10-2-09

DHCD, DBFR 2009 Code Change Process

September 9, 2009 at 9:30 a.m. at DHCD, First Floor Conference Room IRC Sprinkler Sub-group Meeting Summary

1. **Manufactured Homes: Attendees discussed manufactured housing being exempted for mandated sprinklers. Without any opposition this will be off-the-table as a consensus item.**

2. **Fire causes**: Discussed the top causes of home fires. Besides the largest percentage being undetermined, the top causes were smoking, cooking, electrical, heating/fireplaces and candles/playing with matches. These causes are consistent at NFPA and VFIRS data bases.

3. **Data:** Discussed what data might be useful to have before the BHCD that would include age of dwellings and fires in townhomes versus detached homes. Builders want both data fields as they believe homes built from 1996 onward will be safer with less deaths, injuries and property damages. Fire representatives indicated that type of data is unavailable and isn't specifically reported to the VFIRS fire reporting system maintained by the VDFP. Builders believe this data would support their reasons to leave the sprinkler systems as an option. Builders say that new code requirements for GFI's, arc-fault devices, hard-wired smoke detectors, firestopping, less leakage of outside air due to energy provisions making fire propagation less likely and non-building items like fire-safe cigarettes. Builders believe other passive measures can do just as much for improved life safety at less cost than sprinklers. Builders cited incentives and some code measures they could support. Builders noted that the number of deaths in home fires have been decreasing or at least have been stable over the past decade despite nationally millions of new homes and millions in population growth. Fire officials see new furnishings with higher flashover potential and lightweight frame construction as potential problems that only sprinklers can effectively solve and not passive measures. They cited a NIST study where flashover had decreased exiting time from 17 minutes to as little as 3 minutes. Staff is attaching the summary VDFP 2000-2008 Summary Sheet for 1&2 family fires; a 2000 Census sheet on Virginia showing 2.9 million as the total number of housing units that is now 3.3 million in 2009 with nearly 2.1 being detached home and 189,000 manufactured homes; and, the 2009 VDFP 6 months summary for all fires in Virginia.

4. **Passive measures:** Arc-fault devices are required in the 2009 IRC for habitable areas that is an expansion from the bedroom requirements in the 2006 USBC. NFPA and the electrical industry estimate upwards to 200 lives could be saved over time; retrofitting battery smoke detectors in all existing homes has an estimated potential to save 600 lives per year nationally; and, finally fire safe cigarettes has an estimated potential to save 600 lives per year nationally. Staff notes there are 2400 lives lost yearly in 1&2 family homes. During the past 9-years in Virginia, there has been an

average of 40 deaths per year occurring in homes. HBAV does have a code change to not move forward on the arc-fault devices at this time. Cost for these additional new arc-fault devices is estimated from $200 to $600 per home. Virginia has a law that allows localities to require retrofitting of battery smoke detectors. Many have done so, but not all. Effective July 1, 2009 all cigarettes sold here had to be the fire-safe cigarettes. If the experts are correct, and so if these measures were fully implemented, Virginia should see in the next 10 years some significant reductions in lives lost and reduced injuries? Do the stakeholders agree or disagree? Discussion item at next meeting.

5. **Costs-Benefits:** Disagreement continues. Most would agree cost will be higher when well-water needs to be utilized - that additional cost appears to be somewhere between $500 and $1,000 based on input from the well-water contractors. R2904 will make sprinkler cost less as a designed system becomes unnecessary, thus saving the cost of a design professional to seal the construction plans and shop drawings. Somewhere between $3,200 and $5,200 seems to be the average cost point for installation of a sprinkler system in a 2,000 s.f. home/townhome. This average cost would include in most instances the cross-connection device required by the USBC and local water purveyors. There are some evidences that local hook-up fees will be reasonable and not thousands of dollars or will there be separate fire lines to be required that is the case in commercial and multi-family buildings. There has been discussion on insurance rate reductions. The VRSC did have an insurance representative at their early meeting that indicated savings could be possible, but it would be on a case-by-case basis and not over a broad spectrum of housing that was similar to testimony presented in 2008 before the Virginia Housing Commission when the VHC was reviewing legislation to mandate retrofitting of high-rise buildings. To date the mandate for sprinklers is for townhomes. Would it be fair to say that in normal economic times for homebuilding, there are 20,000 homes built and 4,000 are townhomes (25%)? Would the added construction cost for mandated townhome sprinklers be around $3,000 so then the total added cost would be $12 million dollars per year. Would be on next agenda. The BHCD wants to know how the incentives for sprinklers offset the additional costs. What are then ongoing maintenance costs or where localities require annually cross-connection inspections? What is the cost-benefit of mandating sprinklers for IRC built homes over 10, 20 or 30 years? Is the NIST report realistic and how does it address the potential outcomes for save lives and injuries and reduction in property damages or the current IRC requirements and passive measures? Likewise, the same analysis would be necessary for the proposals put forth by the builders.

6. **Problem to solve and goals:** The problem to solve and the goal is to reduce deaths, injuries and property damage. No agreement was reached in this critical area. At our next meeting should stakeholders attempt to reach a 50% goal and target in 10 years or 75% in 20 years to reduce lives lost, injuries and property damage? How do the code changes and options on the table and under discussions from both sides meet these targets in terms of effectiveness, implementation, the prioritization of finite dollar resources being available, the impact on housing options and affordability, the

use of incentives to offset installation costs and estimates on maintenance costs? Can the stakeholders reach a consensus? Is there a need to bring into the discussions on the IRC sprinkler mandate such other factors that includes public education, the local enforcement efforts and the adoption of the USBC maintenance code and the SFPC? There are ICC/IRC 2012 code change hearing for signage on homes regarding construction materials; for townhomes at 3 stories to be sprinkled and not at 1 or 2 stories; for optional sprinklers and for protection of floor and roof joists and trusses. Stakeholders need to review these code changes for their impact on your viewpoints and what, if any, do we need to consider for the 2009 USBC? These will be discussed at the next meeting. Is this a grand opportunity for local code officials and governments to partner with builders in a collaborative effort to pass local smoke detector ordinances and to educate homeowners and tenants on sprinklers, smoke detectors and fire prevention/emergency evacuation planning? Is this the time for increasing the issuance of free smoke detectors to the low-income families and the elderly?

7. Here are the code changes and proposals offered by the VRSC and the builders:

Builders:

- Optional sprinklers
- Collaborative efforts to support local fire prevention education and increased enforcement
- Collaboration and commitment to have HBAV members to put forth in sale materials the sprinkler option
- Fire extinguishers for kitchens as a USBC requirement. A code change submittal would be needed. Foreign countries with better home fire records have this requirement.
- Retroactive smoke detectors for existing homes. Local ordinances would be needed.
- Labeling for lightweight framing-2012 IRC code change
- Consider the protection of trusses and floor joists with ½ hour gysum-2012 IRC code change. Addresses concerns on lightweight framing collapsing prematurely.
- Consider to allow home inspections related to fire protection and alarm devices. Would be done by modifying the SFPC 109.1 Exception
- Arc-fault devices for bedrooms. The 2008 IRC/NEC requires arc-fault devices for other habitable rooms for the proposed 2009 USBC. HBAV has a code change submitted to retain only for bedrooms believing that the devices are costly and there needs to be more time to see if they are dependable.
- Fire-proof cigarettes would positively impact one of the major causes of home fires that being smoking.

VRSC:

- Mandate townhome sprinklers with several incentives of 2 to 1 hour fire wall. Code change submitted. Not a consensus on R313.1 and 313.2 to do only townhomes and not detached homes. VRSC noted this is a major concession from where they were this spring and were disappointed the builders had only

suggestions on passive measures. VRSC noted for consensus there needs to be give and take. Builders believe doing optional sprinklers is the best approach noting only 1 state out of 17 or so have even approved the IRC sprinklers in the adoption of their state codes.

- Code changes to add into the SFPC the IFC appendices for reduced fire flow, fire hydrants and access road widths for sprinkling of a development that would be done by local ordinances not through the SFPC. Not a consensus on F503.2.1 to put into SFPC appendix on fire access roads that can be reduced to 18 feet. Should the submitted VRSC code changes in these three areas be amended to also include there applicability to any development of detached homes that are fully sprinkled? Staff notes for state uniformity and consistency these code changes could be in the SFPC F503 .2.1 section instead of being permissive based on local adoption. All code changes would still have to be coordinated with local policies that might not allow the reductions. VRSC concern to have these code changes in the SFPC was that now some localities already are different. Will remain on table for discussion. Need to evaluate what and how to consider these code changes as incentives or cost offsets.
- Support and agree that passive construction elements still need to be done too, such as protection of lightweight frame construction to minimize flashovers and early collapses of these structural members. Passive measures or warning families to evacuate should not be considered a substitute for sprinklers.
- Support arc-fault devices for all habitable rooms.
- **Consensus to move forward adding P2904 to the R310.1 Exemption as a system that can be used for credit to not have second means of egress in basement with a bedroom.**
- **Consensus to move forward with tweaking of TR302.1 footnote 1 on the fire separation distance moved from 5 to 3 feet. Not likely to have major impact as most zoning ordinances require more anyway, but in some cases is a plus and works with optional sprinklers too where the development is sprinkled by proffers. Shahriar to clarify**.

Builders didn't support any sprinkler mandate, noting townhomes will not have much of impact on reducing deaths, injuries and property damage since they are protected with fire walls and projections require ratings now. Does the unavailability of fire data pose a problem to the stakeholders in reaching a consensus? Builders see that installing and requiring smoke detectors in existing homes is the most economical and the best life safety measure in a far less time frame to save lives, reduce injuries and property damage over the next 10-20 years. Staff would ask HBAV to provide some costs on what it might take to have all existing homes have at least installed 1or 2 smoke detectors such as $60-$80? If it was assumed that there are 1 million homes without smoke detectors, then the cost would be 6-8 million dollars. What might be the outcome to see in 10 or 20 years from the adoption of such retrofit local ordinances or a change to state law for a statewide mandate? Builders noted a report by NFPA on smoke detectors that showed an effectiveness of over 90% getting residents warned of a fire.

The VRSC noted in many urban and suburban localities townhome builders sprinkle them now without any adverse impacts to sales and because some are R-3 IBC townhomes, they are already required to be sprinkled. Townhomes with 4-8 homes connected, even with a fire wall, does have a potentially higher risk factor much like smaller 2-3 story apartments. The NIST study is attached as support from the VRSC on the cost-benefit of mandated sprinklers. Builders counter that every 1,000 dollars added to the base price of a home kicks out purchasers and does the most harm for affordable housing and first time buyers as opposed to the more affluent home buyers. The VRSC members disputed the NFPA smoke detector report noting there is a follow-up report saying the NAHB has misapplied the findings.
One fire official at the end of the meeting thought that a 50% goal might be reasonable to establish. At the next meeting need to have this discussion on the problem solving, the cost and outcomes expected in some period of time as the BHCD members are asking staff for this information as are the Virginia Housing Commission members from a September 29th meeting. Does the NIST report conclude what would be the period of time necessary to see mandated sprinklers produce a significant decrease in lives saved, injuries and property damage in comparison to smoke detectors and other IRC building and life safety measures already adopted or might be adopted would be a discussion item for the next meeting.

8. **Sprinklers on well water systems:** Parties agree there will be some increased costs for sprinklers installed off a well-water system even when townhomes are involved and there is a common water supply that is regulated by VDH. Estimates are that the cost impact could be a few hundred dollars to a few thousand dollars. Shahriar Amiri noted that prices in Montgomery were typically $600 to $1,000 over the sprinkler costs. Well-water representatives will search for some cost data that might be incurred for the need for a pump size increase and to have installed a holding tank of 260 gallons.

9. **ICC code changes 2012:** RB19 takes fire distance separation from 5 feet to 3 feet. RB22 would add back the 2 hour fire wall from 1 hour; and, RB 31 does the ½ hour gypsum to protect joists and trusses. There are a block of code changes that drops the mandatory to optional sprinklers and to do only 3 story townhomes.

10. **Submitted code change by Mr. Gill: Code change to sprinkle if over 7500 square feet; two stories or if not 40 feet separation. No support. Will be off the table.**

11. **Other alternatives:** Mr. Whitney presented information on a fire extinguisher for kitchens for $25 or less and a device tied to the smoke detectors and thermostats to shut down the HVAC fan system in the $200 range. Would need code changes to be considered by the BHCD.

12. **Staff Comments:**

Actually, just the continuation of the dialogue by the stakeholders is a significant achievement from the 2009 spring discussions so hats off to the representative of each group of stakeholders to stick in there and being willing to meet. There has been progress, opening of areas for partnership and real viable options placed on-the-table for the BHCD to deliberate upon next year.

- The focus on townhomes to be sprinkled and leaving the detached homes optional opens the possibility to explore an amendment that both parties might at least want to consider. By not requiring sprinklers for manufactured housing or detached homes, would it make any sense to pick up on a current USBC amendment that states for 16 or less and 2 stories without sufficient water volume of pressure, no sprinklers are required. What if the townhome sprinkler mandate was only for those on a public water system or a VDH community well-water system and 3-story townhomes? This would then mean for the most part that townhomes in the urban and suburban areas would be the first to have a sprinkler mandate. The VRSC members stated this is where most townhomes are being sprinkled now by proffers or the owners wants a fourth floor that are already sprinkled under the IBC. Would place on the agenda for discussion at the next meeting.

Work Group 3 IRC Sprinklers: There will be a meeting on December 3, 2009 at DHCD, 11th floor, 600 East Main Street, Richmond, Virginia from 9:30 a.m. to 12:30 p.m. Please contact Janice Firestone at janice.firestone@dhcd.virginia.gov on you planned attendance. Meeting agenda and materials will be sent out and posted on the DHCD web-site.

Again, your participation is most appreciated

NIST Report on Cost Benefit of Residential Sprinklers
U.S. Department of Commerce Office of Applied Economics
National Institute of Standards and Technology Building and Fire Research Laboratory

Gaithersburg, Maryland 20899
Benefit-Cost Analysis of Residential Fire
Sprinkler Systems
David T. Butry
M. Hayden Brown
Sieglinde K. Fuller
NISTIR 7451
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Cover photos, (clockwise from upper left), courtesy of the United States Fire Administration (USFA), Purdue University, Kellie Beall of the National Institute of Standards and Technology, and the City of Sausalito Fire Department.

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Department of Homeland Security
Michael Chertoff, Secretary
Federal Emergency Management Agency
R. David Paulison, Administrator
U.S. Fire Administration
Gregory B. Cade, Assistant Administrator
U.S. Department of Commerce
Carlos M. Gutierrez, Secretary
National Institute of Standards and Technology
Dr. James M. Turner, Acting Director
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Abstract

This report documents a benefit-cost analysis performed to measure the expected present value
of net benefits resulting from the installation of a multipurpose network fire sprinkler system in a
newly-constructed, single-family house. The benefits and costs associated with the installation
and use of a fire sprinkler system are compared across three prototypical single-family housing
types: colonial, townhouse, and ranch. The installation costs differ by housing types, with the
colonial being the most expensive and the ranch the least.

The benefits experienced by residents of single-family dwellings with sprinkler systems, as

measured in this report, include reductions in the following: the risk of civilian fatalities and injuries, homeowner insurance premiums, uninsured direct property losses, and uninsured indirect costs. The primary costs examined are for initial purchase and installation of the sprinkler system. Maintenance and repair costs are not examined because they are negligible.

Results of the benefit-cost analysis show that multipurpose network sprinkler systems are economical. The expected present value of net benefits (PVNB) in 2005 dollars is estimated as $2919 for the colonial-style house, $3099 for the townhouse, and $4166 for the ranch-style house. A sensitivity analysis is performed to measure the variability of the results to changes in the modeling assumptions. The sensitivity analysis confirms the robustness of the baseline analysis. The PVNB range from $704 to $4801 for the colonial-style house, from $884 to $4981 for the townhouse, and from $1950 to $6048 for the ranch-style house. Multipurpose network systems are the lowest life-cycle cost systems because homeowners can perform their own regular inspections and maintenance, and thereby save on costs they would incur with other systems. Given that they provide a similar level of performance, in terms of fire-risk mitigation, multipurpose network systems then achieve greater cost-effectiveness over alternate systems.

Key Words: building economics, benefit-cost analysis, cost-effective decision, economic analysis, fire sprinkler, life-cycle cost

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Preface

This benefit-cost analysis is conducted for the United States Fire Administration (USFA) by the Office of Applied Economics (OAE) in the Building and Fire Research Laboratory at the National Institute of Standards and Technology. A benefit-cost model is designed and estimated, expanding on the prior cost analysis developed by OAE in NISTIR 7277, Economic Analysis of Residential Fire Sprinkler Systems (Brown 2005). This analysis provides a current estimation of the cost-effectiveness of installing residential fire sprinkler systems, updating a prior National Bureau of Standards (NBS) study, A Benefit-Cost Model of Residential Fire Sprinkler Systems (Ruegg and Fuller 1984).

Brown (2005) documented the design and installation cost of four fire sprinkler systems—three

variants of a stand-alone system and a multipurpose network system—in three housing types.
When compared to a typical stand-alone fire sprinkler system that included a backflow preventer requiring professional maintenance, the multipurpose network system was generally the least costly in life-cycle costs across all three housing types. The multipurpose network system was therefore selected as the fire sprinkler system to be used in this benefit-cost analysis.
Disclaimer: Certain trade names or company products are mentioned in the text to specify adequately the experimental procedure and equipment used. In no case does such identification imply recommendation or endorsement by the National Institute of Standards and Technology or the United States Fire Administration, nor does it imply that the equipment is the best available for the purpose.
Disclaimer Regarding Non-Metric Units: The policy of the National Institute of Standards and Technology is to use metric units in all its published materials. All of the sprinkler system design data such as room dimensions and pipe lengths were obtained in U.S. customary units. Because this report is intended for U.S. builders and contractors who use U.S. customary units, it is more practical and less confusing to use U.S. customary rather than metric units. Measurement values in this report are therefore stated in U.S. customary units first, followed by the corresponding values in metric units within parentheses.
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Acknowledgements

Thanks are due to Dan Madrzykowski of the Fire Research Division of the Building and Fire Research Laboratory. Dan Madrzykowski initiated this project and facilitated the collection of cost data. Thanks are also given to Harold Marshall, Robert Chapman, and Douglas Thomas of the Office of Applied Economics for their many helpful comments and suggestions on the benefit-cost model and comparative analysis. Special appreciation is extended to OAE staff members Julie Wean for her research, and Tessa Beavers for her editing work.

Special thanks are given to Mr. Larry Maruskin of the U.S. Fire Administration for supporting this project. The help of Dr. John R. Hall, Jr., of the National Fire Protection Association, in analyzing fire data was invaluable; without it, this report could not have been written.

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ES-1

Executive Summary

The objective of this study is to measure the expected economic performance of a fire sprinkler system installed in a newly constructed, single-family dwelling in the U.S. The benefit-cost analysis in this report is consistent with ASTM E 1074-06: Practice for Measuring

Net Benefits
for Investments in Buildings and Building Systems, and it is meant to provide a current benefitcost
analysis of residential fire sprinkler systems, updating NBS Technical Note 1203: A Benefit-
Cost Model of Residential Fire Sprinkler Systems, published in 1984. In 1984, evidence
suggested that sprinkler systems were not cost-effective, perhaps explaining the relatively small
number of houses equipped with fire sprinklers today, even while fire professionals maintain that
such systems protect lives and property from fire. Over the past two decades, advancement in
the performance and cost-structure of fire sprinkler technologies have occurred, altering the costeffectiveness
of fire sprinkler systems. This report revisits the topic using the most complete fire
incident data available today.
The benefits experienced by residents of single-family dwellings with sprinkler systems, as
measured in this report, include reductions in the following: the risk of civilian fatalities and
injuries, homeowner insurance premiums, uninsured direct property losses, and uninsured
indirect costs. The primary costs examined are for initial purchase and installation of the
sprinkler system. The measure of benefit-cost performance, the present value net benefits,
compares differently timed benefit and cost cash flows, accruing to a homeowner, by discounting
them to a reference point in time. All dollars presented in this report are in 2005 adjusted
dollars. The present value net benefits are calculated by subtracting present value costs from the
present value benefits.
The quantified benefits of a fire sprinkler system used in a single-family dwelling are based on
reported fire incident data contained within the U.S. Fire Administration's National Fire Incident
Reporting System 5.0 (NFIRS 5.0), and calibrated with reported data based on the National Fire
Protection Association's annual survey of fire departments, over the period of 2002 to 2005.
This study period was selected due to the relative completeness of fire incident records
nationwide, thus ensuring that the nationwide trends and patterns used in this analysis are
representative of U.S. fire risks. Over the 2002 to 2005 study period, houses equipped with
smoke alarms and a fire sprinkler system experienced 100 % fewer civilian fatalities, 57 % fewer
civilian injuries, and 32 % less direct property losses and indirect costs resulting from fire than
houses equipped only with smoke alarms. In addition, homeowners of dwellings with fire
sprinkler systems received an added bonus of an 8 % reduction in their homeowner insurance
premium per year, according ISO. This report finds the monetized value of a residential fire

sprinkler system, over a 30-year analysis period, to yield homeowners $4994 in present value
benefits (see Table ES-1).
The quantified costs of a fire sprinkler system are based on the findings of NISTIR 7277:
Economic Analysis of Residential Fire Sprinkler Systems. NISTIR 7277 documented the design
and installation costs of four different fire sprinkler systems within the three prototypical house
types used in this study. Of the alternative sprinkler systems examined in NISTIR 7277, the
multipurpose network system was generally the least costly (life-cycle cost) across the three
house types because it did not require a backflow preventer, which requires regular professional
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maintenance. The multipurpose network system was therefore selected as the fire sprinkler
system analyzed in this study.
The costs associated with installation of a multipurpose network sprinkler system are based on
the minimum standard required by NFPA 13D: Standard for the Installation of Sprinkler Systems
in One- and Two-Family Dwellings and Manufactured Homes. The three prototypical house
types considered are: a 3338 ft2 (310 m2) two-story colonial with basement, but not including the
garage; a 2257 ft2 (210 m2) three-story townhouse; and an 1171 ft2 (109 m2) single-story ranch.
The present value costs of installation of a multipurpose network sprinkler system are estimated
to be $2075 for the colonial, $1895 for the townhouse, and $829 for the ranch.
Results of the benefit-cost analysis show that multipurpose network sprinkler systems are
economical. The expected present value of net benefits (PVNB) is estimated to be $2919 for the
colonial-style house, $3099 for the townhouse, and $4166 for the ranch-style house (see Table
ES-1). These baseline ("best-guess") estimates indicate that over the past two decades increases
in fire sprinkler performance, coupled with the low life-cycle cost of a multipurpose network
system, have made fire sprinklers cost-effective technologies for residential dwellings. With
respect to multipurpose network systems, failing to install sprinkler systems in residential
dwellings is no longer supported on economic grounds, at least from a homeowners' perspective.
Table ES-1. Summary of Baseline Benefit-Cost Analysis of a Multipurpose Network
Residential Sprinkler System for the Colonial, Townhouse, and Ranch House.

	Colonial	Townhouse	Ranch
Benefits			
Fatalities Averted	$3725.57	$3725.57	$3725.57
Injuries Averted	224.74	224.74	224.74
Direct Uninsured Property Losses Averted	79.64	79.64	79.64
Indirect Costs Averted	15.93	15.93	15.93
Insurance Credit	948.41	948.41	948.41
Benefit Subtotal	4994.29	4994.29	4994.29

Costs			
Installation (50 % Markup)	2075.08	1895.17	828.66
Costs Subtotal	2075.08	1895.17	828.66
Net Present Value	$2919.20	$3099.11	$4165.62

Although the baseline analysis finds strong evidence of cost-effectiveness of residential fire sprinkler systems, a sensitivity analysis is performed to measure the variability of the results to changes in the modeling assumptions and to assess the robustness of the baseline findings. The analysis relies on a number of assumptions generated from NFIRS 5.0, and these assumptions contain a degree of uncertainty. For instance, over the 2002 to 2005 study period of the dwellings examined, wet-pipe sprinkler systems were present in only 0.2 % of all structure fires. Conducting a sensitivity analysis is important because the statistics used to summarize the characteristics of dwellings with sprinklers are drawn from a small segment of the population, and may be influenced by a few outlying, and unrepresentative, fire incidents. The key assumptions are varied based on observed ranges found in the data, expert opinion, and findings reported from other recent fire sprinkler studies.

The sensitivity analysis confirms the robustness of the baseline analysis. Figure ES-1 graphs the cumulative distribution function (CDF) generated from varying the assumptions over their likely values, for each of the three house types. The vertical axis measures the probability that the associated net present value, measured on the horizontal axis, is equal to or less than the specified value. The vertical axis measures the cumulative probability and the horizontal axis measures the range of possible net present values resulting from a multipurpose network sprinkler system installed in a colonial, townhouse, and ranch house. For instance, there exists about a 0.80 probability that the actual net present value from installation of a sprinkler system is equal to or less than the baseline net present value, for each of the house types. However, the graph also indicates there is a 0.0 probability that a homeowner will incur higher present value costs than present value benefits when installing a multipurpose network sprinkler system.

The PVNB generated from the sensitivity analysis range from $704 to $4801 for the colonial-style house, from $884 to $4981 for the townhouse, and from $1950 to $6048 for the ranch-style house. Because multipurpose network systems are the lowest life-cycle cost systems commercially available, the PVNB will be smaller for other, more expensive systems. Provided a similar level of performance, in terms of fire-risk mitigation, multipurpose network systems

then achieve greater cost-effectiveness over alternative systems.

Figure ES-1. The Cumulative Distribution Function Resulting From Latin Hypercube Sampling of Inputs in the Present Value of Net Benefits Calculation of a Multipurpose
Network Sprinkler System for the Colonial, Townhouse, and Ranch House.

ES-3

□
ES-4

□
1
1. Introduction
1.1. Background
According to the National Fire Protection Association (NFPA 2006), between 2002 and 2005, on
average, there were 296 500 residential fires (one- and two-family dwellings), causing 10 188
civilian injuries and 2566 civilian deaths each year. These fires were responsible for $5.3 billion
(in 2005 dollars) in direct residential property losses on average each year.
Since the introduction of the residential sprinkler standard, NFPA 13D (Standard for the
Installation of Sprinkler Systems in One- and Two- Family Dwellings and Manufactured

Homes), in 1975, residential sprinkler systems have proven themselves as life-safety systems.
According to the National Fire Sprinkler Association (NFPA), over 200 communities in the
United States now have regulations requiring residential sprinkler systems. In studies of
Scottsdale, Arizona1 and of Prince George's County, Maryland (Siarnicki 2001), it was shown
that residences with sprinkler systems suffered fewer deaths, injuries, and property damages than
those without. In fact, no civilian fatalities were reported in residences with sprinkler systems in
either study. But, while there is growing recognition of the ability of residential sprinkler
systems to protect life and property from fires, less than 1 % of all existing one- and two-family
dwellings involved in a structure fire in 2005 had a sprinkler system.
Although residential sprinkler systems protect lives and property from fire, earlier research
suggested that sprinkler systems were not cost-effective (Ruegg and Fuller 1984; Juas and
Mattsson 1994). This might partly explain the dearth of fire sprinkler systems in residential
dwellings. However, advancements in newer fire sprinkler technologies, of lower cost and
improved performance, might be significant enough to improve the cost-effectiveness of these
systems.
1.2. Purpose and Scope of Approach

This report designs a benefit-cost analysis and applies it to a multipurpose network fire sprinkler
system in new housing construction. The multipurpose network design connects to the house's
regular water supply and piping. This system, using cross-linked polyethylene (PEX) tubing, is
evaluated because it yielded the minimum life-cycle cost alternative among the sprinkler systems
currently available (Brown 2005).
This benefit-cost analysis adds a benefits dimension to the economic analysis developed in
Brown (2005). While the earlier study described and estimated life-cycle costs of installing fire
sprinkler systems in residential housing, the current study conducts a benefit-cost analysis of
residential sprinklers, using the expected benefits and costs, in present value dollars, associated
with the installation of a multipurpose network fire sprinkler system in new construction. Both
reports provide a current analysis of the cost-effectiveness of installing residential fire sprinkler
1 As reported by the Home Fire Sprinkler Coalition (2007).
□
2
systems, updating a prior National Bureau of Standards (NBS) publication, A Benefit-Cost Model
of Residential Fire Sprinkler Systems (Ruegg and Fuller 1984).
Section 2 briefly introduces benefit-cost analysis and presents the benefit-cost model framework;
Section 3 documents and describes the data used to estimate the benefits and costs; Section 4
presents the results of the baseline ("best-guess") benefit-cost analysis; Section 5 illustrates the
sensitivity of the baseline results using a simulation of many of the parameters used to generate
the baseline values; Section 6 summarizes the benefit-cost analysis results and makes
recommendations for further research; Appendix A develops the benefit and cost equations
needed to perform the benefit-costs analysis; Appendix B discusses the omitted benefits and
costs associated with sprinkler installation and use that were not quantified.
□
3
2. Benefit-Cost Framework
2.1. Introduction to Benefit-Cost Analysis
The benefit-cost analysis in this report is consistent with ASTM E 1074-06 Practice for
Measuring Net Benefits for Investments in Buildings and Building Systems. The economic
impacts to an individual homeowner from installing a fire sprinkler system in each of three
prototypical single-family homes are organized and presented as benefits and costs.
Benefits and costs that occur (or recur) at different times are not directly comparable. Therefore,
these differently timed cash flows are made time equivalent by discounting them to a common
point in time, usually to present values at the analysis date or the beginning of the relevant study

period. The interest rate used for discounting, the discount rate, represents a minimum
acceptable rate of return on investment. This report describes the benefits and costs in present
value terms. The discount formulas for calculating the appropriate discount factors for the 30-
year study period used here are consistent with those described in the Discount Factor Tables of
the Adjunct to ASTM Practice E 917 of the ASTM Standards on Building Economics, 6th edition.

2.2. The Benefit-Cost Model

This section describes benefit and cost variables. The generalized present value of net benefits
equation (PVNB), adapted from ASTM, for comparing benefits and costs attributed to the
addition of a sprinkler system to a house with only smoke alarms, is given by:

. .
. . ..
.
.
.
T
t
t
t t
d
B C
PVNB
0 1
(2-1)

where
Bt is the dollar value of benefits in period t,
Ct is the dollar value of costs in period t,
T is the number of discounting time periods in the study period,
d is the discount rate per time period.

A positive PVNB implies the present value benefits outweigh the present value costs. The
benefit and cost terms from Equation (2-1) can be decomposed into individual components.

Present value benefits (PVB) can be expressed as:

□
4
. . . . PVDI PVPL PVIL PVIP PVOB
d
DI PL IL IP OB
d
B T
t
t
t t t t t
T
t
t
t . . . . .
.
. . . .
.
. . .
.0 1 .0 1

where
DI is the value of death and injury averted due to sprinkler use,
PL is the value of reduced uninsured direct and non-reimbursable property loss due to
sprinkler use,
IL is the value of reduced uninsured indirect and non-reimbursable costs due to sprinkler
use,
IP is the value of reduced homeowner insurance premiums due to sprinkler use,
OB is the expected value of other sprinkler benefits, such as savings from reduced local taxes
due to municipal cost reductions, and lower construction costs due to lower requirements
for fire-resistant construction,
PV denotes present value.
The present value costs (PVC) can be expressed as:
. . . . PVPI PVOP PVM PVOC
d
PI OP M OC
d
C T
t
t
t t t t
T
t
t
t . . . .
.
. . .
.
. . .
.0 1 .0 1
where
PI is the purchase and installation cost of a sprinkler system,
OP is the operating cost of a sprinkler system,
M is the maintenance, repair, and replacement costs of a sprinkler system,
OC is the other cost associated with sprinkler use.
Appendix A presents the benefit and cost equations used to perform the benefit-costs analysis
based on the data described in Section 3.
□
5
3. Data and Assumptions
3.1. Introduction
This section presents the data sources and the manner in which the national fire statistics (e.g.,
probability of fire, number of deaths per fire in a residence with only smoke alarms, average
direct damages resulting from a fire in a house with only smoke alarms) are used to generate data
for analysis in this report. Section 3.2. presents an overview of the datasets used in the benefitcost
analysis. Sections 3.2.1 describes the U.S. Fire Administration's National Fire Incident
Reporting System 5.0 (NFIRS 5.0) dataset, which is the primary source of data driving the
results. Section 3.2.2 describes the statistics reported by the National Fire Protection

Association, that in conjunction with the NFIRS 5.0 data, we use to create the national statistics needed in this analysis. Section 3.2.2.1 details the data calibration process used to generate the national statistics and Section 3.3 summarizes the fire statistics. Section 3.4 provides an explanation of how we derived the values of a statistical life and injury averted due to fire sprinkler use, which are two of the major benefits of fire sprinkler systems. Section 3.5 details the costs associated with the installation of a multipurpose network sprinkler system in the colonial, townhouse, and ranch house. The data presented throughout this section provide the required inputs to the baseline ("best-guess") benefit-cost analysis, shown in Section 4, and for the sensitivity analysis found in Section 5.

3.2. Data Sources

This section presents the data sources and the manner in which the national fire statistics (e.g., probability of fire, number of deaths per fire in a residence with only smoke alarms, average direct damages resulting from a fire in a house with only smoke alarms) are used to generate data for analysis in this report (Section 4 presents the findings).

The two main sources of data used are the U.S. Fire Administration's National Fire Incident Reporting System 5.0 (NFIRS 5.0) for the years 2002 through 2005, and statistics derived from the National Fire Protection Association's annual nationwide survey of fire departments. Other data used include the U.S. Census Bureau's American Housing Survey (AHS) and information from ISO and the Insurance Information Institute regarding insurance premium data. The AHS estimates the number of single-family houses in the U.S. for the years 1997, 1999, 2001, 2003, and 2005. Sprinkler system cost data rely on the estimates developed in Brown (2005). All dollars presented in this report are in 2005 adjusted dollars.2

The NFIRS 5.0 data contain incident information of fires occurring within one- and two-family dwellings. We use this data to generate a number of statistics (e.g., civilian fatality rate for houses with only smoke alarms and civilian fatality rate for houses with smoke alarms and a sprinkler system) required for the benefit-cost analysis. Nationwide fire statistics reported by NFPA, based on their annual survey of fire departments, are used to calibrate the NFIRS 5.0 statistics, making the NFIRS 5.0 generated statistics more representative of nationwide patterns

2 Using Bureau of Labor Statistics (BLS) Consumer Price Index (CPI) data, available at bls.gov.

(see 3.1.2.1). We use the number of single-family houses in the U.S., as reported in the AHS, with the yearly NFPA fire incident estimates to estimate the annual probability of

fire incident in
single-family dwellings.

3.2.1. National Fire Incident Reporting System 5.0

Since 1977, the U.S. Fire Administration has been collecting emergency response incident data
from fire departments. Participating local fire departments submit incident data to their State
reporting authority, which reports to the U.S. Fire Administration's National Fire Data Center.
While reporting is voluntary, it has grown over time. In 2005, NFIRS 5.0 contained
89 % of all single-family fire incidents in the U.S. NFIRS 5.0 is the most complete nationwide
fire incident dataset known.
The data contained within NFIRS 5.0 is quite detailed and provides a rich accounting of fire
incidents in the U.S., including information regarding the ignition and structure ignited, reported
casualties, and property losses. NFIRS 5.0 data also contain information regarding the presence
of smoke alarms and sprinkler systems within the structures involved in a fire.
Fire incident statistics, needed in the estimation of the benefits, are compiled over the years 2002
to 2005 (see Table 3-1). The years 2002 to 2005 are chosen given the relative completeness of
nationwide reporting to NFIRS 5.0 during that period.

Table 3-1. Comparison of One- and Two- Family Dwelling Fire Incidents Reported to NFIRS 5.0 with One- and Two-Family Dwelling Fire Incidents Estimated by NFPA from 2002 to 2005.

Year	NFPA Estimate*	NFIRS 5.0 Reported	Percent Reporting
2002	300 500	165 816	55 %
2003	297 000	207 039	70 %
2004	301 500	224 076	74 %
2005	287 000	254 555	89 %

*The U.S. Fire Problem: One- and Two-Family Dwellings Fires (NFPA 2006)

NFIRS 5.0 fire incidents are filtered to analyze structure fires occurring in one- and two-family
dwellings (including mobile and manufactured houses), and those not under construction (see
Table 3-2 for corresponding NFIRS 5.0 classification of incident characteristics used in this
analysis). Further, dwellings with unknown information regarding the fire detector and detector
type are excluded. Dwellings with either heat or sprinkler water flow detectors are also excluded
(as suggested by Hall 2007)—in this analysis, we are interested in comparing the relative safety
performance between houses equipped only with smoke alarms (the most common fire detection
device) with houses with both smoke alarms and a fire sprinkler system.
Three types of one- and two-family dwellings are examined—those with no smoke alarms, those
with only smoke alarms, and those with smoke alarms and a wet-pipe sprinkler system (see
Table 3-3 for corresponding NFIRS 5.0 classification). The multipurpose network sprinkler, the
focus of this benefit-cost analysis, is a wet-pipe system. Because NFIRS 5.0 does not
□
differentiate between wet-pipe systems (i.e., multipurpose network system versus a

stand alone
system), we assume that all wet-pipe systems perform similarly.

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Table 3-2. NFIRS 5.0 Classification of Fire Incident Attributed Used in Analysis.

NFIRS 5.0 Label NFIRS 5.0 Short-name NFIRS 5.0 Code
Version Version 5.0
Property Use Prop_use 419: 1-or 2-family dwelling, detached, manufactured
home, mobile home not in transit, duplex.
Incident Type Inc_type 111: Building fire. Excludes confined fires (113118).
112: Fire in structure, other than in a building.
Included are fires on or in piers, quays, or
pilings: tunnels or underground connecting
structures; bridges, trestles, or overhead elevated
structures; transformers, power or utility vaults
or equipment; fences; and tents.
113: Cooking fire involving the contents of a
cooking vessel without fire extension
beyond the vessel.
114: Chimney or flue fire originating in and
confined to a chimney or flue. Excludes
fires that extend beyond the chimney (111
or 112).
115: Incinerator overload or malfunction, where
flames cause no damage outside the
incinerator.
116: Fuel burner/boiler, delayed ignition or
malfunction, where flames cause no
damage outside the fire box.
117: Commercial compactor fire, confined to
contents of compactor. Excluded are home
trash compactors.
118: Trash or rubbish fire in a structure, with no
flame damage to structure or its contents.
120: Fire in mobile property, other.
121: Fire in mobile home used as a fixed residence.
Includes mobile homes when not in transit and
used as a structure for residential purposes, and
manufactured homes built on a permanent
chassis.
122: Fire in a motor home, camper, or recreational
vehicle when used as a structure. Includes motor
homes when not in transit and used as a
structure for residential purposes.
123: Fire in a portable building, when used at a fixed
location. Includes portable buildings used for
commerce, industry, or education and trailers
used for commercial purposes.
Presence of Detector Detector N: None present
1: Present
Detector Type Det_type 1: Smoke
3: Combination smoke and heat
5: More than one type present
0: Other
Presence of Automatic Extinguishing Aes_pres N: None present

System 1: Present
2: Partial system present*
U: Undetermined

8

□
9
Type of Automatic Extinguishing
System
Aes_type 1: Wet-pipe sprinkler
Building Status Struc_stat 2: Occupied and operating
3: Idle, not routinely used
4: Under major renovation
5: Vacant and secured
6: Vacant and unsecured
7: Being demolished
0: Other
*This option is only available for 2005.
Table 3-3. NFIRS 5.0 Classification of Types of Fire Systems Analyzed.
Fire System NFIRS 5.0 Codes
None Detector Type (Det_type) = N (none present)
Only Smoke Alarm Detector Type (Det_type) = 1 (present)
Presence of Automatic Extinguishing System (Aes_pres) = N (none present)
Smoke Alarm and
Wet-Pipe Sprinkler
System
Detector Type (Det_type) = 1 (present)
Type of Automatic Extinguishing System (Aes_type) = 1 (wet-pipe sprinkler)
3.2.2. National Fire Protection Association
Using the NFIRS 5.0 incident data to generalize statistics for the U.S. may introduce some degree of systematic bias because reporting is voluntary, rather than collected randomly using statistical design. Thus, to create national estimates of fire incident statistics using the NFIRS 5.0 data, we use data collected as part of NFPA's annual survey of fire departments across the country to supplement the NFIRS 5.0 data. The NFPA survey uses a statistical design to randomly sample 3000 fire departments each year (Ahrens 2007), thus ensuring accurate nationwide statistics. From the survey, NFPA provides national estimates of the number of incidents, the number of civilian deaths and injuries, and direct property losses. We use these national estimates to calibrate other statistics derived from NFIRS 5.0 (e.g., statistics on sprinkler use and effectiveness), so to ensure that these statistics are also more representative of national trends and patterns.
3.2.2.1. Calibration and Scaling Ratios
Calibration techniques, as developed in Hall and Harwood (1989), and used by NFPA and USFA, adjust the statistics generated from NFIRS 5.0 through the use of scaling ratios. Scaling ratios are calculated for fire incidents, civilian fatalities, civilian injuries, and direct property

losses for years 2002 through 2005 (see Table 3-4). These scaling ratios allow calibration of the
NFIRS 5.0 data to produce more accurate estimates of sprinkler use and effectiveness for the
U.S.
□
Table 3-4. Scaling Ratios Used to Project Attributes of the 2002 to 2005 NFIRS 5.0 Oneand
Two-Family Dwelling Fire Incidents into National Estimates.

Year	Fire Incident Scaling Ratio	Civilian Fatality Scaling Ratio	Civilian Injury Scaling Ratio	Property Loss Scaling Ratio
2002	8.46 (12.10)	6.48	5.40	8.39
2003	6.07 (8.47)	6.05	3.97	6.28
2004	5.33 (7.34)	4.86	3.98	4.87
2005	4.33 (5.74)	4.78	3.54	4.34

Note: The fire incident scaling ratios in parenthesis were used for property damage calculations only. A different fire
incident scaling ratio was required because property damage estimates were based only on fire incidents with
reported damage estimates.

We apply scaling ratios to the NFIRS 5.0 generated data to produce nationwide estimates of
smoke alarms and sprinkler system use, and related fatalities, injuries, and loss statistics. To
produce needed national estimates, we make the following adjustments:

U.S. Fire Incidents in One-and
Two-Family Dwellings with a
given Fire Detection and
Sprinkler System Status
=
NFIRS 5.0 Reported Fire
Incidents in One-and Two-
Family Dwellings with a given
Fire Detection and Sprinkler
System Status
X
Fire Incident
Scaling Ratio
U.S. Civilian Fatalities in One-
and Two-Family Dwellings
with a given Fire Detection and
Sprinkler System Status
=
NFIRS 5.0 Reported Civilian
Fatalities in One-and Two-
Family Dwellings with a given
Fire Detection and Sprinkler
System Status
X
Civilian Fatality
Scaling Ratio
U.S. Civilian Injuries in One-
and Two-Family Dwellings
with a given Fire Detection and
Sprinkler System Status

=
NFIRS 5.0 Reported Civilian
Injuries in One-and Two-
Family Dwellings with a given
Fire Detection and Sprinkler
System Status
X
Civilian Injury
Scaling Ratio
U.S. Direct Property and
Content Losses in One-and
Two-Family Dwellings with a
given Fire Detection and
Sprinkler System Status
=
NFIRS 5.0 Reported Direct
Property and Content Losses in
One-and Two-Family
Dwellings with a given Fire
Detection and Sprinkler System
Status
X
Property Loss
Scaling Ratio

For instance, NFPA estimated that 287 000 fires occurred in one-and two-family dwellings in
2005 (NFPA 2006), while the NFIRS 5.0 reported 66 292 fires.3 NFIRS 5.0 also reported that

3 Actually NIFRS 5.0 reports 254 555 one-and two-family dwellings (property type = 419) fire incidents in 2005.
The 66 292 estimate reflects additional filtering, as described in Table 3-2.

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□
36 223 houses contained only smoke alarms (no sprinkler system) and that 143 houses contained
smoke alarms and a wet-pipe sprinkler system. To project, into national estimates, the number of
houses with only smoke alarms, and those with smoke alarms and a sprinkler system, we
multiply the NFIRS 5.0 generated numbers by the scaling ratios. The fire incident scaling ratio
(shown in Table 3-4) is calculated by dividing the NFPA estimated number of fire incidents by
the NFIRS 5.0 generated estimate (287 000/66 292 = 4.33). Multiplying the fire incident scaling
ratio (4.33) by the number of NFIRS 5.0 house fires in houses with only smoke alarms (36 223)
produces a national estimate of house fires in houses with only smoke alarms present of
156 846.4 Likewise, multiplying the fire incident scaling ratio (4.33) by the number of NFIRS

5.0 house fires in houses with smoke alarms and a wet-pipe sprinkler system (143) produces a

national estimate of 619 house fires in houses with smoke alarms and a wet-pipe sprinkler system.

3.3. National Fire Statistics

Sprinkler systems have been designed to reduce the numbers of fatalities, injuries, and property damage resulting from structure fires. Thus residents of single-family dwellings (the focus of this study) benefit from the risk reduction of fire induced civilian fatalities, civilian injuries, and property damages (structure and content loss). To determine the expected benefits of sprinkler use, measures of risk reduction must be quantified. We summarize some of the fire statistics required for the analysis below.

3.3.1. Statistics

On average, over the 2002 to 2005 study period, 36 out of 10 000 single-family houses caught fire each year in the U.S. (Table 3-5). This translates into 296 500 house fires each year, resulting in 2566 civilian fatalities and 10 188 civilian injuries (NFPA 2006). Direct property loss, due to property and content destruction, averaged $5346 million each year, which amounted to $18 052 per fire. So for every 10 000 single-family house fires that occurred, 87 civilians died, another 344 were injured, and $180.5 million in property losses was sustained. See Tables 3-5 and 3-6.

Dwellings without smoke alarms experienced 125 171 fires per year, which amounted to 42 % of the total, on average. Civilian fatalities and injuries occurred at an average rate of 95 and 273 people per 10 000 fires, respectively. Per fire direct property loss amounted to another $13 344 in fire-related damages. See Tables 3-5 and 3-6.

Dwellings with only smoke alarms suffered more fires, a higher rate of civilian injuries, and greater property loss, on average, than dwellings without smoke alarms. These differences likely had less to do with smoke alarms, per se, than in underlying differences between dwellings with smoke alarms and those without. On the other hand, dwellings with smoke alarms had a lower average civilian fatality rate than those without (82 fatalities per 10 000 fires compared to 95). See Tables 3-5 and 3-6.

4 Due to rounding, this number differs from the more precise estimate shown in Table 3-6.

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□

Dwellings with smoke alarms and a wet-pipe sprinkler system had on average lower

civilian
fatality and injury rates, and property damage per fire than dwellings with only smoke alarms.
Over the study period, 2002 to 2005, there were no reported civilian fatalities in one-and two-
family dwellings (a 100 % reduction in fatalities from houses without a wet-pipe sprinkler
system). The average rate of civilian injuries was also lower in dwellings with smoke alarms and
wet-pipe sprinklers: 174 injuries per 10 000 fires compared to 403 injuries (a 57 % reduction).
Direct property damages averaged $15 028 per fire, a 32 % reduction over dwellings with only
smoke alarms. However, caution should be made before assuming that reductions in the rate of
civilian fatalities and injuries, and direct property damage are fully attributed to the presence of a
wet-pipe sprinkler system, just as in the case of comparing dwellings without smoke alarms to
dwellings with smoke alarms. Causation can be inferred only if dwellings with only smoke
alarms were similar in other attributes to dwellings with smoke alarms and a wet-pipe sprinkler
system (other than the presence of a wet-pipe sprinkler system). Such a determination is difficult
given the data available, and beyond the scope of this analysis. The reader is only made aware of
this issue, so as to interpret the results appropriately.

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Table 3-5. National Estimates of Fires and Probability of Ignition Occurrence in One-and Two-Family Dwellings.

Fires1	Houses2	Ignition Probability
2002	300 500	81 660 500	0.0037
2003	297 000	82 143 000	0.0036
2004	301 500	83 446 000	0.0036
2005	287 000	84 749 000	0.0034
Mean	296 500	82 999 625	0.0036

1As reported by NFPA (NFPA 2006), for one-and two-family dwellings.
2As reported by U.S. Census Bureau, American Housing Survey (U.S. Census 2007), for single-family structures. Years 2002 and 2004 were linearly
interpolated using 2001 and 2003, and 2003 and 2005 data, respectively.

Table 3-6. National Estimates of One-and Two-Family Dwelling Fires, Civilian Fatality and Injury Rate for 2002 to 2005,
Using NFIRS 5.0/NFPA Adjusted Data, for Dwellings with Different Fire Technology (No Smoke Alarms [none], Only Smoke
Alarms [smoke], and Smoke Alarms and a Wet-Pipe Sprinkler System [sprinkler]).

Fires Civilian Fatality Rate Civilian Injury Rate

All1 None Smoke Sprinkler All None Smoke Sprinkler All None Smoke Sprinkler

2002 300 500 125 770 171 913 381 0.0076 0.0089 0.0067 0.0000 0.0331 0.0284 0.0367 0.0284
2003 297 000 126 029 166 492 546 0.0092 0.0106 0.0084 0.0000 0.0337 0.0262 0.0397 0.0146
2004 301 500 125 423 166 754 415 0.0089 0.0090 0.0090 0.0000 0.0348 0.0270 0.0414 0.0096
2005 287 000 123 460 156 821 619 0.0090 0.0095 0.0087 0.0000 0.0359 0.0276 0.0434 0.0172
Mean 296 500 125 171 165 495 490 0.0087 0.0095 0.0082 0.0000 0.0344 0.0273 0.0403 0.0174

1As reported by NFPA (NFPA 2006).

Table 3-7. National Direct Property Loss Estimates Resulting From One-and Two-Family Dwelling Fires for 2002 to 2005,
Using NFIRS 5.0/NFPA Adjusted Data, for Dwellings with Different Fire Technology (No Smoke Alarms [none], Only Smoke
Alarms [smoke], and Smoke Alarms and a Wet-Pipe Sprinkler System [sprinkler]).

Total Direct Property Loss1 Direct Property Loss Per Fire ($)
($ million) All None Smoke Sprinkler

2002 5455 18 155 14 241 20 939 25 716
2003 5051 17 007 12 716 22 044 1672
2004 5096 16 904 11 491 20 774 17 304
2005 5781 20 143 14 928 24 202 15 419
Mean 5346 18 052 13 344 21 990 15 028
1Reported by NFPA (NFPA 2006) and adjusted to 2005 $.

□
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3.4. Value of Fatality and Injury Averted
Assigning a dollar value to a statistical life or injury averted has become a generally accepted
part of economic methodology. The magnitude of the values are often a critical input to
economic analysis because a reduction of the risk of death or injury may be a substantial benefit
component. However, empirical estimates of the value of life continue to be subject to
controversy and inconsistency. For example, basing the value of a life on the present value of
earnings potential—a measure that is sometimes used—tends to result in comparatively low
values for the young and the old and, in our present economy, for women and non-Caucasians.
Using court-assigned values for death, pain, and injury inflicted—another approach—results in
widely variable amounts. The value of saving lives and reducing pain and injury implicitly
assigned by other government programs also vary widely among programs and projects.5

3.4.1. Value of a Statistical Life
One approach that is considered to be consistent with economic theory, and which was used in a

1984 sprinkler study performed by NBS (Ruegg and Fuller 1984), is based on the willingness-topay
concept. Willingness-to-pay values are computed according to how much decision makers
are willing to invest to reduce their risk of death or injury by a certain fraction. Using evidence
on labor and product market choices that involve implicit tradeoffs between risk and wage or
between risk and price, economists have developed estimates of the value of a statistical life
(VSL) typically ranging from $4 million to $9 million with a median value of about $7 million
(in 2000 dollars) (Viscusi and Aldy 2003). The inflation adjusted median value of a statistical
life, $7.94 million (in 2005 dollars), is used in this report.6

3.4.2. Value of Injury Averted

The same willingness-to-pay approach that is used to estimate the value of a statistical life saved
can be used to estimate the value of an injury averted. In a survey of 31 studies from the U.S.
labor market and eight studies of labor markets outside the United States, Viscusi and Aldy
(2003) found estimates ranging up to $191 000 with most of the estimates between $20 000 and
$70 000 (in 2000 dollars). The U.S. estimates are mostly based on job-related injury rates and
lost workday rates from the Bureau of Labor Statistics and not specifically on fire-related
injuries. The U.S. Consumer Product Safety Commission (CPSC) recently conducted two studies
of residential fire injuries associated with mattresses and upholstered furniture. These two studies
found estimates of $150 000 (in 2005 dollars) per injury from fires involving mattresses and
$187 000 (in 2004 dollars) per injury from fires involving upholstered furniture (Zamula 2005).
CPSC therefore recommended the amounts of $150 000 and $187 000 as reasonable and reliable

5 For a discussion of approaches to measuring the value of deaths and injuries averted, and deficiencies in these
approaches, see E. J. Mishan, "Evaluation of Life and Limb: A Theoretical Approach," Journal of Political
Economy, July-August 1971, pp. 687-705; or M. W. Jones-Lee, The Value of Life: An Economic Analysis (Chicago,
IL: University of Chicago Press, 1976).

6 This report provides background on recent research on the value of life, without suggesting that it is the only, or
most appropriate value.

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estimates of the value of a fire-related injury averted (Zamula 2004; Zamula 2005; Ray et al.
1993). As the value of an injury averted, the inflation adjusted middle value between CPSC
studies on mattresses and upholstered furniture is used in this report, $171 620.

3.5. Costs of a Residential Multipurpose Network Sprinkler System

The cost information draws on material developed in a previous NIST report by Brown (2005),
Economic Analysis of Residential Fire Sprinkler Systems, NISTIR 7277. Brown (2005)

focused
on the estimated costs to the homeowner of installing a sprinkler system. The system selected
for this study is multipurpose network into the existing cold-water plumbing system. It is chosen
because of its lowest life-cycle cost compared to other systems.
The cost estimations in this section are based largely on Brown's (2005) analysis, where designs
and costs were provided by experts in sprinkler system design and installation. Each expert
itemized the components necessary for his or her installation and provided bare material costs.
Design costs were estimated in either dollar terms or in hours. The installation cost was
estimated from the labor hours necessary to install the sprinkler systems.
The experts who provided these tables were asked to identify all items that should be included in
a system that meets NFPA 13D. Costs specifically excluded were: service entrance materials
from the water main to the distribution manifold, domestic hot and cold water plumbing system
piping and material, final connections to plumbing fixtures, and hose bibs.
Certain situations require additional costs. For example a small number of jurisdictions might
require a separate water system to the curb, perhaps even including a water meter. Rural
developments might be unable to meet requirements without installing a tank, pump, and backup
electric generator. While these situations could arise, they were not considered typical and
therefore costs related to these scenarios were not estimated.
The level of protection was based on the minimum standard required by NFPA 13D. Some

bathrooms and closets, for example, are not required to be covered. Experts used different types
of pipe layouts and sprinkler heads to achieve the NFPA standard. Therefore, there was
variation over the scenarios in the number of sprinkler heads and the length and type of pipe
required.
To the extent that extraneous costs—costs for items not required by NFPA 13D—were
identified, they were removed from analysis. For example, this report removes the cost of extra
sprinkler heads and cabinet exceeding the minimum requirements of NFPA 13D from the
original estimates made by Brown (2005).
Brown (2005) researched the expected life of each sprinkler systems' components. Replacement
costs would only be incurred when major system components wear out. The entire system will
generally last the life of the plumbing system, estimated to be in excess of 30 years, the length of
the study period for this analysis. Therefore, no system replacement costs are included.
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The following tables (3-8, 3-9, 3-10) present the required materials, labor, and costs of the
multipurpose network system when installed in three house scenarios: a 3338 ft2 (310 m2) two-
story colonial with basement, a 2257 ft2 (210 m2) three-story townhouse, and a 1171

ft2 (109 m2)
single-story ranch.7 Each table itemizes the material and labor costs for a single cost estimation.

The Material category includes the subcategories of Fire Sprinklers, Pipe and Fittings, and
Accessories. Labor includes Design and Installation Labor. The total Material and Labor cost
estimate is shown at the bottom right of the table.

Tables 3-8, 3-9, and 3-10 detail the estimated cost of installing the multipurpose network system
using crosslinked polyethylene (PEX) in a colonial house, townhouse and ranch house. This
system was designed using a 65 lbf/in2 (448 kPa) static water supply, but is valid to as low as
45 lbf/in2 (310 kPa). The multipurpose network layout is installed as a system and includes the
cold-water piping for the houses. Therefore, a correction has been applied to remove the costs
related to the domestic cold water system. Without a backflow preventer, all major maintenance
and inspection requirements can be performed by a homeowner. Because the candidate least-
costly system, as identified by Brown (2005) had no backflow preventer, we regarded this a
reasonable assumption. Because inspection can be accomplished by the homeowner, it is not
included in the cost estimate.

7 The colonial square footage does not include the garage.

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Table 3-8. Cost Summary: Multipurpose Network System Using PEX for a New 3338 ft2 (310 m2) Single Family Colonial
House.
Sprinkler System
Cost Component Quantity Units
Bare material
Cost Per Unit
Total Bare
Material Cost Labor Cost
Combined Material
& Labor Cost
Material
Fire Sprinklers
F1/Res 49 (155 °F) (68.3 °C) Recessed Pendent
Assembly, White
24 each $25.03
$600.60
Pipe and Fittings
½ in (12.7 mm) PEX - white, 1000 ft (304.8 m) coil 1 1000 ft. 270.00 270.00
½ in (12.7 mm) PEX - white, 300 ft (91.44 m) coil 1 300 ft. 81.00 81.00
1 in (25.4 mm) Copper Branch Manifold, 10 outlets 1 each 26.63 26.63
PEX Ring ½ in (12.7 mm) (blue print) 150 each 0.06 8.25

PEX Brass Tee, ½ in (12.7 mm) PEX x ½ in (12.7 mm)
PEX
10 each 1.45
14.50
Accessories
Hangers (½ in [12.7 mm], 5/8 in [15.875 mm], ¾ in
[19.05 mm] PEX)
4 each 5.95
23.80
Total Bare Material Cost 1024.78
Labor
Design Cost (4 h at $40.00/h) $160.00
Labor Cost (13 h at $50.31/h) 654.03
Total Labor Cost 814.03
Totals
Total Material and Labor Cost $1838.81
Total Material and Labor Cost without cold water system (117.00) (100.62)
1621.19
Where possible, generic product descriptions have been substituted for product trade names. Material prices do not include any markup to cover overhead and profit. Labor cost is
based on manufacturer's estimation that it would take a 2 person crew 13 h total to install the system. The sprinkler fitter and plumber trades are estimated at $50.31/h (2007
National Construction Estimator, accessed at www.get-a-quote.net). Design cost of $40/h is provided by manufacturer. Extra sprinkler heads and cabinet exceeding the minimum
requirements of NFPA 13D were removed from original estimate. For the estimate without the cold water system, one-third of the combined pipe and 2 h of installation labor are
subtracted.
Source: This table is based on NISTIR 7277, Economic Analysis of Residential Fire Sprinkler Systems (Brown 2005, page 11); however, the labor cost has been changed to $50.31.
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Table 3-9. Cost Summary: Multipurpose Network System Using PEX for a New 2257 ft2 (210 m2) Single Family Townhouse.
Sprinkler System
Cost Component Quantity Units
Bare Material
Cost Per Unit
Total Bare
Material Cost Labor Cost
Combined Material
& Labor Cost
Material
Fire Sprinklers
F1/Res 49 (155 °F) (68.3 °C) Recessed Pendent
Assembly, White
22 each
$25.03 $550.55
Pipe and Fittings
½ in (12.7 mm) PEX - white, 1000 ft (304.8 m) coil 1 1000 ft. 270.00 270.00
½ in (12.7 mm) PEX - white, 100 ft (30.48 m) coil 1 100 ft. 27.00 27.00
1 in (25.4 mm) Copper Branch Manifold, 12 outlets 1 each 32.23 32.23
PEX Ring ½ in (12.7 mm) (blue print) 150 each 0.06 8.25
PEX Brass Tees, ½ in (12.7 mm) PEX x ½ in (12.7 mm)
PEX

10 each
1.45 14.50
Accessories
Hangers (½ in [12.7 mm], 5/8 in [15.875 mm], ¾ in
[19.05 mm] PEX)
3 each
5.95 17.85
Total Bare Material Cost 920.38
Labor
Design Cost (4 h at $40.00/h) $160.00
Labor Cost (12 h at $50.31/h) 603.72
Total Labor Cost 763.72
Totals
Total Material and Labor Cost $1684.10
Total Material and Labor Cost without cold water system (99.00) (100.62) 1484.48

Where possible, generic product descriptions have been substituted for product trade names. Material prices do not include any markup to cover overhead and profit. Labor cost is
based on manufacturer's estimation that it would take a 2 person crew 12 h total to install the system. The sprinkler fitter and plumber trades are estimated at $50.31/h (2007
National Construction Estimator, accessed at www.get-a-quote.net). Design cost of $40/h is provided by manufacturer. Extra sprinkler heads and cabinet exceeding the minimum
requirements of NFPA 13D were removed from original estimate. For the estimates without the cold water system, one-third of the combined pipe and 2 h of installation labor are
subtracted.
Source: This table is based on NISTIR 7277, Economic Analysis of Residential Fire Sprinkler Systems (Brown 2005, page 12); however, the labor cost has been changed to $50.31.
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Table 3-10. Cost Summary: Multipurpose Network System Using PEX for a New 1171 ft2 (109 m2) Single Family Ranch
House.
Sprinkler System
Cost Component Quantity Units
Bare Material
Cost Per Unit
Total Bare
Material Cost
Labor
Cost
Combined Material
& Labor Cost
Material
Fire Sprinklers
F1/Res 49 (155 °F) (68.3 °C) Recessed Pendent
Assembly, White
9 each $25.03
$225.23
Pipe and Fittings
½ in (12.7 mm) PEX plus - white, 300 ft (91.44 m) coil 1 300 ft. 81.00 81.00
½ in (12.7 mm) PEX plus - white, 100 ft (3.048 m) coil 1 100 ft. 27.00 27.00
1 in (25.4 mm) Copper Branch Manifold, 8 outlets 1 each 21.98 21.98
PEX Ring ½ in (12.7 mm) (blue print) 100 each 0.06 5.50
PEX Brass Tees, ½ in (12.7 mm) PEX x ½ in (12.7 mm)

PEX
10 each 1.45
14.50
Accessories
Hangers (½ in [12.7 mm], 5/8 in [15.875 mm], ¾ in
[19.05 mm] PEX)
1 each 5.95
5.95
Total Bare Material Cost 381.16
Labor
Design Cost (4 h at $40.00/h) $160.00
Labor Cost (5 h at $50.31/h) 251.55
Total Labor Cost 411.55
Totals
Total Material and Labor Cost $792.71
Total Material and Labor Cost w/o cold water system (36.00) (100.62) 656.09
Where possible, generic product descriptions have been substituted for product trade names. Material prices do not include any markup to cover overhead and profit. Labor cost is
based on manufacturer's estimation that it would take a 2 person crew 12 h total to install the system. The sprinkler fitter and plumber trades are estimated at $50.31/h (2007
National Construction Estimator, accessed at www.get-a-quote.net). Design cost of $40/h is provided by manufacturer. Extra sprinkler heads and cabinet exceeding the minimum
requirements of NFPA 13D were removed from original estimate. For the estimates without the cold water system, one-third of the combined pipe and 2 h of installation labor are
subtracted.
Source: This table is based on NISTIR 7277, Economic Analysis of Residential Fire Sprinkler Systems (Brown 2005, page 13); however, the labor cost has been changed to $50.31.
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4. Baseline Benefit-Cost Analysis of Multipurpose Network
Sprinkler Systems in Residential Dwellings
4.1. Introduction
This section applies the data reported in Section 3, using the benefit-cost framework discussed in
Section 2, to estimate the present value of net benefits of installation of a multipurpose network
sprinkler system in a residential dwelling. The benefits estimated in this analysis include: (1)
reduced risk of civilian fatalities; (2) reduced risk of civilian injuries; (3) reduced expectation of
uninsured direct property loss; (4) reduced expectation of uninsured indirect costs; and (5)
reduced homeowner insurance premiums. The costs used in this analysis include the installation
cost of the multipurpose network sprinkler system and are based on Brown's (2005) estimates.
Results are presented as the present value of net benefits (PVNB) of installing residential fire
sprinkler systems and are summarized in Table 4-4.
The uniform present worth factor of 15.729 (see Appendix A for formula) for annually

recurring
amounts is based on a 30-year study period and a real discount rate of 4.8 %, which reflects the
real, after-tax annual rate of return on large-cap stocks over the period 1925 to 2005 (Ibbotson
2005).
In the cases for fatalities, injuries, and property losses, no difference in benefits is estimated for
the occupant and the owner of a rental unit. This is because it is assumed that the owner of a
rental unit will receive benefits equivalent in amount to those of the occupant through a rent
premium that reflects the tenant's benefit of reduced risk of indirect costs.

4.2. Estimated Benefits of Multipurpose Network Sprinkler Systems in Residential Dwellings

Table 4-1 summarizes the data used to calculate the present value benefits for the five classes of
benefits described in Sections 4.2.1 through 4.2.5. It includes benefits from fatalities averted,
injuries averted, direct property losses averted, indirect costs averted, and an insurance credit due
to sprinkler use within residential properties. Appendix A discusses how the calculations are
made and are based on the statistics reported in Section 3. Installation of a sprinkler system is
expected to yield a present value benefit of $4994, over the 30-year study period. Each benefit
component is detailed below.

4.2.1. Fatalities Averted

One- and two-family dwellings with a wet-pipe sprinkler system were found to have zero
reported fatalities over the study period 2002 to 2005. However, field tests indicate sprinklers
fail to activate 3 % of the time (Hall 2007), so a 100 % reduction in fatalities, over dwellings
with only smoke alarms, may be too optimistic. Section 5 deals with this uncertainty and its
effects on the results. As discussed in the previous section, the value of a fatality averted is
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estimated at $7.94 million. Thus, a 100 % reduction in fatality rate results in an expected present
value benefit of $3726 per dwelling fire.

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Table 4-1. Calculation of Present Value Benefits of Wet-Pipe Sprinkler Systems.

Input Parameters Calculated Outputs

Fatalities Averted
Probability of Fire
Occurrence
0.0036

Reduction in Annual Probability of Fatality,
Given Fire, Between Dwelling with Only
Smoke Alarms and Dwelling with Smoke
Alarms and a Sprinkler System
1.0000
Expected Number of
Fatalities, Per Fire, in
Dwellings with Only
Smoke Alarms
0.0082
Value of Statistical
Life ($ million)
7.94
Annual Benefit ($)
236.86
Present Value
Benefit ($)
3725.57
Injuries Averted
Probability of Fire
Occurrence
0.0036
Reduction in Annual Probability of Injury,
Given Fire, Between Dwelling with Only
Smoke Alarms and Dwelling with Smoke
Alarms and a Sprinkler System
0.5679
Expected Number of
Injuries, Per Fire, in
Dwellings with Only
Smoke Alarms
0.0403
Value of Statistical
Injury ($)
171 620
Annual Benefit ($)
14.29
Present Value
Benefit ($)
224.74
Direct Property Losses
Averted
Probability of Fire
Occurrence
0.0036
Reduction in Annual Probability of Direct
Uninsured Property Loss, Given Fire,
Between Dwelling with Only Smoke Alarms
and Dwelling with Smoke Alarms and a
Sprinkler System
0.3166
Expected Direct Uninsured
Property Loss, Per Fire, in
Dwellings with Only
Smoke Alarms
4397.96
Annual Benefit ($)
5.06
Present Value

Benefit ($)
79.64
Indirect Costs Averted
Probability of Fire
Occurrence
0.0036
Reduction in Annual Probability of Indirect
Cost, Given Fire, Between Dwelling with
Only Smoke Alarms and Dwelling with
Smoke Alarms and a Sprinkler System
0.3166
Expected Indirect Cost, Per
Fire, in Dwellings with
Only Smoke Alarms
879.59
Annual Benefit ($)
1.01
Present Value
Benefit ($)
15.93
Insurance Credit
Annual Homeowner
Insurance Premium ($)
753.70
Reduction in Annual Homeowner Insurance
Premium for Sprinkler System
0.08
Annual Benefit ($)
60.30
Present Value
Benefit ($)
948.41
Total Present
Value
$317.52 $4994.29

Note: Annual benefits are expressed in constant 2005 dollars. Present value benefits are based on a 30-year study period. Input parameters shown are rounded.

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4.2.2. Injuries Averted

One-and two-family dwellings with a wet-pipe sprinkler system were found to have a 57 % reduction in injuries over dwellings equipped with only smoke alarms. As discussed in the previous section, the value of an injury averted was estimated at $171 620. The 57 % reduction in the injury rate results in an expected present value benefit of $225.

4.2.3. Direct Uninsured Property Loss Averted

One-and two-family dwellings with a wet-pipe sprinkler system were found to have a 32 % reduction in direct property damages over dwellings equipped with only smoke alarms. The average direct property loss was found to be $21 990 per fire for dwellings only equipped with smoke alarms. Because insurance is assumed to cover 80 % of any property loss (Ruegg and Fuller 1984), the uninsured direct property loss, responsible to the owner, was then

$4398 per fire. Thus the reduction in uninsured direct property damages yields a present value benefit of $80 to residents in dwellings with smoke alarms and a sprinkler system.

4.2.4. Indirect Uninsured Costs Averted

Indirect costs in one-and two-family dwellings refers to costs such as temporary shelter, missed work, extra food costs, legal expenses, transportation, emotional counseling, and child care. Indirect losses have been systematically analyzed for house fires in a study by Munson and Ohls (1980). A review of this study leads the NFPA to use 10 % of the direct property loss as an estimate of the indirect property loss (Hall 2004). The average direct property loss per fire was found to be $21 990, meaning the estimated indirect cost per fire is $2199 for dwellings only equipped with smoke alarms. Part of the indirect loss of fires is covered by insurance. Munson and Ohls (1980) estimated that on average 60 % of indirect costs per fire are insured. Thus, the average uninsured indirect costs per fire were estimated at $880. Given that one-and two-family dwellings with wet-pipe sprinkler system were found to have a 32 % reduction in direct property damages over the study period 2002 to 2005, a reduction in indirect costs results in a present value benefit of $16.

4.2.5. Insurance Premium Credit

The U.S. average insurance premium is estimated to be $7548 and sprinklers in residential dwellings are expected to receive an 8 % reduction in the annual premium (Curry 2007). The credit results in an expected present benefit of $949.

8 The Insurance Information Institute (2007) states that the average yearly homeowner insurance premium, as estimated by the National Association of Insurance Commissioners, was $729 in 2004.

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4.3. Estimated Costs of Multipurpose Network Sprinkler Systems in Residential Dwellings

The purchase and installation cost estimates were discussed in Section 3. Table 4-2 presents the installation cost estimates with material mark-up applied, where material markup increases incrementally from 50 % to 100% (increments of 10 %). The installation cost estimates range from $2075 to $2529 for the colonial, $1895 to $2306 for the townhouse, and $829 to $1001 for the ranch. We use the 50 % markup in the benefit-cost analysis, as we contend this to be the most reasonable.

Table 4-2. Cost Estimate Summary Table.

Material Markup ($)	50 %	60 %	70 %	80 %	90 %	100%
Colonial	2075.08	2165.86	2256.64	2347.41	2438.19	2528.97
Townhouse	1895.17	1977.31	2059.45	2141.58	2223.72	2305.86
Ranch	828.66	863.18	897.69	932.21	966.72	1001.24

Source: This table is based on data in NISTIR 7277, Economic Analysis of Residential Fire Sprinkler Systems (Brown 2005, pages 11-13).

4.3.1. Installation Cost Comparison

In 1984, Ruegg and Fuller estimated the benefits and costs of installing fire sprinkler systems in residential homes. In that report, two purchase and installation costs were estimated. The low cost estimate was $0.50 / ft2 ($5.38 / m2), and the high cost estimate was $0.80 / ft2 ($8.61 / m2) in 1982 dollars.9 These two estimates translate to $1.01 / ft2 ($10.87 / m2) and $1.62 / ft2 ($17.43 / m2) in 2005 prices. Table 4-3 shows that the fire sprinkler system designed in the 1984 report costs, in 2005 prices, were substantially more than the multipurpose network sprinkler system used here, even with a 100 % material markup (the exception being the townhouse at the 100 % markup).

Table 4-3. 1982 Fire Sprinkler System Purchase and Installation Cost (2005 $)

	Purchase and Installation Cost Estimate ($) Low	High
	($1.01 / ft2; $10.87 / m2)	($1.62 / ft2; $17.43 / m2)
Colonial	3371.38	5407.56
Townhouse	2279.57	3656.34
Ranch	1182.71	1897.02

9 This is purchase and installation cost only; Ruegg and Fuller (1984) also estimated additional costs attributable to operating, maintenance, repair and replacement costs. The reduction or elimination of those additional costs in a modern multipurpose network fire sprinkler system, in addition to the reduced up-front purchase and installation cost, illustrates the significant cost reductions achieved in fire sprinkler systems over the past two decades.

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The analysis presented in this report, when compared to those in Ruegg and Fuller (1984), suggests that fire sprinkler systems have become much more affordable over the past two decades. Should this trend continue, future developments in fire sprinkler technology and installation techniques would continue to reduce the costs of fire sprinkler systems, and improve

their cost-effectiveness.

4.4. Benefit-Cost Comparison
The benefits and costs accruing to homeowners and residents in one-and two-family dwellings
from the addition of a multipurpose network sprinkler system in new housing construction are
summarized in Table 4-4.10 The results indicate that a multipurpose network sprinkler system to
be quite economical (benefits outweigh the costs). The baseline analysis yields a present value
of net benefits of $2919 for the colonial, $3099 for the townhouse, and $4166 for the ranch
house assuming a 50 % materials markup for each house type.

Table 4-4. Summary of Baseline Benefit-Cost Analysis of a Multipurpose Network Residential Sprinkler System.

	Colonial	Townhouse	Ranch
Benefits			
Fatalities Averted	$3725.57	$3725.57	$3725.57
Injuries Averted	224.74	224.74	224.74
Direct Uninsured Property Losses Averted	79.64	79.64	79.64
Indirect Costs Averted	15.93	15.93	15.93
Insurance Credit	948.41	948.41	948.41
Benefit Subtotal	4994.29	4994.29	4994.29
Costs			
Installation (50 % Markup)	2075.08	1895.17	828.66
Costs Subtotal	2075.08	1895.17	828.66
Net Present Value	$2919.20	$3099.11	$4165.62

4.4.1. Benefit-Cost Analysis of a Multipurpose Network Residential Sprinkler System Installed in the Colonial
The baseline net present value of installing a multipurpose network sprinkler system into the
colonial house is $2919 (50 % material markup), implying that present value benefits of a

10 Although NFIRS 5.0 contains fire incident data on one-and two-family dwellings (property use 419) as well as
multifamily dwellings, including condos, townhouses, and apartments (property use 429), the NFIRS 5.0 statistics
for townhouses are based on the one-and two-family dwelling fire incident data. It is difficult to separate
townhouses from apartments in the property use 429 category, and it assumed that fire risks are different for
apartments than single-family houses, which townhouses are ordinarily considered.

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sprinkler system outweigh the installation costs. Even at a 100 % material markup, the sprinkler
system still yields positive present value net benefits of $2465.

4.4.2. Benefit-Cost Analysis of a Multipurpose Network Residential Sprinkler System Installed in the Townhouse
The baseline net present value of installing a multipurpose network sprinkler system

into the
townhouse is $3099 (50 % material markup), implying that present value benefits of a sprinkler
system outweigh the installation costs. Even at a 100 % material markup, the sprinkler system
still yields positive present value net benefits of $2688.

4.4.3. Benefit-Cost Analysis of a Multipurpose Network Residential Sprinkler System Installed in the Ranch
The baseline net present value of installing a multipurpose network sprinkler system into the
ranch house is $4166 (50 % material markup), implying that present value benefits of a sprinkler
system outweigh the installation costs. Even at a 100 % material markup, the sprinkler system
still yields positive present value net benefits of $3993.

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5. Sensitivity Analysis of the Baseline Benefit-Cost Analysis of
Multipurpose Network Sprinkler Systems in Residential Dwellings
5.1. Introduction
The baseline analysis provides point estimates of the present value of net benefits of the
multipurpose network sprinkler system installed within new construction in a colonial,
townhouse, and ranch setting. A sensitivity analysis is performed to examine the influence
assumptions and input statistics, generated from the NFIRS 5.0, have on the PVNB results.
Conducting a sensitivity analysis is important because the statistics used to summarize
characteristics of dwellings with wet-pipe sprinklers are drawn from a small segment of the
population. Over the 2002 to 2005 study period of the one- and two-family dwellings examined,
houses with wet-pipe sprinkler systems accounted for 0.2 % of all structure fires. Houses only
equipped with smoke alarms accounted for 56 %.
The sensitivity analysis examines the influence the assumptions have on the benefit-cost results.
In the sensitivity analysis, statistics used in the analysis, such as the probability of fire
occurrence, are varied randomly over a range of values, based on their assumed distribution.
Random draws are conducted using Latin Hypercube sampling. The software Crystal Ball 7.3
(see Crystal Ball 2007 for details) is used to conduct the sensitivity analysis. While Monte Carlo
sampling achieves more randomness, Latin Hypercube sampling achieves more precise estimates
because Latin Hypercube sampling ensures that the tails of the distribution will be

accurately
represented (Crystal Ball 2007).

5.2. Simulated Distributions

The values (assumptions) generated from the NFIRS 5.0 and NFPA data used in estimating the
benefits are varied using a Latin Hypercube sampling approach. The values (assumptions)
varied in the sensitivity analysis are the input parameters presented in Table 4-1, with the
exception of the value of a statistical life, value of a statistical injury, and the insurance credit.
Table 5-1 describes the simulated distributions used, along with the parameters of the
distributions derived from NFIRS 5.0 2002-2005 fire incident records and calibrated using
NFPA (2006) fire statistics (see Section 3), unless otherwise noted in Table 5-1. Some of the
parameters used were suggested by fire statistics experts at NFPA (Hall 2007) that meshed with
historical observations, while others were motivated by the Scottsdale, AZ sprinkler study.11
11 The Prince George's County, MD (Siarnicki 2001) sprinkler study was also considered, although the values
derived from the Scottsdale, AZ sprinkler study were relatively similar.
□
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Table 5-1. Description of the Simulated Distributions Used in the Sensitivity Analysis.

Assumption Distribution Parameters Notes
Probability of Fire Occurrence
Normal
Mean: 0.0036
Standard Deviation: 0.0001
Reduction in Probability of Fatality, Given Fire, Between Dwellings with Only Smoke Alarms and Dwellings with Smoke Alarms and a Sprinkler System
Triangular
Minimum: 0.6700
Most Likely: 1.0000
Maximum: 1.0000
Minimum per Hall (2007).
Expected Number of Fatalities, Per Fire, in Dwellings with Only Smoke Alarms
Normal
Mean: 0.0082
Standard Deviation: 0.0010
Reduction in Probability of Injury, Given Fire, Between Dwellings with Only Smoke Alarms and Dwellings with Smoke Alarms and a Sprinkler System
Triangular
Minimum: 0.0000
Most Likely: 0.5679
Maximum: 0.5679
Minimum per Hall (2007).
Expected Number of Injuries, Per Fire, in Dwellings with Only Smoke Alarms
Normal
Mean: 0.0403
Standard Deviation: 0.0029

Reduction in Probability of Direct Uninsured Property Loss, Given Fire, Between Dwellings with Only Smoke Alarms and Dwellings with Smoke Alarms and a Sprinkler System1
Triangular
Minimum: 0.0000
Most Likely: 0.3166
Maximum: 0.9520
Minimum per authors' judgment.
Maximum based on Scottsdale, AZ study.2
Expected Direct Uninsured Property Loss, Per Fire, in Dwellings with Only Smoke Alarms
Triangular
Minimum: $0
Most Likely: $4397.96
Maximum: $9003.80
Minimum per Hall (2007). Maximum based on Scottsdale, AZ study.3
Expected Indirect Cost, Per Fire, in Dwellings with Only Smoke Alarms
Triangular
Minimum: $0
Most Likely: $879.59
Maximum: $1800.76
Minimum per Hall (2007). Maximum based on Scottsdale, AZ study.4
Parameters derived using NFIRS 5.0 2002-2005 fire incident records and calibrated using NFPA (2006) fire statistics unless otherwise noted.
1Assumed equal to reduction in probability of indirect cost, given fire, between dwellings with smoke alarms and dwellings with smoke alarms and a sprinkler system.
2The study reports a $45 019 direct property loss in houses without sprinkler systems (although the presence of smoke alarms was not specified) and $2166 for those with, implying a 95.2 % reduction in direct property loss.
3See note 2 above. Assuming insurance covers 80 % of direct property losses, $9003.80 is uninsured.
4See note 2 above. Assuming indirect costs equal 10 % of direct property loss, with insurance covering 60 %, $1800.76 is uninsured.
□

5.3. Results of Sensitivity Analysis

The sensitivity analysis confirms the conclusions of the baseline analysis, namely that multipurpose network residential sprinkler systems are likely to be cost-effective in the single-family houses studied. Results of the sensitivity analysis can be seen in Table 5-2 and in Figures 5-1, 5-2, and 5-3. Table 5-2 summarizes the statistics generated from the sensitivity analysis. Figures 5-1 through 5-3 were constructed by sorting the observed simulation value from smallest to largest.

Table 5-2. Summary Statistics of the Sensitivity Analysis.

Colonial Townhouse Ranch
Trials 10 000 10 000 10 000
Mean $2467.96 $2647.87 $3714.38
Median 2454.96 2634.87 3701.38
Minimum 703.67 883.58 1950.08

Maximum 4801.20 4981.11 6047.62
Standard Deviation 530.03 530.03 530.03
Mean Standard Error 5.30 5.30 5.30

For the colonial house, the mean net present value is positive, at $2468, although 15 % lower than the baseline estimate of $2919. Figure 5-1 graphs the cumulative distribution function (CDF) generated from the simulation. The vertical axis measures the probability that the associated net present value, measured on the horizontal axis, is equal to or less than the specified value. The vertical axis measures the cumulative probability and the horizontal axis measures the range of possible net present values resulting from a multipurpose network sprinkler system installed in a colonial house. For instance, there exists about a 0.80 probability that the actual net present value from installation of a sprinkler system is equal to or less than the baseline net present value of $2919 (i.e., 80 % of the observed simulation values are less than or equal to $2919). Further, based on the sensitivity analysis, there is a probability of 1.0 that the actual net present value is less than or equal to the maximum, $4801. However, there is a probability of 0.0 that the present net value is less than or equal to $703, which is of course still a positive present value net benefit. Thus, in every case examined, multipurpose network sprinklers are cost-effective.

For the townhouse, the mean net present value is positive, at $2648, although 15 % lower than the baseline estimate. Figure 5-2 graphs the CDF generated from the simulation. The vertical axis measures the cumulative probability and the horizontal axis measures the range of possible net present values resulting from a multipurpose network sprinkler system installed in a townhouse. Figure 5-2 shows that there exists about a 0.80 probability that the actual net present value from installation of a sprinkler system is equal to or less than the baseline net present value of $3099. Further, based on the sensitivity analysis, there is a probability of 1.0 that the actual net present value is less than or equal to the maximum, $4981. However, there is a probability of

0.0 that the present net value is less than or equal to $884.
31

□
For the ranch house, the mean net present value is positive, at $3714, although 11 % lower than the baseline estimate. Figure 5-3 graphs the CDF generated from the simulation. The vertical axis measures the cumulative probability and the horizontal axis measures the range

of possible
net present values resulting from a multipurpose network sprinkler system installed in a ranch
house. Figure 5-3 shows that there exists about a 0.80 probability that the actual net present
value from installation of a sprinkler system is equal to or less than the baseline net present value
of $4166. Further, based on the sensitivity analysis, there is a probability of 1.0 that the actual
net present value is less than or equal to the maximum, $6048. However, there is a probability of

0.0 that the present net value is less than or equal to $1950.
32

□
Figure 5-1. The Cumulative Distribution Function Resulting From Latin Hypercube Sampling of Inputs in the Present Value of Net Benefits Calculation for the Colonial House.

Figure 5-2. The Cumulative Distribution Function Resulting From Latin Hypercube Sampling of Inputs in the Present Value of Net Benefits Calculation for the Townhouse.

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□
Figure 5-3. The Cumulative Distribution Function Resulting From Latin Hypercube Sampling of Inputs in the Present Value of Net Benefits Calculation for the Ranch House.

Of the eight variables on which assumptions are made, three of those variables are clearly more
influential than the other five. They are the expected number of fatalities, per fire, in dwellings
with only smoke alarms; the reduction in annual probability of fatality, given fire, between
dwellings with only smoke alarms and dwellings with smoke alarms and a sprinkler system; and
the probability of fire occurrence. The eight variables are listed in order of importance on the net
present value in Table 5-3. It also presents the contribution to variance and rank correlation of
the assumptions to the net present value calculation. The larger these measures, the larger is the
influence the associated assumption has on the net present calculation. Thus, changes in the
expected number of fatalities, per fire, in dwellings with only smoke alarms has the greatest
exhibited influence on the magnitude of the net present value of the installation of a
multipurpose network residential sprinkler system (contribution to variance of 62.7 % and a rank
correlation of 0.76).

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□
Table 5-3. Contribution to Variance and Rank Correlation of the Assumptions to the Net
Present Value Calculation.

Assumption Contribution to Rank
Variance (%) Correlation

Expected Number of Fatalities, Per Fire, in Dwellings with 62.7 0.76
only Smoke Alarms

Reduction in Annual Probability of Fatality, Given Fire, 28.9

0.52
Between Dwellings with Smoke Alarms Only and Dwellings
with Smoke Alarms and a Sprinkler System
Probability of Fire Occurrence 6.0 0.24

Reduction in Annual Probability of Property Loss, Given Fire, 1.1 0.10
Between Dwelling with Smoke Alarms and a Sprinkler
System

Reduction in Annual Probability of Injury, Given Fire, 0.8 0.09
Between Dwellings with Smoke Alarms and a Sprinkler
System

Expected Direct Loss, Per Fire, in Dwellings with only Smoke 0.5 0.07
Alarms

Expected Number of Injuries, Per Fire, in Dwellings with only 0.0 0.01
Smoke Alarms

Expected Indirect Cost, Per Fire, in Dwellings with only 0.0 0.00
Smoke Alarms

Note: Contribution to variance is an approximated amount of variance (variability) of the simulated net present
values explained by the assumption (Crystal Ball 2007). Rank correlation is the correlation coefficient derived from
comparing two variables with their values sorted from low to high (Crystal Ball 2007).

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□
5.3.1. Sensitivity Analysis Varying Only One Assumption
Instead of allowing all variables to vary at once, the three most influential variables are varied
each at a time. Thus, the Latin Hypercube sampling is re-run, but this time only one assumption
varied.

Table 5-4. Summary Statistics of the Sensitivity Analysis When Varying One Assumption
at a Time.

Assumption Varied
Reduction in Annual Probability of
Fatality, Given Fire, Between a
Expected Number of Dwelling with Only Smoke Alarms
Fatalities, Per Fire, in and a Dwelling with Smoke Alarms Probability of Fire
Dwellings with only Smoke and a Sprinkler System Occurrence
Alarms
Colonial
Trials 10 000 10 000 10 000
Mean $2919.45 $2509.41 $2919.20
Median 2919.24 2559.09 2919.18
Minimum 1408.48 1693.60 2295.52
Maximum 4976.29 2919.15 3451.25
Standard Deviation 470.45 289.76 143.09
Mean Standard Error 4.70 2.90 1.43
Townhouse
Trials 10 000 10 000 10 000
Mean $3099.36 $2689.32 $3099.11
Median 3099.15 2739.00 3099.09
Minimum 1588.39 1873.51 2475.43
Maximum 5156.20 3099.06 3631.16
Standard Deviation 470.45 289.76 143.09
Mean Standard Error 4.70 2.90 1.43
Ranch
Trials 10 000 10 000 10 000
Mean $4165.86 $3755.82 $4165.61
Median 4165.66 3805.51 4165.60
Minimum 2654.90 2940.02 3541.94
Maximum 6222.70 4165.57 4697.67
Standard Deviation 470.45 289.76 143.09
Mean Standard Error 4.70 2.90 1.43

Consistent with the findings above in Table 5-3, the expected number of fatalities, per fire, in dwellings with only smoke alarms has the largest effect on the variation in the estimates (largest standard deviation). Thus, variation in number of fatalities tends to have the largest effect on

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□
changes in the net present value of sprinklers (i.e., standard deviation for a colonial is $470), while variation in the probability of fire occurrence tends to have the least (i.e., standard deviation for a colonial is $143). This also results in a larger certainty range when varying the number of fatalities (i.e., the minimum and maximum values for the colonial are $3568 apart) than when varying the probability of fire occurrence (i.e., the minimum and maximum values for the colonial are $1156 apart). The implication is that the uncertainty surrounding the number of fatalities has a larger effect on the certainty of the net present value estimate than does the uncertainty associated with the other assumptions.

Varying the number of fatalities and the probability of fire occurrence (separately

of course)
produces summary statistics (i.e., mean, median, minimum, maximum) that are much larger than
those produced while varying all the assumptions at once. For instance, the mean, minimum,
and maximum values generated when varying the number of fatalities for the colonial house are
$2919, $1408, and $4976, respectively. When varying all the assumptions, the corresponding
mean, minimum, and maximum are $2468, $704, and $4801, respectively. A similar pattern
holds across housing types (for the townhouse and ranch) and also when varying the probability
of fire occurrence. This result is likely due to the fact that while varying these assumptions, all
other assumptions are held at their baseline value; so that, the reduction in annual probability of
fatality, given a fire, between a dwelling with only smoke alarms and a dwelling with smoke
alarms and a sprinkler system is set to its baseline value of 1.0. When the reduction in this risk is
high, the net present benefits from sprinklers is also high.

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6. Summary, Conclusion, and Recommendations for Future Research
6.1. Summary
This report described and calculated the present value of net expected benefits accruing to a
homeowner from installing a multipurpose network fire sprinkler system in each of three
prototypical single-family homes (colonial, townhouse, and ranch). Anticipated benefits were
estimated for reduced risk of death and injury, reduced risk of direct property loss, reduced risk
of indirect costs and reduced homeowner insurance premiums; and costs were the purchase and
installation cost of a multipurpose network fire sprinkler system.
Brown (2005) documented the design and installation costs of four different fire sprinkler
systems in three house types. When compared to three typical variants of the stand-alone fire
sprinkler system that included a backflow preventer requiring professional maintenance, the
multipurpose network system was generally the least costly across the three house types (lowest
life-cycle cost). The multipurpose network system was therefore selected as the fire sprinkler
system to be used in the current benefit-cost analysis.
This report estimated the benefits and costs to a homeowner of adding a fire sprinkler system to a

new house construction design in which smoke detectors were already present. Based on the U.S. Fire Administration's National Fire Incident Report System 5.0 (NFIRS 5.0) and national fire statistics provided by the National Fire Protection Association (NFPA), expected present value of net benefits (PVNB) were positive for the three prototypical single-family houses. When a house fire occurs, one- and two-family dwellings with a wet-pipe sprinkler system (multipurpose network fire sprinkler systems are wet-pipe sprinklers) and smoke alarms were found, on average, to have 100 % fewer civilian fatalities, 57 % fewer civilian injuries, and 32 % less direct property loss than one- and two-family dwellings equipped with only smoke alarms. These benefits coupled with homeowner insurance credits of an 8 % reduction in annual premiums, resulted in expected PVNB (in 2005 dollars) of $2919 for the colonial-style house, $3099 for the townhouse, and $4166 for the ranch-style house.

6.2. Conclusions

A sensitivity analysis was performed to measure the variability of the results to changes in the assumptions made (inputs derived from the NFIRS 5.0 and NFPA data). The sensitivity analysis confirmed the robustness of the baseline analysis. In the sensitivity analysis, the PVNB ranged from $704 to $4801 for the colonial-style house, from $884 to $4981 for the townhouse, and from $1950 to $6048 for the ranch-style house. Multipurpose network sprinkler systems appear to be highly cost-effective.

Brown (2005) presented the life-cycle costs of three other residential sprinkler systems. Two of the three allowed for a backflow preventer to be installed, which requires annual professional maintenance. The annual cost was estimated at $100 to $200 per year. Installing the sprinkler system "D" (the most expensive) and adding the present value expense of an annually occurring maintenance charge of $200 would have increased the present value costs to $6446 for the colonial, $5995 for the townhouse, and $4812 for the ranch. The baseline net present value would change to -$1451 for the colonial, -$1001 for the townhouse, and -$182 for the ranch.12 A sensitivity analysis finds the probability that the net present value is less than or equal to zero to be 0.9995 for the colonial, 0.9960 for the townhouse, and 0.6999 for the ranch with the higher cost system.13 These probabilities imply that, out of the 10 000 simulated trials, 5, 40, and 3001 trials are cost-effective for the colonial, townhouse, and ranch house, respectively. Thus, the finding that multipurpose network residential sprinkler systems are highly cost-effective does not appear to hold for other sprinkler system designs. But, because homeowners can

perform regular
inspections and maintenance on multipurpose network systems themselves, they offer a lower
life-cycle cost alternative to other systems, and given a similar level of performance, in terms of
fire risk mitigation, they also achieve greater cost-effectiveness.

6.3. Recommendations for Future Research
A community-based approach to computing the net benefits of sprinklers might show that
higher-cost sprinkler systems are cost-effective when considering how benefit spillovers from
sprinklers in one house would reduce the probability of ignition in an adjacent home, and may
reduce fatalities and injuries experienced by firefighters and other emergency first-responders.
An internal economic study at NIST in 2007-2009 will address this issue.

12 Using the Benefit Subtotal for each housing type from Table 4-4 and subtracting from it the corresponding present
value costs presented in Section 5.2, produces these present value net benefits figures.
13 Analysis not shown.

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Appendix A. Benefit and Cost Calculation Equations
A.1. Benefits
The benefits to a homeowner of acquiring a sprinkler system come primarily from reduced risk
of death and injury; reduced risk of property loss; reduced risk of related indirect costs; and other
benefits such as lower insurance costs and reduced housing costs.
A.1.1. Reduced Risk of Death and Injury
The present value benefits of reduced death and injury to the homeowner due to installation of a
sprinkler system in a house with smoke alarms, PVDI, are calculated as follows:
PVDI P F .. E D F S V . . E I F S V .. U D D I I . ( ) . . . [| ,]. . . . [| ,].
. 0 0
where
P(.) denotes probability,
E[.] is the mathematical expectations operator,
P(F) is the annual probability of fire ignition (F) of a house,
D . is the reduction in annual probability of death (D), given fire (F), of a house with
only smoke alarms (S0), compared to a house with smoke alarms and a sprinkler
system (S1). Mathematically this is defined as:
(| ,)
(| ,) (| ,)
0
0 1
P D F S
P D F S . P D F S
,
(| ,) 0 P D F S is the annual probability of death (D), given fire (F), in a house with only smoke
alarms (S0) ,
(| ,) 1 P D F S is the annual probability of death (D), given fire (F), in a house with smoke
alarms and a sprinkler system (S1),
[| ,] 0 E D F S is the expected number of deaths (D) per fire in a house with smoke alarms only
(S0),
D V is the value of statistical life,
I . is the reduction in annual probability of injury (D), given fire (F), of a house with
only smoke alarms (S0), compared to a house with smoke alarms and a sprinkler
system (S1). Mathematically this is defined as:
(| ,)
(| ,) (| ,)
0
0 1
P I F S
P I F S . P I F S
,
□
44
(| ,) 0 P I F S is the annual probability of injury (I), given fire (F), in a house with smoke alarms
only (S0),

(| ,) 1 P I F S is the annual probability of injury (I), given fire (F), in a house with smoke alarms
and a sprinkler system (S1),
[| ,] 0 E I F S is the expected number of injuries (I) per fire in a house with smoke alarms only
(S0),
I V is the value of statistical injury averted,
U is the uniform present worth factor that when multiplied by a value, returns its discounted present value, over T years, at a discount rate of d. Mathematically this

is defined as: T
T
d d
d
(1)
(1) 1
. .
. .
.
A.1.2. Reduced Risk of Direct Losses
The present-value benefits or reduced risk of uninsured and non-reimbursable direct losses to the
homeowner (PVPL) are calculated as:
PVDL P F .E L F S E L F S . U D D . ( ) . [| ,]. [| ,] . 0 1
where
[| ,] 0 E L F S D is the expected direct uninsured and non-reimbursable fire loss (LD) per fire in
houses with smoke alarms only (S0),
[| ,] 1 E L F S D is the expected direct uninsured and non-reimbursable fire loss (LD) per fire in
houses with smoke alarms and a sprinkler system (S1),
A.1.3. Reduced Risk of Indirect Costs
The present value benefits of reduced risk of out-of-pocket indirect costs PVC, such as legal
expenses, temporary shelter, and transportation, are calculated as:
PVIL P F .E L F S E L F S . U I I . ( ) . [| ,] . [| ,] . 0 1
where,
□
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[| ,] 0 E L F S I is the expected indirect uninsured and non-reimbursable fire loss (LI) per fire in
houses with smoke alarms only (S0),
[| ,] 1 E L F S I is the expected indirect uninsured and non-reimbursable fire loss (LI) per fire in
houses with smoke alarms and a sprinkler system (S1).
A.1.4. Reduced Insurance Premiums
The present value of reduced homeowner insurance premiums is calculated as:
PVIP . IP . R .U
where
IP is the annually re-occurring homeowner insurance premium,
R is the annually re-occurring proportional reduction in the homeowner insurance due to the
installation and use of a residential sprinkler system.
A.1.5. Other Sprinkler Benefits
The present value of other sprinkler benefits include mortgage tax deductions, local tax savings
due to municipal cost reductions, and increased present value of resale proceeds (see Appendix
B). The present value of these benefits is calculated as:

PVOB . OB.U
where
OB is the annually re-occurring other benefits to homeowners with smoke alarms and a

sprinkler system.
A.2. Cost Variables
The present value costs of installation of a residential sprinkler system equation are calculated as:
PVC . PI ..OP .M .OC..U
where
PI is the purchase and installation costs,
OP is the annually re-occurring operating costs,
□
M is the annually re-occurring maintenance, repair, and replacement costs,

OC is the annually re-occurring other costs due to sprinkler use.

Only the largest and most significant cost, PI, has been estimated in this report, due to the performance characteristics of the selected multipurpose network fire sprinkler system. The multipurpose network system is integrated with the regular cold-water plumbing inside the house, and has no separable maintenance needs. The system also does not require a backflow preventer. Maintenance, repair, and replacement costs are, therefore, not estimated.

Additionally, because available information indicates that fire sprinkler systems have very small rates of accidental activation, these costs are not estimated (see Appendix B).

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Appendix B. Discussion of Non-Quantified Benefits and Costs
In this report, the economic impacts to an individual homeowner from adding a fire sprinkler system to smoke detectors in each of three prototypical single-family homes are organized and presented as benefits and costs, not all of which are quantified. Appendix B describes benefits that were not quantified—the mortgage interest tax deduction, the increased present value of resale proceeds, and local tax savings—and one cost that was not quantified—accidental activation of the sprinkler system.
B.1. Mortgage Interest Tax Deduction
For both an owner/occupant and an owner of a rental unit, the interest payments on a loan to finance the purchase of the system are deductible from taxable income, effectively reducing the acquisition cost of the system. With a fixed rate/uniform payment loan, the interest and principal components of each loan payment change over time. Because only the interest component is tax deductible, it must be separately estimated. This can be done period-by-period by calculating

interest on the remaining principal balance, subtracting the interest from the payment amount - thereby determining the contribution of that payment to reducing the principal - and then reapplying the interest rate to the new loan balance. The resulting cash flow is then multiplied by the marginal income tax rate, each value is discounted to present value, and the results summed to find the present value savings of interest expense deductions.

B.2. Increased Present Value of Resale Proceeds

An additional factor that could be modeled as a benefit variable is the increased present value of resale proceeds. The increased proceeds realizable from selling the house prior to the end of the sprinkler system's useful life could be deducted from purchase and installation costs.

B.3. Local Tax Savings

For areas with local residential fire sprinkler system regulations, communities (municipalities) could experience savings related to firefighting and emergency rescue cost reductions (i.e., from fewer fatalities, injuries, and damage attributed to sprinkler use) that are passed back to residents in the form of tax savings. Community-scale residential sprinkler system benefits are the focus of future NIST research (see Section 6.3).

B.4. Accidental Activation

The Home Fire Sprinkler Coalition, citing manufacturers of residential fire sprinklers, gives the estimated odds of an accidental discharge, due to a manufacturing defect, as 1 in 16 million. In this report, additional costs due to accidental discharge were judged to be negligible. This report does not estimate the probability of accidental activation due to improper installation or user error.

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