

-A White Paper-

Maintaining Life Safety Effectiveness in the New Building Codes

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Smoke detectors, containment area, passive fire protection and automatic fire sprinklers - taken in concert, this quartet of construction features is responsible for an improving record of life and property protection in commercial buildings that have been constructed in the U.S. over the past several decades. Unfortunately, some participants in the Building Code development and enforcement processes attribute this safety record to sprinklers alone - an invalid and dangerous assumption.

Sprinklers alone - without limitations on containment size, without tested and inspected passive fire protection, and without smoke detection - cannot deliver equivalent results. It is crucial that the new Building Codes reflect a clear understanding of the systems nature of effective fire protection if we are to avoid sanctioning the construction of buildings that are code- compliant but unsafe for life and property.



Figure 1 - Effective fire protection requires a systems approach with four primary elements in place, installed in accordance with established standards, and monitored for continuing effectiveness. Sprinklers alone cannot effectively protect life and property.

This paper reviews key issues in fire protection that pertain to new Building Codes presently under consideration, summarizes important information from primary industry sources, and suggests a smoke control rating standard that augment sprinklers and will help maintain a level of fire protection effectiveness and public safety in the future.

Background

Proposed revisions to the 2000 International Building Code and the draft NFPA 5000 Building Code contain significant changes with regard to emphasis on active fire control (i.e., sprinkler systems) over passive fire control (construction using rated fire containment compartments with tested, inspected smoke and fire barriers). Pressure is being applied by certain special interest groups to move away from proven and tested life safety practices in the model Building Codes for reasons of economy. These interest groups propose eliminating penetration firestops, fire-rated gypsum board, fire doors, fire dampers, structural fire-proofing and fire-rated ceiling tiles from the Building Code in favor of sprinkler systems.

The proposed code changes include further reducing or eliminating fire-rated corridors and fire rated assemblies in buildings, and substantially increasing the height and area values that govern fire containment compartments in exchange for use of sprinklers. More and more fire ratings are being reduced as a financial incentive to encourage the use of sprinklers. However, as noted in the following material, there are serious questions related to the ultimate safety of this practice

Dependence solely or primarily on the use of automatic fire sprinklers without attention to effective smoke control along paths of emergency egress will expose building occupants to increased danger compared to traditional construction that provides for fire-rated and smoke sealed egress stairwells and hallways. Smoke barriers fire rated for one hour actually offer more protection than a fire partition rated for one hour. Additionally, the philosophy of the IBC and the NFPA 5000 pertaining to the movement of smoke is ambiguous, and provides indefinite guidelines for both construction and subsequent inspection of these crucial smoke systems. In effect, the suggested Building Code

modifications serve to roll back the level of public safety and reduce the level of protection that has been achieved in structural fire safety over the past several decades without technical substantiation.

The Situation

According to “America Burning Revisited,” published by NFPA, the United States along with Canada still has the worst fire death rate for all the industrialized countries for which we have comparable data. The U.S. fire deaths per million in population are almost twice the average fire death rates for other industrialized countries.¹

During 1999 there were 3,570 civilian fire deaths in the U.S., and one civilian fire injury occurred every 24 minutes. There were 523,000 fires in structures, and 240,500 (46%) of these fires were classified as occurring in buildings other than one and two-family dwellings. Total structural property loss was \$8,490,000,000 with \$4,367,000,000 (51.4%) in structures other than one or two family dwellings.²

Smoke kills approximately 75 percent of the fire victims in the United States. These deaths occur in areas remote from the room of fire origin and are due to the toxic effects of the smoke as it migrates throughout a building.³ Smoke contaminates escape routes, including stairs, hallways and elevators, trapping occupants, inhibiting safe egress.

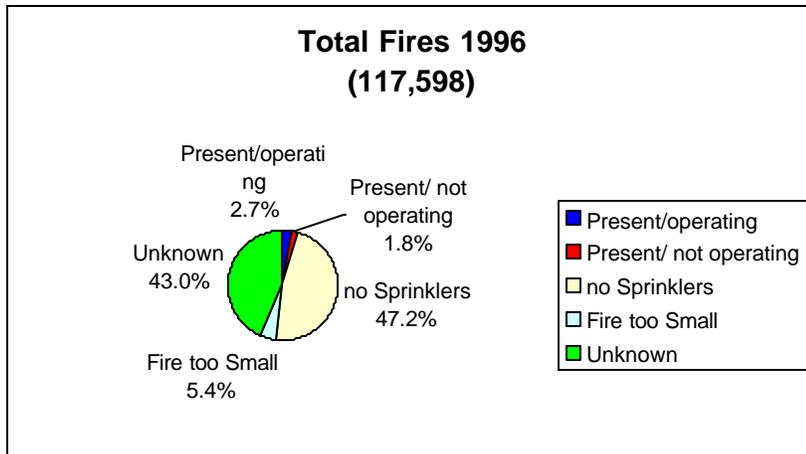
IBC 2000 provides the following definition for a smoke barrier on page 92: “...a continuous membrane, either vertical or horizontal, such as a wall or floor, or ceiling assembly, that is designed and constructed to restrict the movement of smoke.” It further discusses penetrations and joints and their requirements by saying: “The space around penetrating items and in joints shall be filled with an approved material to limit the free passage of smoke.” Neither the IBC nor the proposed NFPA 5000 provides any method for quantifying or testing smoke seals. It is not clear just what is meant by the term “approved material” as to standard of measurement or degree of effectiveness.

Measuring Sprinkler Effectiveness

The U.S. Fire Administration's most recent tabulated data from the National Fire Incident Reporting System (*Fire in The United States 1987-1996 11th Edition*⁴) shows that sprinklers have been ineffective in stopping the migration of smoke in reported fires. This conclusion is based on study of fire incidents in sprinklered high-rise buildings where smoke migrated beyond the floor of origin to expose occupants to toxic smoke dangers. Statistics on the performance of sprinkler systems in the U.S. are incomplete. However, published performance information is instructive for this discussion.

Sprinklers	Apartment Fires	Non-residential Fires	Total Fires
Present/ operating	708	2,419	3,127
Not/operating	1,549	513	2,06
Present fire to small	0	6,379	6,379
No Sprinklers	30,984	44,435	55,456
Unknown	11,021	19,504	50,488
Total Fires	44,264	73,325	117,589

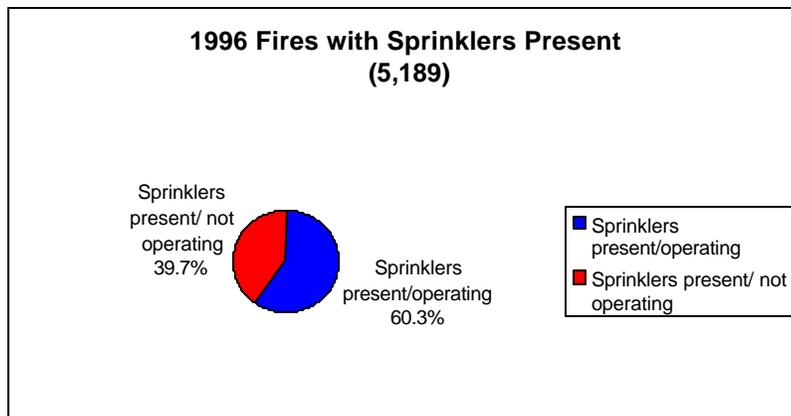
Based on this data, some have concluded that sprinkler performance is 98.2% effective. (2,062/117,598 = 1.8%)



However, on closer examination, the facts reveal:

Total Sprinklered Fires (5,189 fires, not including events too small to activate sprinkler systems):

Sprinklers present and operating 3,127 (60.3%)
 Sprinklers present but not operating 2,062 (39.7%)



These figures show four out of ten fires occur in sprinklered buildings where sprinklers do not activate, or do not effectively control the fire. This clearly recommends against eliminating compartmentation in favor of sprinklers alone.

A primary problem in the U.S. today is that many buildings do not have sprinkler systems, and if sprinklers are installed, there is no established mechanism for maintenance enforcement that can ensure sprinkler effectiveness. Sprinkler system failures can be caused by human error, loss of water supply, poor maintenance, component failures, and are subject to being overpowered by fast-growing fires. Sprinkler systems are also vulnerable to intentional disabling in an arson attempt.

NFPA data⁵ collected from 1925 through 1969 shows that the major causes for unsatisfactory sprinkler performance has been failure to maintain systems in operational status. Human error accounts for more than half the cases of unsatisfactory sprinkler performance, but nothing in the proposed code changes accounts for this continuing eventuality. Sprinkler systems fail to meet expectations when building owners neglect to assure that the system in place is complete and adequate for the current use of the property.

Without secondary passive fire protection, buildings and occupants are left with no protection in the event of sprinkler failure, a smoldering, shielded fire, or a fire that overwhelms the sprinkler system.

The 1987 – 1996 US Fire Administration report referenced above examined fire records for a nine-year period to compare the degree of smoke and fire spread in sprinklered and non-sprinklered mid-rise and high-rise buildings. Researchers found that 11.4% of fires in sprinklered high-rise buildings resulted in smoke propagation and damage beyond the floor of origin, compared to 15.4% of fires in non-sprinklered buildings. The equivalent numbers for mid-rise buildings was 15.7% versus 34.4%.

The significant difference between these two ranges is likely due to the fact that high-rise buildings are more commonly built with compartmentation and extensive use of fire and smoke-rated floors and walls than are mid-rise structures. The multi-layer, balanced approach to fire protection clearly pays off in improved life safety and property protection.

The use of sprinklers along with compartmentation has contributed to a record of effective protection of life and property where there has been a balanced approach to fire protection. It is of serious concern that the critical passive fire protection features that have supported this record are being eliminated in proposed code revisions.

The most recent FEMA report on Fire in the United States⁴ (11th Edition) concludes, *"...the losses per fire were less when sprinklers operated than when they did not. However, the difference in 1996 is far less than in 1994 when the dollar loss per-fire was twice as high when sprinklers did not operate. This suggests the need for additional analysis as to the effectiveness of sprinklers in properties where they are installed."*

Analyzing Code Effectiveness

The trend to a singular, sprinkler-based approach to fire control and life safety can be traced to changes in the BOCA National Building Code in the early 1980s. The logic appeared to be based upon the assumption that sprinklers could perform all aspects of safety performance. Sprinklers can be an effective fire protection measure, but experience shows that this fire control method has limitations, and that the risks of damage, injury and death are reduced with the additive benefits of a multi-layer, active *and* passive approach to fire safety, incorporating effective control of smoke for safe egress.

The design of the new IBC code is based in part on using the least restrictive provisions of the three current regional Building Codes (SBCCI Standard Building Code, BOCA National Building Code, and ICBO Uniform Building Code). One of the arguments heard at code hearings is, "We have been constructing buildings based on the three regional codes, and there are no significant data in the fire record that would indicate that one code is superior to another in terms of fire protection." However, 1999 NFPA statistics² do not support this claim (Table 1).

Region	Number of Fires per 1000 Population	Civilian Deaths per Million Population	Civilian Injuries per Million Population	Property Loss Per Capita
Nationwide	6.7	13.1	80.4	\$36.8
Northeast	7.6	13.4	103.7	\$38.3
North Central	6.3	14.2	81.2	\$45.4*
South	7.8	15.1	79.7	\$38.5
West	4.6	7.4	65.2	\$23.9

Y. . Reflects the large loss generating plant fires in Michigan and Missouri.

Table 1 - NFPA 1999 National Fire Statistics.

In general, the U.S. code-governing areas are National Building Code for the Northeast, Standard Building Code in the South, and Uniform Building Code in the West. The Uniform Building Code is the most balanced of the three model building codes (that is, offering fewer sprinkler trade-offs and specifying more compartmentation). NFPA data Compiled for the Smoke Safety Council in 2000 (Multi Story Building Fire Loss Comparison - 1988-1997), includes the following conclusions for these code regions:

- Civilian fire deaths per million people are 61% higher than the national average in the Northeast and the South (averaging 4.5 deaths/million people annually), while the West's incident rate at 2.8 deaths/million people is 86% below the national average.
- Property damage as measured in dollars/person from fires in the Northeast and South is \$6.50/person, making it 46% higher than the national average of \$4.40/person. The West's property damage rate of \$1.90/person is 56% of the national average.
- The annual rate of civilian injuries in the Northeast (34.9 injuries/million people) is 58% higher than the national average. The rate in the South (27.4 injuries/million people) is 24% higher than the national average of 22.1 injuries/million people. The civilian injury rate in the West is 8.5 injuries/million people, making it 62% less than the national average.

This data indicates that there is a clear and substantial difference in loss of life, injuries, and property damage between the regions governed by the Uniform, National and Standard Building Codes, with the best performance provided by the more balanced fire protection provisions of the Uniform Building Code.

The Smoke Issue

As the code approach is changed with less emphasis on fire, and more on smoke-rated assemblies with sprinklers, careful attention must be paid to how smoke will be controlled and eliminated. It is important that smoke levels be quantified, with the necessary containment level established (i.e., cu.ft./minute smoke passage through the required smoke barrier), based on the type of structure in question, the characterization of the occupants, and their expected time to egress.

Smoke is widely recognized as the primary killer in structural fires. It asphyxiates, limits visibility, reduces the possibility of escape, endangers fire fighters, and hampers their efforts. It is in the highest interest of all concerned that proposed code revisions do not weaken construction requirements that pertain to smoke control and life safety.

Forces unleashed during a building fire are awe-inspiring and deadly. Tiny openings in walls, floors and ceilings can become blowtorch nozzles, spitting fire into the next room with jets of smoke and toxic gases. Every time a wall is penetrated for mechanical, electrical, telephone or structural elements, it must be restored to smoke barrier effectiveness using proven tested materials if a smoke seal is to be maintained.

The horrific Las Vegas MGM Grand Hotel fire in 1980 is a particularly chilling example of the deadly effects of fumes that spread quickly throughout a building without effective smoke control. Poisonous smoke trapped guests in hallways, rooms and stairwells, killing 84 people. Most of them were overcome and asphyxiated many floors away from the fire.

The 1993 bombing beneath the Vista Hotel in the New York City World Trade Center complex resulted in six deaths and more than 1,000 injuries. Fifty-thousand people had to be evacuated, some after being trapped for up to eleven hours in the upper floors of Trade Center towers. Firefighters reported voluminous amounts of smoke, which migrated quickly into the hotel and up shafts in the Trade Center Towers. The blast disabled sprinklers in the explosion and fire area, and a power loss trapped people in hotel and tower elevators. This deadly act of terrorism demonstrated the critical importance of smoke control and passive fire and smoke containment.

Under some conditions a fire may smolder or burn at a low intensity for some time (producing a large volume of toxic gases) before it generates sufficient heat to activate a sprinkler system. In such a situation, the active sprinkler system would have little life-safety value. Structures having large fire containment compartments and incomplete smoke seal provisions will expose occupants to substantially increased risk under such fire conditions. Should flames break out in a tall space, the standard sprinkler activation temperature of 135 °F - 170 °F may not be reached until fire intensity is sufficient to activate sprinklers, and smoke volume has grown to a substantial and life-threatening level.

According to the National Research Council of Canada⁶, the wet and cooler burning conditions that result when sprinklers are activated lead to increased smoke generation

and elevated toxic CO and CO₂ levels. The NRC report states (p. 134), "...Even when a sprinkler system meets the performance intentions of NFPA 13 with respect to achieving fire control, enough smoke can be produced by a shielded fire to fill the fire floor, stair shafts and other floors with smoke. It is reasonably likely that fires in office settings will be poorly ventilated, with the result that the carbon monoxide concentration in the smoke may be dangerously high. If no measures are taken to prevent smoke spread, smoke from a shielded, sprinklered fire will create a threat to life safety in the building."

Smoke Movement

The proposed code sections do not adequately address the issue of smoke migration in a structure, which is one of the most crucial aspects of fire protection. Smoke movement impacts the safety of occupants, search and rescue, and firefighting efforts even more than flame and high temperatures.

Fire creates an immediate pressure differential, and even a single 1/4-inch diameter opening in a wall or partition could allow an adjacent space to fill with life-threatening toxic gases in a matter of minutes. Elevated pressure forces hot gases through unsealed cracks and openings to create immediate an immediate threat to building occupants. Table 3 shows smoke flow through representative openings between building spaces^{7,8} based on a pressure differential of 75 Pa, which is representative of pressure differences that have been measured in actual compartment fires.

Item	Gap	CFM	CFM/Ft. ²
DOOR (3'X7') no smoke seal	.078"	200	128
DOOR (3'X7') no smoke seal	.16"	400	125
DOOR (3'X7') no smoke seal	.24"	600	125
Door (3x7) smoke sealed	.24"	2	<0.1
Door Elevator (3.5'x7')	.24"	600	119
Door Elevator (3.5'x7')	.31"	1000	154
Walls	Tight	-	0.1
	Average	-	0.3
	Loose	-	0.6
Joint no smoke seal	.67"	1800	134
Joint Seals UL data	Various	-	<0.1-10
Penetration Seals UL Data	Various	-	<0.1-400

Table 3 - Smoke Flow through barrier openings. NFPA #SCHR-94'

Smoke flow between spaces has substantial impact on visibility and life safety. For example, a 100-foot long, 8-foot high x 10-foot wide corridor adjacent to a smoke filled space, having an unsealed, top-of-wall joint of 0.67 inches wide and 20-foot long, would fill with smoke in four to five minutes. The volume of such a corridor is 8000 cubic feet, and the leakage rate of the 20-foot long, 0.67-inch wide joint is 1800 CFM.

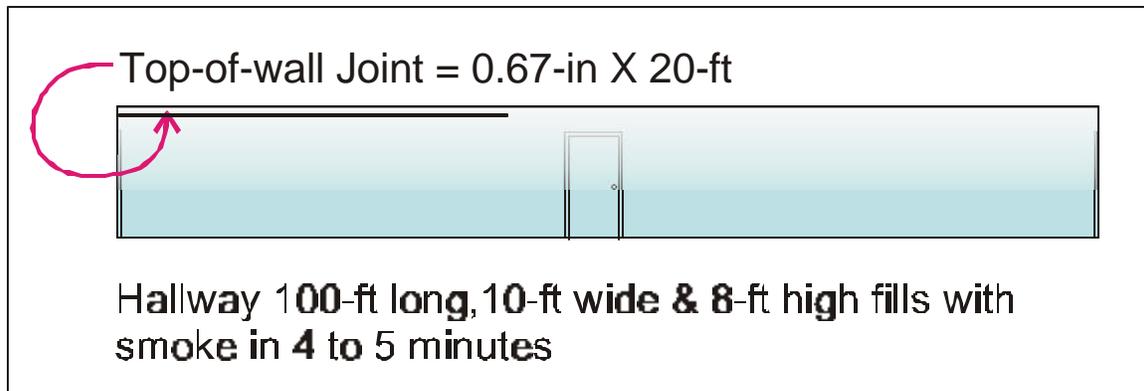


Figure 2 - Without smoke seals, egress areas and spaces adjacent to a fire rapidly fill with toxic smoke.

However, if the top-of-wall joint in this example was protected with a smoke seal having a leakage rating reduced to 1CFM/square foot (13.4 CFM), it would require 597 minutes for the corridor to fill to an equivalent smoke density, assuming this single source of smoke leakage in both cases.

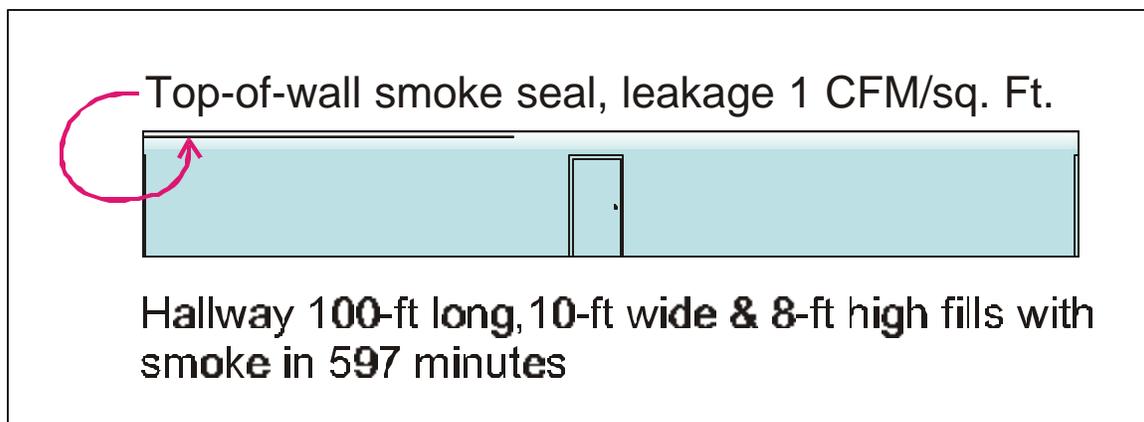


Figure 3 - Effective smoke seals reduce smoke migration and dramatically improve egress conditions.

The toxicity of combustion byproducts in smoke is compounded by the mix of materials used today in the construction and furnishing of modern buildings. This life safety threat can be further compounded by sprinkler action, which tends to increase the level of smoke and toxins created by burning materials.

The Hughes Associates *Analysis of Smoke Movement in a Building Via Elevator Shafts*⁹ reports that leakage in the area of elevator doors is a primary factor in allowing smoke to migrate to upper floors of a building. If this leakage is controlled, a three-fold increase in visibility can be attained on the upper floors of a typical multi-story building, whether the facility is sprinklered or not, extending safe egress time and providing a substantial increase in life safety for occupants, particularly on upper floors remote from the fire. Considerable attention needs to be paid to this and other mechanisms of smoke travel.

This above-referenced study is based on a mathematical network model used to analyze the spread of contamination throughout a building, predicting air flow and pressure differences through the spaces. It explains that both large openings such as doors and open areas and very small cracks and penetrations are important to smoke migration. The report stresses that for the sake of life safety, a whole-building approach to smoke management must be developed, involving both active and passive systems in building design.

Proposed Smoke Seal Guidelines

With the proposed larger rated spaces and the elimination of corridor fire ratings, it will be more difficult for occupants to safely exit a burning building. The vague "continuously sealed" statement in the International Code and the proposed NFPA 5000 Building Code is thus far without definition, and provides no measurable standard for designers, builders, owners or code officials. If standards are to be established for smoke seals, then there must be a mechanism for analyzing their performance in stopping smoke, and for providing a valid basis for inspection.

Key questions are:

- What is the demonstrated ability of an installed barrier system to accomplish a given level of smoke control (based on industry ratings and instrumented fire testing)?
- Has this system been installed properly so as to perform to expected levels?

A smoke barrier seal using existing tested, approved firestop materials and methods will effectively restrict the spread of flame, smoke and toxic gases. However, makeshift drywall compounds, paints, hardware caulks or grout plugs do not deliver dependable protection. Over time it is likely that these materials may dry out, shrink, crack from prolonged expansion and contraction, be dislodged by movement of the building structure, and may fail when subjected to even mildly elevated smoke temperatures remote from the fire source.

Unlike rated fire-protection materials, grout cannot expand to fill the void left around plastic pipe, plastic wire insulation or rubber-insulated pipe. There are many different types of smoke barrier penetrations and joints, and a range of tested, certified products are required to form an effective smoke barrier in a typical wall or partition.

The UL Standard 1479 for penetration seals and UL 2079 (Standard Test Method for Fire-Resistive Joint Systems) for joint seals are established and credible guidelines for smoke control effectiveness. These standards incorporate language for measuring air leakage through a joint or fire barrier penetration, and both include criteria for measuring "cold" as well as "warm" smoke, and the passage of hot gases when in close proximity to the fire.

There are two reasons for cold and warm smoke seal testing. First, the temperature at the ceiling in a non-sprinklered building will exceed 1500°F, and in a sprinkler building with

a shielded fire, the temperature at the ceiling will drop to about 400°F. The second reason is based on the cold-side temperature requirements of many of the ASTM test standards, where the maximum temperature on the non-fire side must be limited to less than 400F.

Efforts to include the UL smoke standards in the draft NFPA 5000 and International Building Codes are being met with strong resistance because of perceived projected cost to building owners. In fact, rated seals are already required for fire barrier joints and penetrations in the current code, and retaining this level of smoke control for smoke barriers and partitions will maintain at least a consistent through reduced level of safety in an environment of larger rated spaces, without adding to construction cost.

Establishing Smoke Control by Class of Occupancy

The author proposes that draft NFPA 5000 and IBC code provisions require that all smoke barriers be required to be sealed and measured per UL 1479 or UL 2079, against a performance level based on the class of structure in question. A proposal for such a classification system is shown in Table 2. This suggested structural classification is based on the nature of occupancy, ease of and requirement for egress, and established smoke flow data.

Category	Smoke Flow	Situation	Building Type
Class A	< 1 CFM/Square-Ft.	<i>Egress is Difficult (Some occupants not capable of self preservation)</i>	Hospitals, Nursing homes, High-rises, Underground structures
Class B	< 25 CFM/Square-Ft	<i>Sleeping Occupancy</i>	Apartments, Hotels, etc.
Class C	< 100 CFM/Square- Ft	<i>Occupants who are unfamiliar with spaces and exits</i>	Stores, Malls, etc.
Class D	< 400 CFM/Square- Ft	<i>Low occupancy</i>	Warehouses, storage buildings

Table 2 - Proposed categories of smoke control rating

Conclusion

In summary, reliance exclusively on sprinkler systems as an alternate to fire containment and specific smoke control code provisions is a serious error because:

1. Sprinkler systems are subject to component failure and human error in a measurable percentage of fire occurrences.
2. Sprinkler systems can be overwhelmed, for example, by a rapidly growing fire.
3. Sprinkler systems can contribute to the generation of toxic smoke, which limits visibility.
4. A sprinkler system will not suppress nor control a hidden or shielded fire, and may be slow to respond in spaces built to increased height and area standards.

Tamura⁷ states (page 19), "One of the principal means in limiting the extent of the fire is through the use of compartmentation, by which various parts of the building, including exits, are separated by barriers having suitable fire endurance. ...Although fire may be confined to the compartment of origin, smoke can readily spread through any openings in the enclosure to regions beyond the fire compartment. Fire-resistive construction confines property loss to the compartment of fire origin, but it does not prevent property and life losses caused by smoke spreading through openings to the rest of the building."

A commission formed by FEMA in 2000 to examine the evolving role of the nation's fire services in the safety of U.S. communities, concluded, in part, "*The frequency and severity of fires in America is a result of our nation's failure to adequately apply and fund known loss reduction strategies. ...America today has the highest fire loss in terms of both frequency and total losses of any modern technological society...*"¹⁰

Lives lost by fire in the U.S. greatly exceed combined casualties from floods, tornadoes, earthquakes and other natural disasters. Yet there is comparatively little awareness of the tremendous life safety threat posed by structural fires, and the need to fully implement all of the knowledge about fire protection that has been gained through research and practical experience over the past several decades.

We know without question that sprinklers alone - without an ongoing process to ensure proper sprinkler function, without limitations on containment size, without approved and inspected passive fire protection for smoke control, and without smoke detection - cannot effectively protect life and property. Installing sprinklers in exchange for fire and smoke containment within rated spaces will not change the fact that fires generate large volumes of smoke, and this smoke is the primary cause of death.

The unspecific nature of the draft code provision on smoke barriers will lead to *undesignated, undefined* and *ineffective* smoke protection, and seriously-compromised life safety. If passive fire protection is to be diluted in the new codes, at the very least there must be provision for effective, defined and inspected smoke systems.

U.S. Building Codes need to maintain a *balanced* approach to building construction, relying on active *and* passive fire protection systems to protect life and property. Smoke containment that is designed to meet building occupancy requirements - accomplished on the basis of specific and measurable code provisions - will save lives.

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