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

Summary technical report

THE FIRE PROTECTION RESEARCH FOUNDATION

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Prepared by

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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.

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

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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.

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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.

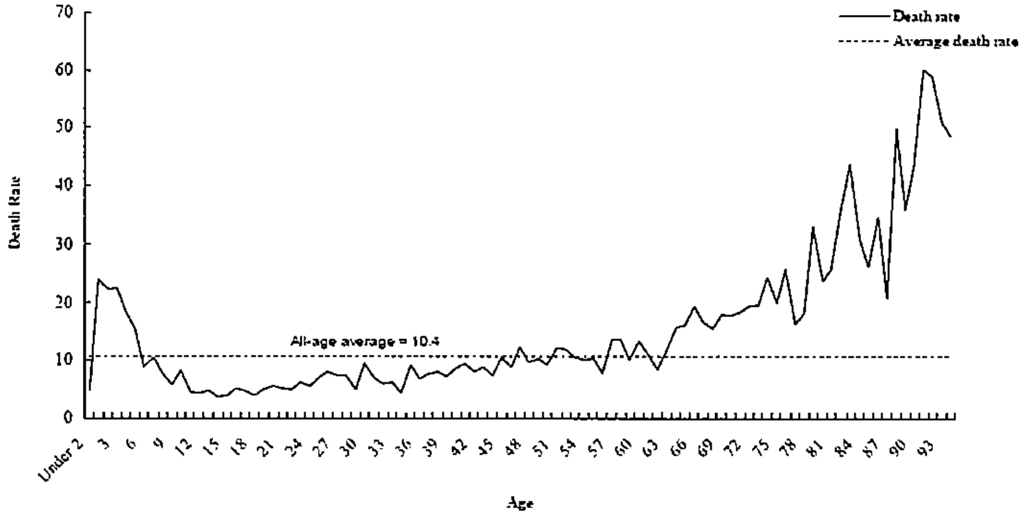


Figure 1 — Fire death rate in home fires as a function of age of the victim [Hall, 2005].

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).

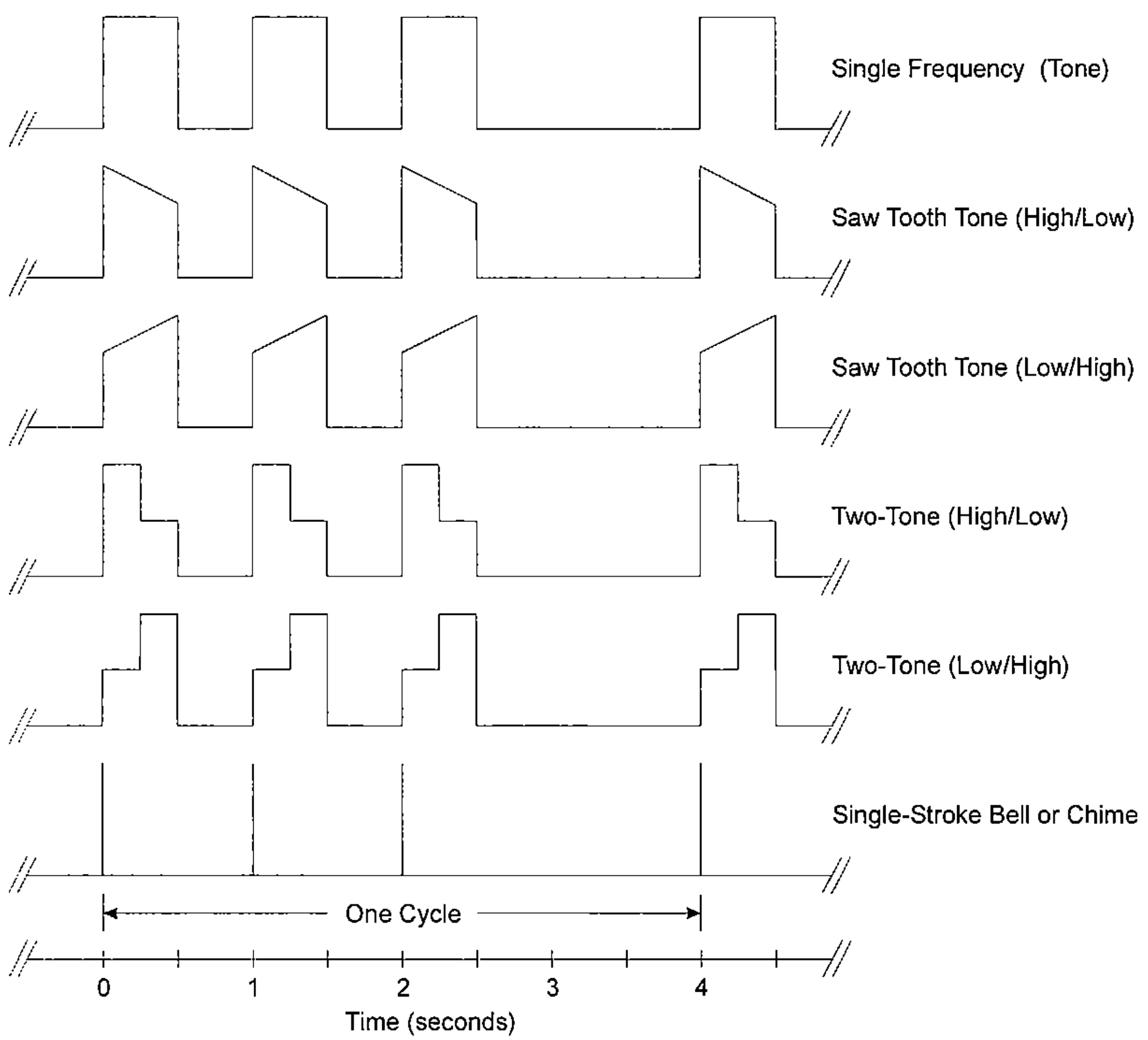


Figure 2 — Examples of the temporal-three (T-3) smoke alarm signal.

2.2 Waking Thresholds

Several studies have examined the response of adult occupants to the smoke alarm signal [Nober, et al., 1981; Kahn, 1984; Bruck and Horasan, 1995]. Bruck [2001] provides a summary of these and several other studies. In general, an unimpaired sleeping adult will awake quickly to a smoke alarm signal that reaches the occupants at a sound level of 55–60 dBA [Bruck, 2001]. Early work by Nober, et al. [1981] indicated that 18–29 year old adults could be aroused from sleep by a 55 dBA sound level in a relatively quiet environment. In a more noisy environment (window air conditioner running), a 70 dBA signal was required. Kahn [1984] obtained similar results when he presented male, college-age students (mean age 21.3) with alarm signals of 44, 54, and 78 dBA with background noise of 44 dBA. All participants awoke for the 78 dBA signal, 50 percent awoke for the 54 dBA signal, and 25 percent awoke for the 44 dBA signal. Bruck and Horasan [1995] found that 75–87 percent of the 18–24 year olds studied awoke to a smoke alarm signal of 60 dBA with background noise of less than 30 dBA, depending on their sleep stage.

Data from the auditory arousal threshold (AAT) literature, such as Zepelin, et al. [1984] or that used in the review by Berry [1978], suggests occupants would be less responsive to a 55–60 dBA signal than was cited in the previous studies. However, the frequency of the sound used in the AAT studies was typically significantly different than that of a smoke alarm [Bruck, 2001]. Nevertheless, Berry [1978] concludes from a review of the literature that 75 dBA "can reasonably be expected to awaken a person under most circumstances."

Berry [1978] and Bruck [2001] both note numerous factors which can affect responsiveness and should be considered when applying AATs, including:

- Large individual variation in AAT,
- Hearing impairments,
- Sleep medication,
- Background noise levels,
- Drug/alcohol use,
- Sleep deprivation,
- Being a child/teenager, and
- Being an older adult.

2.3 Audibility in Typical Residential Dwellings

A study recently published by the Consumer Product Safety Commission (CPSC) examined sound levels from smoke alarms in several residential dwellings [Lee, 2005a]. Sound measurements were taken in three homes constructed from 1960 to 1989, ranging in size from approximately 1,100 to 3,300 ft^2.

The first home in which sound measurements were taken was a typical 1,100 ft^2 suburban ranch house built in 1960. Directly under operating smoke alarms, sound levels of approximately 90–105 dBA were recorded. Sound measurements taken in three bedrooms with a smoke alarm operating in the adjacent hallway ranged from 85–96 dBA with the door open and 71–88 dBA with the doors to the bedrooms closed. A smoke alarm operating in one of the bedrooms produced sound levels at the pillow of approximately 90 dBA, regardless of whether the door to the bedroom was open or closed. The sound level in the master bedroom of the ranch home was as low as 45 dBA (with the bedroom door closed) with a smoke alarm operating in the basement (at the bottom of the basement stairway on the ceiling, 5 feet from the stairs).

The second home in which sound measurements were taken was a 2,300 ft^2, two-story home (no basement) built in 1973. A smoke alarm operating in the first floor hallway produced sound levels as low as 42 dBA in the second floor bedrooms when the bedroom doors were closed. The final home in which smoke alarm measurements were taken was a 3,300 ft^2 two-story (plus a basement) Georgian colonial-style home. Sound levels measured in the second floor bedrooms with a smoke alarm operating on the first floor were as low as 61 dBA with the bedroom doors closed. The sound level in the master bedroom of the colonial home (on the second floor) was as low as 34 dBA with the bedroom door closed and a smoke alarm operating in the basement (at the bottom of the basement stairway on the ceiling, 5 feet from the stairs).

Based on their measurements of sound levels in typical residential homes, the CPSC estimated that residential interior doors attenuate a smoke alarm signal approximately 10–20 dBA and that each level of the home through which the signal must travel attenuates an additional 20 dBA [Lee, 2005a]. From these results, the CPSC concluded that the signal from smoke alarms that are not interconnected may not be able to alert all occupants throughout two- or three-level homes. Therefore, interconnected smoke alarms or notification appliances on at least every level, and possibly in bedrooms as well, may be necessary to provide adequate protection throughout a dwelling.

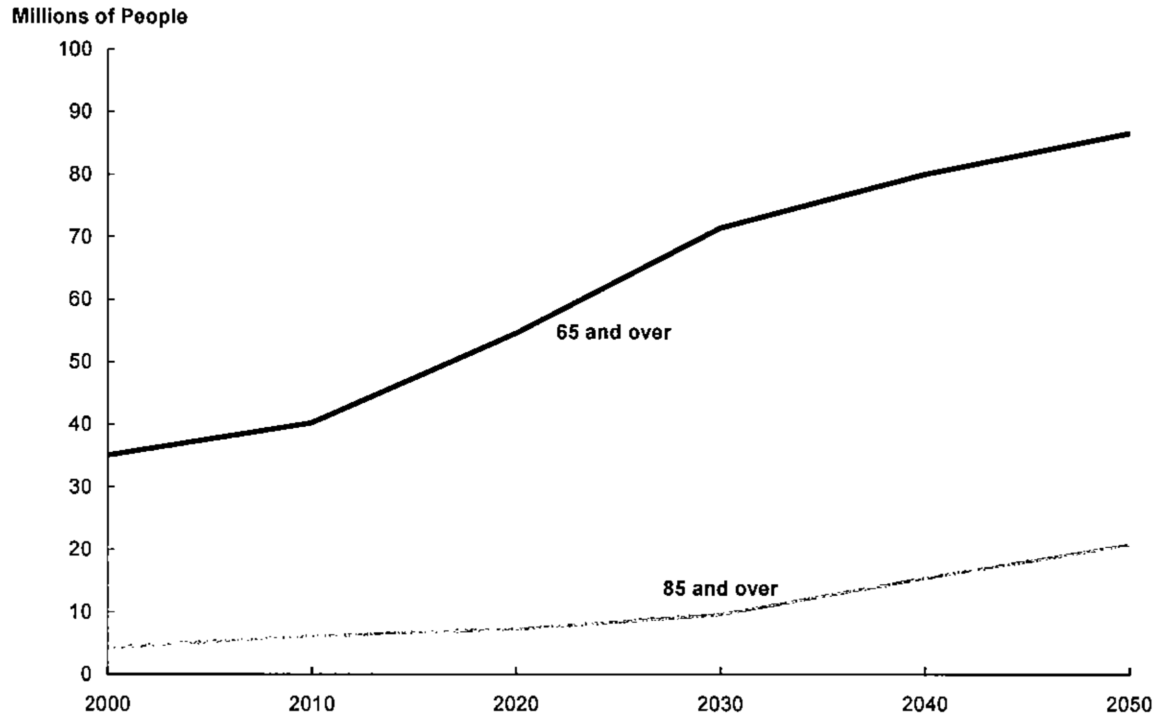
3.0 CHARACTERIZATION OF THE OLDER ADULT POPULATION

Several important distinctions can be made between older adults (65 years and older) and the overall population that are relevant to this analysis. Two recent reports highlight some of these differences [Smith, 2005; USFA, 2006]. The first report, published by the CPSC addresses age-related differences in the perceptual, cognitive, and physical abilities in adults and relates this understanding to improving product safety [Smith, 2005]. This CPSC report is based on an extensive literature review and serves as a valuable overview of characteristics of older adults in relation to safety. Similarly, the USFA published a report on fire and older adults, which contains a characterization of older adults and discusses several fire risk factors relevant to this population. This section provides a general characterization of the older adult population in terms of their population trends, impairments and disabilities, and housing conditions. For more detailed information on this topic, consult [Smith, 2005] and [USFA, 2006].

3.1 Population Trends

According to the U.S. Census Bureau, there were 35.0 million people 65 years of age and over in the United States in 2000 [Hetzel and Smith, 2001]. The older adult population represents 12.4 percent of the total population of the United States. Despite an increase in the number of the people in this age group, the proportion of the U.S. population in this age group declined slightly (from 12.6 percent in 1990 to 12.4 percent in 2000). This trend is expected to reverse as the "baby boomers" (those born 1946 to 1964) reach 65 years of age starting in 2011 [Federal Interagency Forum on Aging-Related Statistics, 2004]. Figure 3 shows population data from the most recent (2000) decennial U.S. Census, as well as projected population estimates for the next 50 years for people 65 years of age and over.

Over the last century, the older adult population in the U.S. grew from 3 million to 35 million, with the population age 85 and over growing from 100,000 to 4.2 million [Federal Interagency Forum on Aging-Related Statistics, 2004]. According to the U.S. Census Bureau, the number of older adults will increase dramatically during the 2010–2030 period. By 2030, the older adult population is expected to more than double its numbers from 2000, representing approximately 20 percent of the U.S. population. Rapid growth is expected in the population 85 years of age and over beyond 2030. This age group is projected to reach nearly 21 million people in 2050, representing nearly one quarter of older adults [Federal Interagency Forum on Aging-Related Statistics, 2004].



Source: U.S. Census Bureau [2004]

Figure 3 — Current and projected number of people age 65 and over in the U.S.

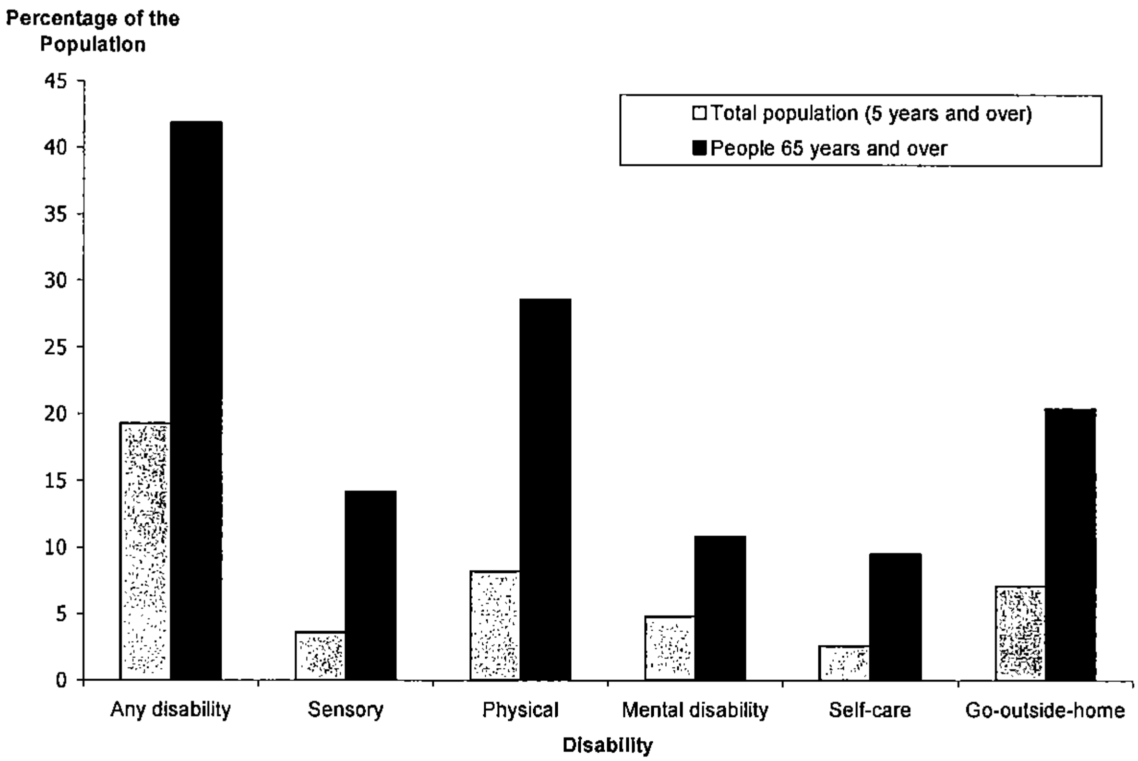
3.2 Impairments and Disabilities

3.2.1 General

According to the U.S. Census Bureau, 42 percent of the population 65 years of age and over reported some type of long term condition or disability in 2000 [Gist and Hetzel, 2004]. Census 2000 showed disability rates rising with age for both sexes [Waldrop and Stern, 2003]. The Census provides information on five categories of disabilities [Gist and Hetzel, 2004]:

- Sensory—long-lasting blindness, deafness, or hearing impairment
- Physical—long-lasting, substantial limitation on one or more basic physical activities, such as walking, climbing stairs, reaching, lifting, or carrying
- Mental—Learning, remembering, or concentrating
- Self-care—Dressing, bathing, or getting around inside the home
- Difficulty going outside the home—Going outside the home alone to shop or visit a doctor's office

Figure 4 compares the percentages of older adults and the general population that report each of the five disability categories distinguished in Census 2000. For three of the five disabilities measured by Census 2000, the disability rate for those 65 years of age and over was at least triple the rate of the total population [Gist and Hetzel, 2004]. Sensory disabilities, which include long lasting blindness, deafness, or hearing impairment, affect 14.2 percent of older adults. This is nearly four times the rate at which sensory disabilities affect the total population. Similarly, 28.6 percent of older adults are affected by physical disabilities, which are described as long lasting, substantial limitation on one or more basic physical activities such as walking, climbing stairs, reaching, lifting, or carrying. The rate of physical disability among the total population is only 8.2 percent. Due to long term physical, mental, or emotional conditions, 9.5 percent of older adults have difficulties providing self-care (dressing, bathing, or getting around inside the home). This is greater than three times the rate at which the total population has difficulty providing self-care (2.6 percent).



Source: U.S. Census Bureau [Waldrop and Stern, 2003]

Figure 4 — Disability status of older adults and overall U.S. population.

For the remaining two disabilities measured by Census 2000, the disability rate for those 65 years of age and over was at least double that of the total population. Mental difficulties, such as problems learning, remembering, or concentrating, were reported by 10.8 percent of older adults. This is over twice the rate at which these difficulties were reported by the total population. Over 20 percent of older adults reported difficulties going outside the home alone to shop or visit a doctor's office. The total population reported only 7.1 percent with this disability.

Over 50 percent of the population over the age of 85 reported a physical disability, with 47 percent indicating difficulties going outside the home [Gist and Hetzel, 2004]. For comparison, only 13 percent of people 65 to 74 years of age reported difficulties going outside the home. Similar trends were reported for sensory disabilities; nearly 35 percent of those 85 years and older reporting blindness, deafness, or hearing impairment, whereas only approximately 9 percent of those age 65 to 74 years reported similar difficulties.

The Census data on disabilities does not provide details regarding the extent of the disability. It is also possible, maybe even likely, that this data underestimates the magnitude of the problem since the information is based on the perception of the respondent. Regardless, since disabilities can affect people's ability to escape, this data suggests that the high rate of disabilities in older adults may contribute to their high risk of death in home fires.

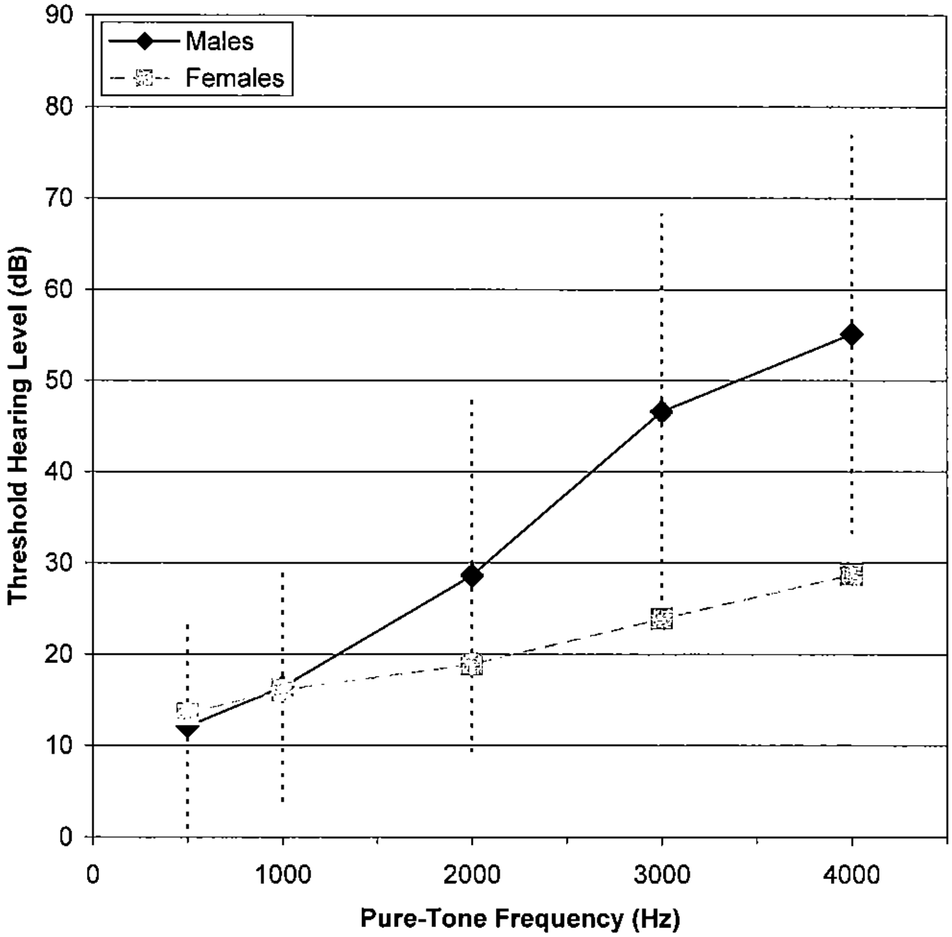
3.2.2 Hearing Impairment

The National Institute on Deafness and Other Communication Disorders (NIDCD), one of the institutes that comprise the National Institutes of Health (NIH), estimates that 28 million people in the U.S. are deaf or hard of hearing [NIDCD, 1996]. Hearing impairments affect a significant portion of the older adult population. Older adults comprise approximately 37 percent of all hearing-impaired individuals in the United States, despite representing only around 12 percent of the total U.S. population [Desai et al., 2001]. Around 30 percent of older adults are affected by presbycusis, gradual age-related hearing loss [Gates, et al., 1990]

Cruickshanks et al. [1998] conducted a large epidemiological study to measure the prevalence of hearing loss in older adults using standard audiometric testing. Study participants ranged in age from 48–92 years, with a mean age of about 66 years. Overall, 46 percent of the study participants had a hearing loss of at least 25 dB in the worse ear. They also found that the risk of hearing loss increases with age such that almost 90 percent of participants over 80 years of age experienced hearing loss. Figure 5 shows mean hearing threshold levels for men and women
60–69 years of age. The error bars in Figure 5 show one standard deviation and are only presented for males. Age-related hearing loss is primarily at the higher frequencies (greater than 2,000 Hz) and is greater for men than women, as shown in Figure 5. Hearing thresholds were slightly worse (higher) for left ears than right ears at frequencies above 250 Hz. The worse ear was used to determine the prevalence of hearing loss, so average hearing thresholds from the left ear are presented in Figure 5. As the number of older adults increases in the future, the number of older adults with hearing impairments will likely increase as well.

It is also important to recognize that many older adults may be unaware of their hearing difficulties. In the human behavior portion of this project [Bruck, et al., 2006], approximately 15 percent of the potential participants, who believed they had average or better hearing for their age, failed the hearing screening. Although this screening was fairly stringent, requiring each person to perform within one standard deviation of the mean threshold sound level for their age and sex at each frequency (500, 1000, 2000, 3000, and 4000 Hz) in both ears, these results highlight the prevalence and lack of awareness of hearing impairments among older adults.

A significant proportion of the older adult population with hearing impairments has not taken corrective action. In 1995, 76 percent of people age 70 and older with a hearing problem had seen a doctor for the problem; however, only 34 percent used a hearing aid [Desai, et al., 2001]. In contrast, over 98 percent of those age 70 or older with a visual problem had seen a doctor and 93 percent wore glasses. Similar statistics exist for the overall population of those with hearing loss. Of the 28 million Americans with hearing loss only about 25 percent currently use hearing aids [SHHH, 2006]. Thirty percent of those with hearing loss cannot afford hearing aids, 33 percent deny or hid their hearing loss and 7 percent are unaware of their hearing loss [SHHH, 2006]. Only around 5 percent of those with hearing loss require medical or surgical procedures to treat their hearing loss [SHHH, 2006]. In the context of this report, it is important to note that people that use hearing aids typically do not wear their hearing aids while sleeping.



Source: Cruickshanks et al. [1998]

Figure 5 — Hearing threshold levels among adults age 60–69 years.

3.3 Housing

Data from the 2000 U.S. Census can be used to characterize the types of housing that older adults occupy. Census data regarding housing is typically characterized according to households and householders. Households include all people who occupy a housing unit (i.e. a house, an apartment, a mobile home or trailer, a group of rooms, or a single room occupied as separate living quarters). A householder is the person, or one of the people, in whose name the home is owned, being bought, or rented [U.S. Census Bureau, 2006]. Previous versions of the Census used the term "head of household" rather than householder.

Table 1 shows that there were 35 million people age 65 years and over, which was 12 percent of the 281 million total U.S. population. Of the 35 million older adults, 33 million (94%) were in occupied households, as opposed to group living quarters. Consequently, the statistics related to occupied households represent the vast majority of the older adult population. As shown in Table 1, the rate of home ownership among those 65 years of age and over was higher than the general population. Seventy-eight percent of householders age 65 and over owned the home they occupied, whereas only 66 percent of all householders owned the home they occupied. However, the percentage owning their home declined with age within the 65 and over age group [Gist and Hetzel, 2004]. Table 2 provides further information on the types of homes that older adults occupy. Among householders 65 years of age and over who owned a home, 84 percent (around 15 million households), lived in single-unit attached or detached structures (i.e. single-family homes). When combined with renter-occupied structures, 71 percent (around 16 million households) of householders 65 years of age and older lived in single-unit structures.

Older adults are also more likely to live in older structures. As Table 3 shows the year in which the structure was built was relatively consistent for owner- and renter-occupied households. Only 5 percent of housing units with householders age 65 and over were built within the five years preceding Census 2000 (1995–2000). It is not surprising then that 90 percent of the housing units in which older adults live were built prior to 1990 and 60 percent were built prior to 1970.

Table 1 — Home ownership among older adults and overall U.S. populations.

	Total for All Ages		65 years and over	
	Number [1]	Percent	Number [1]	Percent [2]
Population	281.4	100%	35.0	12%
Occupied Households	105.5	100%	22.6	21%
Owner-Occupied Households	69.8	66%	17.6	78%
Renter-Occupied Households	35.7	34%	5.1	22%

1. Number in millions (people or households, as appropriate).
2. Percentages for population and occupied households are based on the total for all ages. Percentages of owner- and renter-occupied households are based on the number of occupied households in the age group specified.
Source: Census 2000, Summary File 3

Table 2 — Types of homes in which older adults live.

Units in Structure	Owner-occupied		Renter-occupied		Total	
	Million Households	Percent	Million Households	Percent	Million Households	Percent
Single Unit (detached or attached)	14.8	84%	1.2	23%	16.0	71%
Multiple Units (apartments)	1.3	8%	3.7	73%	5.0	22%
Mobile home, boat, rv, van, etc.	1.4	8%	0.2	3%	1.6	7%
Total	17.6	100%	5.1	100%	22.6	100%

All values are based on the number of housing units in which the householder was 65 years of age or over.
Source: Census 2000, Summary File 4

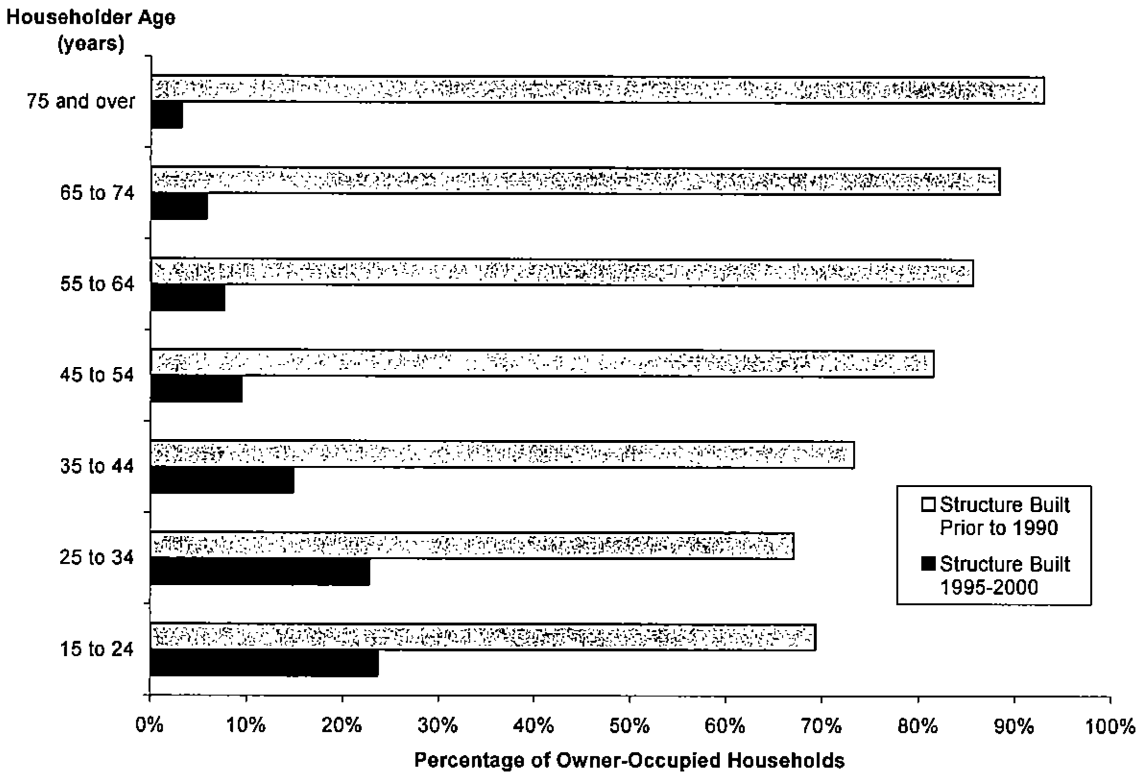
Table 3 — Age of structures in which older adults live.

Year Structure was Built	Owner-Occupied Households		Renter-Occupied Households		Total Households	
	Million Households	Percent	Million Households	Percent	Million Households	Percent
Built 1995 to 2000	0.8	5%	0.3	6%	1.1	5%
Built prior to 1990	15.9	91%	4.5	88%	20.4	90%
Built prior to 1970	11.0	63%	2.6	51%	13.6	60%
Total	17.6	100%	5.1	100%	22.6	100%

Data for householders age 65 years and over.
Source: Census 2000, Summary File 3

According to Table 1, the vast majority of housing units in which the householder was age 65 and over were owner-occupied structures (78%). Therefore, the remainder of this discussion will focus on owner-occupied housing units. As Figure 6 shows, the percentage of owner-occupied households in which the structure was built prior to 1990 increased with age of the householder. Likewise, percentage of owner-occupied households in which the structure was built 1995–2000 decreased with age of the householder. In contrast to the housing units in which older adults live (see Table 3), nearly one in four owner-occupied structures with householders 34 years of age and younger were built 1995–2000.

Another distinction made in the Census data regarding housing is the type of household. There are a variety of different household types, but one type that is of interest is non-family households in which the householder lives alone. Table 4 summarizes statistics from Census 2000 regarding the number of people that live alone. In the overall population, approximately 10 percent of people live alone. However, nearly one in three people age 65 and over live alone. In addition, a significantly higher proportion of older adult women live alone (36 percent) compared to older adult men (17 percent).



Source: Census 2000, Summary File 3

Figure 6 — Percentages of households living in structures built prior to 1990 and built from 1995–2000 according to the age of the householder.

Table 4 — Older adult and overall U.S. populations by sex and the portion of those living alone.

	All Ages		65 years and over	
	Million People	Percent	Million People	Percent
Total Population	281.4	100%	35.0	100%
Total Males	138.1	49%	14.4	41%
Total Females	143.4	51%	20.6	59%
Total, living alone	**27.2**	**10%**	**9.7**	**28%**
Males, living alone	11.8	9%	2.4	17%
Females, living alone	15.5	11%	7.3	36%

Source: Census 2000, Summary File 1

4.0 STATUS OF FIRE SAFETY AMONG OLDER ADULTS

Older adults clearly face a higher risk of death in fires than other groups; this was established in Section 1.0. However, simply knowing that older adults are at high risk is not sufficient. This section aims to provide insights into why this high risk situation may exist for older adults. With the data currently available, it is not possible to positively identify the cause(s) of the elevated fire risk of older adults. Nevertheless, risk factors believed to be the most significant and relevant are identified and discussed. Smoke alarm usage among older adults is also analyzed, including examining the presence, operability, and locations of smoke alarms in older adult households. This section also analyses the potential benefits of smoke alarms that provide improved waking effectiveness for older adults.

4.1 Risk Factors

A number of studies have examined potential fire death risk factors, including many that are applicable to older adults. A series of studies by the USFA are particularly relevant to this discussion [USFA, 1999; USFA, 1999b; USFA, 1999c; USFA, 2006]. These reports address the fire risks of people that are blind or visually impaired, have mobility impairments, that are deaf or hard of hearing, and of older adults in general, respectively. Hall [2005] also discusses a variety of risk factors associated with fire deaths, although not specifically targeting the older adult population.

Figure 7 presents a list of potential fire death risk factors. This list is largely based off the discussion of risk factors by Hall [2005] and is not meant to be exhaustive, but rather to provide an idea of the characteristics that have been considered by previous studies. Many of these risk factors seem intuitive, but their statistical power as a risk indicator varies. For this study, the risk factors receiving the primary focus are the age of the victim (older adults versus other populations), whether or not the victims were sleeping, and the presence and operation of smoke alarms. However, several of the other factors shown in Figure 7 are also discussed, based on the limited data available.

One of the difficulties faced when trying to assess many of these risk factors is the limited amount of data and the disconnected nature of the available data. This problem was also noted in the USFA studies mentioned earlier:

> Neither of the two national sources for fire death data—the National Center for Health Statistics (NCHS) and the National Fire Incident Reporting System (NFIRS)—provides for data collection of ancillary information on the deceased.

For example, although NFIRS may have some general information on the condition of a fire victim, this information is often unreliable given that emergency personnel do not necessarily know the medical history of fire victims. Therefore, they are only able to report information that is readily observable at the fire scene. More reliable data on the condition of the victims may be available from medical reports, but the data is typically not linked to other fire statistics of interest (for example, the presence and operability of smoke alarms during the fire). In addition, there may be some reluctance to report intoxication or disabilities in fire victims.

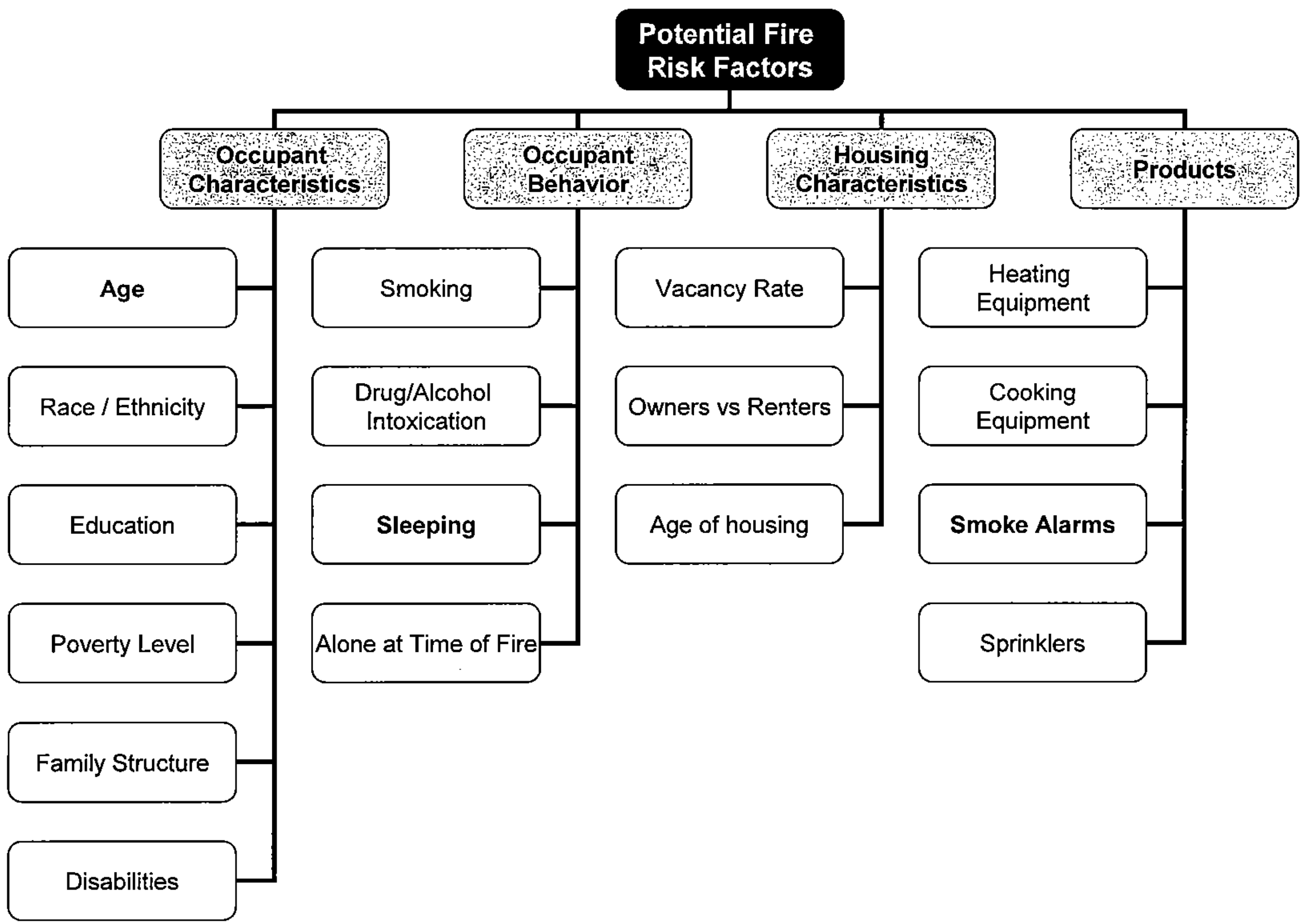


Figure 7 — Potential fire risk factors.

Some of the risk factors identified in Figure 7 seem to logically apply to older adults, but are not supported by the data. For example, given the prevalence of older housing among older adults, as discussed in Section 3.3, one might expect that the age of housing would be important. However, previous studies have shown that the age of a home is not a primary driver of fire risk [Hall, 2005]. Another example is the expectation of an increased risk of cooking-related fire deaths for older adults; however the data does not support this.

There is some data regarding risk factors associated with occupant behavior and product choices. Smoking materials are a significant contributor to fire risk—they "are the leading cause of home fire deaths, overall and for victims in every age group from age 35 up" [Hall, 2005]. For older adults (age 65 and over), smoking materials cause 32 percent of fatal home fires, which is consistent with the percentages of other age groups. The highest percentage of fire deaths attributed to smoking materials for any age group was for those 65–74 years of age, which had 37 percent of fire deaths caused by smoking materials. These statistics are somewhat surprising when the prevalence of smoking among older adults is considered. A study by the CDC in 2004 found that people age 65 and older have the lowest prevalence of current cigarette smoking (8.8 percent) among all adults [CDC, 2005]. In comparison, approximately 20.9 percent of U.S. adults were current smokers in 2004. Older adults appear to be at a disproportionately high risk of death in smoking-related fires, compared to the number of smokers in this age group.

Although alcohol intoxication certainly increases fire risk, it is not clear that the problem is sufficiently prevalent to significantly contribute to the high fire death risk of older adults. Studies from several states in which the blood alcohol levels of fire victims was examined found that 45–51 percent of adult fire victims had blood alcohol contents over 0.1 percent [Berl and Halpin, 1978; McGwin et al., 2000; Hall, 2005]. In the study on Maryland fire deaths [Berl and Halpin, 1978], 39 percent of fire victims age 60 and over were intoxicated compared to 51 percent of those age 20 and over. Similarly, a study of Minnesota fire deaths found that 21 percent of fire victims age 60 and over were intoxicated, compared to 46 percent of those age 20 and over (data from Minnesota Fire Marshal's Office in [Hall, 2005]). Older adults consume alcohol on more days each month than younger adults, but typically consume less in one sitting [USFA, 2006]. This may be significant given that Ball and Bruck [2004] found the greatest effect of alcohol on waking thresholds at only moderate levels of alcohol consumption (a blood alcohol content of 0.05).

Fahy and Molis [2004] conducted a study done in which they examined detailed narratives of fires from 1997–1998 where fatalities occurred in spite of smoke alarms operating. This work is of particular interest to the current discussion. Fahy and Molis examined 218 fires and 277 deaths, including 72 people over age 70. Forty-three percent of the older adult fire deaths in this study resulted from smoking-related fires; over a quarter of these older adults were smoking while on oxygen. The percentage of fire deaths associated with smoking for older adults is not significantly more than that of the overall population, in which 36 percent of deaths were from smoking-related fires. These statistics are consistent with the overall fire experience, discussed earlier. Fahy and Molis also found that 43 percent of the older adult fire victims in their study were believed to have some type of disability. This is significantly higher than the overall population (18 percent), but is relatively consistent with the disparity of disability rates between older adults and the overall population. Another risk factor that was examined by Fahy and