WHITE PAPER

HOME SMOKE ALARMS

AND OTHER FIRE DETECTION AND ALARM EQUIPMENT

Public/Private Fire Safety Council

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Executive Summary

In 2003, fire departments responded to 388,500 home structure fires in the United States that claimed the lives of an estimated 3,145 people. Working smoke alarms greatly reduce the likelihood of a residential fire-related fatal injury by providing occupants with early warning and giving them additional time to escape. The smoke alarm strategy, therefore, is to achieve universal home use of effective, reliable fire detection/alarm equipment. (A smoke alarm combines the detector and the alarm in a single unit without use of a central panel.)

The Public/Private Fire Safety Council prepared this paper as the first of a series of white papers that will outline major strategies for reducing the annual death toll from residential fires, specifically home fires. The Public/Private Fire Safety Council is a 16-member council of federal agencies and non-government organizations, created to develop a coordinated national effort to eliminate residential fire deaths by the year 2020.

As highlighted in this white paper, a number of important issues must be addressed to maximize the impact of the smoke alarm strategy on residential fire deaths.

Smoke alarms are still missing in 4% of U.S. homes. This group accounts for 39% of reported home fires and nearly half of all the reported home fire deaths. They represent just over 4 million housing units.

An estimated 20% of U.S. homes have smoke alarms present but none that are working. Nearly all of this 20% involves dead or missing batteries, as opposed to problems with AC power. Nearly half of the households with non-operational smoke alarms that gave a reason cited nuisance alarms or continuous alarming as the reason for disabling the smoke alarm. They represent roughly 21 million housing units and an estimated thirty million or more smoke alarms.

Available research indicates that programs are more successful if smoke alarm distribution is supplemented by direct installation, and combined with supporting education and scheduled follow-up visits. Also important, program evaluations must be designed to refine program features as needed and demonstrate program effectiveness.

The needs of special populations often dictate special features in the design of smoke alarms or in other aspects of smoke alarm programs. These special populations include:

- Children, differentiating young children from older children
- Older adults
- Disabled populations (addressed by disability type)
- Non-English speakers
- Adults with low literacy levels in their native language
- Renters, whose protection may be partly or wholly the responsibility of a landlord

Further research could improve the effectiveness and reliability of smoke alarms through technological means. Improvements could include:

- Greater waking effectiveness for certain identified populations;
- Quicker, more certain responses to the range of fire types coupled with reduced nuisance alarms;
- More affordable ways to interconnect the alarms in existing homes

Continued research is needed to improve smoke alarm performance and to improve measurement of smoke alarm performance.

A greater understanding of human behavior is needed to inform educational approaches to change behaviors that support the smoke alarm strategy, particularly including the following related behaviors:

- Home escape planning
- Inspection, maintenance and replacement of smoke alarms
- Safe options for dealing with nuisance alarms without sacrificing smoke alarm protection

Human behavior in residential fire requires careful analysis to determine effective cues, adaptive environments, egress skills development under stressful conditions, and strategies to reduce the learned irrelevance of alarms, due to the high frequency of nuisance alarms, and to increase the perceived value of immediate escape.

Priorities for research and programs need to consider differences in estimated life-saving potential and cost-effectiveness. Standardization and compilations of best practices are established methods of translating research into consistent practice.

With so many agencies and organizations pursuing smoke alarm programs, it makes sense that they should be harmonized and coordinated to avoid duplication and to reinforce effects. This includes coordination and risk-based prioritization on planning, budgeting, scheduling, regional focus, and other decisions, with appropriate consideration of lead times. It extends to regional, state, and local agencies and organizations, as well as national organizations.

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Introduction

In 2003, fire departments responded to 402,000 residential fires in the United States that claimed the lives of an estimated 3,165 people and injured another 14,075 (not including firefighters).[1] In a typical year, four out of five fire deaths take place in residential properties and specifically in homes. (See Appendix A for more on data sources.)

What is a home?

"Home" includes single-family dwellings as well as two-family dwellings (e.g., duplexes), townhouses, apartments, and flats. "Residence" refers to a single-family dwelling, including manufactured homes. "Residential" includes homes but also includes hotels, motels, barracks, boarding homes, and dormitories. In 2003, fire departments responded to 388,500 home structure fires in the United States that claimed the lives of an estimated 3,145 people and injured another 13,650 (not including firefighters).[1]

What is a smoke alarm?

This white paper synthesizes information about the promotion and use of smoke alarms or other fire detection and alarm equipment as a key strategy to reduce residential fire deaths. "Fire detection and alarm equipment" refer to equipment and systems designed to rapidly detect unwanted fires and to notify occupants of an exposed building or other space. "Smoke alarms" detect fires through the detection of smoke, as contrasted with heat or distinctive gases, and include the alarm horn in a single unit, as contrasted with systems that have separate detectors and alarm horns connected and coordinated by a central panel.

Fire detection and alarm equipment for homes are now typically smoke alarms; the only exceptions might be common-area coverage systems in some apartment buildings. This white paper will use the term "smoke alarm" except where the more general term is warranted.

Overview of white paper

In this paper, the authors define the strategy, consider its history and evolution, and describe where it is working and where further improvement is needed. A comprehensive overview of existing smoke alarm programs is followed by a review of the evaluation research and a look at best practices. The text then concludes with a summary of additional research and program needs. Appendices are then provided that give more detail on some topics referenced in the text.

Intended audience

The intended audience for this white paper includes policy-makers, managers, and others active in the cause of home fire safety for whom rapid, effective detection and notification are, or should be, key elements of their programs or strategies. This includes fire marshals and others from the fire service who perform or oversee fire prevention and mitigation efforts; national, state or local agencies and organizations that advocate for fire safety with an emphasis on life safety, including those focused on high-risk groups; agencies and organizations concerned about the fire safety performance and other attributes of products, including standardization, testing, certification, labeling, and compliance assurance; executives and legislatures who make resource allocation and program decisions that affect fire safety and may or may not emphasize smoke alarms; and agencies and organizations concerned about the performance and affordability of building features and other aspects of home construction, including insurance. If you are reading this white paper and have any ability to act on it, you are part of the intended audience.

The Public/Private Fire Safety Council

The Public/Private Fire Safety Council prepared this paper as the first of a series of white papers that will outline major strategies for reducing the annual death toll from residential fires, specifically home fires. The Public/Private Fire Safety Council is a 16-member council of federal agencies and non-government organizations, created to develop a coordinated national effort to eliminate residential fire deaths by the year 2020.

Statement of the topic

Defining the strategy

Working smoke alarms greatly reduce the likelihood of a residential fire-related fatal injury by providing occupants with early warning and giving them additional time to escape. The smoke alarm strategy, therefore, is to achieve universal home use of effective, reliable fire detection/alarm equipment in the U.S. Following are choices and considerations relevant to use, effectiveness, and reliability.

- Fire cue that triggers the alarm (e.g., smoke particles by size, toxic gas, heat) – for smoke alarms, the cue is smoke particles;

- Power source for the device (e.g., battery, hard-wired, plug-in);

- Alarm coverage (e.g., one alarm for an entire housing unit, every level, every level plus bedrooms, every room) – for smoke *alarms*, the unit is self-contained and includes both detection sensor and alarm horn, while smoke *detectors* may not include an alarm horn and are normally part of a larger system with a fire alarm panel;

- Interconnection (is each smoke alarm a single station, where the alarm sounds only when the sensor for that unit detects fire, or are the units connected, by wiring or broadcast, so that all alarms sound when any unit detects fire);

- Behaviors and education specific to smoke alarm effectiveness (e.g., proper installation, proper maintenance, escape planning). The success of this strategy depends as much on securing behavior change as it does on the actual smoke alarm or its physical environment. Any fire safety program focused on smoke alarm use must have a strong and effective behavioral change component.

Types of smoke alarm programs

A smoke alarm program is defined by a target audience and a program goal, which is a part of the smoke alarm strategy goals of universal use of effective, reliable smoke alarms. Some programs refer to a goal of increasing the number of homes with working smoke alarms, a goal that combines the goals of increased use and reliability. Some programs have goals that work as means to the end of achieving the strategy goals. For example, increased testing or maintenance is intended to increase reliability, while increased affordability is intended to promote increased use.

Community-based programs are programs with a target audience defined by a community or neighborhood. Typically, program personnel operate in the community and have direct contact with members of the target audience. The community scale permits manageable cost and administration. Special emphasis can be given to the high-risk part of the community, where benefits from increased smoke alarm use will be greatest, or communities can be selected on the basis of elevated risk for the entire community.

Most community-based programs are regarded as pilots for national programs, as well as valuable in their own right. Some national organizations have used their resources to support community-based programs and extend successful programs to other parts of the country. There are no known examples of complete national coverage by a network of community-based programs for home smoke alarms, but there are examples (e.g., local health departments, local fire departments) of community-based organizations that form a network covering the entire country and could be the organizational basis for national coverage by a community-based program.

Other national programs are intended to improve effectiveness, reliability or affordability, typically through changes in related technologies, standards, or educational programs or through program evaluations that help identify the most effective programs and point to program changes that will improve program effectiveness.

Magnitude of the problem

The target problem is all civilian home fire deaths.

Home fire deaths have declined substantially since the years before widespread home smoke alarm use. In 1977, when 22% of homes had smoke alarms, there were 5,865 home fire deaths. In 2003, when 95+% of homes had smoke alarms, the death toll had declined by 46% to 3,145.[1] The home fire death rate, relative to resident population, declined by 59% in the same period.[2,3]

Sidebar: A Short History of Home Smoke Alarms

(from J.R. Hall, "A brief history of home smoke alarms,"
presentation to New York State Fire Academy, May 2000;
and private communication from David Conover, ICCSAFE, June 2005)

- 1955: The first home fire detectors use heat/temperature as the fire cue.

- 1960s and 1970s: Studies determine *smoke* detectors (photoelectric or ionization) provide reliable early warning while *heat* detectors do not.

- 1965: The first single-station home smoke alarm (i.e., with power source, detection sensor, and alarm horn in one unit; not connected to a central panel) is invented, using AC power and photoelectric detection principle; these self-contained units are termed "smoke alarms" distinguished from the more general "smoke detectors" and the even more general "fire detectors."

- 1967: The first standard for home smoke alarms (National Fire Protection Association's (NFPA's) *NFPA 74*) is established.

- 1970: The first single-station battery-powered home smoke alarm is invented. It uses 9-volt batteries and the ionization detection principle.

- Mid-1970s: Sales of home smoke alarms accelerate.

- 1976: The *Life Safety Code (NFPA 101)* first requires smoke alarms in homes.

- 1973-1979: Council of American Building Officials (CABO) dwelling code (now *International Residential Code*), Building Officials and Code Administrators (BOCA) *National Building Code*, International Council of Building Officials (ICBO) *Uniform Building Code*, and Southern Building Code Congress (SBCCI) *Standard Building Code* (all now consolidated and replaced by the International Code Council (ICC) *International Building Code*) require smoke alarms in all one- and two- family dwellings.

- Mid-1970s: Federal agencies involved in mortgage lending (Federal Housing Administration and Veterans Administration) require smoke alarms in all homes to qualify for funding.*

* The U.S. Department of Housing and Urban Development currently requires smoke alarms in housing covered by its programs, with most programs requiring both initial and periodic ongoing inspections to assure proper installation and continuing operationality. This includes programs of the Office of Public and Indian Housing, the Federal Housing Administration, the Office of Manufactured Housing Programs, the

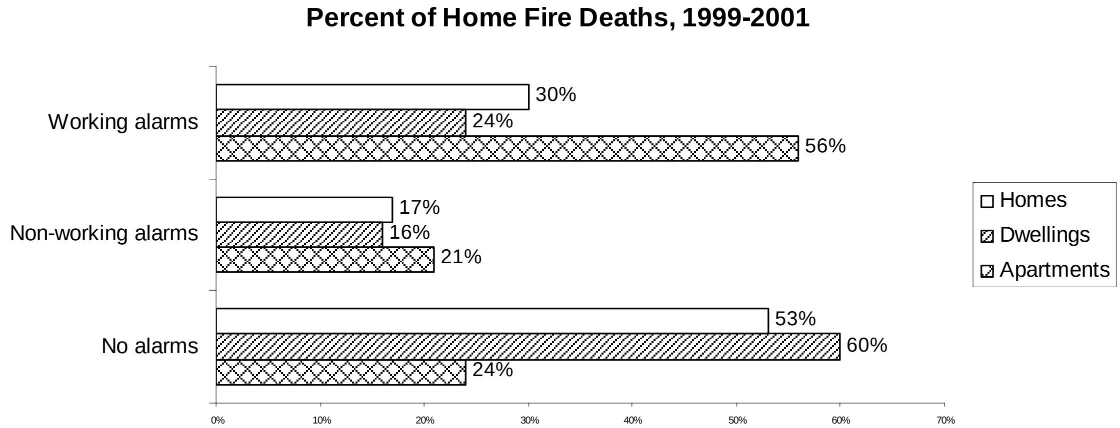
HOME Investment Partnership Program, and the Community Development Block Grant Program when applied to rehabilitation.

Sidebar: A Short History of Home Smoke Alarms (continued)

(from J.R. Hall, "A brief history of home smoke alarms," presentation to New York State Fire Academy, May 2000; and private communication from David Conover, ICCSAFE, June 2005)

- 1976: The first standard for certification of smoke alarm products (*UL 217*) is established; it remains the fundamental standard for that purpose to this day.
- 1977: Indiana Dunes test series provides best information to date regarding performance of alternative home fire detection equipment.
- 1978: The standard for home smoke alarms first sets coverage requirements at every-level protection (*NFPA 74*).
- 1980: Half the country has at least one home smoke alarm.
- 1982: Two-thirds of the country have at least one home smoke alarm.
- 1984: Three-fourths of the country have at least one home smoke alarm.
- 1984: BOCA, ICBO, and SBCCI model building codes begin requiring smoke alarms at each level of occupancy in homes.
- 1985: Smoke alarm sensitivity requirements (in *UL 217*) are modified to reduce susceptibility to nuisance alarms.
- 1988: BOCA, ICBO, and SBCCI model building codes begin requiring smoke alarms to be interconnected and begin requiring smoke alarms in all sleeping rooms, both in new construction.
- 1989: *NFPA 74* first requires that smoke alarms be interconnected in new home construction.
- 1993: *NFPA 72* first requires that smoke alarms be placed in all bedrooms in new construction.
- 1995: The 10-year-lithium-battery-powered smoke alarm is introduced.
- 1999: *NFPA 72* first requires replacement of smoke alarms after 10 years.

Homes with smoke alarms (whether or not they operated) typically have a fire death rate that is 40-50% lower than the rate for homes without smoke alarms.[2] The home fire death rate relative to number of fires is essentially unchanged from 1977 to 2003.[3] There is limited evidence, however, that smoke alarm use has contributed to the decline in reported home fires, by allowing occupants to discover and control many fires that would have otherwise grown large enough to require fire department intervention.[2]



Assurance that smoke alarms are working will achieve a further reduction. In 1999-2001:[2]

- 53% of home fire deaths occurred in homes with no smoke alarms. These circumstances represent a gap in usage. The percentages are 60% for one- and two-family dwellings, including manufactured homes, and 24% for apartments.

- 17% of home fire deaths occurred in homes with smoke alarms where the smoke alarms were not working. These circumstances represent a gap in reliability. The percentages are 16% for one- and two-family dwellings, including manufactured homes, and 21% for apartments.

- 70% of home fire deaths therefore occurred in homes without working smoke alarms. The percentages are 76% for one- and two-family dwellings and 44% for apartments.

- 30% of home fire deaths occurred in homes with working smoke alarms. These represent a gap in effectiveness. The percentages are 24% for one- and two-family dwellings, including manufactured homes, and 56% for apartments.

When only data reported directly in National Fire Incident Reporting System (NFIRS) Version 5.0 is used (see Appendix A), the percentage of deaths where smoke alarms were absent is much lower for apartments (8%) and the percentage where working smoke alarms were present is much higher (67%). (See also Appendixes B and C for more on circumstances in fatal fires with working smoke alarms present.)

Some deaths will not be prevented even when working smoke alarms are present. Deaths that may not be prevented even with working smoke alarms include those that happen so quickly that there is insufficient time for smoke alarms to react to fire and occupants to react to smoke alarms. This can occur with fast-developing fires, victims very close to the site of ignition, or slow-responding smoke alarms. Deaths that may not be prevented also include victims who are unable to respond effectively to smoke alarms. In some fires, the occupants may not have been able to hear the smoke alarm activation because of sound barriers (doors, walls, floors) between occupant and smoke alarm. In addition, even though smoke alarms may have been present, they may not have been properly located or there may not have been a sufficient number of smoke alarms within the structure.

High-risk populations

For the smoke alarm strategy, high-risk populations have either a high risk of death due to fire or heightened difficulty in benefiting from smoke alarms. A higher risk of death indicates a greater potential benefit from smoke alarm programs, while heightened difficulty in benefiting from smoke alarms indicates special needs that require attention in order for smoke alarm programs to be fully effective for those populations. High-risk characteristics include:

- <u>Age</u>. In 2002, children 4 years and younger had a fire death rate (1.2 per 100,000 population) nearly 1.5 times that of the general population (0.9 per 100,000 population). Their relative risk has declined substantially since the U.S. Consumer Product Safety Commission (CPSC) issued requirements for child-resistant lighters in 1994.

  Older adults are also at increased risk, and the risk increases with age. In 2002, adults 65 years and older had a fire death rate (2.4 per 100,000 population) 2.5 times that of the general population. Those 75 years and older had a fire death rate (3.1 per 100,000 population) three times the national average.[4] Increased risk for older adults may arise in part from decreased mobility, hearing loss, and resistance to new technologies. Smoke alarm affordability is not likely a factor, because older adults are less likely to be poor than the rest of the population.

- Recent studies have indicated that smoke alarms are less effective at waking children than adults.[6] Many older adults suffer hearing loss that may make them harder to wake as well.

- <u>Socioeconomic characteristics</u>. The correlated characteristics of education, poverty and race are associated with an increased risk for fire-related death.[7,8] African Americans and Native Americans/Alaskan Natives have higher fire death rates than white Americans, who have higher fire death rates than Asian Americans. The relative statistical strength of race, education and poverty vary from study to study.

High-risk groups defined by socioeconomic characteristics are also slightly less likely to have smoke alarms than other populations.[2] Poor households with smoke alarms are less likely to have their smoke alarms working.[9] It is also reasonable to hypothesize that poorer, less-educated households may be less likely to have other features of the most effective and reliable home smoke alarm choices, such as working batteries, every-level protection, protection of bedrooms, inter-connection, and hard-wiring.

- Disabilities. People with hearing, vision, or other physical or mental limitations or disabilities may need smoke alarms with special features. For example, hearing-impaired people may need a louder alarm horn or an alarm signal not based on sound, such as vibrations or strobe lights.

- Smoking. Smokers have a substantially higher risk of fire-related death than non-smokers.[7] Fatal victims of smoking-related fires also are much more likely to be close to the point of fire origin than fatal victims of most other types of fires.[10] This proximity can lead to fatal injury faster than smoke alarms can react.

- Use of alcohol and other drugs. Nearly half of all adult victims of home fires are impaired by alcohol when fatally injured, based on special studies that had access to blood alcohol testing of victims.[7] Alcohol and other drugs, whether prescription, non-prescription or illegal, all can make users harder to wake.[6]

- Apartment vs. dwelling. Apartment dwellers have a higher fire incident rate, relative to population, than occupants of one- or two-family homes, but a lower fire death rate.[7] Home ownership is not a strong predictor of fire risk.

  Usage of smoke alarms and other smoke detection equipment has long been higher in apartment buildings than dwellings[2], and related requirements are stronger for multiple-unit housing, but it is not clear how different usage is if one separates usage in common areas only, which available data does not do. The percentages of fire deaths where equipment was present and where working equipment was present both are much higher for apartments than for dwellings.[2] In rental properties, there may be uncertainty about renter responsibility vs. landlord responsibility for smoke alarm installation and maintenance.

- Communication barriers to comprehension. All smoke alarm programs, but especially educational programs, depend on effective communication for success. As of the year 2000 U.S. Census, 18% of the U.S. population age 5 or older spoke a language other than English at home.[11] These divided into 8% who did not speak English very well and 10% who did speak English very well.[11] This indicates one person in 12 in the general population would likely need non-English communication to participate fully and effectively in a program.

- Literacy. In the U.S. Department of Education's 1992 National Adult Literacy Survey (the latest data available), at least 40 million U.S. adults tested at Level 1 and another 50 million tested at Level 2, both indicating significant skills deficiencies in prose, document and quantitative/math literacy.[12] Having low literacy affects a person's ability to understand a barrage of written messages every day, many of them vitally important to their safety and well-being. Adults with Level 1 or 2 literacy are likely to struggle to understand basic beneficial information that other adults take for granted, such as prescription dosages, warning labels on poisonous products and appliance maintenance steps.

  When a consumer cannot read or comprehend safety information or a product or appliance's fire safety warnings, he or she may not take the necessary actions to reduce the risk of fire at home. To be effective for these individuals, safety messages need to have simplified instructions, use graphic illustrations instead of text, and be supported by local partnerships with community organizations having expertise in reaching adults with low literacy skills (see www.firesafetyliteracyproject.org).

The highest risk of all is the assumption that one's own fire risk is negligible. When many households still did not have smoke alarms, the leading reason given was that they did not believe they needed a smoke alarm because they did not believe they would have a fire. Even today, smoke alarm programs need to confirm that their target audience sees fire as a real threat and therefore sees the need for smoke alarms. If not, convincing them of that need becomes the first task of the program.[13]

Factors in effectiveness of smoke alarm strategy

Gaps in use

In 2004, smoke alarms were present in 96 percent of all U.S. homes (i.e., one- and two-family dwellings and apartments). In 2001, smoke alarms were present in only 61 percent of all U.S. home fires that were serious enough to require fire department response.[2] This means homes without smoke alarms are 15 times as likely to report a home fire as are those with alarms installed. For this reason, the goal of truly universal coverage remains essential to the overall success of this strategy.

Gaps in reliability

Gaps in reliability are illustrated by the following data from two studies:

- An estimated 20 percent of homes have smoke alarms installed, none of which are working.[9]

- Among fire-service attended fires in 2001 in homes where a smoke alarm was present, alarms were operational in three out of four fires.[2]

Hard-wired smoke alarms are much more likely to be operational than battery-powered smoke alarms.[9] When smoke alarms of either type were non-operable, it was most often because residents had disconnected them from their power source due to a perceived high rate of nuisance alarms. In a 1980 study of home smoke alarms in one Texas community, nuisance alarms were found to be five times as likely with ionization alarms as with photoelectric alarms.[14] Field performance may have changed considerably since then, as a result of changes in technology and modifications to the smoldering and flaming response requirements of *UL 217*. The National Institute for Standards and Technology recommended development of tests for standard nuisance signals so that performance of smoke alarms can be more systematically evaluated and improved.[15]

The following modifications to smoke alarms and related behaviors have helped or could help to address these problems.

- <u>Increased power source reliability</u> (e.g., requiring hard-wired smoke alarms in new construction, low-battery signal, encouraging use of battery back-up for hard-wired smoke alarms to address power failures, and use of 10-year lithium batteries rather than 9-volt batteries);

- <u>Smoke alarms that are more difficult to disable</u> (e.g., sealing 10-year batteries into the smoke alarm unit, reducing the susceptibility of smoke alarms to removal or to disabling by application of tape or other material to block smoke intake ports);

- <u>Reduced nuisance alarm rates</u> (e.g., modifying smoldering and flaming response characteristics in *UL 217* approval test, encouraging use of photoelectric smoke alarms, educating users in proper placement of smoke alarms to avoid nuisance alarms from cooking fumes or bath/shower steam);

- <u>More regular inspection</u> (e.g., weekly or monthly testing), <u>maintenance</u> (e.g., periodic cleaning) <u>and replacement</u> (e.g., batteries annually on an easily-memorized date, smoke alarms as a whole every 10 years);

- <u>Better signal discrimination</u> (e.g., use of multiple signals with or without algorithms to distinguish nuisance alarms from hostile fires).

Gaps in effectiveness

<u>Faster-developing fires</u>. Typical home furnishings in use today result in faster-developing fires and more rapid onset of lethal fire conditions than did the furnishings in use three decades ago, when smoke alarm usage first became widespread.[15] Combined with improved estimates of the speed with which fire conditions become incapacitating and the reaction times of occupants, these recent revisions to the fire development timeline mean that the time available for safe egress is shorter than it used to be and is estimated to be much shorter than the estimates used three decades ago.

Smoldering fires. Smoldering fire conditions extend the time required for fire conditions to become lethal but also extend the time required for detection by ionization-mode smoke alarms. The largest estimated times available for safe egress are achieved by photoelectric-mode smoke alarms for smoldering fire conditions. Best estimates are that at most 3% of home fire fatalities involve fires that never transition from smoldering to flaming, and the majority of those are fires where the fatal victim is intimate with ignition, i.e., very close to the point of fire origin.[16]

However, more than one-fourth of home fire deaths (all or nearly all of those involving smoking materials and some others) involve an extended initial smoldering phase. [16] A recent study found unsatisfactory performance (available escape time was less than estimated required escape time) by ionization-mode smoke alarms against fire scenarios that involved 30 to 120 minutes of initial smoldering.[15] There is insufficient data to determine whether the fires that smolder long enough to defeat ionization-mode smoke alarms are closer to 3% or 25% of the total.

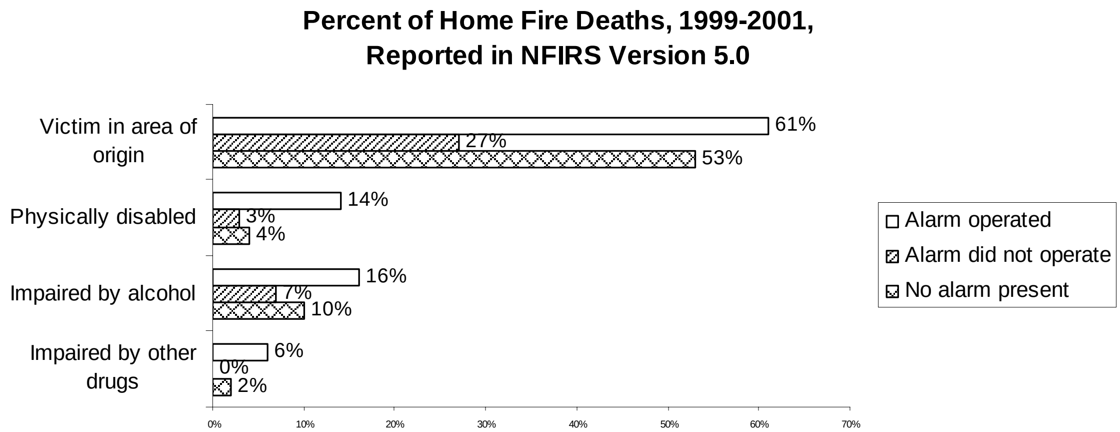
The same study found that available escape times were tight or insufficient for bedroom or living room flaming fires with either ionization- or photoelectric-mode smoke alarms.[15] Three of ten fatal victims of home fires with smoke alarms present have some condition – disability, age-related limitation, impairment by alcohol or other drugs – that could require additional escape time or assistance.[2] If the available times are tight under ordinary conditions, they might well be insufficient under high-risk conditions.

Audibility and waking effectiveness. Current smoke alarms have problems of audibility in certain situations and problems with waking effectiveness for some people.

Audibility is a problem if the distance from smoke alarm to occupant is too great (e.g., fire and first smoke alarm activated by fire not on same level of home as occupant) or if a sound-attenuating barrier (e.g., closed bedroom door) lies between alarm and person. (See Appendix D for more details.) In a 1993 study, one-fourth (26%) of households with smoke alarms had fewer smoke alarms than floors, which implies a lack of every-level protection.[9] This will mean delay in detection of some fires by the nearest smoke alarm and/or greater distance between alarm and occupant, resulting in reduced audibility.

Waking effectiveness has been documented as a problem for children and adults impaired by alcohol or some other drugs.[6] (See also Appendix C.) Overall, 38% of fatal victims were asleep when fatally injured where smoke alarms were present and operated vs. 57% where smoke alarms were present but did not operate and 49% where smoke alarms were not present (in 1999-2001 NFIRS data reported directly in Version 5.0).[2]

Occupants not able to respond effectively. Victims of fatal fires where working smoke alarms were present are more likely to have some complicating condition that interferes with the effectiveness of their response. This is true for four such conditions shown in the following chart as examples.[2] The conditions are not strict alternatives; more than one can apply to the same victim. Note that in each case, the percentages are highest for the case where someone died despite the presence of a smoke alarm that operated. The last



three conditions are characteristics of occupants that reduce their ability to respond effectively to a smoke alarm's warning. The first condition is a characteristic of an occupant relative to the fire that reduces the time available for escape.

The following modifications to smoke alarms and related behaviors have helped or could help to address some or all of these problems.

- Detection principle. Current photoelectric-mode smoke alarms appear to provide a significant reduction in the frequency of nuisance alarms compared to current ionization-mode smoke alarms, although field data is not available on the difference in rates of nuisance alarms after the changes in *UL 217* response requirements. Photoelectric-mode smoke alarms will provide an improvement in speed of detection of fires in their smoldering phase.[15] Under current conditions, photoelectric-mode smoke alarms cost two to three times as much as ionization-mode smoke alarms. If *UL 217* were modified to require faster detection of smoldering-phase fires, thereby addressing the most critical of the performance problems identified in the 2004 NIST study, the necessary changes to ionization-mode smoke alarms could also make photoelectric-mode smoke alarms or combination-mode smoke alarms more cost-attractive.

- "Smart" smoke alarms. Commercial smoke detectors include units that can detect multiple fire signatures and use algorithms to more reliably distinguish between hostile fires and nuisance sources. If modified for and applied to the home, such technologies could provide both greatly reduced nuisance alarm rates and earlier confirmation and alarm for hostile fires. Under current conditions, this technology is much more expensive than current home devices.

- Smoke alarms in bedrooms. Current standards for new construction require interconnected smoke alarms with units in all bedrooms. Single-station smoke alarms in bedrooms will be of value primarily to occupants of the bedrooms, because of audibility limitations and barriers between rooms. An alarm in the bedroom could be particularly valuable for older adults, anyone who lives alone and can't rely on occupants in other rooms for rescue, and those with special needs who may require extra time to escape. Single-station smoke alarms in bedrooms will provide some additional life-saving benefit to bedroom occupants, particularly if parallel changes to bedroom furnishings (e.g., improved resistance of mattresses or bedding to small open-flame ignitions) result in significant delay in fire development and onset of incapacitating or lethal conditions. (See Appendix E.)

- Interconnection of smoke alarms. Current codes for new construction require the operation of one smoke alarm to cause all smoke alarms to sound. This interconnection has historically been accomplished through hard wiring between smoke alarms. Innovative technologies, including wireless broadcast between units, could make retrofitting of interconnection practical and affordable. Interconnection reduces the time between fire detection by the first unit and activation of an audible alarm near remote occupants. The majority of fatal victims of U.S. home fires are located in a different room from the point of fire origin, so there is considerable room for benefits from this change.

- Changes in alarm tone for better waking effectiveness. Recent research indicates that lower pitches than those now specified greatly improve audibility. Voice messages, particularly those recorded using a familiar voice, also improve waking effectiveness, in part because voices fall in a lower pitch range when compared with the current signal. The focus is on groups, like children, newly identified as not reliably waking to current alarm signals.

- More development and rehearsal of home escape plans. The goal is to reduce pre-movement time and improve choices made in responding to an alarm. This will improve the chances of safe escape, in part by reducing the likelihood of movement into more hazardous areas or more risky behaviors (e.g., attempting to fight fire when it is no longer contained). Occupants with special conditions (e.g., mobility, vision, or hearing disabilities; learning difficulties) can have those conditions addressed in a customized plan before a fire occurs. In view of the waking effectiveness problems of smoke alarms where children are concerned, parents should incorporate into their plans the need for adults to wake sleeping children.

Gaps in understanding human behavior

Researchers are beginning to understand that environment and technology are not the only determinants of successfully surviving a fire but that human behavior plays a dominant role, too.[17] Behavioral reactions to fire, to fire detection, and to fire alarms can often mean the difference between who dies and who survives.[18] Behavioral models that incorporate early detection and planned and practiced escape can measurably improve survivability.[19,20] While researchers and practitioners understand the importance of testing and maintaining smoke alarms and practicing escape plans in the event of home fires, more work is needed to understand what incentives are needed to encourage people to actually practice these safety behaviors.

Driving usage by marketing vs. standardization

The period of rapid growth in installation of home smoke alarms preceded the adoption of codes or regulations governing existing homes in most states. For example, in 1983, a year after smoke alarm usage had already reached two-thirds of households, only 16 states had any smoke alarm requirements for single-family dwellings.[21] The clear implication is that most households with smoke alarms must have freely chosen them based on perceived value and affordability rather than a need to comply with applicable rules.

However, the gains in usage of the past decade or so, the period when most of the higher-risk households have first acquired smoke alarms, has been driven by codes and regulations. Standardization has also been the driver behind implementation of revisions in the requirements designed to improve effectiveness and reliability, such as hard-wiring and interconnection. These improvements all raised the cost of equipping a home with smoke alarms, and the solutions to problems outlined above will make the technology even more expensive. Every increase in cost reduces the potential of ordinary marketing to achieve universal implementation. Standardization will become ever more important.

Smoke alarm standardization is largely decentralized among private standards-developing organizations. Model building, fire and life safety codes specify whether a property is required to have smoke alarm protection and where such protection is to be provided, if required. The NFPA and ICC both develop such model codes, and NFPA also develops reference standards that address what is to be done to provide protection and how compliance is to be achieved. Code and standard provisions are generally differentiated by occupancy type (office, residential care, high rise residential, etc.) and are detailed as to type of protection required and how exactly it is to be located in the building and connected with other building systems. Other standards referenced, such as those by Underwriters Laboratories (UL), establish performance standards that the smoke alarm devices themselves must satisfy.

In combination, these decentralized standards have helped to achieve today's near-universal smoke alarm coverage with proven results. Coordinating changes in the applicable documents, however, can be cumbersome (since as many as three separate organizations can be involved). In addition, local and state authorities are involved because they must adopt the model codes into law before the codes can become binding. That introduces a fourth decision-making body into the equation. These authorities can adopt the model requirements in whole or only in part, with or without modifications. The authorities then are responsible for inspection and enforcement to make sure the rules are followed.

All of this is further complicated for existing buildings. Model building codes provide requirements only for new construction. The ICC *International Fire Code®*, the *International Existing Building Code®*, the NFPA *Life Safety Code®*, and the *Uniform*

Fire Code®, include requirements for existing properties, but not every state adopts any model or other requirements for existing homes.

To further ensure compliance with these codes and standards, manufacturers of smoke alarm equipment and system components must provide evidence that their products comply with the referenced standards. Third-party testing and certification agencies will undertake testing of the products to verify they satisfy the applicable standards and also perform continuing follow-up inspections at the manufacturing plant to ensure that continued product production is in compliance with the standards. The placement of a label on the product is an indication of its acceptability with respect to the product standard, something very important in ensuring desired product performance with respect to smoke detection and notification.

This complicated multi-organizational process has implications for the design of any program that seeks to achieve rapid improvement in usage, effectiveness or reliability of home smoke alarms via the standardization route. Advocates must first seek changes in the appropriate codes and standards through the processes appropriate to the organizations that publish those documents. If model building and fire codes or the *Life Safety Code* are involved, advocates must then appeal to states individually to encourage them to adopt into law the new editions of the model requirements. (The NFPA standard on home smoke alarms becomes effective by reference in the adopted model codes, and the UL requirements on smoke alarms become effective when manufacturers test their units in order to obtain the UL mark.) Finally, advocates must follow through at the community level to make sure local inspection and enforcement is conducted effectively.

Existing community-based programs to increase use or reliability

Direct distribution

- Local fire and emergency service organizations are the primary distributors of smoke alarms directly to households.

- Various local, state and national community-based organizations also distribute alarms. They may distribute alarms directly to households or provide smoke alarms to more locally based organizations who perform the actual distribution. Other distributors or sources of smoke alarms for distribution include retail stores, smoke alarm manufacturers, and home builders that include smoke alarms in new homes (details about these distribution programs were not captured in this review).

- Replacement batteries can also be the subject of direct distribution programs.

- Elements of choice in programs include:

- manner of distribution (e.g. door-to-door in targeted areas, distribution to unprotected homes visited by fire department for a non-fire emergency);
- characteristics of targeted population (e.g., high-risk characteristics);
- type of equipment distributed (e.g., 10-year lithium battery units, interconnected systems, and photoelectric, ionization or combination alarms);
- type of equipment replaced (e.g., smoke alarms more than 10 years old);
- locations in home to be covered (e.g., basic every-level protection; bedrooms even if not required in existing homes);
- extent of related fire safety education provided (e.g., specific guidance on escape plans, prevention education, whether to keep doors closed); and
- extent of other related programs offered (e.g., smoke-alarm hotline).

- Elements that have been included in programs include:
  - advertising, news and announcements, to create awareness and increase participation by eligible households and to improve receptiveness to door-to-door contacts (e.g., local news coverage, public service announcements, publicity through local churches, publicity through health departments or clinics);
  - door-to-door canvassing, to identify eligible households in need without being affected by gaps in existing lists (e.g., canvassing by fire companies on marked fire apparatus);
  - organizational details (e.g., coordinators and supervisors to oversee a large force in the field; recruitment of sponsors and partners to support costs, provide smoke alarms for distribution, publicize program, facilitate communication and built trust between program and target audience);
  - special needs of target audience (e.g., non-English speaking, not majority culture, history of distrust of officials and authority figures, poverty);
  - motivational techniques (e.g., use of incentives and recognition for volunteers, tax incentives to manufacturers or retailers for donations of smoke alarms for distribution);
  - funding sources (e.g., grants from USFA, CDC, American Red Cross; donations of smoke alarms or replacement batteries);
  - program evaluation, to improve design of program for greater effectiveness, to attract and retain participants, funders, partners, and community leaders and members (e.g., by evaluation experts from a partner academic institution or qualified national advocacy group) (See Appendix J for more on measures to use in program evaluation);
  - number of channels or approaches used, in order to avoid gaps and weaknesses of even the best single approach and in order to achieve maximum coverage and effectiveness (e.g., mixing multiple broadcast channels and print sources; mixing mass media with organization-sponsored communications such as church bulletins).

Program results

There have been scores of documented community-based fire safety programs using home smoke alarms as the principal component. Appendix F describes candidate measures of effectiveness for such programs, but most documented studies have very limited effects measurement. Appendix G provides a summary of characteristics of 42 programs that are mostly not included in the summary below of the program evaluation literature.

Change in usage. Specific results assembled from 13 programs showed an estimated total of 400,000 smoke alarms installed in roughly 235,000 homes. (These estimates use the average of 1-2/3 alarms per home from the only program to provide results on both alarms and homes.) If 4% of homes now lack smoke alarms,[2] the 235,000 homes reached by these program represent roughly 1/20 of the homes still needing alarms.

Effectiveness of smoke alarm strategy. Two systematic reviews and several recent studies assessed the effectiveness of fire injury prevention interventions. The reviews included programs that focused specifically on smoke alarm distribution as well as more general programs aimed at reducing fire-related injuries. A review by DiGuiseppi focused primarily on controlled trials of interventions to promote smoke alarms[22]. A broader review by Warda considered all house fire injury prevention interventions, regardless of whether smoke alarms were involved[23].

DiGuiseppi identified thirteen randomized controlled trials and conducted a meta-analysis of their results. Eight were delivered in clinical settings (including prenatal, well child, and parenting classes held in clinics and hospitals)[24,25,26,27,28,29,30,31], four were delivered at home[32,33,34,35], and one was in school[36]. Burn and fire safety were the focus of only two trials[31, 36]. The other trials addressed general injury prevention. Seven trials occurred in the United States[25, 27, 28, 29, 30, 32, 36], three in Canada[31, 33, 34], and three in the United Kingdom[24, 26, 35].

Among nine trials that were completed and for which data were available at the time of the DiGuiseppi review [24,25,26,27,28, 31,32,33, 36], **smoke alarm ownership** at follow-up appeared somewhat more likely in the intervention group, although the differences were not statistically significant (odds ratio = 1.26, 95% confidence interval = 0.87 to 1.81). Similarly modest positive, statistically non-significant effects on **functioning smoke alarms** (OR=1.19, 95% CI=0.85-1.66), on **new acquisitions of smoke alarms** (OR=1.59, 95% CI=0.73-3.49), and **functioning newly acquired smoke alarms** (OR=1.34, 95% CI=0.892-1.94) were found in studies that measured these outcomes. Offering discounted or free smoke alarms had a stronger effect on smoke alarm ownership (OR=1.81; 95% CI=0.63-5.19) than did education alone, though the effects were not statistically meaningful.

DiGuiseppi also presented thirteen non-randomized controlled trials, with eight having been completed with results available at the time of the review. Two of the trials evaluated safety advice provided during routine child health surveillance visits[37, 38], one evaluated education provided during mandatory tenants' meetings[39], and the other five evaluated community programs involving mass media, school or community education, clinical counseling, free smoke alarms, and/or alarm installation [40,41,42,43,44,45,46,47,48]. Among studies reporting smoke alarm outcomes, those that involved general safety advice during routine child health surveillance showed similar effects to those of the randomized trials[37, 38]. One of the trials reported a modest but non-significant effect by offering free smoke alarms compared to counseling alone[38]. Two community trials of general injury prevention reported no effects on alarm ownership or installation[46, 47]. In contrast, installation of free smoke alarms increased the prevalence of functioning smoke alarms by 19% (p<0.001)[48].

One trial that required participants to attend a mandatory lecture and watch a video about fire safety and prevention found that **fire incidence** in the intervention group (new tenants) was significantly lower compared to the control group (existing tenants), relative risk = 0.18 (95% CI=0.16 – 0.21)[39]. Another trial showed that while a community-wide distribution of free alarms plus fire prevention brochures had little effect on fire incidence[48], it did decrease fire-related **injury rates**[48].

The review article by Warda identified five additional studies that examined smoke alarm use and function[49, 50,51,52,53]. None were randomized clinical trials. In one program, follow-up home inspections at 4-9 months demonstrated that 81% of homes that received a smoke alarm still had an **installed and operational alarm**[49]. Another study examined the effect of legislation[51]. One county with a “retrofit” law requiring smoke alarms in all homes regardless of the home’s age was compared to a nearby county with legislation requiring smoke alarms in new homes only. Homes in the “retrofit” county were less likely to have no **operational alarm** (17% vs. 30%) or **no alarm** at all (6% vs. 16%).

Thus, the reviews found no randomized controlled trials with evidence of functioning smoke alarms as a result of the interventions. Among less scientifically rigorous studies, however, interventions that featured installations, installations plus information, and policies calling for retrofitting with smoke alarms all had evidence of effectiveness. While the results may be encouraging, these less scientifically sound studies are subject to validity challenges (e.g. sampling bias, history effects, and recall bias).

Five studies that have been published since the DiGuiseppi and Warda papers add relevant information about smoke alarms interventions. In 1998, Douglas, et al., found that among four methods to solicit participants to **receive free smoke alarm**, door-to-door canvassing was much more effective at distributing alarms than were notification by mail, fliers left on the doors of home, and fliers posted in public places[54]. Harvey et al., in 2004, randomly assigned households in comparable communities in four states to either have smoke alarms installed or receive a voucher for free smoke alarms. Results showed that 6 to 12 months following the interventions, 90% of installation homes had working smoke alarms whereas 65% of voucher homes had functioning alarms (p<0.00001).

To examine the effectiveness of installation programs, three studies investigated the operability of alarms over time. One study found that 83% of the alarms installed in program homes were still functioning after six months[56], another observed that 87% of the alarms worked after one year[57], and a third found 64% of the alarms were operational after about 3 years[58]. These studies suggest that while smoke alarm installation programs may be effective initially, the effects may wane after several years. This decline in operability may be due to batteries that are missing, disconnected, or dead. People are most likely to remove or disconnect batteries because of nuisance activations.[9]

Features of effective interventions. Evidence consistently does not support the many versions of "education only" or "distribution only" efforts. However, programs that show promise actually install alarms properly in homes in contrast to programs that only give out free alarms or vouchers for free alarms. While we must continue to develop and test effective interventions, especially those that benefit from leadership and promote community-based norms for fire prevention, we also need to benefit from what we already know. Recent studies, especially those by Douglas[54] and by Harvey[55], indicate that smoke alarm installation programs work, especially when combined with education and awareness of their proper use and maintenance.

Moving from research-based interventions involving smoke alarm installation to effective community-based programs requires a translation process[59]. A recent paper by Ballesteros et al.[60] identifies key elements that are essential to such a program and aspects that can be adapted and tailored to local circumstances:

- targeting communities at greatest risk,
- developing strong collaborations with individuals and community organizations,
- partnering with local fire departments,
- using local coordinators,
- developing pre-intervention advertising of the program,
- door-to-door canvassing (in urban and suburban areas),
- scheduling appointments in rural areas,
- combining smoke alarm installations with fire safety education,
- providing incentives and recognition for program staff and volunteers, and
- evaluating the program.

Research and program needs

As highlighted in this white paper, a number of important issues must be addressed to maximize the impact of the smoke alarm strategy on residential fire deaths.

Gaps in usage

- Smoke alarms must be installed in the last 4% of U.S. homes without them. This group accounts for 39% of reported home fires and nearly half of all the reported home fire deaths. This 4% represents just over 4 million housing units.

Gaps in reliability

- Smoke alarms must be restored to full operational status in the 20% of U.S. homes that have non-working alarms installed. Nearly all of this 20% involves dead or missing batteries, as opposed to AC power.[9] Nearly half of the households with non-operational smoke alarms that gave a reason cited removal due to nuisance alarms or continuous alarming.[9] More than half cited problems of oversight or difficulty (e.g., costly battery type) in replacing batteries known to be dead.[9] Improvement in the operational percentage will therefore most likely require a significant reduction of the nuisance alarm problem, as well as changes that address oversights and difficulties in replacing batteries. The 20% represents roughly 21 million housing units and an estimated 30+ million smoke alarms.

Gaps in effectiveness

- Available programmatic research indicates that programs are more successful if smoke alarm distribution is supplemented by direct installation and combined with supporting education and scheduled follow-up visits. Also important, program evaluations must be sufficient to refine program features as needed and demonstrate program effectiveness.

- The needs of special populations often dictate special features in the design of smoke alarms or in other aspects of smoke alarm programs. These special populations include:
    - Children, differentiating young children from older children
    - Older adults
    - Disabled populations (addressed by disability type)
    - Non-English speakers
    - Adults with low literacy levels in their native language
    - Renters, whose protection may be partly or wholly the responsibility of a landlord

- Further research could improve the effectiveness and reliability of smoke alarms through technological means. Improvements could include:
    - Greater waking effectiveness for certain identified populations;
    - Quicker, more certain responses to the range of fire types coupled with reduced nuisance alarms;
    - More affordable ways to interconnect the alarms in existing homes

- Continued research is needed to improve smoke alarm performance and to improve measurement of smoke alarm performance, so as to provide better information for refinement of codes, standards, and other requirements and to support compliance assurance. One example is a new fundamental research program, being undertaken by Underwriters Laboratories and the Fire Protection Research Foundation, to characterize the smoke arising from commonly available materials found in the home in both smoldering and flaming modes. The purpose of the work is to develop baseline data on highly characterized “reference” materials to facilitate improvements in smoke detection technology and serve as a basis for review and possible revision of the UL 217 Smoke Alarm standard. The research objectives are as follows:

1. Characterize the chemistry, thermal decomposition and combustibility of materials found in residential structures.
2. Develop smoke particle size data and smoke profiles in the UL smoke detector room for materials found in residential settings for both smoldering and flaming modes of combustion.
3. Develop recommendations for changes to the current smoke detector standard (UL 217).

- With so many research possibilities and program features that could be generally adopted, it is important to set priorities based on estimates of life-saving potential and cost-effectiveness. This includes special interest in demonstration projects that include key elements at a low cost-per-person and it includes evaluation of any demonstration projects sufficiently to inform decisions on broader adoption. Implementation of proven technologies and program elements can be usefully pursued through both best practices and standardization for both new and existing homes.

Gaps in understanding of human behavior

- A greater understanding of human behavior is needed to inform educational approaches to change behaviors that support the smoke alarm strategy, particularly including the following related behaviors:
    - Home escape planning
    - Inspection, maintenance and replacement of smoke alarms
    - Safe options for dealing with nuisance alarms without sacrificing smoke alarm protection

- Human behavior in residential fire requires careful analysis to determine effective cues, adaptive environments, egress skills development under stressful conditions, and strategies to reduce the learned irrelevance of alarms, due to the high frequency of nuisance alarms, and to increase the perceived value of immediate escape.

National coordination using the white paper

- With so many agencies and organizations pursuing smoke alarm programs, it makes sense that they should be harmonized and coordinated to avoid duplication and to reinforce effects. This includes coordination and risk-based prioritization on planning, budgeting, scheduling, regional focus, and other decisions, with appropriate consideration of lead times. It extends to regional, state, and local agencies and organizations, as well as national organizations.

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Appendix A – Principal Data Sources

Data describing the presence and operation of smoke alarms in home fires is collected by the local fire departments who respond to the fires. Participating states and jurisdictions submit these data to the U.S. Fire Administration where they are compiled into a single database – the National Fire Incident Reporting System (NFIRS). In addition to smoke alarm data, NFIRS includes a variety of other information including the characteristics involved in fire ignition, fire spread, casualties, and property loss.

The database captures about 150,000 residential fires annually, but it is not a probability sample. To produce national estimates, users apply NFIRS database distributions to NFPA published projections of aggregate residential fires and fire losses for the time period being evaluated. The NFPA survey of fire experience, like NFIRS, only estimates those fires reported to local fire departments. Unlike NFIRS, however, the NFPA survey is designed as a stratified random-sample survey to achieve appropriate weighting by region and community size.

Since 1999, NFIRS has captured detection/alarm equipment type, power supply, operation, effectiveness in alerting occupants, and reason for alarm failure. Before 1999, only operation was captured, and it was necessary to assume that all home fire detection/ alarm equipment was smoke alarms.

NFIRS also changed the coding choices for smoke alarm presence. Before 1999, the data element recorded "smoke alarm operated" vs. "smoke alarm did not operate" for smoke alarms in vs. not in the room of fire origin. Fires that were too small to activate an operational smoke alarm were to be coded separately, not as "did not operate," in a code that did not distinguish smoke alarm location relative to fire. Now, the coding only asks whether a detector was present or absent in the "area" of the fire. There is no option to indicate that a detector was or was not present outside the area of the fire, even if such a smoke alarm was the closest unit to the fire.

Before 1999, an apartment building with smoke alarms in the common areas but not in the individual units would have a fire in the apartment unit coded as "smoke alarm present, not in room of fire origin." The same coding would also apply if a fire began in a bedroom, for example, while the nearest smoke alarm was in the hallway within the apartment unit. Since 1999, all these fires would be coded as "smoke alarm not present in area of fire origin."

The CDC's National Center for Health Statistics maintains a database of death certificate data that provides some of the data available describing overall fire death patterns and trends. The NCHS database is a census rather than a sample projection, but it does not include data about smoke alarms, fire causes or other fire details.

In terms of timeliness, the NFPA survey data is typically available 1-2 years sooner than either the NFIRS or NCHS data.

Appendix B – U.S. Residential Fire Fatalities Where Smoke Alarms Operated

Gayle Kelch, U.S. Fire Administration

From 2001 to 2002, the estimated number of fire fatalities where smoke alarms were present and operated decreased from 1,223 to 909 in all residential structures; from 897 to 673 in one- and two-family dwellings, and from 325 to 199 in apartments. During this same time period, the percentage[1] of fire fatalities that occurred in homes where smoke alarms were present and operated decreased from 39 percent to 34 percent in all residential structures; from 34 percent to 30 percent in one- and two-family dwellings, and from 71 percent to 51 percent in apartments (see Tables 1 and 2). Note that “all residential structures” also includes properties (e.g., hotels, motels, dormitories, barracks) that are not homes, i.e., not one- and two-family dwellings and not apartments.

While the percentage of fire deaths that occurred in apartments where smoke alarms were present and operated decreased substantially, the remaining 51 percent is troublesome, especially because it is thought that most apartment alarms are hard-wired and professionally maintained by the apartment management. (The uncertainty primarily involves smoke alarms inside the apartment units, which are often the sole responsibility of the occupants rather than the management.) Possible explanations include hallway or other common-area alarms that sound after victims are overcome, or fewer escape routes for residents, particularly those living on higher floors. Fewer escape routes can mean longer escape paths, which can mean longer times inside the building and potentially exposed to fire effects. Additionally, apartments may experience more frequent false alarms caused by smoke from burning food or pots. Such repetitive incidents may lead tenants to ignore fire alarms.[2] These suppositions require further investigation beyond the scope of this analysis.

The large relative percentage decrease in apartment fire deaths between 2001 and 2002 may be due in part to the increased number of apartment fire deaths reported to NFIRS Version 5.0 in 2002. The increase in reported deaths allows for a more meaningful representation of the data. As the percentage of fire fatalities decreased for apartments between 2001 and 2002, the percentage of fatalities with unknown smoke alarm status increased from 14 percent to 24 percent. To account for the fire deaths where the smoke alarm status was unknown, these unknown cases were distributed in the same proportion as those with known status.

It is important to note that NFIRS data may fluctuate from year to year, resulting in variability. It is possible that either 2001 or 2002 was an anomalous year for this data. As

[1] Percentages in Tables 1 and 2 are rounded to one decimal point. Textual discussions cite these percentages as rounded whole numbers.

[2] *Fire in the United States 1992-2001 Thirteenth Edition*, U.S. Fire Administration.

more fire departments report incidents using NFIRS Version 5.0, researchers will be better able to analyze trends in fire fatalities where smoke alarms are present and operate and therefore better able to define the magnitude of the problem and understand the factors contributing to it.

It also is important to note that in the above analyses, the sum of the estimated numbers of deaths where smoke alarms were present and operated for one- and two-family dwellings, apartments, and other residential structures (the latter not included in this report) do not equal the estimated number of comparable deaths if all residential structures are scaled up together. This is because there are differences in the distributions of the number of deaths for NFIRS and NFPA between one- and two-family dwellings and apartments. In essence, the unknowns are handled differently when analyzed separately for the two types of homes than when analyzed as one combined group of homes.

Methodology

The residential fire fatality estimates in this analysis were derived from the 2001-2002 National Fire Incident Reporting System (NFIRS), using only data reported directly in Version 5.0, and from the National Fire Protection Association's annual National Fire Experience Survey. The variable OTH_DEATH from the NFIRS basic incident file was used to determine the number of fire deaths. The presence of fire detectors (variable name: DETECTOR) and the alarm operation (variable name: DET_OPERAT) fields from the NFIRS structure fire module were used in the analysis to determine the presence and operation of smoke alarms where residential fire fatalities occurred. No attempt was made to screen out fire detectors that were not smoke alarms.

The DETECTOR field identified whether a smoke alarm was present, no alarm was present, or the smoke alarm presence was unknown. Fire deaths where DETECTOR status was unknown (blank or null) were distributed proportionally, based on those with known DETECTOR status.

For incidents where an alarm was present, the DET_OPERAT field indicated whether the fire was too small to activate the alarm, the alarm operated, the alarm failed to operate, or the operational status was unknown. From this data, excluding cases with status unknown, it is possible to calculate the percentage of fire deaths where smoke alarms operated vs. the percentage where they failed to operate or where the fire was too small to activate the alarm. (These two conditions were combined in this analysis.)

To compute the *number* of residential fire deaths where a smoke alarm was present and operated, the following methodology was used. The number of NFIRS fatalities (including allocation of cases where the detector presence was unknown) for which the DETECTOR status was determined to be present is multiplied by the percentage of fire deaths for which the smoke alarm was present and operated (including allocation of cases with detectors present for which operation was unknown). This resulted in an adjusted count of fire deaths where the smoke alarm was present and operated. The same procedure was also used to determine the adjusted count of fire deaths where the smoke alarm was present and did not operate. In essence, then a new variable was created that included three categories: alarm present and operated, alarm present and did not operate, and no alarm present. Then, based on this new variable, the percentage of fire deaths where the smoke alarm was present and operated was determined based on the total number of reported NFIRS residential civilian fire deaths. This percentage was then multiplied by the NFPA estimate of the total number of residential fire deaths to compute the *number* of fire deaths where a smoke alarm was present and operated. The same methodology was used to compute the percentages and estimates for one- and two-family dwellings and apartments.

Table 1. 2001 Residential Civilian Fire Fatalities Where Smoke Alarms Were Present and Operated

	All Residences	**One- and Two Family Residences**	**Apartments**
NFPA Fires	396,500	295,500	88,000
NFPA Civilian Fire Deaths	3,140	2,650	460
NFIRS Reported Civilian Fire Deaths	534	455	57
Percentage of Deaths Where Smoke Alarms Present* (2001 NFIRS)	59.7%	53.6%	94.8%
Percentage of Deaths Where Smoke Alarms Present and Operated* (2001 NFIRS)	**39.0%**	**33.8%**	**70.7%**
Estimated Number of Deaths Where Smoke Alarms Present and Operated	**1,223**	**897**	**325**

Source: NFPA's *Fire Loss in the United States During 2001*; 2001 NFIRS Version 5.0 Data Only

* For fatalities where the presence and operational status of a smoke alarm is unknown, the unknowns are distributed in the same proportion as those with known status.

**Table 2. 2002 Residential Civilian Fire Fatalities
Where Smoke Alarms Were Present and Operated**

	All Residences	One- and Two Family Residences	Apartments
NFPA Fires	401,000	300,500	88,500
NFPA Civilian Fire Deaths	2,695	2,280	390
NFIRS Reported Civilian Fire Deaths	685	539	102
Percentage of Deaths Where Smoke Alarms Present* (2002 NFIRS)	56.5%	51.6%	76.5%
Percentage of Deaths Where Smoke Alarms Present and Operated* (2002 NFIRS)	**33.7%**	**29.5%**	**51.0%**
Estimated Number of Deaths Where Smoke Alarms Present and Operated	**909**	**673**	**199**

Source: NFPA's *Fire Loss in the United States During 2002*; 2002 NFIRS Version 5.0 Data Only
* For fatalities where the presence and operational status of a smoke alarm is unknown, the unknowns are distributed in the same proportion as those with known status.

Implications of Using NFIRS Version 5.0 Data

This analysis was completed using only NFIRS Version 5.0 data and therefore without converted version 4.1 data from the same years. The NFIRS version 5.0 data collection system is notably different from the previous 4.1 system. The decision to use only 5.0 data for the smoke alarm analysis was based on conversion issues for some of the smoke alarm data fields between the version 4.1 and 5.0 systems. Differences between the two versions, the result of both coding changes and data element design changes, have necessitated revisions to long-standing groupings and analyses. This was the rationale for not combining data from the two different systems, especially with an intended use of computing trend analyses.[3]

In 2001, 48 percent of the NFIRS reported fires were reported using the version 5.0 system, whereas in 2002, 65 percent of the reported fires were reported using the version 5.0 system. As time progresses, still more fire departments will report incidents using the 5.0 system. Until that happens, concrete conclusions should not be drawn from the data.

[3] *Fire in the United States 1992-2001 Thirteenth Edition*, U.S. Fire Administration.

Appendix C – Why Are People Dying in Homes That Have Working Smoke Alarms?

Marty Ahrens, National Fire Protection Association

In pursuing the strategy of saving lives through the use of home smoke alarms, there are three questions that must be answered in order to obtain the maximum possible benefit from the strategy:

- How do we place smoke alarms in every home? With estimated usage now around 96%, this question has been very nearly answered. Elsewhere in this white paper are discussions of programs designed to provide smoke alarms to the few homes that still do not have them.

- How do we assure that all smoke alarms are working? Elsewhere in this white paper are discussions of engineering and educational options to answer this question.

- How do we assure that everyone provided with working smoke alarms is able to escape fatal injury if fire occurs? That is the question addressed in this section.

This seemingly simple question, as rephrased in the title to this section, seems to imply that working smoke alarms should suffice for life safety. Identifying the circumstances when they do not requires answers to questions about the expected life-saving impact of smoke alarms, fire circumstances, human factors and the technology itself.

How big is the problem?

During 1999-2001, NFPA estimates, 30% of U.S. home fire fatalities occurred in homes with working smoke alarms. Working smoke alarms were present in fires that claimed the lives of 24% of the victims of one-and two-family dwelling fires, and 56% of the victims of apartment fires. These statistics exclude fires that were too small to activate an alarm (note this exclusion differs from the analytic approach used in Appendix B) and fires in which the smoke alarm presence, status or operation was unknown or unclassified.

Data originally collected in NFIRS Version 4.1 was converted back to the original Version 4.1 categories using percentages taken from 1989-1998 data. This allowed the Version 4.1 data to be reconverted into the categories used for the analysis, where it could then be combined with data originally collected in Version 5.0. This procedure was used to identify numbers and percentages of fires and fire deaths where smoke alarms were present and operated. (The use of data originally reported in NFIRS Version 4.1 also differs from the analytic approach used in Appendix B.)

Version 5.0 of NFIRS also captures some information that Version 4.1 did not capture, including data about the effectiveness of operating smoke alarms. The statistics that follow on these points are based on 1999-2001 home fires with data collected in Version 5.0 only. Unknowns were excluded from all analyses.

Did the victim hear the alarm?

A single-station smoke alarm may not be heard throughout a home. An alarm sounding on one floor of a home may not alert a resident on another floor or even in another room on the same floor if the door is closed. Therefore, many homes need more than one smoke alarm for code-compliant complete protection. For example, CPSC's 1993 National Smoke Detector Project found that 26% of U.S. households surveyed had fewer than one alarm per floor, meaning these homes did not have every-level protection and were not code compliant.[1] Even on a single floor, widely separated sleeping areas may require more than one smoke alarm on a floor, which means some of the 74% with at least one smoke alarm per floor still may not have been code compliant.

In 1999-2001 U.S. home fires where smoke alarms were present and operated, the alarms failed to alert the occupants in 3% of fires. This may be a further indication of problems of audibility of alarms.

Do some fire scenarios make the presence of a smoke alarm irrelevant?

In some situations, fire victims already are aware of the fire or intimate with ignition. A working smoking alarm is irrelevant to an individual who is awake and whose clothing is burning.

The United Kingdom collects information about smoke alarm operation, how fatal and nonfatal fires are discovered, and how alarms are raised (which is the British expression for actions taken by one person aware of the fire to alert others). In 2001, smoke alarms operated but did not raise the alarm in 4% of reported U.K. home fires.[2] Analysis of these cases revealed that:

- in 55% of these fires, an occupant was aware of the fire (e.g., by being in the same room where it started) and raised the alarm before a smoke alarm sounded;
- in 21% of these fires, occupants were not within earshot of a working alarm; and
- in 11% of these fires, the occupants failed to respond.

1. Charles L. Smith, Smoke Detector Operability Survey – Report on Findings, Bethesda, MD: U.S. Consumer Product Safety Commission, November 1993, p. 24.

2. Lorraine Watson, Georgina Ford, Darren Sugg, and Jon Gamble, *Fire Statistics –- United Kingdom 2001,* London, U.K., Office of the Deputy Prime Minister, Fire Statistics and Research, April 29, 2003, p. 41, at http://www.odpm.gov.uk/stellent/groups/odpm_fire/documents/page/odpm_fire_608483.hcsp.

Could the victim respond?

In 1999-2001 U.S. home fires where smoke alarms were present and operated, occupants were alerted of a fire and able to respond in 81% of the cases. In only 2% of the cases were occupants alerted without responding, but these cases accounted for 28% of the deaths where smoke alarms were present and operated. It is not known whether the smoke alarm provided the first notification of the fire in these cases.

Also, as noted in the text and in the tables to this appendix, victims of fatal fires where smoke alarms were present and operated are more likely than victims of fatal fires in other circumstances to have some specific impairment, disability, or circumstance that would be expected either to delay their response or to make that response less effective.

Did the victim respond in a way that would have maximized his or her chance of survival?

In 1999-2001 U.S. home fatal fires, victims were more likely to be engaged in fire control (9%) or rescue (7%) activities when smoke alarms were present and operating than were victims of fires in which smoke alarms did not sound (2% and 2%, respectively) or were not present at all (1% and 4%, respectively).

Are smoke alarms more helpful when occupants are sleeping and therefore less likely to discover fire except with the help of a working smoke alarm?

Being asleep is a condition that makes an occupant less able to respond in the absence of a signal from a working smoke alarm and so should be *less* often cited as a factor for fire fatalities when smoke alarms were present and operated.

In 1999-2001 in the U.S., 38% of those killed in home fires where smoke alarms were present and operated were sleeping at the time of death (under the "activity at time of injury" data element), much less than the 57% of those killed who were sleeping in homes with non-operational smoke alarms and the 49% of those killed who were sleeping in homes with no smoke alarms at all.

Being asleep was mentioned as a "human factor contributing to injury" for 27% of those who were killed when smoke alarms were present and operated, much less than the 42% of those who were killed when smoke alarms were present but did not operate and the 38% of those with no alarms, in 1999-2001 U.S. home fires.

Alcohol and other drugs were cited earlier as factors that can make an occupant less able to respond effectively to a working smoke alarm's signal. This is also true if one focuses on victims who were sleeping at the time. In 1999-2001 U.S. home fire fatalities where sleep was cited as a human factor and smoke alarms operated, 20% of the victims were impaired by alcohol and 13% were impaired by other drugs.[3] By comparison, alcohol was

3 To be precise, the coding for alcohol is phrased as "possibly" impaired by alcohol and the coding for other drugs is phrased as "possibly" impaired by "other drug or chemical."

cited for only 8% and other drugs were cited for 0% when victims were asleep and had smoke alarms that did not operate. Alcohol was also cited for only 8% and other drugs for 1% when victims were asleep and had no smoke alarms at all.

Are smoke alarms as effective with all classes of sleeping persons?

This section is not based on reported fire incident data. In her literature review of smoke alarms' ability to wake sleeping individuals, Dorothy Bruck concluded that:

- "Young children are unlikely to arouse at 75 dBA;
- Those [adults] who are sleep deprived will be harder to arouse;
- Significant background noise increases arousal thresholds;
- 25% of those over 60 years may be unlikely to wake to a 55 dBA alarm and 10% of those over 70 years may sleep through 75 dBA (due to hearing loss at the higher frequencies in older persons);
- Significant individual differences in arousal thresholds exist;
- If the nature of the alarm signal or its perceived intensity is insufficiently unique to be a meaningful stimuli, responsiveness will be reduced;
- Those under the influence of sleep inducing medication are unlikely to arouse to 75 dBA (and such medication is in high use among the elderly);
- Those under the influence of alcohol and marijuana are likely to be harder to arouse than the non-intoxicated due to the changes in sleep patterns increasing deep sleep."[4]

Bruck and her colleagues also studied the effectiveness of a pre-recording of the mother's voice, a female actor's voice, a standard Australian smoke alarm with a high pitch signal of roughly 4000 Hz, and a lower-pitch (dominant tones of 500Hz, 1500 Hz, and 2500 Hz) temporal three (T-3) signal in waking sleeping children between 6 to 10 years of age. The voice alarms and the T-3 signal were more effective than the high-pitched standard

[4] Dorothy Bruck, "The Who, What, Where and Why of Waking to Fire Alarms: A Review, "*Fire Safety Journal*, Volume 36 (2001), pages 623-639.

signal, suggesting that lower frequency may be the most important component in effectiveness.[5]

In a study on the effects of alcohol on young adults' waking to fire alarm signals, Ball and Bruck found that a female voice and the T-3 signal were more effective than the high-pitched Australian standard alarm. However, even a blood alcohol concentration (BAC) of .05% significantly reduced the likelihood that the young adults would wake to any of the auditory signals. With a BAC of .08%, the likelihood of waking was even less, though the difference between .05% and .08% was smaller than that between the sober and the .05% BAC. Individual responses varied widely.[6]

Are smoke alarms as effective when occupants are located close to the point of fire origin?

Among those killed in U.S. home fires in 1999-2001, 39% of victims with smoke alarms that operated were not in the general area of fire origin at the time of death, compared to 73% of victims in homes with smoke alarms that did not operate, and 47% of victims in homes without any alarms. In other words, it was much less likely that occupants away from the point of fire origin would become fatal victims when smoke alarms operated, and so it was much more likely that victims of fatal fires where smoke alarms operated had the disadvantage of being close to the fire's point of origin.

Among those who died in homes with working smoke alarms, 40% were killed by fires in which flame damage was confined to the object or room of origin. Only 25% of those killed in homes with non-working smoke alarms and 19% of those who died in homes without any smoke alarms succumbed to fires with such limited damage. A small fire is less likely to generate sufficient fire effects to fatally injure a remote victim. Therefore, this is further evidence that proportionally more fatal victims in homes where smoke alarms operated were located close to the fire's point of origin, in this case close enough to be fatally injured even by a fire whose maximum size was not that great.

Was an exit available? Did the victim know that there was an exit? Was there an escape plan?

This section also does not present data from fire incident reports.

A smoke alarm merely alerts occupants to a fire. If the fire blocks all of the exits, or if the exits are obstructed by burglar bars, furniture, clutter, or other items, the early warning will do little good. Even if exits are not blocked or rendered unusable, occupants may

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[5] Dorothy Bruck, Sharnie Reid, Jefoon Kouzma, and Michelle Ball, "The Effectiveness of Different Alarms in Waking Sleeping Children," *Proceedings of the 3rd International Symposium on Human Behavior in Fire 2004*, London, England, Interscience Communications Limited 2004, pp. 279-289.

[6] Michelle Ball and Dorothy Bruck, "The Effect of Alcohol upon Response to Fire Alarm Signals in Sleeping Adults," *Proceedings of the 3rd International Symposium on Human Behavior in Fire 2004,* London, England, Interscience Communications Limited 2004, pp. 291-301.

lose precious time while escaping if they have not practiced escape and planned for the possibility that escape along their usual route into and out of the home may not be possible during a fire.

Many households have not developed escape plans. In the 1994 CDC study, *Residential Smoke Alarms and Fire Escape Plans*, 60% of U.S. respondents had designed or at least talked about a fire escape plan, but only 17% of these households reported practicing the plans. Therefore, only 10% of households had both developed and practiced a home escape plan.[7]

In a 1997 study sponsored by the NFPA, 53% of U.S. households surveyed said they had escape plans. The majority of the plans were limited to planned routes and exits; researchers did not evaluate the realism of the plans. Only 21% of the households with a plan reported having practiced it. Therefore, only 16% of all households surveyed had developed and practiced an escape plan.[8]

In a follow-up study conducted in 1999, NFPA showed that 60% of surveyed households said they had escape plans, and 42% reported having practiced it. Therefore, as of 1999, 25% of U.S. households had developed *and* practiced an escape plan.[9]

In 2004, NFPA learned that 66% of those surveyed in a follow-up study said they had a home escape plan, though only 35% had practiced it.[10] This means the net percentage of households that had developed and practiced an escape plan was virtually unchanged from 1999, at 24%.

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[7] Pauline A. Harvey, Jeffrey J. Sacks, George W. Ryan, and Patricia F. Bender, "Residential Smoke Alarms and Fire Escape Plans," *Public Health Reports,* September/October 1998, Rockville, MD, Volume 113, pp. 459-464.

[8] *1997 Fire Awareness/Escape Planning Study* for National Fire Protection Association, Quincy, MA, August 1997, Table 3.

[9] *1999 NFPA National Fire Escape Survey*, pp. 19-20, available from http://www.nfpa.org/Research/NFPAFactSheets/FireEscapeSurvey/FireEscapeSurvey.asp.

[10] 2004 Fire Prevention Week Survey conducted for National Fire Protection Association by Harris Interactive Market Research, p. 16.

Effectiveness of Operating Smoke Alarms in
Home Structure Fires Reported in Version 5.0 of NFIRS
1999-2001 Annual Averages

Effectiveness	**Percent**
Occupants were alerted and responded	81.2%
No occupants	13.5%
Occupants were alerted but failed to respond	2.3%
Failed to alert occupants	2.9%
Total	100.0%

Victim's General Location at Time of Fatal Injury by Smoke Alarm Presence and Operation in Home Structure Fires Reported in Version 5.0 of NFIRS 1999-2001 Annual Averages

Victim's General Location	Present and Operated	Present but Didn't Operate	None Present
In area of origin	61%	27%	53%
In building, but not in area of origin	39%	72%	47%
Outside, not in area of origin	0%	1%	0%
Total	100%	100%	100%

Extent of Flame Damage by Smoke Alarm Presence and Operation in Home Structure Fire Deaths Reported in Version 5.0 of NFIRS 1999-2001 Annual Averages

Extent of Flame Damage	Present and Operated	Present but Didn't Operate	None Present
Confined to object of origin	13%	11%	10%
Confined to room of origin	27%	14%	9%
Confined to floor of origin	11%	13%	8%
Confined to building of origin	37%	58%	57%
Beyond building of origin	12%	4%	16%
Total	100%	100%	100%

Note: Percentages were calculated on known data only.
Source: National estimates based on NFIRS and NFPA survey.

Activity at Time of Victim's Fatal Injury by Smoke Alarm Presence and Operation in Home Structure Fires Reported in Version 5.0 of NFIRS 1999-2001 Annual Averages

Activity	Present and Operated	Present but Didn't Operate	None Present
Sleeping	38%	57%	49%
Escaping	21%	20%	27%
Unable to act	10%	14%	11%
Fire control	9%	2%	1%
Rescue attempt	7%	2%	4%
Irrational act	7%	0%	5%
Unclassified activity	5%	4%	1%
Returning to vicinity of fire before control	4%	0%	2%
Total	100%	100%	100%

Note: Percentages were calculated on known data only.
Source: National estimates based on NFIRS and NFPA survey.

Fatal Home Fire Victims by Human Factor Contributing to Injury And by Smoke Alarm Presence and Operation in Home Structure Fires Reported in Version 5.0 of NFIRS 1999-2001 Annual Averages

Human Factors	Present and Operated	Present but Didn't Operate	None Present
Asleep	27%	42%	38%
Unconscious	2%	1%	1%
Possibly impaired by alcohol	16%	7%	10%
Possibly impaired by other drug or chemical	6%	0%	2%
Possibly mentally disabled	4%	0%	3%
Physically disabled	14%	3%	4%
Physically restrained	1%	1%	0%
Unattended or unsupervised person	1%	14%	1%

Fatal Home Fire Victims with Human Factor of Asleep by Other Human Factors Contributing to Injury and Smoke Alarm Presence and Operation in Home Structure Fires Reported in Version 5.0 of NFIRS 1999-2001 Annual Averages

Other Human Factors	Present and Operated	Present but Didn't Operate	None Present
Possibly impaired by alcohol	20%	8%	8%
Possibly impaired by other drug or chemical	13%	0%	1%
Possibly mentally disabled	6%	0%	3%
Physically disabled	3%	3%	3%
Unconscious	3%	0%	1%
Unattended or unsupervised person	0%	8%	1%

Note: Percentages were calculated on known data only. The field Human Factors Contributing to Injury is in the "Check all that apply" format. Some have no human factors and others have multiple factors.

Source: National estimates based on NFIRS and NFPA survey.

Home Structure Fire Deaths by Victim's Age and Smoke Alarm Status in Fires Reported in Version 5.0 of NFIRS

1999-2001 Annual Averages

Age Group	Present and Operated	Present but Didn't Operate	None Present
Under 5	9%	24%	13%
5-14	4%	23%	10%
15-17	2%	3%	3%
18-64	51%	32%	51%
65 and over	34%	18%	23%
Total	100%	100%	100%

Home Structure Fire Deaths in which "Asleep" Was a Human Factor Contributing to Injury by Victim's Age and Smoke Alarm Status in Fires Reported in Version 5.0 of NFIRS

1999-2001 Annual Averages

Age Group	Present and Operated	Present but Didn't Operate	None Present
Under 5	7%	20%	15%
5-14	3%	34%	15%
15-17	0%	3%	2%
18-64	59%	29%	51%
65 and over	31%	14%	17%
Total	100%	100%	100%

Home Structure Fire Deaths in which the Victim's Activity at Time of Injury Was Sleeping by Victim's Age and Smoke Alarm Status in Fires Reported in Version 5.0 of NFIRS

1999-2001 Annual Averages

Age Group	Present and Operated	Present but Didn't Operate	None Present
Under 5	22%	23%	15%
5-14	4%	40%	24%
15-17	0%	7%	2%
18-64	35%	20%	46%
65 and over	39%	10%	13%
Total	100%	100%	100%

Note: Percentages were calculated on known data only. Multiple entries were allowed for human factors.

Source: National estimates based on NFIRS and NFPA survey.

Appendix D – Smoke Alarm Audibility

Arthur S. Lee, U.S. Consumer Product Safety Commission*

Recent CPSC staff testing of smoke alarm audibility indicated that the presence of closed doors reduced the sound level in other rooms, though the sound level was likely adequate to awaken adults.[1]

The CPSC staff conducted sound loss measurements in three different test homes using single station smoke alarms. The homes were built between 1970 and 1989. The sizes of the homes ranged from approximately 1,000 square feet to 3,300 square feet, and they each had either two or three levels. Sound loss measurements were taken with doors closed and opened. Results indicated that a single station smoke alarm installed in a small, single-level home may be sufficient to alert occupants, even when bedroom doors are closed. For one series of tests, the testing showed between 9dBA and 16dBA attenuation of the smoke alarm signal when the bedroom doors were closed.

Test Home 1 was built in 1960 and is a classic suburban ranch house typical of many homes found in major U.S. cities. The house is approximately 1,120 square feet and has a first floor and a basement. The first floor has three bedrooms, a living room, full bath, breakfast/dining room, and a kitchen. The master bedroom is approximately 11' x 10'. Bedroom 2 is used as an office and is approximately 14' x 10'. Bedroom 3 is a guest bedroom and is approximately 9' x 12'.

The smoke alarm was mounted on the ceiling of bedroom 3, approximately 5 feet from the door. Sound levels were measured with the door to bedroom 3 opened and closed. The difference in sound level under the smoke alarm was 10 dBA, 90 dBA with the bedroom door opened and 100 dBA with it closed.

Sound levels were measured in the other bedrooms with the doors opened and closed. The sound levels were lower when the bedroom doors were closed, as expected. With the doors closed, the sound level was 9 dBA lower in bedroom 2 and 16 dBA lower in the master bedroom (see Table H-1). Compared to the sound level in bedroom 3, the sound levels in the other bedrooms with the doors closed were almost 40 dBA lower.

Table H-1. Test Home 1 – Sound Levels Measured, Smoke Alarm in Bedroom 3

Microphone Location	Peak (dBA)	
	Bedroom Doors Opened	Bedroom Doors Closed
Under Smoke Alarm	90	100
Master Bedroom	78	62
Bedroom 2	70	61

Even though the sound level was reduced by the closed bedroom doors, the sound level was above 60 dBA, which may be sufficient to awaken adults. Some data suggest that a minimum of 70 dBA is required to awaken adults from sleep when there are significant background noises, although sound levels as low as 55-60 dBA can awaken some adults when the background noise levels are low.[2] Factors that affect auditory arousal from sleep include sound intensity and frequency, time of night, current sleep stage, level of fatigue or sleep deprivation, the use of medication, alcohol or drugs, hearing loss, and whether or not the subject is primed to hear an alarm.

If a fire occurs in the bedroom, the elapsed time for the smoke to escape the bedroom and trigger the hallway smoke alarm may reduce the available escape time for the occupants. This time delay also may eliminate any chance for an occupant in the room of origin to escape while decreasing the chances for occupants in other parts of the home to be alerted in time to assist or rescue occupants from the bedroom fire.

* These comments are those of the CPSC staff, have not been reviewed or approved by, and may not necessarily reflect the views of, the Commission.

1. Arthur Lee, The Audibility of Smoke Alarms in Residential Homes, U.S. Consumer Product Safety Commission, Bethesda, MD, August 2005.
2. Dorothy Bruck, “The Who, What, Where and Why of Waking to Fire Alarms: A Review, “ *Fire Safety Journal,* Volume 36 (2001), pp. 623-639.

Appendix E – Predicted Effect of New Mattress Restrictions on Available Time to Escape

Linda Smith, U.S. Consumer Product Safety Commission*

Mattresses meeting the new CPSC open flame flammability standard (16 CFR 1633) will be required to limit the peak rate of heat release to 200kW during a 30 minute test. Mattresses constructed to meet the flammability requirements will be less flammable designs that contribute significantly less to a fire, slowing the rate of fire growth and severity to prevent or delay flashover.

This is expected to increase the time available for occupants in the room of origin to discover the fire and escape. Escape time is expected to increase to about 10 to 15 minutes.

In comparison, tests on traditional mattress designs (16CFR1632 compliant) without bedclothes measured peak heat release rates that exceeded 2000kW in less than 5 minutes.[1]

With the improved designs, if there is no flashover, the air in the room below the smoke layer will still be breathable. Smoke will be generated at a very early stage and typically accumulate about 1 to 3 feet from the ceiling at about 100kW, producing ample smoke at this stage to operate a smoke alarm mounted on the ceiling. Occupants intimate with ignition may be injured when the bedclothes ignite, but those capable of responding quickly are not expected to die in most cases.

* These comments are those of the CPSC staff, have not been reviewed or approved by, and may not necessarily reflect the views of, the Commission.

1. Memorandum from Allyson Tenney, ES, to Margaret Neily, Project Manager for Mattresses and Bedding, Background and Technical Rationale for Draft Proposed Standard for Open-Flame Mattress Flammability, Tab B, Briefing Package, Notice of Proposed Rulemaking for the Flammability (Open Flame) of Mattresses and Foundations and Options for Addressing Bedclothes Involvement in Mattress/Bedding Fires, U.S. Consumer Product Safety Commission, November 2004 .

Appendix F – Measures of Effectiveness for Program Evaluation of Home Smoke Alarm Programs

Mick Ballesteros, Ellen Sogolow, and Christine Branche,
U.S. Centers for Disease Control and Prevention

For programs, such as those involving home smoke alarms, the ultimate issue is whether they are effective. Has the program achieved the desired outcomes, goals, and objectives?[1] This is understood through an evaluation of the program. The purpose of an evaluation includes to monitor whether programs are producing the desired results, to monitor progress toward the program's goals, to produce data on which to base future programs, and to demonstrate the effectiveness of the program to the target population, to the public, to others who want to conduct similar programs, and to those who fund the program[2].

Measures of effectiveness are a function of the characteristics of the program. To facilitate our understanding of the measurement issues, we classify the outcomes based on their proximity to the program. Proximal measures are those most closely related to program activities and the farthest (or most indirectly) related to injury and death. In contrast, distal measures are those more closely associated with the occurrence of morbidity and mortality, and less related to the actual program activities.

For programs that give away free alarms or vouchers, or provide installation, more proximal measures could include the **number of homes canvassed,** the **number of homes enrolled,** the **number of vouchers or smoke alarms distributed,** and/or the **number of smoke alarms installed.** The number of homes canvassed could include all homes that were visited, including those where no one was home or the household declined to participate. The number of homes enrolled could include only home in which smoke alarm operability was checked and/or at least one smoke alarm was installed. For programs that seek to educate a population about the importance of smoke alarms and the need for routine testing (e.g. *Risk Watch, Remembering When),* **knowledge** and **attitudes** might be the focus of measurement. Tests can be given before and/or after the program. Specific questions (e.g. where should smoke alarms be located, how important are smoke alarms to protecting your family) can be asked to determine program effectiveness.

Measurement may require self-report of specific **behaviors** (e.g. Did you **test your alarm** last year? **how often**?). Alternatively, telephone survey callers may ask for a **test demonstration** (e.g. please put down the phone and go test the alarm so that I can hear it.)

More distal measures of effectiveness may include the **number of alarms operational at six months,** the **number of alarms operational at 1 year,** and so on**.** With increased use of long lasting (8-10 years) lithium batteries, meaningful follow-up becomes a challenge to most studies that are funded for five years or less. Another distal measure is one used in a national home survey. In its periodic American Health Home Survey, the U.S. Housing and Urban Development uses a tailored **home diagram** to mark the locations and **operability** of smoke alarms. This provides detailed, direct information on the adequacy of coverage and on operational status, both of which can be used for effectiveness measurement.

Measures that are most distal to program interventions, **fire incidents with and without injuries or deaths,** are often considered the gold standard for measures of smoke alarm presence and operability (with fire incidents defined as those requiring response from a fire department). Many fire departments report to the National Fire Incident Reporting System (NFIRS) or collect similar information locally. NFIRS contains data fields to capture the presence of detectors, the type of detectors (e.g. smoke, heat, combination, etc.), the detector's power supply, whether the detector activated, whether occupants were alerted by detectors, and the reason detectors failed to operate, if applicable. Working with such measures can be difficult because incident reports are not always available and, by definition, they do not account for **unreported incidents**. Because an unreported incident is most likely a fire that residents brought under control, gathering such outcomes data may require techniques to aid with recall such as use of monthly calendars.

Statistics regarding **fire-related injuries** can be identified using fire incident reports (which often document civilian casualties), ambulance run sheets, emergencey department and hospital admission records, and death certficates. Each data source generally captures injuries only above a certain severity level. Unfortunately, minor injuries that did not require medical attention will not be captured. Also, many of the listed data sources do not collect information regarding the circumstances of the fire and injury. These and other types of errors and omissions must be addressed in any use of reported injury data as measures of program effectiveness.

While fire incidents and injuries are the most desirable outcomes data, they are also the least feasible to measure. First, fire incidents are rare events. Second, when programs provide primary fire prevention education as well as smoke alarm installation, fire incidents can become even more unlikely. Third, even with a rare fire event, there may be no injury.   If we are to eliminate fire-related deaths and injuries, we need to strengthen our program design efforts and use more proximal measures to assess program effectiveness.

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[1] – Singleton RA, Straits BC. *Approaches to Social Research*. New York: Oxford University Press, 1999.

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Appendix G – Additional Material on Existing Programs

Marjean Meyer, U.S. Fire Administration

Listed at the end of this section are 42 published accounts of smoke alarm programs. Shown below are table displays cross-walking characteristics of programs with the programs having those characteristics.

Criteria for target population

Screening by need, including high risk	S-1	S-2	S-4	S-8	S-13	S-17
	S-19	S-22	S-23	S-25	S-32	S-36
	S-39	S-40	S-41	S-42		
Unprotected homes identified during EMS calls	S-32					
All homes in community	S-34					

What is provided to target population

Smoke alarms and installation	S-1	S-2	S-10	S-13	S-34	S-38
	S-41					
Testing of existing smoke alarms	S-2	S-10	S-13	S-38	S-41	
Information on maintenance and replacement also provided	S-1	S-2	S-10	S-12	S-13	S-15
	S-17	S-22	S-30	S-38	S-41	
10-year lithium-battery smoke alarms	S-3	S-12	S-23	S-35		
Follow-up checks re continued operation and to provide maintenance	S-15	S-16	S-29	S-30	S-36	
Replacement of smoke alarms at least 10 years old	S-12	S-23	S-30			
Smoke alarms in locations as required by applicable state or local code	S-3	S-12	S-35			
Smoke alarm location emphasizes sleeping areas	S-10	S-17				
Promote interconnection of smoke alarms	S-9	S-28				
Fire safety education also provided	S-1	S-2	S-3	S-6	S-13	S-14
	S-15	S-19	S-23	S-27	S-34	S-39
	S-41	S-42				
Smoke alarm hotline	S-37					

Funding and sponsorship sources

Smoke alarms and/or replacement batteries obtained free from sponsors	S-1	S-8	S-19	S-23	S-32	S-34
	S-39	S-40	S-41	S-42		
Grant (USFA residential fire prevention)	S-2	S-3	S-42			
Study and evaluation funded (NCIPC)	S-10	S-11				

Use of incentives

Free pizza to contacted households whose smoke alarms are working	S-22

What channels are used for outreach to target population?

Door-to-door canvassing (free inspection provided; verify location and operationality of smoke alarms)	S-14	S-15	S-30	S-37		
Door-to-door canvassing (in fire apparatus)	S-2					
Door-to-door survey (to determine need)	S-11	S-37				
Public service announcements (TV and/or radio)	S-2	S-3	S-10	S-13	S-14	S-19
	S-38	S-42				
Newspapers	S-3	S-10	S-13	S-14	S-19	S-38
	S-42					
Telephone (survey)	S-3	S-10	S-11	S-13	S-14	S-19
	S-37	S-38	S-42			
Flyers and mailed materials	S-3	S-10	S-13	S-14	S-19	S-38
	S-42					
Billboards	S-3	S-10	S-13	S-14	S-19	S-38
	S-42					
Markings on vehicles (fire apparatus, Red Cross vehicles)	S-3	S-10	S-13	S-14	S-19	S-38
	S-42					

What other programs or organizations (in addition to fire department) provide channels for outreach?

Schools	S-2	S-3	S-13	S-14	S-36	
Churches	S-2	S-3	S-10	S-13	S-14	S-19
	S-38	S-42				
Civic groups (e.g., Boy Scouts)	S-2	S-3	S-13	S-14		
Health departments						
Women and Infant Care (WIC)	S-2					
Eldercare	S-2					
Community events (e.g., fairs)	S-2					
Supermarkets (site for posting of notices)	S-2					
Member chapters of national sponsor	S-39	S-41				

Issues raised

Revisit recommendation to sleep with bedroom doors closed	S-7	
Need for better ways to cover hard-to-reach populations	S-13	S-31
Effectiveness and cost-effectiveness of smoke alarm provision needs to be examined	S-26	

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