NISTIR 6941

Review of Residential Sprinkler Systems: Research and Standards

Daniel Madrzykowski, P.E.

Building and Fire Research Laboratory
National Institute of Standards and Technology
Gaithersburg, MD

Russell P. Fleming, P.E.

National Fire Sprinkler Association
Patterson, NY

January 2002
Revised December 2002

U.S. Department of Commerce
Donald L. Evans, *Secretary*
Technology Administration
Phillip J. Bond, *Under Secretary for Technology*
National Institute of Standards and Technology
Arden L. Bement, Jr., *Director*

Sponsored in part by:
Federal Emergency Management Administration
Joe M. Allbaugh, *Director*
U.S. Fire Administration
R. David Paulison, *Administrator*

REVIEW of RESIDENTIAL SPRINKLER SYSTEMS: RESEARCH and STANDARDS

Daniel Madrzykowski, P.E.
National Institute of Standards and Technology
Gaithersburg, MD

Russell P. Fleming, P.E.
National Fire Sprinkler Association
Patterson, NY

Introduction

Automatic sprinkler systems have been successfully used to protect industrial and commercial buildings and their occupants for more than 100 years. Historically the place which has offered the least amount of fire protection to occupants, was and still is, their own home. This was brought to light in 1973 by the Report of the National Commission on Fire Prevention and Control, *America Burning*. At the time of the report approximately 8,000 people died in structure fires every year in the United States. Nine out of ten of those victims died in their home[1].

In the 25 years since *America Burning* was published the number of lives lost in fires in the United States has decreased to approximately 4,000 per year. Unfortunately 8 out of 10 victims still died in a residential structure fire[2]. While residential sprinkler installations are increasing, it is estimated that less than 3 % of the one and two family homes in the United States have them installed[3].

In response to the information from the *America Burning* report, The National Fire Protection Committee on Automatic Sprinklers assigned a subcommittee to develop a standard for residential sprinkler systems. The *Standard on the Installation of Sprinkler Systems in One- and Two- Family Dwellings and Mobile Homes* (hereinafter referred to as NFPA 13D) was adopted in May of 1975, based on expert judgment and the best information available at that time. (Note the term “Mobile Homes” in the title was replaced with “Manufactured Homes” in the 1994 ed.).

Significant testing and development of residential sprinkler systems has continued since then resulting in the evolution of NFPA 13D and the development of the *Standard for the Installation of Sprinkler Systems in Residential Occupancies up to and Including Four Stories in Height*, NFPA 13R.

The purpose of the residential sprinkler system standards is to “provide a sprinkler system that aids in detection and control of residential fires and thus provides improved protection against injury, life loss and property damage” [4]. From a performance perspective, if the room of fire origin is sprinklered, a sprinkler system designed and installed in accordance with the residential sprinkler standards is expected to prevent flashover and improve the occupant’s opportunity to escape or to be rescued [4].

Residential sprinkler systems designed and installed in accordance with NFPA 13D or NFPA 13R have significantly different requirements than those for a residential occupancy that is required to be designed in accordance with the *Standard for the Installation of Sprinkler Systems, NFPA 13.* NFPA 13D and NFPA 13R systems have been optimized for specific types of residential occupancy buildings in an effort to minimize the cost of the system while providing fire safety.

New developments in residential sprinkler system technology continue to be made in an effort to increase the ease of installation and reduce the cost of installation while maintaining the effectiveness and reliability of the system.

In several communities, residential sprinkler systems have been required in dwellings for more than a decade. Information from these communities are providing compelling data for installing residential sprinklers. These experiences, in addition to code requirements and other incentives, are increasing the numbers of sprinkler installations around the country.

DEVELOPING A SPRINKLER SYSTEM IN RESPONSE TO THE RESIDENTIAL FIRE PROBLEM

The development of a residential sprinkler standard with the main focus on life safety required a multi-faceted approach. Fire incident data had to be collected and analyzed to understand the nature of the residential fire safety problem. In addition, technical challenges had to be overcome to develop an effective, practical and economically acceptable design for a residential sprinkler system.

The residential fire hazard had to be characterized in terms of area of origin (Table 1) [4]. Additional fire data was sought to determine which areas of the home yield the most fatal fires (Table 2) [4]. Analysis of this data determined which rooms of the residence needed to be sprinklered, in order to have a cost–effective system with a positive impact on life safety. Based on the data presented in Table 1, 83% of all residential fires start in either a living room, a bedroom or a kitchen area. Table 2 shows the number of fire fatalities and injuries based on the area of origin. Almost 80 % of the fire fatalities and more than 70% of the injuries are the result of fires starting in a living room, bedroom or kitchen. The need for sprinklers in these locations was clear. Tables 3 and 4 show the first item ignited and the source of the ignition, respectively [4]. These tables show that the majority of residential fires involved the ignition of furniture or bedding typically by a relatively small heat source. This information helped characterize of the fire hazard that residential sprinklers would have to control.

Another aspect of the residential fire problem involves the demographics of residential fire fatalities. Figures 1and 2 present the number of fire deaths per million people of a given age range and the relative risk of dying in a fire by age respectively[3]. Both tables show the trends that children 4 years of age and under and adults 60 years of age and older are more likely to die in a fire than other segments of the population. For adults over 60, the risk increases significantly with age. Because these high-risk groups may depend on assistance to exit the dwelling, "anything less than automatic suppression may not be enough to save them" [5].

Another group that can benefit from the use of residential sprinklers are firefighters. The majority of firefighter deaths and injuries on the fire ground occur at residential fires. Figures 3 and 4 exhibit the supporting data from 1998 as complied by the U.S. Fire Administration[3]. Figure 4 shows that approximately 73% of firefighter fire ground injuries occur at residential fires. Twice as many firefighters are injured each year performing fire ground duties as there are fire injuries to the civilian population (43,000 vs 23,100 in 1998) from reported fires[3].

Once it was determined where sprinklers in a home would be most effective in reducing life loss, the technical challenge of developing an effective and economically viable sprinkler system had to be solved. The system would have to automatically activate while a fire was small and the smoke and heat conditions in the home were survivable. Once the system was activated it needed to control the fire with a small amount of water relative to a sprinkler system designed in accordance with NFPA 13.

NFPA 13D, First Edition 1975

Based on the review of fire incident data the committee developed a residential sprinkler installation standard that covered the normal use areas of a dwelling and that met the goals of: 1) preventing flashover, 2) providing sufficient time for safe egress or rescue, and 3) economical viability.

As specified in the initial version of NFPA 13D, a residential sprinkler system would use a ½ in (12.7 mm) orifice, standard sprinkler, with a maximum of 256 ft^2 (23.8 m^2) coverage, and a spray density of 0.10 gpm/ft^2 (4.1 L/m^2) yielding a 25 gpm (94.6 Lpm) flow rate. If the system was not supplied by an adequate public water source, a 250 gal (946.3 Lpm) stored water supply was required to provide a 10 minute water supply.

To keep costs down and focus the impact of the sprinklers where they were most needed, sprinklers were not required in bathrooms 40 ft^2 (3.7 m^2) or less, small closets, 24 ft^2 (2.2 m^2) or less, attics not used as a living space, porches, carports, garages, and foyers. The system was to have a local water flow alarm. NFPA 13D permitted sprinklers to be omitted from certain areas where the incidence of life loss from fires was shown statistically to be low. NFPA 13 had always required complete sprinkler protection in order to safeguard property adequately. In departing from this ideal full complete protection, the 1975 edition of NFPA 13D became the first attempt at a "life safety" sprinkler standard. In spite of those concessions, actual installations based on this standard were rare, primarily due to cost.

The initial residential sprinkler system was based on existing technology and improvements were needed. Jensen noted that " much of this first edition was based on the collective experience of the committee members; little was based on real-world fire testing"[6].

Residential Sprinkler Research

Beginning in 1976, the National Fire Prevention and Control Administration, renamed the United States Fire Administration (USFA) in 1979, supported a significant number of research programs on a wide variety of topics relating to residential sprinkler systems. The objective of the USFA research program was to assess the impact sprinklers would have on reducing deaths and injuries in residential fires.[7] The USFA working in conjunction with the National Fire Protection Association, Factory Mutual Research Corporation, Underwriters' Laboratories and many others evaluated the design, installation, practical usage, and water acceptance factors that would have an impact on achieving reliable and acceptable systems[8], the minimum water discharge rates and automatic sprinkler flow required, and response sensitivity and design criteria[9-11]. Full-scale fire experiments were conducted to develop residential sprinkler designs and validate their effectiveness [12-16]. In addition, standards for residential sprinklers were developed. These included tenability criteria that were required to be maintained in the room of fire origin during sprinkler operation.

Residential Sprinkler Sensitivity and Response

Although, researchers at the Factory Mutual Fire Insurance Companies recognized the need for "faster" or more "sensitive" sprinklers back in 1884, it was not until the late 1960s that a "quick-response sprinkler" subcommittee was formed within the NFPA 13 committee.

The research showed that a more sensitive sprinkler was needed to respond faster to both smoldering and fast-developing residential fires for two reasons. First, fires had to be controlled quickly in order to prevent the development of lethal conditions in small residential compartments. Second, fires had to be attacked while still small if they were to be controlled with the water supplies typically available in residences, i.e., 20 to 30 gpm (76 to 114 L/min).

Much of the original work in the area of measuring sprinkler sensitivity was done at Factory Mutual Research Corporation (FMRC) under the sponsorship of the United States Fire Administration (USFA) during the development of the residential sprinkler.[17,18] Important contributing research was also performed at the British Fire Research Station and the National Institute of Standards and Technology (NIST).[19-22]

The progress in this area climaxed late in 1990, when an agreement was reached within the working group on sprinkler and water spray equipment of the International Standards Organization (ISO) for a standardized approach to sprinkler sensitivity requirements and testing. The agreement, included in ISO 6182/1, "Requirements and Methods of Test for Sprinklers," uses a combination of sprinkler test procedures developed by laboratories in the United States and Europe and establishes the three ranges of sprinkler sensitivity characteristics shown in Figure 5.[23]

These ranges of sensitivity are based both on the response time index (RTI) of the device and on its conductivity (C). RTI is a measure of pure thermal sensitivity, which indicates how fast the sprinkler can absorb heat from its surroundings sufficient to cause activation.

The conductivity factor is important in measuring how much of the heat transferred from the surrounding air to the sensing element will be lost to the sprinkler frame and waterway.[24]

Figure 5 shows three broad ranges of sprinkler sensitivity: standard, special, and fast response. Traditional sprinkler hardware falls into the standard-response category. The fast-response category is being used for new types of sprinklers for which fast response is considered important. The special-response category is being used in some countries for special types of sprinklers that may be installed in conformance with appropriate national installation standards. In the United States, this includes some of the extended coverage sprinklers.

Sprinkler response time as a function of the temperature rating of the operating element is well understood, that is, a 165°F (74°C) rated sprinkler would operate when its temperature reaches 165°F (74°C), plus or minus a few degrees. Because of the "thermal lag" of the link or bulb mass, however, the air temperature may be significantly higher before the element operates. The smaller mass of the operating element of a fast-response sprinkler permits it to follow a temperature rise in the surrounding air more rapidly, resulting in faster operation. The actual sensitivity requirements of the first fast-response sprinklers, intended as residential sprinklers, were arrived at somewhat by trial and error during developmental test work. To measure sensitivity, FMRC researchers first applied the concept of the "tau" factor and later developed the RTI. [17,18]

Both the tau factor and RTI refer to the performance of a sprinkler or its operating element in a standardized air oven tunnel or thermal sensitivity test. The test is known as a "plunge" test because a sprinkler at room temperature is plunged into a heated air stream of known constant temperature and velocity.[17,18] In the plunge test, the tau factor is the time at which the temperature of the sensing element of the sprinkler is approximately 63 percent of the difference between the hot gas temperature and the original temperature of the sensing element. In other words, the tau factor is the time at which the temperature of the sprinkler thermal element has risen 63 percent of the way to the higher temperature of the heated air. The smaller the tau factor, the faster the sprinkler sensing element heats up and operates. Figure 6 shows a time temperature graph for several tau values ranging from 25 to 200.[25]

The tau factor is independent of the air temperature used in the plunge test, but is inversely proportional to the square root of the air velocity. During the early development of the residential sprinkler, a tau factor of 21 seconds was considered to indicate the needed level of sensitivity, but this was associated with the specific velocity of 5 ft/s (1.52 m/s) used in the FMRC plunge test. Since the tau factor changes with the velocity of heated air moving past the sprinkler, it is a fairly inconvenient measure of sprinkler sensitivity.

The RTI has replaced the tau factor as the measure of sensitivity and is determined simply by multiplying the tau factor by the square root of the air velocity at which it is found. The RTI is therefore practically independent of both air temperature and air velocity. Comparisons of RTI give a good indication of relative sprinkler sensitivity.

The smaller the RTI, the faster the sprinkler operation. Standard response sprinklers have RTIs in the range of 180 to 650 $s^{1/2}ft^{1/2}$ (100 to 360 $s^{1/2}m^{1/2}$), while the RTI range for residential sprinklers is about 50 to 90 $s^{1/2}ft^{1/2}$ (28 to 50 $s^{1/2}m^{1/2}$).

The need to add a conductivity term to the model of sprinkler response was recognized in 1986.[24,26] This term accounts for the loss of heat from the sprinkler operating element to the sprinkler frame, its mounting, and even the water in the pipe. These losses can become significant under low-velocity conditions, particularly for some of the flush-type sprinkler designs with little insulation between the operating element and the sprinkler body.

Full-scale tests conducted by FMRC resulted in the development of a prototype fast-response sprinkler that could control or suppress typical residential fires with the operation of not more than two sprinklers. It could also operate fast enough to maintain survivable conditions within the room of fire origin.[12] Survivable conditions were established as follows:
1. Maximum gas temperature at eye level of 200°F (93°C).
2. Maximum ceiling surface temperature of 500°F (260°C).
3. Maximum carbon monoxide volume fraction of 0.15%.

Thus, the sprinkler concept expanded from the traditional role of property protection to include life safety. Full-scale field tests were then conducted in Los Angeles to establish system design parameters using the new prototype fast-response "residential sprinkler."[13-16] The data from these tests were studied by the National Fire Protection Association Technical Committee on Automatic Sprinklers and used to establish the criteria for the 1980 edition of NFPA 13D.

RESIDENTIAL SPRINKLER STANDARDS

It is important to recognize that, in addition to their fast-response characteristics, residential sprinklers have a special water distribution pattern. Because the effective control of residential fires often depends on a single sprinkler in the room of fire origin, the water distribution pattern of residential sprinklers is required to be more uniform than that of standard spray sprinklers, which in large areas can rely upon the overlapping patterns of several sprinklers to make up for voids. Additionally, residential sprinklers are required to wet sofas, drapes, and similar furnishings at the periphery of the room. In their discharge patterns, therefore, the sprinklers must not only be capable of delivering water to the walls of the areas where they are installed, but high enough up on the walls to prevent the fire from getting "above" the sprinklers. The water delivered close to the ceiling not only protects the portion of the wall close to the ceiling, but also enhances the capacity of the spray to cool gases at the ceiling level, thus reducing the likelihood of excessive sprinkler openings.

Because of their differences, residential sprinklers are not listed by product evaluation organizations under the same product standards as standard sprinklers. Underwriters Laboratories Inc., for example, has developed UL 1626 for residential sprinklers, and FMRC has published Approval Standard FM 2030 for residential sprinklers. Both of these standards include a plunge test with specific sensitivity requirements and a distribution test that checks the spray pattern in the vertical plane, as well as the horizontal plane. The product standards for standard spray sprinklers do not include either of these two tests.

Both UL 1626 and FM 2030 also include a fire test that is intended to simulate a residential fire in the corner of a room containing combustible materials representative of a living room environment.

The UL 1626 fuel package and test procedure was recently revised to: 1) enhance the reproducibility of the tests and 2) increase the similarity between the fire performance of the fuel package used in the standard tests and that of the fuel packages used as part of the principle residential sprinkler research effort.[13, 15, 16]

The details of the UL 1626 simulated furniture are shown in Figure 7. The three fire test configurations are shown in figures 8a-c. Figure 8a shows the configuration used to test pendent, upright, flush, recessed pendent and concealed sprinklers. Figures 8b and 8c present the configurations used to test sidewall sprinklers, in the first case the sprinklers are located opposite the fuel package and in the second case the sprinklers are located on the same wall as the fuel package.

The floor plan dimensions of the test room are dependent on the rated sprinkler coverage. As shown in Figure 8a, the width of the test room, w, equals the rated sprinkler coverage width and the length of the test room, 2L,equals twice the rated coverage length. For the sidewall sprinkler configurations the dimensions of the test room should be the rated sprinkler coverage length, L, by 1-1/2 times the sprinkler coverage width, w, plus 9 ft (2.7 m). The ceiling height in all cases is a nominal 8 ft (2.4 m).

The fuel package is composed several different components: a wood crib, two simulated sofa ends covered with foam, 2 sheets of ¼ in (6.3 mm) Douglas fir plywood, a pan with heptane and two heptane soaked cotton wicks. A wood crib composed of 16 pieces of nominal 1-1/2 by 1-1/2 in (38 x 38 mm) kiln-dried spruce or fir lumber 12 in (300 mm) in length and weighing between 5.5 and 7.0 lbs (2.5 to 3.2 kg). The pieces of lumber are to be arranged in 4 layers with 4 pieces of wood per layer. The piece of lumber should be evenly spaced along the length of the previous layer of wood members and stapled in place. The layers of lumber are to be placed at right angles to the layer below. The finished size of the wood crib is approximately 12 in (305 mm) on a side and 6 in (152 mm) high.

The simulated sofa ends are composed of a wood frame support and a ½ in (12.7 mm) thick piece of plywood, 33 by 31 in (840 x 790 mm) high in a vertical position. The plywood has 3 in (76-mm) thick uncovered urethane foam cushions 30 in (760 mm) high by 32 in (810 mm) wide attached to the side facing the crib. The foam has a density of 1.70 to 1.90 lbs/ft^3 (27.2 to 30.4 kg/m^3).

The walls of the test room are covered with 4 ft by 8 ft by 1/4 in. (1.2 m × 2.4 m × 6.4 mm) Douglas fir plywood paneling (flame spread rating 130 ± 30) attached to wood furring strips. The ceiling of the test room is 8 ft (2.4 m) high and covered with 2 ft × 4 ft

× 1/2 in. (0.61 m× 1.20 m × 12.7 mm) thick acoustical panels (flame spread rating 25 or less) with a density of 13.5 ± 1.5 lb/ft^3 (216 ± 24 kg/m^3) attached to wood furring strips.

Flame spread rating or index is a relative ranking from Steiner Tunnel Test results when conducted and analyzed in accordance with NFPA 255, Standard Method of Test of Surface Burning Characteristics of Building Materials, where inorganic cement board has a flame spread rating of 0 and red oak has a flame spread rating of 100.

A 12 x12 x 4 in (305 x 305 x 104 mm) high steel pan containing 16 oz. (0.5 l) of water and 8 oz. (0.24 l) of heptane is positioned under the wood crib and ignited to start the test.

To meet the UL 1626 test criteria, residential sprinklers, installed in a fire test enclosure with an 8 ft (2.4 m) ceiling are required to control a fire for 10 minutes with the following limits:

1. The maximum gas or air temperature adjacent to the sprinkler—3 in. (76.2 mm) below the ceiling and 8 in. (203 mm) horizontally away from the sprinkler—must not exceed 600°F (316°C).
2. The maximum temperature—5 ft, 3 in. (1.6 m) above the floor and half the room length away from each wall—must be less than 200°F (93°C) during the entire test. This temperature must not exceed 130°F (54°C) for more than a 2-min period.
3. The maximum temperature $^1/_4$ in. (6.3 mm) behind the finished surface of the ceiling material directly above the test fire must not exceed 500°F (260°C).
4. No more than two residential sprinklers in the test enclosure can operate.

The enclosure is kept at an initial ambient temperature of 80°F (27°C) ± 5°F (3°C), and it is ventilated through two door openings on opposite walls.

The fire test is conducted for 10 minutes after the ignition of the wood crib. The water flow to the first sprinkler that operates and the total water flow when the second sprinkler operates are specified as part of the listing limitations for the sprinklers in the test. The total water flow for two sprinklers must be a minimum of 1.2 times the minimum flow for a single sprinkler.

The water distribution test requirements are based on the distribution pattern of the prototype residential sprinkler used in the Los Angeles test fires.[16] The distribution requirements involve collections in both the horizontal and vertical planes.

All residential sprinklers in the test must discharge water at the flow rate specified by the manufacturer for a 10-minute period simulating one sprinkler operating and two sprinklers operating. The quantity of water collected on both the horizontal and vertical surfaces is measured and recorded.

Sprinklers being tested are required to discharge a minimum of 0.02 gpm per sq ft [0.8(L/min)/m^2] over the entire horizontal design area, with the exception that no more than four 1 foot square (0.09 m^2) areas shall be allowed to be at least 0.015 gpm per sq ft [0.6(L/min)/m^2]. They must also wet the walls of the test enclosure to a height not less than 28 in. (711 mm) below the ceiling with one sprinkler operating. Each wall surrounding the coverage area is required to be wetted with a minimum of 5 percent of the sprinkler flow.

In May of 2000, a Tentative Interim Amendment was issued by the NFPA Standards Council to the 1999 edition of NFPA 13 that requires residential sprinklers installed in an NFPA 13 system to be used at a minimum water spray density of 0.1 gpm/sq. ft. (4.1 L/m^2). In 2002, the NFPA Technical Committee on Residential Sprinkler Systems proposed a minimum water spray density of 0.05 gpm/sq.ft. (2.0 L/m^2) for sprinklers used in NFPA 13D and 13R systems, based on research conducted by FM and UL (add refs). This proposal was accepted at the NFPA Annual meeting in May of 2002. UL changed their testing requirements in accordance with the proposed standards.

Revised NFPA 13D Design Requirements
The design criteria in the 1980 edition of NFPA 13D included for the first time the requirement that all sprinklers be "listed residential sprinklers". Other initial basic design requirements in the revamped NFPA 13D were as follows:

Performance criteria: To prevent flashover in the room of fire origin, when sprinklered, and to improve the chance for occupants to escape or be evacuated.

Design criteria:
1. Only listed residential sprinklers to be used.
2. Minimum 18 gpm (68 L/min) to any single operating sprinkler and 13 gpm (49 L/min) to all operating sprinklers in the design area up to a maximum of two sprinklers.
3. Maximum area protected by a single sprinkler of 144 sq ft (13.4 m^2).
4. Maximum distance between sprinklers of 12 ft (3.7 m).
5. Minimum distance between sprinklers of 8 ft (2.4 m).
6. Maximum distance from a sprinkler to a wall or partition of 6 ft (1.8 m).
Application rates, design areas, areas of coverage, and minimum design pressures other than those specified above were permitted to be used with special sprinklers listed for such special residential installation conditions.

Sprinkler coverage: Sprinklers to be installed in all areas with the following exceptions.
Exception No. 1: Sprinklers allowed to be omitted from bathrooms no larger than 55 sq ft (5.1 m^2).
Exception No. 2: Sprinklers allowed to be omitted from closets where the least dimension does not exceed 3 ft (0.9 m), the area does not exceed 24 sq ft (2.2 m^2), and the walls and ceiling are surfaced with noncombustible materials.
Exception No. 3: Sprinklers allowed to be omitted from open-attached porches, garages, carports, and similar structures.
Exception No. 4: Sprinklers allowed to be omitted from attics and crawl spaces that are not used or intended for living purposes or storage.
Exception No. 5: Sprinklers allowed to be omitted from entrance foyers that are not the only means of egress.

In the twenty years, following the development of the residential sprinkler, special listings involving expanded protection areas and reduced flows proliferated to the point that the original flow and spacing criteria have become all but obsolete. Residential sprinklers are now listed for coverage areas up to 400 sq ft (37.2 m^2) per sprinkler.

Since 1985, the use of residential sprinklers has also been permitted under some conditions in accordance with NFPA 13. Essentially, NFPA 13 allows residential sprinklers in dwelling units located in any occupancy, provided they are installed in conformance with the requirements of their listing and the positioning requirements of NFPA 13D. A dwelling unit is defined as one or more rooms arranged for the use of one or more individuals living together, as in a single housekeeping unit normally having cooking, living, sanitary, and sleeping facilities. Dwelling units include hotel rooms, dormitory rooms, sleeping rooms in nursing homes, and similar living units. Occupancies encompassing dwelling units include apartment buildings, board and care facilities, dormitories, condominiums, lodging and rooming houses, and other multiple-family dwellings.

For NFPA 13 applications involving residential sprinklers in dwelling units, the design area is required to consist of the four most hydraulically demanding sprinklers.
Other areas, such as attics, basements, or other types of occupancies outside of dwelling units but within the same structure, are required to be protected in accordance with regular provisions of NFPA 13, including the appropriate water supply requirements. The decision as to which areas are to be protected with sprinklers is also regulated in accordance with the normal provisions of NFPA 13. This means, for example, that combustible concealed spaces generally require sprinklers. Although the four-sprinkler design area can be used in the dwelling units when protected with residential sprinklers, any sprinklers installed within such concealed spaces would have to use a different design approach.

Residential sprinklers installed in systems designed to NFPA 13 requirements are spaced and positioned in accordance with their residential listings, not with the spacing requirements of NFPA 13. The water demands for the residential sprinklers are the same as in NFPA 13 applications, except that the multiple sprinkler flow requirement is extended to four sprinklers rather than the two stipulated for one- and two-family dwellings and manufactured homes in NFPA 13D. The less restrictive piping, component, hanger, location, and water supply duration allowances of NFPA 13D are not permitted in these systems.

Beginning in 1996, NFPA 13 required residential sprinklers or fast-response sprinklers in residential areas.

Development of NFPA 13R

In 1989, a new standard was developed to bridge the gap between NFPA 13 and NFPA 13D. The new standard is NFPA 13R*, Standard for the Installation of Sprinkler Systems in Residential Occupancies up to and Including Four Stories in Height* (hereinafter referred to as NFPA 13R).

Like NFPA 13D, NFPA 13R is oriented toward economical life safety protection. Sprinklers are omitted from building areas that have been found to have a low incidence of fatal fires, including combustible concealed spaces, small bathrooms and closets, and attached porches. As with NFPA 13D, residential sprinklers are required throughout dwelling units, with some minor exceptions. A four-sprinkler design area is required unless the largest compartment contains fewer sprinklers.

In recognition of the greater risk associated with multifamily occupancies, however, NFPA 13R is more conservative than NFPA 13D, in some areas. Requirements for plans, hydraulic calculations, and system acceptance certificates parallel those of NFPA 13. Unlike NFPA 13D, NFPA 13R requires a consideration of the likelihood that simultaneous domestic flows might occur through combined service piping. In addition, pumps and other key equipment are required to be listed. In NFPA 13R systems, areas outside dwelling units can be protected with standard spray sprinklers, using NFPA 13 design criteria.

NEW TECHNOLOGY IN RESIDENTIAL SPRINKLER SYSTEMS

Multi-purpose piping systems

Although NFPA 13D has had the option for a combined or multi-purpose piping system for many years, in 1999 the committee further encouraged the use of this option by allowing non-listed pipe to be connected to the sprinkler system for the purpose of supplying plumbing fixtures and by specifying a working pressure requirement of not less than 130 psi (8.9 bar) at not less than 120 ºF (49 ºC). The combined system may be a means to integrate the sprinkler system into new homes as a standard feature instead of as an option.

The multi-purpose system uses the cold water piping to serve as a supply for both the domestic fixtures, i.e. sinks, showers, etc, and the fire sprinklers. Given the potential for a reduced amount of pipe and fittings, there is a potential for reduced system cost.

Supplying the sprinklers from the domestic water system can provide increased system reliability since any impairment to the water supply would be more quickly recognized. In addition a combined system eliminates the need for back flow prevention devices. This also helps to reduce the cost of the system and eliminates any water pressure losses that would be incurred by a backflow prevention device.

New piping materials composed of cross-linked polyethylene have recently been listed by UL for use in residential sprinkler systems. [27] This piping is similar to piping already used in domestic plumbing systems and therefore is easily used in combined systems.

Residential Water Mist System

Residential fire suppression/control systems are also being developed under NFPA 750, Standard on Water Mist Fire Protection Systems. A water mist system uses very fine water sprays "… to control or extinguish fires by cooling of the flame and fire plume, oxygen displacement by water vapor, and radiant heat attenuation" [28].

Water mist systems typically use smaller amounts of water at significantly higher pressures when compared to a NFPA 13D residential sprinkler system. The spacing of water mist nozzles tends to be smaller than the spacing of residential sprinklers, hence more nozzles are needed to provide fire protection for a given area. Studies sponsored by the U.S. Fire Administration showed that in some cases water mist systems could provide equivalent levels of fire safety relative to a residential sprinkler system, however at a significantly higher cost. [29,30]

RESIDENTIAL SPRINKLER EXPERIENCE

Scottsdale AZ, Case Study

Due to the proven effectiveness of residential fire sprinklers, communities in 25 states require sprinklers in 1 and 2 family homes.[31] One of these communities, Scottsdale, AZ, has conducted a detailed 10 year study on the impact of residential fire sprinklers on their community. In June of 1985, the City of Scottsdale passed a comprehensive fire sprinkler ordinance which required all new multi-family and commercial structures to be protected by sprinklers beginning in July of 1985 and all new single family homes beginning in January of 1986. [32]

The results of the study held some surprises. The average installation cost of a residential sprinkler system decreased significantly over the ten year period. In 1986, the average installation cost was \$1.14/ ft^2. By January of 1996, the average cost was \$.59/ ft^2, a decrease of approximately 45%.[32] Surveys of the home insurance companies in the Scottsdale area yielded an average discount of 10% for homes with residential sprinkler systems installed. [32]

The Scottsdale study also examined the issue of water usage during a fire incident. The first 38 sprinklered fire incidents, a combination of fires in commercial, multi-family and single family units, were investigated. Based on the incident timelines, the water flow times for the sprinkler systems were determined and the total water flow was calculated. The average amount of water used per fire was 357 gallons. Assuming that manual suppression could be accomplished in the same amount of time as the sprinkler flow time, the average amount of water used per fire incident by the fire department would amount to more than 4,800 gallons. [32]

In 1996, a review of the 109 fires that had occurred in sprinklered buildings in Scottsdale included 44 residential fires. In more than 90% of the incidents, the fire was controlled with 1 or 2 sprinklers activated. The average amount of water flowed by the sprinklers was 299 gallons per fire vs. an estimated manual suppression usage of approximately 6,000 gallons per fire. Most importantly, the study indicates that at a minimum 8 lives were saved in these fires by the residential sprinkler systems. [32]

This study is yet another measure that demonstrates with real world experience how sprinklers can decrease the amount of property damage from both the fire and the suppression of the fire, while providing improved life safety.

INCENTIVES TO MORE WIDESPREAD USE OF RESIDENTIAL SPRINKLERS

There are certain incentives that can stimulate interest in residential sprinklers. These incentives are discussed in the following paragraphs.

Reduction in Government Spending
Reduction in all forms of government spending, resulting from public pressure to reduce property taxes, is a prime factor in the future growth of the residential sprinkler concept. Many fire departments are forced to protect larger areas and more subdivisions with the same number of, or even fewer people, in several communities since financial restrictions hamper a fire department's ability to grow with the community. As a result, alternates to traditional fire-fighting techniques must be found. One of them is the use of residential sprinklers.

San Clemente, CA, was the first community in the United States to pass a residential sprinkler ordinance in 1980 as part of the fire department's master plan. This ordinance requires automatic sprinkler systems to be installed in all new residential construction. The prime motivation for the passage of this ordinance was San Clemente's cutbacks in government spending brought about by Proposition 13, the state's tax-capping measure. Many communities across the country face similar situations. Automatic sprinklers in residences may be the answer to fewer fire fighters and longer response times from the fire department.

Insurance Savings
Although the greatest benefit from widespread installation of residential sprinklers will be the lives saved and injuries prevented, lower property losses will be a secondary and substantial benefit. An ad-hoc committee from the insurance industry sponsored a number of the test fires in Los Angeles and concluded that residential sprinklers have the potential for reducing homeowners' claim payment expenses.[33] As a result, the Insurance Services Office (ISO) Personal Lines Committee recommended that a 15-percent reduction in the homeowner's policy premium be given for installation of an NFPA 13D residential sprinkler system. While this would not pay for the system over a short period of time, as is the case in many commercial installations, the continuing increases in the cost of insuring a single-family home make this a significant incentive nonetheless.

Real Estate Tax Reductions
In 1981, the State of Alaska enacted into law a significant piece of legislation that has a dramatic impact on the installation of sprinkler systems throughout that state. The law provides that 2 percent of the assessed value of any structure is exempt from taxation if the structure is protected with a fire protection system. The word "structure" is significant in the law, since it also applies to homes. In effect, if a home were assessed at $100,000 for purposes of taxation, the assessed value would be computed at $98,000, provided that it contained a fire protection system.

Buyers' Attitude
While one study indicated that 30 percent of the people interviewed perceived no need for a residential sprinkler system,[8] a 1980 survey published by the National Association of Home Builders on luxury features that buyers want in a new home showed that 14.3 percent indicated "fire suppression systems" as a choice. For potential buyers with incomes over $50,000, the percentage rose to over 20 percent.

Zoning
Greater land use may be possible with zoning changes that would permit fully sprinklered residences to be built on smaller parcels of land. The assumption is that the space between houses will not be as important from a fire protection standpoint if an entire street or neighborhood is fully sprinklered. One could argue, however, that if the sprinkler system fails, the resultant fire involving a number of residences could be much greater.

Sprinkler Legislation
In addition to the San Clemente ordinance, a number of other California communities have passed residential sprinkler legislation, including Orange County and Los Angeles County. By 1993, more than 4 million Californians lived in communities in which residential sprinklers were mandated in all new homes.[34]

Since 1982, Greenburgh, NY, and several surrounding communities have enacted sprinkler ordinances that require the installation of automatic sprinklers in virtually all new construction, including all new multiple- and one- and two-family dwellings. A similar law went into effect in Prince Georges County, Maryland, in 1992.
The State of Florida in 1983 passed a law requiring that all public lodging and time-share units three stories or more high in the state be sprinklered. It also required that all existing units be sprinklered by 1988.

In 1983, the City of Honolulu, HI, adopted legislation that required all new and existing high-rise hotels, which are those more than 75 ft (23 m) above grade, to be sprinklered.
In the late 1980s, additional jurisdictions, including Atlanta, GA, the State of Connecticut, and the Commonwealth of Massachusetts, acted to retroactively require the installation of sprinkler systems in high-rise residential buildings.

In 1990, the federal government enacted the Hotel and Motel Fire Safety Act, which contains strong incentives for complete sprinkler protection of hotels, since only hotels with satisfactory levels of fire protection are eligible for federal employee travel.
The Federal Fire Safety Act of 1992 requires automatic sprinkler systems or an equivalent level of safety in all federally assisted housing four or more stories in height, as well as in office buildings owned or leased for more than 25 federal employees.

Perhaps the most significant legislation promoting the use of sprinkler systems, however, is the 1990 Americans with Disabilities Act. In 1991, the U.S. Department of Justice published criteria that became mandatory for places of public accommodation and commercial facilities designed for first occupation after January 26, 1993. Alterations to existing buildings must also comply. A key feature of the criteria is the need for areas of refuge. Floors of buildings that do not have direct access to the exterior at grade must provide areas of rescue assistance, except those buildings that have a supervised automatic sprinkler system.

Construction Incentives
Many Authorities Having Jurisdiction have used building code modifications as an incentive to install sprinklers. Cobb County, GA, was one of the first communities to amend its Buildings and Construction Code to include such an approach for multi-family structures equipped with residential sprinkler systems. While these construction alterations can be a major incentive to install residential sprinklers, the disaster potential must always be considered if a fire, for whatever reason, should overpower the sprinkler system. This is especially true if the system is designed with the minimal water supplies required by NFPA 13D.

The City of Dallas, TX, adopted a building code that requires all new buildings or those undergoing major renovation, having an area greater than 7,500 sq ft (697 m^2), to have automatic sprinklers. At the same time, this building code encourages the installation of sprinkler systems by allowing design options that may allow different levels of “passive” fire protection features in exchange for “active” automatic sprinkler alternatives.

Code Requirements
Beginning with the 1991 edition, NFPA 101®, *Life Safety Code®,* required the use of quick-response or residential sprinklers in new health care occupancies in smoke compartments containing patient sleeping rooms. This generally means all patient rooms and their adjacent corridors. Beginning with the 1994 edition, quick-response or residential sprinklers were also required in all new hotel and dormitory guest rooms and guest room suites.

SUMMARY

Since the introduction of the residential sprinkler standard, NFPA 13D, in 1975, residential sprinkler systems have proven themselves as life safety systems. Because of improvements in system design and the incentives listed above, the use of new technology, such as residential and quick-response sprinklers, nearly tripled in the United States between 1987 and 1994, even though the total number of sprinklers installed increased only slightly.[35] While there is growing recognition of the enhanced ability of fast-response sprinklers to protect life and property from fires, it is estimated that less than 3 % of the one and two family homes in the United States have them installed[3].

ACKNOWLEDGEMENTS

The authors would like to thank Mr. George Laverick from Underwriters' Laboratories Inc, for providing the graphics representing the revised UL 1626 fire test fuel package and layout. The authors would also like to thank Mr. Larry Maruskin from the U.S. Fire Administration for his support of the development of this document.

REFERENCES

1. America Burning, The Report of the National Commission on Fire Prevention and Control, U.S. G.P.O.: 1973-O-495-792, May 1973.
2. Karter, Michael J., 1998 Fire Loss in the United States, NFPA Journal, Vol. 93, No 5 Sept/Oct 1999.
3. Fire in the United States 1989-1998, 12th ed. Federal Emergency Management Agency, United States Fire Administration, National Fire Data Center, FA-216, August 2001.
4. NFPA 13D, Standard for the Installation of Sprinkler Systems in One- and Two-Family Dwellings and Manufactured Homes, 1999 ed., National Fire Protection Association, Quincy, MA.
5. Bryan, John, L. Automatic Sprinkler and Standpipe Systems, 2nd ed. National Fire Protection Association, Quincy, MA. 1990.
6. Jensen, Rolf, P.E., A Brief History of Sprinklers, Sprinkler Systems and the NFPA Sprinkler Standards. Automatic Sprinkler System Handbook 8th ed. Supplement, National Fire Protection Association, 1999.
7. Halpin, B. M., Dinan, J. J., and Deters, O. J., "Assessment of the Potential Impact of Fire Protection Systems on Actual Fire Incidents," Johns Hopkins University—Applied Physics Laboratory (JHU/APL), Laurel, MD, Oct. 1978.
8. Yurkonis, P., "Study to Establish the Existing Automatic Fire Suppression Technology for Use in Residential Occupancies," Rolf Jensen & Associates, Inc., Deerfield, IL., Dec. 1980.
9. Kung, H. C., Haines, D., and Green, R., Jr., "Development of Low-Cost Residential Sprinkler Protection," Factory Mutual Research Corp., Norwood, MA, Feb. 1978.
10. Henderson, N. C., Riegel, P. S., Patton, R. M., and Larcomb, D. B., "Investigation of Low-Cost Residential Sprinkler Systems," Battelle Columbus Laboratories, Columbus, OH, June 1978.
11. Clark, G., "Performance Specifications for Low-Cost Residential Sprinkler System," Factory Mutual Research Corp., Norwood, MA, Jan. 1978.
12. Kung, H. C., Spaulding, R. D., and Hill, E. E., Jr., "Sprinkler Performance in Residential Fire Tests," Factory Mutual Research Corp., Norwood, MA, Dec. 1980.
13. Cote, A. E., and Moore, D., "Field Test and Evaluation of Residential Sprinkler Systems," Los Angeles Test Series (A report for the NFPA 13D Subcommittee), National Fire Protection Association, Quincy, MA, Apr. 1980.
14. Moore, D., "Data Summary of the North Carolina Test Series of USFA Grant 79027 Field Test and Evaluation of Residential Sprinkler Systems, (a report for the NFPA 13D Subcommittee)," National Fire Protection Association, Quincy, MA, Sept. 1980.
15. Kung, H. C., Spaulding, R. D., Hill, E. E., Jr., and Symonds, A. P., "Technical Report, Field Evaluation of Residential Prototype Sprinkler Los Angeles Fire Test Program," Feb. 1982, Factory Mutual Research Corp., Norwood, MA.
16. Cote, A. E., "Final Report on Field Test and Evaluation of Residential Sprinkler Systems," July 1982, National Fire Protection Association, Quincy, MA.
17. Heskestad, G., and Smith, H., "Investigation of a New Sprinkler Sensitivity Approval Test: The Plunge Test," FMRC No. 22485, Dec., 1976, Factory Mutual Research Corp., Norwood, MA.

18. Heskestad, G., and Smith, H., "Plunge Test for Determination of Sprinkler Sensitivity," FMRC J.I.3A1E2.RR, 1980, Factory Mutual Research Corp., Norwood, MA.
19. Pickard, R. W., Hird, D., and Nash, P., "The Thermal Testing of Heat-Sensitive Fire Detectors," F.R. Note No. 247, Jan. 1957, Fire Research Station, Borehamwood, Herts, U.K.
20. Evans, D. D., and Madrzykowski, D., "Characterizing the Thermal Response of Fusible-Link Sprinklers," NBSIR 81-2329, Aug. 1981, National Bureau of Standards, Washington, DC.
21. Theobald, C. R., "FRS Ramp Test for Thermal Sensitivity of Sprinklers," *Journal of Fire Protection Engineering*, Vol. 1, No. 1, Jan.–Mar. 1989, p. 23.
22. Beever, P. F., "Estimating the Response of Thermal Detectors," *Journal of Fire Protection Engineering*, Vol. 2, No. 1, Jan.–Mar. 1990, p. 11.
23. Cote, A.E. and Fleming, R.P., "Fast-Response Sprinkler Technology", Fire Protection Handbook, 18th ed., National Fire Protection Association, Quincy, MA, 1997, p. 6-181.
24. Heskestad, G., and Bill, R. G., "Conduction Heat-Loss Effects on Thermal Response of Automatic Sprinklers," FMRC J.I. OMOJ5.RU, Sept. 1987, Factory Mutual Research Corp., Norwood, MA.
25. Madrzykowski, D., The Effect of Recessed Sprinkler Installation on Sprinkler Activation Time and Prediction, Master's Thesis University of Maryland, College Park, MD, November 1993.
26. Pepi, J. S., "Design Characteristics of Quick-Response Sprinklers," Grinnell Fire Protection Systems Co., Providence, RI, May 1986.
27. www.ul.com/database category cross-linked polyethlyne (PEX) sprinkler pipe & fittings VIXR.
28. NFPA 750, Standard on Water Mist Fire Protection Systems, 2000 ed., National Fire Protection Association, Quincy, MA.
29. Feasibility Study of Water Mist Applications for Residential Fires, Contract No. EMW-93-4247. Hughes Associates, Inc., Baltimore, MD. February 9, 1995.
30. Bill, R.G., Stavrianidis, P., Hill, E.E., Brown, W.R., Water Mist Fire Protection in Residential Occupancies, FMRC J.I.OY1N9.RA OZOJ1.RA Factory Mutual Research Corporation, Norwood, MA., November 1995
31. Residential Fire Safety Institute, www.firesafehome.org/1-2fam.html 6/9/01.
32. Automatic Sprinklers, A 10 year Study, A Detailed History of the Effects of the Automatic Sprinkler Code in Scottsdale, Arizona, Rural/Metro Fire Department, Scottsdale, AZ, 1997.
33. Jackson, R. J., "Report of 1980 Property Loss Comparison Fires," 1980, FEMA/USFA, Washington, DC.
34. Hart, S., "Executive Summary Report on the 1993 Fire Sprinkler Ordinance Survey," May 31, 1993, Fire Sprinkler Advisory Board of Southern California, Cerritos, CA.
35. Viniello, J.A. NFSA Statistics, Private Communication, Oct. 2001.

Area of Origin (Based on 6066 incidents where area of origin was reported)	
Living room	41%
Bedroom	27%
Kitchen	15%
Storage area	4%
Heating equipment room	3%
Structural area	2%
Other areas	8%

Source: FIDO Database 1973-1982, NFPA Fire Analysis Department

Table 1. Area of origin in one- and two-family dwelling fires that resulted in one or more deaths.

Area of Origin	Civilian Deaths	Civilian Percent	Fires	Percent	Injuries	Percent
Living room, family room, or den	1,330	37.1	42,600	10.5	2,546	18.6
Bedroom	919	25.6	50,200	12.4	3,250	23.7
Kitchen	541	15.1	92,670	22.9	3,987	29.1
Dining room	83	2.3	3,780	0.9	189	1.4
Heating equipment room or area	62	1.7	15,130	3.7	374	2.7
Hallway or corridor	48	1.3	3,690	0.9	155	1.1
Laundry room or area	47	1.3	15,370	3.8	363	2.7
Garage or carport*	45	1.2	14,580	3.6	524	3.8
Bathroom	44	1.2	8,040	2.0	271	2.0
Unclassified structural area	43	1.2	4,530	1.1	104	0.8
Crawl space or substructure space	41	1.2	11,200	2.8	317	2.3
Multiple areas	41	1.1	3,350	0.8	96	0.7
Ceiling/floor assembly or concealed space	32	0.9	3,470	0.9	64	0.5
Wall assembly or concealed space	27	0.8	7,090	1.8	93	0.7
Closet	23	0.6	5,020	1.2	186	1.4
Exterior balcony or open porch	22	0.6	5,570	1.4	121	0.9
Exterior wall surface	22	0.6	14,620	3.6	118	0.9
Unclassified area	21	0.6	2,590	0.6	87	0.6
Attic or ceiling/roof assembly or concealed space	21	0.6	10,740	2.7	98	0.7
Tool room or other supply storage room or area	20	0.5	4,160	1.0	133	1.0
Lobby or entrance way	17	0.5	1,410	0.3	44	0.3
Interior stairway	17	0.5	1,100	0.3	41	0.3
Chimney	17	0.5	60,530	14.9	75	0.5
Unclassified function area	17	0.5	1,090	0.3	43	0.3
Unclassified storage area	14	0.4	2,460	0.6	80	0.6
Area not applicable	11	0.3	1,180	0.3	22	0.2
Exterior stairway	8	0.2	1,090	0.3	25	0.2
Lawn or field	7	0.2	1,670	0.4	24	0.2
Trash room or area	5	0.1	1,140	0.3	14	0.1
Product storage area	5	0.1	780	0.2	23	0.2
Unclassified means of egress	5	0.1	610	0.2	15	0.1
Unclassified service or equipment area	4	0.1	380	0.1	12	0.1
Library	3	0.1	180	0.0	11	0.0
Other known area	26	0.7	12,880	3.2	195	1.4
Total	3,589	100.0	404,900	100.0	13,691	100.0

Note: Fires and estimated to the nearest 10; civilian deaths and injuries are estimated to the nearest 1.

*Does not include dwelling garages coded as a separate property, which averaged 19 deaths, 259 injuries, and 21,170 fires per year.

Source: 1986–1990 NFIRS and NFPA survey.

Table 2. Fires and associated deaths and injuries in Dwellings, duplexes, and manufactured homes by area of origin: annual average of 1986-1990 structure fires reported to U.S. fire departments.

Form of Materials Ignited (Based on 5080 incidents where form of material ignited was reported)	
Furniture	27%
Bedding	18%
Combustible liquid or gas	13%
Interior finish	9%
Structural member	9%
Waste, rubbish	4%
Clothing (on a person)	3%
Cooking materials	3%
Electrical insulation	2%
Curtains, draperies	2%
Other	10%

Source: FIDO Database 1973-1982, NFPA Fire Analysis Department

Table 3. Causal factor in one- and two-family dwelling fires that resulted in one or more deaths, first item ignited.

Form of Heat of Ignition (Based on 5016 incidents where form of heat of ignition was reported)	
Smoking materials	36%
Heat from fuel-fire or powered object	25%
Heat from miscellaneous open flame (including match)	15%
Heat from electrical equipment arcing or overload	14%
Hot objects, including properly operating electrical equipment	7%
Other	3%

Note: Total number of incidents reported: 10,194.

Source: FIDO Database 1973 to 1982, NFPA Fire Analysis Department.

Table 4. Causal factor in one- and two-family dwelling fires that resulted in one or more deaths, source of ignition.

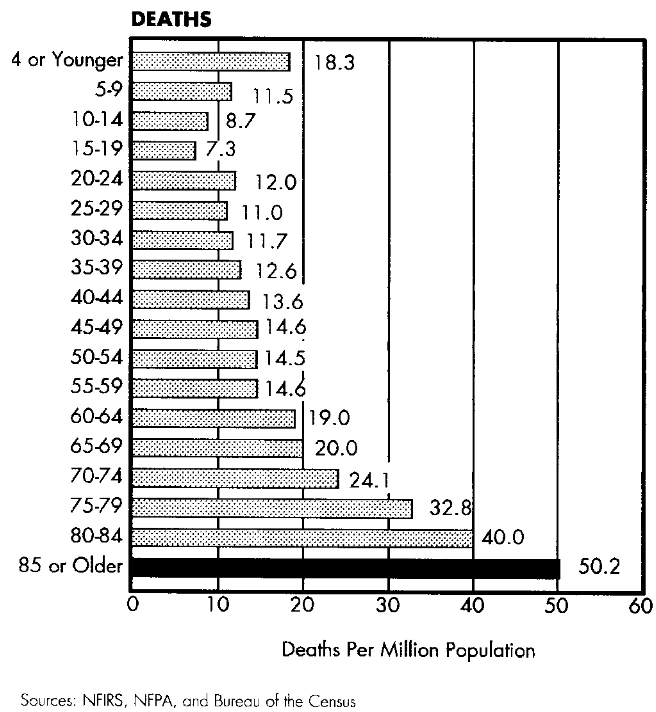

Figure 1. Fire deaths per million population by age.

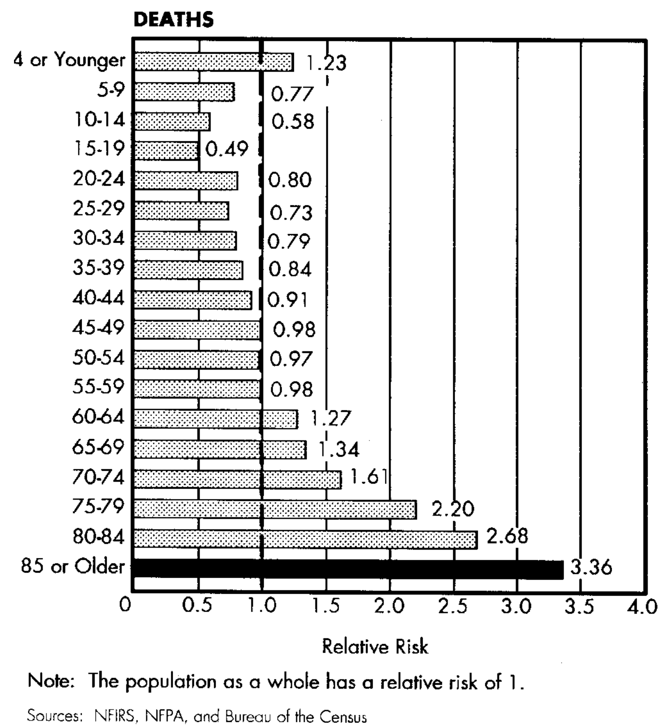

Figure 2. Relative risk of fire casualties by age.

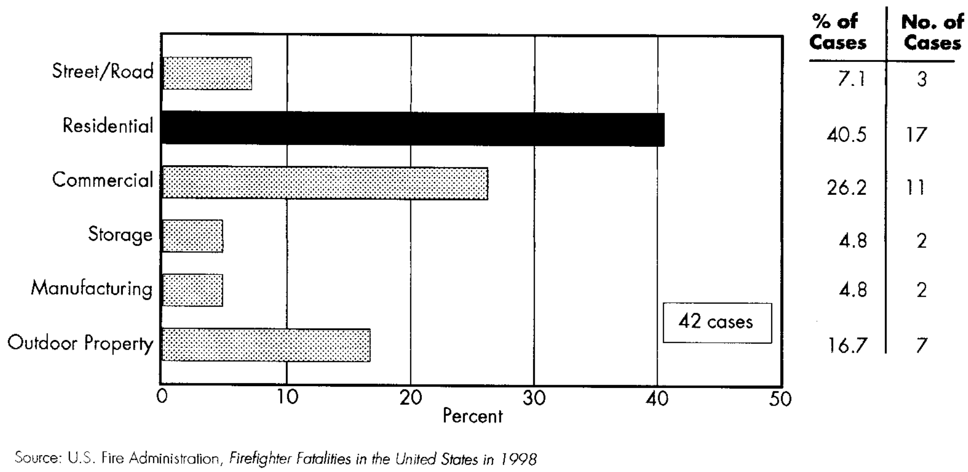

Figure 3. Fire fighter deaths on fire ground by fixed property use in 1998.

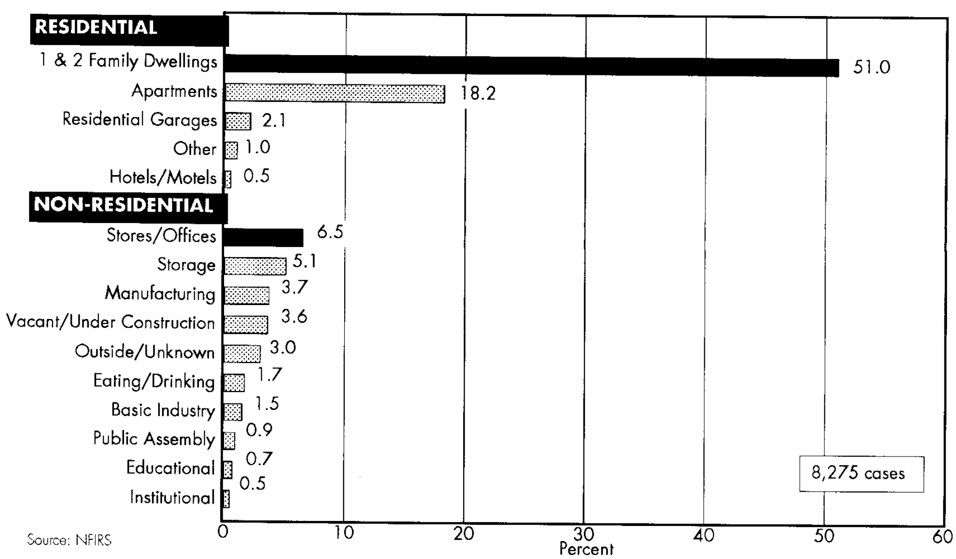

Figure 4. Fire fighter injuries by fixed property use, structure fires in 1998.

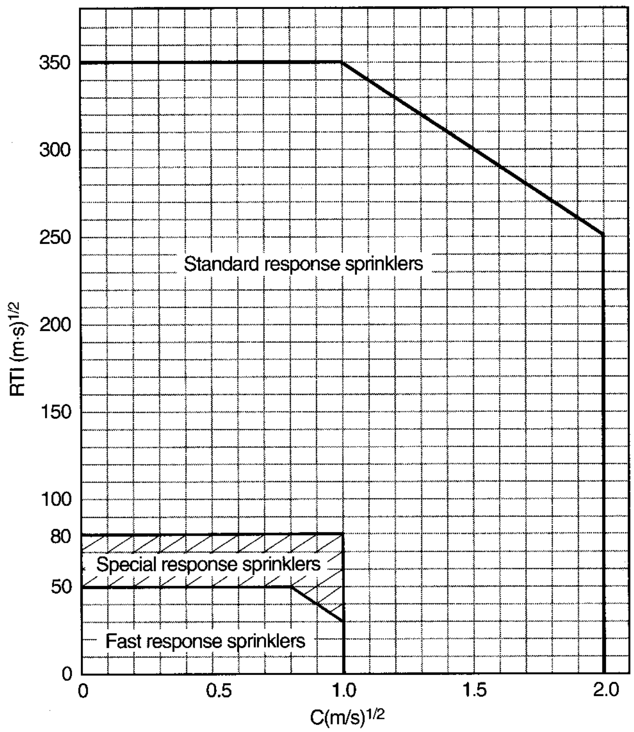

Figure 5. International sprinkler sensitivity ranges, response time index (RTI) vs conductivity (C). (For U.S. conversion: 1 ft = 0.305 m)

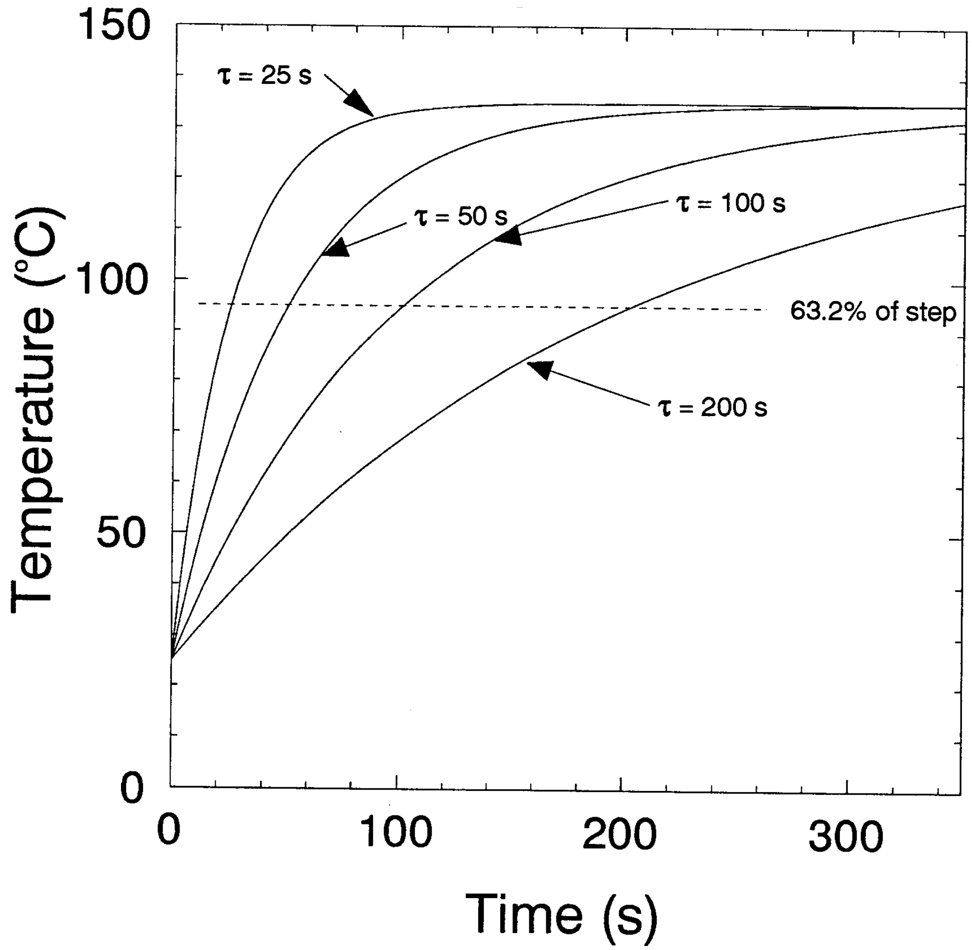

Figure 6. Calculated sprinkler "tau" values responding to a step change temperature increase of 90 °C with a gas velocity of 2.54 m/s (8.33 ft/s). τ=25 would be equivalent to an RTI of 40 $m^{1/2}s^{1/2}$ (73 $ft^{1/2}s^{1/2}$) while τ=200 would be equivalent to an RTI of 320 $m^{1/2}s^{1/2}$ (580 $ft^{1/2}s^{1/2}$). For a given activation temperature of 68 °C (155 °F), a fast response sprinkler will activate in less than 14 seconds compared to the greater than 100 second activation time of the slowest standard response sprinkler.

Figure 7. Simulated fuel package for UL 1626. The fuel package is composed of several different components: a wood crib, two simulated sofa ends covered with foam, 2 sheets of ¼ in (6.3 mm) Douglas fir plywood, a pan with heptane and two heptane soaked cotton wicks. The arrangement of the fuel package within the test room is shown at the upper left of the figure.

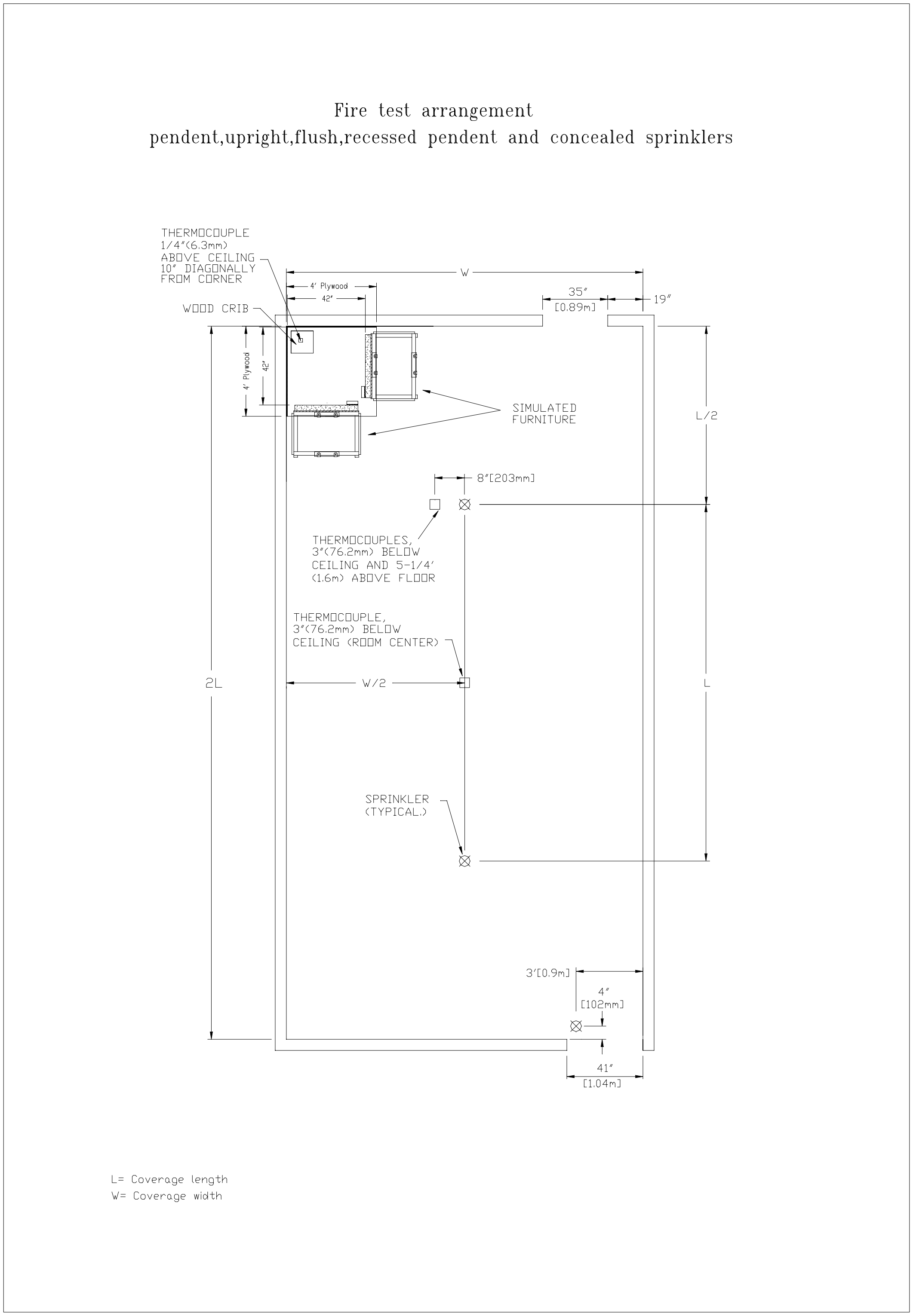

Figure 8a. Fire test arrangement for UL 1626, for pendent, upright, flush recessed pendent and concealed sprinklers.

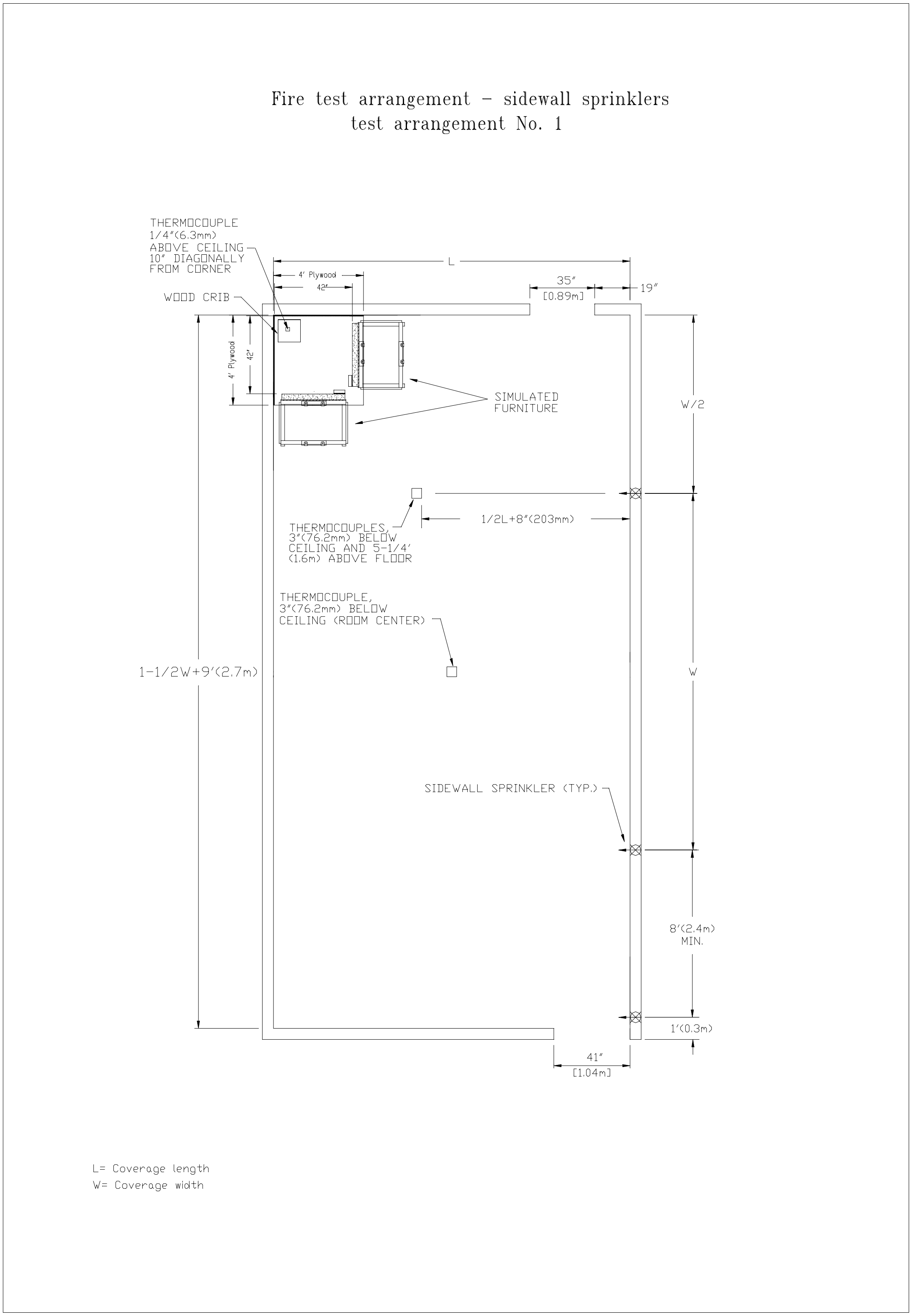

Figure 8b. Fire test arrangement from UL 1626 for sidewall sprinklers, test arrangement 1.

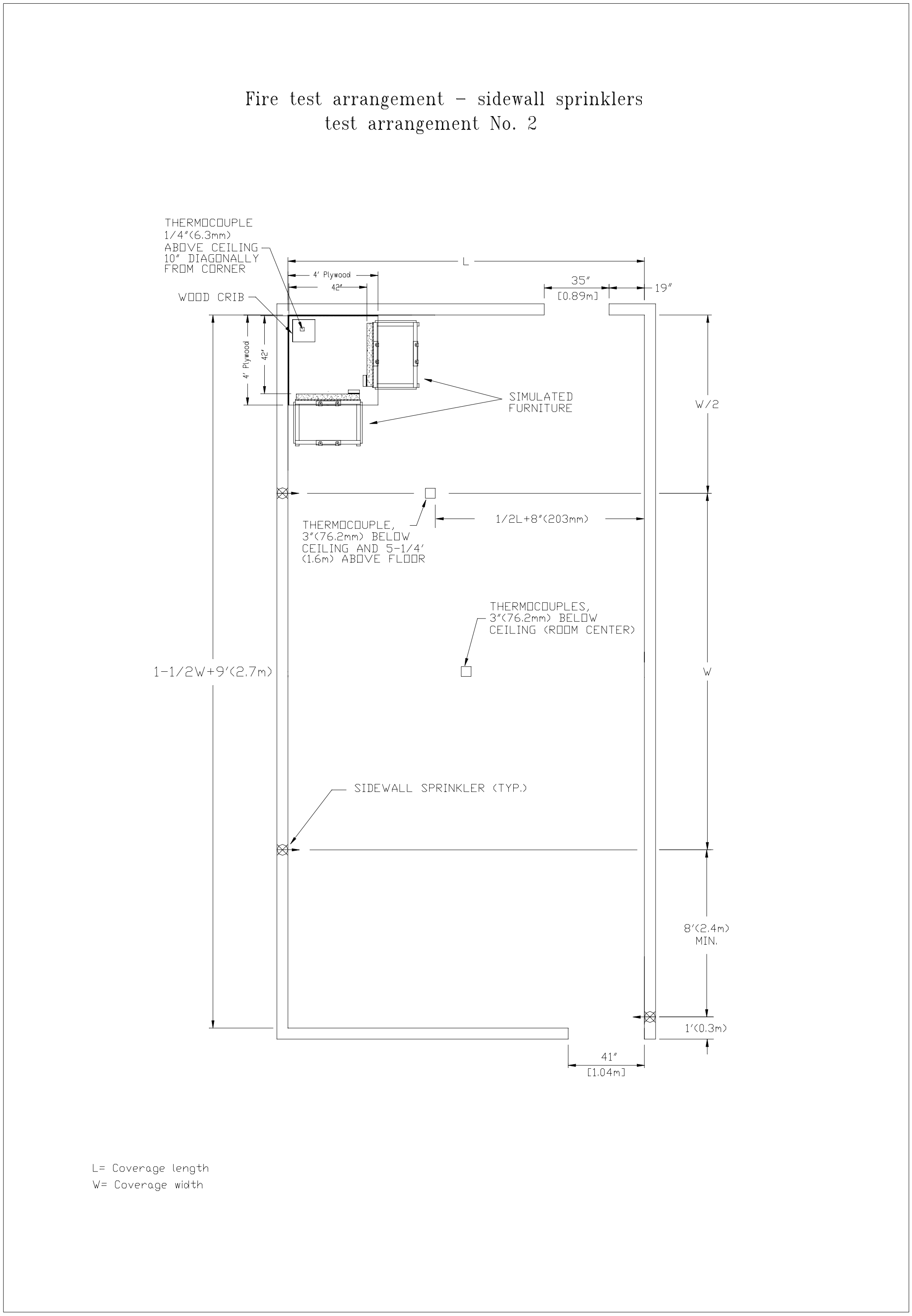

Figure 8c. Fire test arrangement from UL 1626 for sidewall sprinklers, test arrangement 2.