Reducing Fire Deaths in Older Adults: Optimizing the Smoke Alarm Signal
Research Project

Summary technical report

THE
FIRE PROTECTION
RESEARCH FOUNDATION

FIRE RESEARCH

THE FIRE PROTECTION
RESEARCH FOUNDATION

ONE BATTERYMARCH PARK
QUINCY, MASSACHUSETTS, U.S.A. 02269
E-MAIL: Foundation@NFPA.org

Reducing Fire Deaths in Older Adults: Optimizing the Smoke Alarm Signal
Research Project

Summary technical report

Prepared by

Justin A. Geiman
Daniel T. Gottuk

Hughes Associates, Inc.

THE
FIRE PROTECTION
RESEARCH FOUNDATION

FIRE RESEARCH

THE FIRE PROTECTION
RESEARCH FOUNDATION

ONE BATTERYMARCH PARK
QUINCY, MASSACHUSETTS, U.S.A. 02269
E-MAIL: Foundation@NFPA.org

FOREWORD

Smoke alarm and signaling systems are a proven strategy for reduction of fire fatalities in the general population. However, studies have shown that the elderly do not fully benefit from conventional smoke alarm systems, particularly during the sleeping hours. In April of 2005, the Fire Protection Research Foundation was awarded a Fire Prevention and Safety Grant by the US Fire Administration for a new project to study this topic.

The overall goal of the project was to optimize the performance requirements for alarm and signaling systems to meet the needs of an aging population. This reports presents the results of the study, which involved several tasks including a risk assessment to estimate the potential impact in lives saved of changes in waking effectiveness of smoke alarms for older adults, quantifying the human behavior aspects of the problem, developing benchmark performance criteria for alarm and signaling systems, and reviewing new and promising technologies that address the performance criteria.

A portion of the study involved the conduct of human behavior studies to investigate the arousal thresholds from sleep in older adults to the current US smoke alarm and compare these thresholds to several alternative signals, and to investigate the performance abilities of older adults when awoken suddenly by an alarm. The detailed results of this portion of the study are presented in a companion report entitled "Investigation of Auditory Arousal With Different Alarm Signals in Sleeping Older Adults".

The Research Foundation expresses gratitude to: the report authors: Justin Geiman and Daniel Gottuk, Hughes Associates, Inc., the Project Technical Panel: Guylene Proulx, David Albert, Dana Mulvany, Arthur Lee, Donald Sievers, Rita Fahy, Wendy Gifford, Isaac Papier, Karen Boyce, Leonard Belliveau, Paul Patty, and Lee Richardson; and the project sponsors: US Fire Administration, BRK Brands/First Alert, Innovalarm, SimplexGrinnell, Siemens Building Technologies, National Electrical Manufacturers Association, GE Security, Honeywell, and Kidde.

The content, opinions and conclusions contained in this report are solely those of the authors.

Reducing Fire Deaths in Older Adults: Optimizing the Smoke Alarm Signal Research Project

Technical Panel

David Albert, InnovAlarm

Leonard Belliveau, Hughes Associates, Inc.

Karen Boyce, University of Ulster

Rita Fahy, NFPA

Wendy Gifford, Invensys Controls/Firex

Arthur Lee, U.S. Consumer Product Safety Commission

Dana Mulvany

Isaac Papier, Honeywell Life Safety

Paul Patty, Underwriters Laboratories Inc.

Guylene Proulx, National Research Council of Canada

Lee Richardson, NFPA

Donald Sievers, D.E. Sievers & Associates, Ltd.

Sponsors

U.S. Fire Adminsitration

BRK Brands/First Alert

GE Security

Honeywell

InnovAlarm

Kidde

National Electrical Manufacturers Association

Siemens Building Technologies

SimplexGrinnell

Reducing Fire Deaths in Older Adults: Optimizing the Smoke Alarm Signal

Prepared for:

The Fire Protection Research Foundation
1 Batterymarch Park
Quincy, MA 02169-7471

Prepared by:

Justin A. Geiman and Daniel T. Gottuk
Hughes Associates, Inc.
3610 Commerce Drive, Suite 817
Baltimore, MD 21227-1652

May 30, 2006

EXECUTIVE SUMMARY

Older adults (those 65 years of age and over) have been identified as a high risk group in terms of fire safety. People age 65 and over have a fire death rate more than twice that of the national average and the disparity in fire death rate increases with age. Given that the U.S. Census Bureau estimates that the older adult population will more than double over the next thirty years, there is certainly cause for concern. The use of smoke alarm and signaling systems is associated with a reduction in fire fatalities in the general population—reducing the chances of dying in a fire by 40 to 50 percent when present. However, recent studies suggest that older adults may not fully benefit from conventional smoke alarm systems, particularly during sleeping hours. The tendency for older adults to experience high frequency hearing loss has been attributed as a potential fire safety problem since typical residential smoke alarms have a high frequency signal, between 3,000–4,000 Hertz (Hz).

The objective of this project was to assess and optimize the performance requirements for alarm and signaling systems to meet the needs of an aging population. This project was separated into several tasks in order to achieve its objective. First, the older adult population was characterized relative to potential risk factors. Second, a risk assessment of older adults was performed to quantify the potential impact of improving the waking effectiveness of smoke alarms, in terms of the number of potential lives saved. This assessment was based on existing data regarding the characteristics of fire victims and fires. Third, the human behavior aspects of the problem were addressed; this work consisted of a sleep study of older adults and the details are presented in a companion report. Both the arousal thresholds from sleep for various frequencies and types of alarm signals, as well as the cognitive and physical abilities upon waking were examined in the sleep study. Fourth, a review was conducted of new and promising technologies that may improve the waking effectiveness of smoke alarms for older adults and improve their overall fire safety.

Numerous factors associated with the risk of fire death have been identified in the literature, including many that are likely to be significant to older adults. The primary focus of this study is on risk factors such as the age of the occupant, whether the victim was sleeping at the time of the fire, and whether smoke alarms were present and operated. Beyond simply the age of the occupant, other characteristics and behaviors of the occupant likely affect the fire risk of older adults, such as disabilities, smoking, chemical substance use (e.g., medicine and alcohol), and being home alone at the time of the fire. The rate of disabilities among older adults are at least two to three times that of the general population. Intuitively, since many disabilities impact the ability to quickly escape, the high rate of disabilities among older adults may be a primary factor in their higher risk of fire death. However, little data exists to assess the importance of disabilities to the fire death risk of older adults. Smoking materials are the leading cause of death in all age groups over 35, including older adults. Despite having the lowest prevalence of smokers (less than half of the general population), older adults have an equal or greater risk of dying in smoking related fires. Alcohol intoxication is a significant and often underreported factor in fire deaths. Although intoxicated older adults certainly are at a higher risk of death in fire, alcohol intoxication appears to be less common in older adults than the general population. In several studies, around half of all adult fire victims were legally intoxicated. However, for older adults the proportion of fire victims that were intoxicated was as low as one in five. Another risk factor that is not often addressed, but may be a contributor for older adults with

disabilities or for those with difficulty hearing the alarm, is whether the victim was alone at the time of the fire. Older adults, particularly women, are approximately three times more likely than the general population to be living alone. One study found that nearly half of all older adult fire victims that died despite having a smoke alarm that operated were alone at the time of the fire.

Operable smoke alarms are associated with a reduction fire death risk. However, several small studies have indicated that older adults may be more likely to have maintenance issues with their smoke alarms than the general population. Also, these studies found a significant number (at least 20 percent) of the alarms found in the homes of older adults were believed to be over 10 years old and needed replacement. Likewise, based on a review of smoke alarm requirements and the ages of homes older adults typically occupy, it is estimated that up to 90 percent of older adult households do not have interconnected smoke alarms or smoke alarms in bedrooms. With interconnected smoke alarms, when one smoke alarm goes into alarm, all connected smoke alarms also alarm. This arrangement increases the sound levels of audible alarms throughout a home so occupants are aware of fires, even if the fire is on the other end of the home or on a different story of the home. Instant notification from the first smoke alarm increases the time available for escape compared to waiting for additional alarms closer to the occupant to respond. Overall, the limited data available on smoke alarm usage among older adults indicates that they may not be receiving the full benefit provided by current code requirements for operational smoke alarms that are interconnected and located on every floor and in bedrooms.

In an effort to understand the potential impact of improving the waking effectiveness of smoke alarms for older adults, a risk analysis was performed to determine the reduction in risk associated with such changes. Based on national estimates derived from the National Fire Incident Reporting System (NFIRS) and annual National Fire Protection Association (NFPA) surveys, smoke alarms that are improved to wake all sleeping occupants would reduce the estimated risk to older adults by 27–32 percent. There are two primary reasons for the modest risk reduction found. First, even if all occupants were awakened, some of the occupants would still be expected to die as a result of unsuccessful escape attempts or because the occupant selects an activity, such as firefighting or attempting to rescue others, that may involve indefinitely extended time in hazardous conditions. Secondly, only 36–38 percent of older adult fire fatalities were reported to be sleeping when fatally injured. Therefore, a 27–32 percent risk reduction for older adults represents a realistic upper bound to the potential impact of improving the smoke alarm signal. This equates to an annual reduction in home fire deaths of 230–270 people age 65 and over, based on the annual average of older adult home fire deaths from 1999–2002.

The practicality of achieving the risk reduction expected from improved waking effectiveness must be assessed in light of the presence and operability of smoke alarms. Victims that do not have an operable smoke alarm will not benefit from an improved smoke alarm signal. Less than one out of four older adult fire victims who were sleeping when fatally injured had an operable smoke alarm.

The risk reduction expected from improvements in the waking effectiveness of smoke alarms for other age groups was also analyzed for comparison to older adults. For both the under 18 and 18–64 age groups, larger risk reductions than those expected for older adults are estimated. The primary driver of the larger risk reduction for these two age groups is that they have a greater percentage of occupants sleeping when fatally injured (56–58 percent for those under age 18 and 44–45 percent for those 18–64 years) compared to older adults (36–38 percent). The statistics on smoke alarm presence and operability for fire fatalities in the under 18 and 18–64 age groups were remarkably similar to those of older adult fire fatalities. The implication of these statistics is that although improving the waking effectiveness of smoke alarms is important, it is also necessary to increase the presence and operability of smoke alarms. In order to realize the benefits of improved smoke alarm waking effectiveness, smoke alarms must be present and operable. This conclusion applies to older adults, as well as the general population.

The sleep study portion of this project provided insights into the human behavior aspects of waking older adults exposed to varying types of signals and varying sound levels. A total of 42 older adults, ranging in age from 65–85 years, participated in the study. Four signals were examined, including a 3000 Hz high-frequency T-3 alarm signal (typical of that used in U.S. smoke alarms), a 500 Hz low-frequency T-3 alarm signal, a 500–2500 Hz mixed frequency T-3 alarm signal, and a male voice (200–2500Hz) alarm signal. The results showed that the mixed frequency T-3 alarm signal provided the greatest waking effectiveness of the signals evaluated, including the high frequency T-3, typical of most current alarms. In fact, the high-frequency T-3 performed the most poorly of the alternative signals tested. There was a substantial difference in the median auditory arousal thresholds (20 dBA) between the high-frequency T-3 alarm signal and the mixed frequency T-3. The results also indicate that a male voice alarm is not suitable for older adults. In terms of the cognitive and physical abilities of older adults upon waking to an alarm, a decrement in physical functioning of around 10–17 percent was observed, with no important effects on simple or cognitive functioning.

In summary, the sleep study concluded that the high frequency alarm signal that is typically used in current smoke alarms should be replaced by an alternative signal that offers significantly better waking effectiveness across the general population, once the nature of the best signal has been determined. While the research to determine such a signal is ongoing, it is imperative that the use of interconnected smoke alarm in bedrooms be encouraged to provide the maximum potential benefit of current and future alarms. Proper use and maintenance of smoke alarms is also critical to realizing the benefits of smoke alarms.

Numerous, current and promising technologies are available that may improve the waking effectiveness of smoke alarms for older adults and improve their fire safety. These technologies can be broadly categorized as those that provide alternative audible alarm signals, those that provide alternative sensory stimuli (visual, tactile), those related to the interconnection of smoke alarms and notification devices, and those that facilitate testing and maintenance of alarms. Despite research, including the work done as part of this project, that shows alternative audible alarm signals may benefit smoke alarm users, including older adults, there are few products currently available that address this issue. The focus of the smoke alarm industry in terms of addressing the needs of the hearing impaired has largely been on technologies that provide visual stimuli (i.e. strobes) to supplement audible alarms. However, recent research has focused

renewed interest on tactile (vibratory) stimuli as an effective means of waking occupants. Although the technology is available, there has been only limited use and commercial development of tactile (vibratory) notification technology integrated with smoke alarms.

Recent technological advances have occurred that facilitate the interconnection of smoke alarms with other smoke alarms, as well as with supplemental notification devices. Interconnection of smoke alarms and connecting smoke alarms with supplemental notification devices can be achieved with RF wireless technologies, acoustic monitoring, and powerline communication. These emerging technologies and products provide two important improvements to the fire safety of older adults and the entire population. First, they readily enable increased sound levels of audible alarms throughout a home so occupants are aware of fires, even if the fire occurs remote from the current location of the occupant and the nearest smoke alarm. Secondly, the interconnection of supplemental notification devices provides the opportunity to better meet the needs of select populations. Delivery of alternative audible signals, visual signals, and vibratory alarm signals are all possible with supplemental notification devices that are wirelessly connected to smoke alarms.

Although technologies that facilitate testing and maintenance of smoke alarms do not influence the waking effectiveness of smoke alarms, they are expected to be able to impact the overall fire safety of older adults. Maintenance problems with battery-operated smoke alarms, such as difficulty testing alarms or missing, dead, and disconnected batteries, are being addressed by various smoke alarm technologies. Technologies are available that allow users to test the operation of smoke alarms remotely and that eliminate battery changes for the life of the smoke alarm. Designs of battery doors and drawers allow replacement of smoke alarm batteries without removing the alarm from the ceiling, and silence features allow the user to temporarily silence alarms without removing the batteries from the alarm.

ACKNOWLEDGEMENTS

This project was conducted for the Fire Protection Research Foundation under a grant from the U.S. Fire Administration. This work reflects a collaborative effort between three principal organizations, Victoria University, the National Fire Protection Association (NFPA) and Hughes Associates, Inc. The authors gratefully acknowledge the insightful discussions and contributions by Professor Dorothy Bruck of Victoria University and Dr. John Hall and Dr. Rita Fahy of the NFPA. In particular, we would like to thank Dr. Hall for conducting the risk analysis presented in this report and the multiple, interesting and productive discussions.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

AAT	Auditory Arousal Threshold
AC	Alternating Current
ADA	Americans with Disabilities Act
ANSI	American National Standards Institute
CPSC	Consumer Product Safety Commission
dBA	Decibels (A-weighting)
ISO	International Organization for Standardization
NAEEEC	National Appliance and Equipment Energy Efficiency Committee (Australia)
NCHS	National Center for Health Statistics
NFIRS	National Fire Incident Reporting System
NIDCD	National Institute on Deafness and Other Communication Disorders
NRL	Naval Research Laboratory
CDC	Centers for Disease Control and Prevention
NFPA	National Fire Protection Association
RF	Radio Frequency
SHHH	Self Help for Hard of Hearing People
UL	Underwriters Laboratories
USFA	United States Fire Administration

1.0 INTRODUCTION

The U.S. Fire Administration (USFA) has identified older adults (those 65 years of age and over) as a high risk group in terms of fire safety. Recent estimates of fatalities in home fires by NFPA, based on data from 1999–2002, indicate approximately 2,960 fire deaths occur in the U.S. each year. In terms of a fire death rate, or fire risk, this equates to 10.4 deaths per million people annually. People age 65 and older have a fire death rate (22.7 deaths/million) more than twice that of the national average [Hall, 2005]. In total, older adults account for around 800 fire deaths per year. Although older adults comprise around 12 percent of the U.S. population, they experience approximately 27 percent of the home fire fatalities.

The disparity in fire death rate increases with age. Figure 1 shows the trend in the fire death rate (deaths per million people per year) as a function of the age of the victim. People age 75 and older have a fire death rate three times the national average and those age 85 and over have a fire death rate more than four times the national average [Hall, 2005]. It is believed that various changes associated with aging may be a factor in the increased fire death rate among older adults.

The use of smoke alarm and signaling systems is associated with a reduction of fire fatalities in the general population, particularly for occupants of one and two family dwellings. The chances of dying in a fire are reduced by 40 to 50 percent when smoke alarms are present [Ahrens, 2004]. Sekizawa [2005] found a similar reduction in fire death risk in Japanese and UK fire statistics. When smoke alarms are known to be operational and provide the alarm, Hall [2004] found a 60 to 80 percent reduction in fire death risk. However, older adults may not fully benefit from conventional smoke alarm systems, particularly during sleeping hours. Recent studies [Bruck, 2001] have indicated that as many as 25 percent of older adults may not awake from a hallway smoke alarm; however, this data is incomplete. Reduced waking effectiveness in older adults may be a result of factors such as high frequency hearing loss or ingestion of sleep aid medication. Even when awakened by a smoke alarm, older adults may have a reduced ability to evacuate quickly as a result of impaired mobility or increased cognitive confusion / sleep inertia.

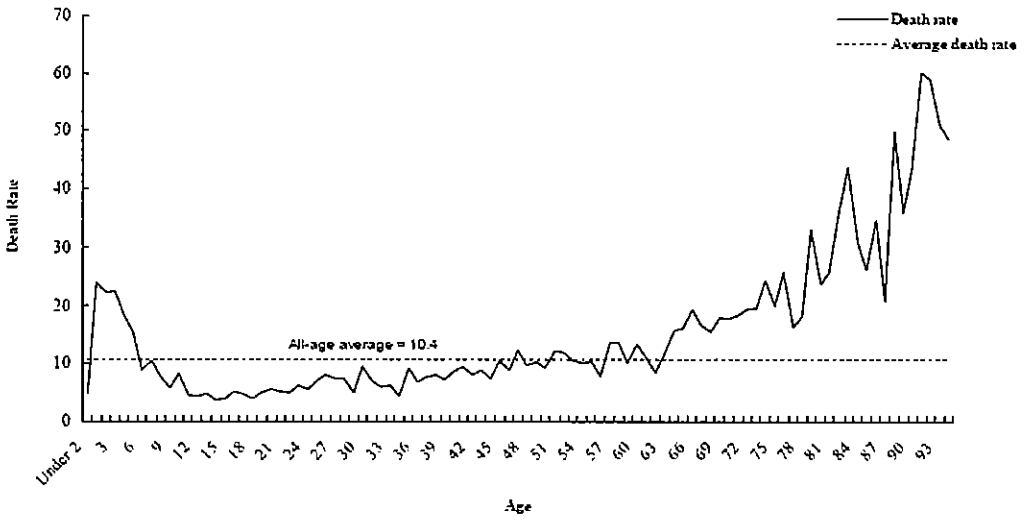

Figure 1 — Fire death rate in home fires as a function of age of the victim [Hall, 2005].

The objective of this project was to assess and optimize the performance requirements for alarm and signaling systems to meet the needs of an aging population. This project was separated into several tasks in order to achieve its objective. First, a risk assessment of older adults was performed to quantify the potential impact of improving the waking effectiveness of smoke alarms, in terms of the number of potential lives saved. This assessment was based on existing data regarding the characteristics of fire victims and fires. Second, the human behavior aspects of the problem were addressed; this work consisted of a sleep study of older adults and is presented in a separate report [Bruck, et al., 2006]. Both the arousal thresholds from sleep for various frequencies and types of alarm signals, as well as the cognitive and physical abilities upon waking were examined in the sleep study. A review was conducted of new and promising technologies that may improve the waking effectiveness of smoke alarms for older adults and improve their overall fire safety. Finally, the previous tasks are integrated to determine research needs to further address the fire safety of older adults.

2.0 THE SMOKE ALARM SIGNAL

It is important to understand the current smoke alarm signal prior to considering alternative signals. Subsequent sections describe the current requirements for the smoke alarm signal, the audibility of the signal in typical residential homes, and the waking thresholds typically associated with the signal in the general population.

2.1 Requirements

Since 1996, NFPA 72, *National Fire Alarm Code*, has required the use of a three-pulse temporal pattern, or temporal-three (T-3), as an alarm signal for new buildings. This signal is intended to indicate that immediate evacuation of the building is required. Although this signal is a relatively recent requirement, it has been recommended by NFPA 72 (and its predecessors) since 1979. This signal has also been adopted as an American National Standard (ANSI S3.41,

Audible Emergency Evacuation Signal) and an International Standard (ISO 8201, *Audible Emergency Evacuation Signal*).

Identifying an optimal evacuation signal that will reach occupants and be heard and recognized can be difficult because of variations (e.g., loudness, frequency, pattern) in background noise among occupancies as well as various human factors. The T-3 standards only specify the on/off pattern of the signal. This approach allows manufacturers to select appropriate frequencies for an acoustic signal that may differ for given applications. This approach also allows visual and tactile signals to take advantage of the standard temporal-three pattern.

The T-3 pattern consists of a 0.5 second ON phase, followed by a 0.5 OFF phase. After the third ON phase, a 1.5 second OFF phase completes the cycle. The total time through one cycle of the signal is 4 seconds. Supplemental verbal instructions are allowed to be inserted in the 1.5 second OFF phase. There is also an exception made for single-stroke bells or chimes, which are allowed to chime at three consecutive one second intervals, followed by a two second OFF phase. Figure 2 illustrates several examples of the T-3 pattern; the topmost figure is typical of the signal used in residential smoke alarms.

Although not mandated as part of the requirements of ANSI S3.41 or ISO 8201, residential smoke alarms typically employ an alarm frequency of 3,000–4,000 Hz. In tests of one residential smoke alarm, the U.S. Consumer Product Safety Commission (CPSC) determined the operating frequency of the smoke alarm to be 3,200 Hz [Lee, 2005a]. The alarm signal in a smoke alarm is typically generated with a piezoelectric horn. These devices are used due to their ability to produce significant sound levels while using relatively little power, which is essential when relying on batteries as a power source.

The voluntary UL standard for single-station smoke alarms, UL 217, also provides requirements for the smoke alarm signal. These requirements include the use of the temporal-three pattern and also require that a minimum sound level of 85 dBA be produced at 10 feet from a smoke alarm operating in a room of a specific configuration (see Section 65 of UL 217 for details).