Prevention Code are used BOCAFPC requires installation according to NFPIA 74. 1989 edition was used here.
Tennessee	Knoxville	Adopted 1988 SFPC & NFPA101*	New and existing 1& 2 family, multifamily & residential rental	Yes, hotels & dorms	Mounted on the ceiling or wall centrally located in the area giving access to sleeping rooms.	Yes	One on each level	Upper level if the lower level is less than one story below	New 1&2 family, hotels, dorms, rooming houses*	Yes, split level with a door		The city adopted the 1988 Standard Fire Prevention Code (NFPA 74-84 by reference) and 1988 NFPA 101. Entries here are from these codes. Battery power is acceptable for rooming houses on the word of the Authority having jurisdiction. the code was effective 4/4/89.
Texas	Lewisville	Uses 1991 UBC*	New and existing 1& 2 family, multifamily & residential rental	Yes	Centrally located in the area of bed rooms and on the ceiling close to the stairway when bedroooms are on the upper level	Yes	One on each level	Upper level or both levels if a sleeping room on is on the lower level	New & $1000+ renovation and adding a bedroom			The city does not have an individual code. A copy of the 1991 Uniform Building Code was provided.
Texas	Winona	No										
Utah	Magna	Uses County of Salt Lake*	New and existing 1& 2 family, multifamily & residential rental		Centrally located in the area giving access to each seperate sleeping area and above the stairway when sleeping rooms are on the upper level	Basement when a stairway opens from it into the dwelling						The city of Magna is not an incororated city and does not have a city government. The building code is the one for the county of Salt Lake. The 1991 Uniform Fire code on detectors was provided.
Wisconsin	Antigo	Yes	New and existing 1&2 family			Yes						A Uniform Dwelling Code Coordinator memo cites specifications from the state code which require a detector on each floor and in the basement. He indicates that adjacent to sleeping areas and battery backup are only recommendations.