when detectors don't work

Despite the widespread presence of smoke detectors in homes in the United States, fire deaths and injuries continue to occur when detectors fail to operate. In fact, national fire data indicate that smoke detectors didn't alarm in about 32 percent of fires in homes that had a smoke detector when the fire generated enough smoke to have caused it to alarm.[1]

To reduce the number of such incidents, the U.S. Consumer Product Safety Commission (CPSC) began the National Smoke Detector Project, whose goal was to decrease residential fire deaths by increas-

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Illustration: Philippe Weisbecker

ing the number of working smoke detectors.2 One of the most important things we hoped to learn from this project was why so many detectors fail to operate during fires. However, we recognized that accurately assessing the cause of failure is difficult if a detector's been damaged by fire, smoke, or suppression efforts. As a result, we decided to conduct two studies. In one, we looked at the causes of failure in smoke detectors that hadn't operated during fires. In the other, we examined how well—or how poorly—smoke detectors operated in the general population of households that hadn't had a fire.

Studies conducted

The operability survey of the general population, conducted in the fall of 1992, was based on a sample selected to produce a representative rural/urban distribution and a subsample of households of lower socioeconomic status.3 These households were screened to give us an estimate of the number with and without smoke detectors. We conducted about 1,000 on-site interviews, which included testing the detectors' ability to operate.

We then conducted the study of detector performance in actual fires in 15 randomly selected, midsized U.S. cities over 11 months, ending in February 1993.[4,5] A fire was included in the study if we believed that the detector hadn't alarmed, even though there'd been enough smoke to have caused it to do so.

We used the same detector testing procedures and criteria for sample collection in both studies, and we tested more than one detector when more than one was present. We also included many of the same questions in both studies so that results could be compared. However, we didn't explore some of the questions included in the fire household study as fully as we did those in the general population survey because we weren't sure that the responses we'd get after a fire would be valid.

Table 1

DETECTOR CHARACTERISTICS

	General Population (n=273)	Fire Households* (n=1260)
Mean number of detectors per household	1.6	1.2
Percent of households with detectors that have only one detector	59	81
Power source (percent)		
Battery	72	81
AC	26	18
Combination	2	1
Percent ionization	87	89

**Includes only households in which a detector was present but didn't operate in the fire.*

Source: U. S. Consumer Product Safety Commission, EHHA

What we learned

According to the results of the general population survey, an estimated 88 percent of U.S. households—that is, about 84.5 million homes—had at least one smoke detector at the time of the survey. (More recent data indicate that 93 percent of U.S. homes had smoke detectors as of 1994.[6]) That meant that about 11 million households had no smoke detectors.

The mean number of detectors owned by the general population of detector-owning households was 1.6 per household (see Table 1). Fifty-nine percent of households with detectors had only one, while 87 percent had either one or two. About three-quarters of households had at least as many detectors as floors in the dwelling.

About 72 percent of these detectors were battery-powered. Another 26 percent were AC-powered, and about 2 percent were a combination of battery and AC. About 87 percent of the detectors were ionization detectors.

Households in which detectors didn't operate during a fire had a mean number of 1.2 detectors per household. A greater percentage of these homes—81 percent—had only one detector, and a larger percentage of the detectors—again, 81 percent—were battery-powered. Eighty-nine percent of the detectors in homes that had experienced a fire were ionization detectors, about the same proportion we found in the general population.

Test results

We conducted the on-site testing to evaluate detector operability for single-station detectors only, not for those connected to central alarm systems. The procedure was the same in both studies.

Without moving the detector, an investigator sprayed it with an aerosol that simulated smoke. If the detector sounded, the investigator pushed the test button. Detectors that responded to both the aerosol and the pushed button were considered operable. Those that didn't respond to the test button were considered inoperable. If the detector didn't respond to the aerosol smoke test, the investigator put in a new battery or restored AC power, then resprayed it and pushed the test button.

Among the detectors tested in the general population, 75 percent alarmed in response to the first set of aerosol spray and test button tests and were considered operable. The remaining 25 percent didn't alarm. In terms of households, no detectors responded to the test procedures in about 20 percent of those that had detectors. This was true for about 16 million households, more than the 11 million households that had no detectors at all. Households with incomes of less than $15,000 accounted for a disproportionate share of homes that didn't have at least one working detector: These families made up 23 percent of all households but 33 percent of households without a working detector.

By far the most common reason that 25 percent of detectors in the general population failed to alarm during the screening tests was a missing or disconnected power source. This was the reason 60 percent of the detectors didn't sound (see Table 2). Among households that had had fires, the power sources of 59 percent of the detectors that failed to alarm were missing or had been disconnected.

When asked why the power to their detectors was missing or had been disconnected, respondents in the general population were allowed multiple, open-ended responses. More than one-third of those

We looked at the causes of failure in smoke detectors that hadn't operated during fires.

who answered cited nuisance alarms as the reason. Fire study respondents whose detectors were missing or disconnected were asked only if they'd had a problem with the detector. Thirty-five percent—almost the same percentage as in the general population—said that they had.

Respondents in the general population who gave additional reasons for missing or disconnected power sources most commonly cited maintenance. Generally, they said they'd forgotten to replace the battery, but other responses also pointed to maintenance issues: "never looked," "no batteries in house," "didn't have a chance to install." We didn't ask those in households that'd had fires for this level of response because we were concerned about inaccurate reporting.

Causes of nuisance alarms

When participants in either study said that the power to their detectors was missing or had been disconnected because they'd had a problem with it, we asked them to describe what was wrong. Those in the general population, including those whose detectors had dead batteries, generally said that the detectors went off when they were cooking. This accounted for about 28 percent of all complaints. Twenty-seven percent said that their detectors sounded continuously when powered, and 21 percent said that they alarmed too often for unspecified reasons. Alarms that sounded as a result of steam and humidity or cigarette smoke were cited much less often, at 10 percent and 5 percent, respectively. Some occupants cited multiple problems, and some reported the low-battery chirp as a problem.

Table 2

FIELD FINDINGS AMONG DETECTORS THAT FAILED TO ALARM

	General Population (n=395)	Fire Households* (n=273)
Missing/disconnected power source	60%	59%
Missing/disconnected power with problem	33%	35%
Most common problems cited	Cooking, alarms too often	Cooking, alarms too often
Dead batteries	20%	8%
Alarmed when power restored	15%	35%

** Includes only households in which a detector was present but didn't operate in the fire.*

Source: U. S. Consumer Product Safety Commission, EHHA

The responses of those in the fire study were similar. The most common problems were that the detectors alarmed too often, which 40 percent cited, and that they sounded during cooking, which 30 percent cited. These households also cited, albeit infrequently, alarms to steam and humidity or to cigarette smoke.

Before testing started, respondents in the general population were asked to describe how their detectors had performed in the past. Just over half said that their detectors had alarmed when there was no fire. When asked why, 80 percent cited cooking, and 20 percent cited the low-battery signal, which most of them apparently thought was an alarm. Complaints about steam and other sources ranked relatively low, as they did among the reasons cited for nonfunctional power. Even if their detectors sounded when there was no fire, occupants didn't always respond by disabling the detector.

Dead batteries

A detector was considered to have a dead battery if it didn't alarm when tested but did alarm when its old battery was replaced. We found that about 20 percent of all detectors in the general population that didn't alarm during the first smoke test had a dead battery. When this happened, we asked the occupant if they'd heard a low-battery beep or chirp. More than one-third said that they hadn't.

Among households in which detectors hadn't operated during fires, we found that about 8 percent of the detectors had dead batteries—a much smaller percentage than among detectors in the general population that didn't alarm during the first smoke test. Of course, these detectors had been involved in fires, and the effects could have reduced the number of detectors that responded to the test. Occupants in the fire study were also asked if they'd heard a chirp or beep. About 50 percent of those who responded said that they hadn't.

We found that the power source in battery-powered detectors in both studies was more likely than the power source of AC-powered detectors to be nonfunctional; this meant that the batteries were dead, missing, or disconnected, or that the AC power had been disconnected. Ninety-three percent of the detectors in the general population that didn't alarm during testing and were found to have nonfunctional power sources were battery-powered—a disproportionate number, since 72 percent of detectors in households were battery-powered. We also found that 78 percent of battery-powered units in households in which detectors failed to function during an actual fire had no functional power source, compared to 37 percent of AC-powered units. Fire damage at some other location could have increased the percentage of inoperable AC units compared to their prefire condition.

To cut down on the frequency with which people disconnect the power to their detectors to stop nuisance alarms, community fire safety programs may have to be tailored to individual households.

Our study results focused on the status of the power source as we initially found it. During testing, however, we restored power to non-functioning detectors whenever possible. In the general population, 60 percent of the detectors that didn't alarm initially—which accounted for 15 percent of all the detectors in the general population—did so after power was restored. About 35 percent of all the detectors in households in which detectors didn't operate during fires did operate after power was restored. Of course, the effects of the fire could have reduced the number of detectors that responded to this procedure.

Sample analyses

After testing the detectors, we collected 155 that failed from the general population survey and 114 that failed from the fire study to evaluate in the CPSC Engineering Laboratory. Most of them failed to pass the aerosol spray or push button tests, while others lacked a functional power source, either because their owners had disconnected them to stop nuisance alarms or because they had let the batteries die. Some were collected for several reasons. The test procedure included five performance tests based on the Underwriters Laboratories (UL) standard, including the UL sensitivity test.[7]

Among the failed detectors collected from the general population, about 28 percent actually functioned properly when tested in the laboratory (see Table 3). One possible reason for their apparent recovery is that debris in the detectors had shaken loose by the time they reached the lab. Another reason might have been horn corrosion. Over time, a detector's horn can corrode in a residential environment. In some cases, function can be restored by slight movement, such as the handling and shipping that occurred during collection. Manufacturers report that routine testing may also have this effect.

Another 15 percent of the detectors also functioned when tested in the laboratory. These 33 detectors may, in fact, have functioned while they were still installed in the households, but we collected them so we could evaluate nuisance alarms. All but one of these detectors were ionization detectors, a higher proportion than their presence in the population would indicate.

Three factors seemed to contribute to the nuisance problem. First, many of the detectors had been installed within 10 feet of the source of the problem, which was generally cooking. Others hadn't been maintained, as revealed by excessive debris and insect infestations inside them. And finally, we found that sensitivity in more than half of the detectors we collected was high enough to lead to nuisance alarm problems.

We also found that about 36 percent of the detectors collected from the general population had malfunctioning components. These detectors exhibited a variety of problems, including failed capacitors and resistors, inoperable light sources, damaged horns and circuit boards, and loose or missing battery terminals. Deteriorated pads on the horn contacts were the most significant component problem, found in both battery-powered and AC units.

About 11 percent of the collected detectors alarmed continuously in the laboratory, and we couldn't determine why.

Not surprisingly, we found that evaluating the detectors collected in the fire households was complicated by the effects of fire, and some couldn't be tested due to fire or suppression damage. As in the detectors collected from the general population, many of those that reportedly didn't work in the home—39 percent—actually did pass the testing procedure in the laboratory. Another 17 percent that we collected to explore the causes of nuisance alarms also operated in the laboratory.

We were able to identify specific component failures in a smaller proportion of samples in the fire study—16 percent—than we were in the general population study. To some extent, this difference might be due to the effects of fire, which prevented restoration of function. As in the general study, component problems included malfunctioning horn elements, loose wires and connections, and deteriorated test button contacts.

About 10 percent of the detectors we collected in the fire study alarmed continuously in the laboratory, a result similar to that found in detectors collected from the general population. We think that some of these were affected by soot or smoke from the fire.

Where do we go from here?

The causes of many smoke detectors' inability to operate in the general population and in these fire households are generally similar, and

Table 3

SAMPLE EVALUATION ENGINEERING LABORATORY TEST RESULTS

	General Population (n=155)	Fire Households* (n=114)
Functions	28%	39%
Functions (nuisance alarm)	15%	17%
Component problems	36%	16%
Alarms continuously	11%	10%
Other, unable to determine	10%	17%

* *Includes only households in which a detector was present but didn't operate in the fire.*

Source: U. S. Consumer Product Safety Commission, EHHA

By far the most common reason that 25 percent of detectors in the general population failed to alarm during the screening tests was a missing or disconnected power source.

observable differences were primarily a matter of gradation. Although the fire households we studied may not represent all fire households, they nonetheless represent the households that are at greater risk of fire casualities than those that have operating detectors. These results indicate that efforts to reach high-risk populations should include the same messages as those aimed at the general population—and some additional features.

For example, these studies indicate that high-risk households may not have enough smoke detectors. Fire safety programs should begin paying attention to the number of detectors needed to achieve the recommended coverage, rather than being satisfied with one detector per dwelling. The high proportion of households that actually had a fire and had only one detector supports this action. If such households have only one detector and it becomes inoperative, they have absolutely no detector coverage. Results from the general population survey found that the more smoke detectors a household had, the greater the likelihood that one of them worked.

Some households may have special problems. For instance, a recent study of a Native American population around Aberdeen, South Dakota, found that almost half the smoke detectors in the 80 households studied were inoperable.[8] In 86 percent of the cases, they'd been disconnected or their batteries had been removed because they'd sounded nuisance alarms, apparently in reaction to high-temperature cooking. Most of the detectors in these cases were ionization detectors, and the disproportionate number of ionization detectors involved in nuisance alarms in CPSC's general population study supports the finding that ionization detectors are sensitive to cooking. In this situation, greater use of photoelectric detectors might be effective in reducing nuisance alarms.

To cut down on the frequency with which people disconnect the power to their detectors to stop nuisance alarms, community fire safety programs may have to be tailored to individual households. This could take the form of moving the detectors, for example, or replacing them with different types.

It's widely recognized that detector performance suffers when consumers have to replace the detectors' batteries themselves. In both CPSC studies, we found that AC-powered detectors were more frequently operable. Since most older dwellings haven't been retrofitted with AC detectors, installing detectors with 10-year batteries or installing 10-year batteries in existing detectors may greatly increase the level of detector operability.

This increase will occur primarily in the segment of detectors that didn't work when initially tested because they'd been disabled. Such detectors constituted 15 percent of all detectors in the general population and 35 percent of the detectors that didn't function during a fire. Since detectors with 10-year batteries can still be disabled, problems with nuisance alarms will still reduce the effectiveness of this strategy. To keep people from removing batteries, silence buttons that can temporarily stop nuisance alarms have been incorporated into 10-year detectors.

In view of these findings, a multifaceted approach is appropriate for community organizations concerned with fire safety. Among other things, they should support the trend toward requiring AC detectors with battery back-up in new installations. They should also install 10-year batteries as replacements in existing detectors and provide new units with 10-year batteries. Any household that hasn't achieved the recommended level of detector coverage should be included in give-away programs, and consumers should be told how to care for their detectors. Finally, such organizations should be prepared to provide people with alternatives, such as moving the detector or installing a photoelectric detector, when they need help dealing with nuisance alarms. None of these approaches is a radical departure from current practice. When taken together, however, they hold promise for incremental improvements in the long-term operability of smoke detectors in U.S. households.

**The opinions expressed by the authors don't necessarily represent the views of the CPSC. Data were collected on 273 detectors in 263 fire households. Although results, such as the number of detectors, may not be representative of all fire households, they nonetheless represent the segment of fire households at increased risk of fire casualties.*

1. *Smith, L. E.,* Fire Incident Study: National Smoke Detector Project, *U.S. Consumer Product Safety Commission, January 1995.*

2. *The National Smoke Detector Project was coordinated jointly by CPSC, the U.S. Fire Administration, NFPA, and the Congressional Fire Services Institute with the participation of a variety of fire safety education organizations, smoke detector manufacturers, laboratories, and other organizations interested in fire safety.*

3. *Smith, C. L.,* Smoke Detector Operability Survey: Report on Findings *(revised), U.S. Consumer Product Safety Commission, October 1994. Results published in the* International Journal for Consumer Safety, *Neily, M., Smith, C., and Shapiro, J., "Residential Smoke Detector Performance in the United States," Vol. 1, No.1 (March 1994), pp. 43–50.*

4. *Smith, L. E.,* Fire Incident Study: National Smoke Detector Project, *U. S. Consumer Product Safety Commission, January 1995.*

5. *Buffalo, New York; Corpus Christi, Texas; El Paso, Texas; Ft. Worth, Texas; Memphis, Tennessee; Miami, Florida; New Orleans, Louisiana; Oklahoma City, Oklahoma; Phoenix, Arizona; Portland, Oregon; Sacramento, California; Seattle, Washington; Tampa, Florida; Tulsa, Oklahoma; and Virginia Beach, Virginia.*

6. *Hall, John R., Jr.,* U.S. Experience with Smoke Detectors and Other Fire Detectors, *National Fire Protection Association, June 1995.*

7. *UL 217,* Single- and Multiple-Station Smoke Detectors, *4th edition.*

8. *Kuklinski, D., Berger, L., and Weaver, J., "Smoke Detector Nuisance Alarms: A Field Study in a Native American Community,"* NFPA Journal, *Vol. 90, No. 5 (September/October 1996), pp. 65–72.*