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# Fire Service and Fire Science: A Winning Combination

*To test their ability to fight high-rise fires, the Louisville Fire Department had to simulate one. And to do that, they needed the help of the National Institute of Standards and Technology.*



**above photo:**  
**FIGURE 1**  
Louisville fire truck  
outside the building  
used for the  
training exercise.

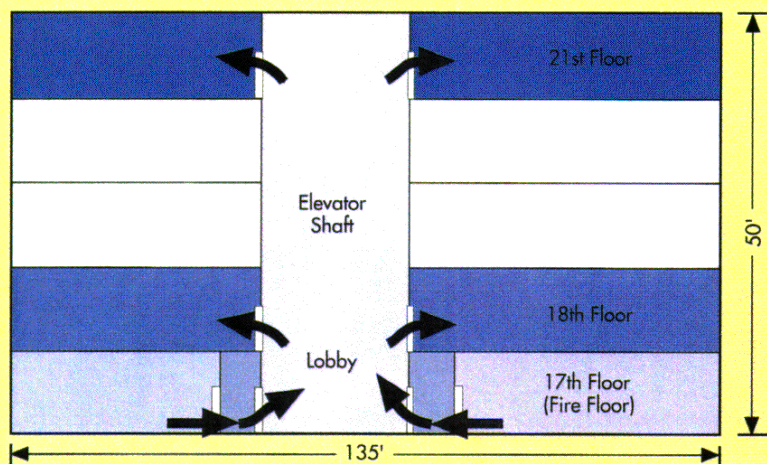
In April 1993, the Louisville, Kentucky, Fire Department was given a 21-story office building in downtown Louisville to use as a training facility for high-rise firefighting (see Figure 1). They say that timing is everything in life, and the timing in this case could not have been better.

For the past few years, we at the Louisville Fire Department have wanted to test our ability to fight a fire in a high-rise building, of which there are about 90 in the city. As a department, we are eminently qualified to handle any problem that may arise in our territory. Six hundred firefighters currently protect a population of 300,000 with 20 engines, 8 trucks, 4 special units, and 2 quints.

The Louisville Fire Department is a disciplined, well-trained department. During the past 7 years, however, nearly 350 of our most experienced firefighters have retired, and the young, strong, intelligent individuals who replaced them were long on enthusiasm but short on experience.

GERRY HAYNES / BFL

**FIGURE 2**  
**Simplified Elevation of the Building Areas Modeled with HAZARD I**



And experience has shown that high-rise fires are a fact of life in any metropolitan area. In 1986, for example, a fire at the Alexis Nihon Plaza in Montréal, Canada, spread from the 10th floor to the 16th floor while more than 240 firefighters worked to stop it. It took 13 hours to bring the blaze under control.<sup>1</sup> In 1988, a fire at the First Interstate Bank Building in Los Angeles gutted 4 floors of the 62-story building in 3½ hours. It took 383 firefighters to control that fire. And in 1991, a fire at One Meridian Plaza in Philadelphia destroyed 9 of the building's 38 floors over an 18-hour period before the flames were halted by an automatic sprinkler system on the 30th floor.<sup>2</sup> Three hundred and sixteen firefighters took part in extinguishing that blaze.<sup>3</sup>

Even though firefighters used differ-

ent tactics at each of these incidents, they were unable to control fire and smoke spread effectively above the floor

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of fire origin. Despite their best efforts, these three fires resulted in the loss of several lives and did hundreds of millions of dollars worth of damage.

### **Researching the problem**

In an effort to gain some insight into the

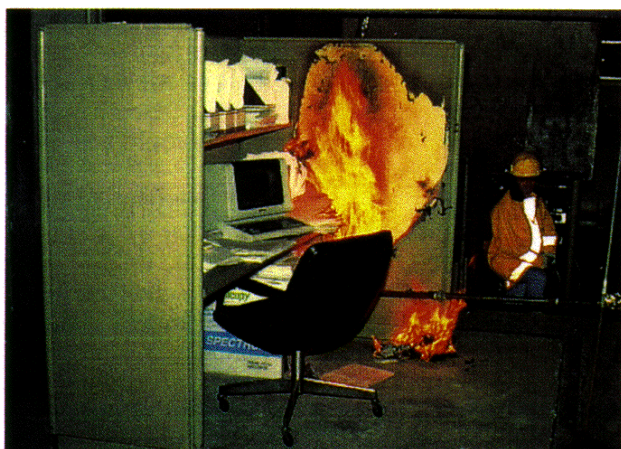
problem of high-rise firefighting, the Louisville Fire Department recently studied a number of high-rise fires and talked to chiefs and commissioners who personally had experienced disastrous high-rise fires. During these discussions, we asked them why they had been unsuccessful in managing the fire and smoke spread and what factor or factors would have changed the outcome.

Naturally, we found that the chiefs' strategies and tactics differed somewhat. Nonetheless, they all agreed on several points. Their firefighters had been unable to control fire and smoke spread above the floor of fire origin because the fire and smoke had spread rapidly both vertically and horizontally, because it was difficult to get firefighters and equipment to the upper floors, because the heat kept them from getting their firefighters above the fire floor, because smoke and fatigue wore them down, and because they could not ventilate smoke from the building. In addition, they had to deal with myriad special problems, such as falling glass, a lack of water, heavy smoke in the stairwells, and so on.

Each chief interviewed had a different strategy for combatting a high-rise fire, but they all agreed on one thing: A properly installed, working automatic sprinkler system would have prevented the disastrous results they each experienced. No matter how extensive its resources, no fire department can effectively manage a fire in an unsprinklered, open high-rise building once flashover has occurred.

If the Louisville Fire Department's short-term goal was to train its personnel in high-rise firefighting, these discussions helped us crystalize our long-term goal: We had to actively address the problem of unsprinklered high-rise

**FIGURE 4**



**Thirty seconds after ignition, the NIST workstation test fire reached a heat release rate of 110 kW.**

**FIGURE 5**



**Six and a half minutes after ignition, the workstation test fire reached a heat release rate of 950 kW.**

TEST PHOTOS, JAY MCEBOY / BERL

buildings in Louisville. We would have to initiate legislation calling for Louisville's high-rise buildings to be retrofitted with sprinklers.

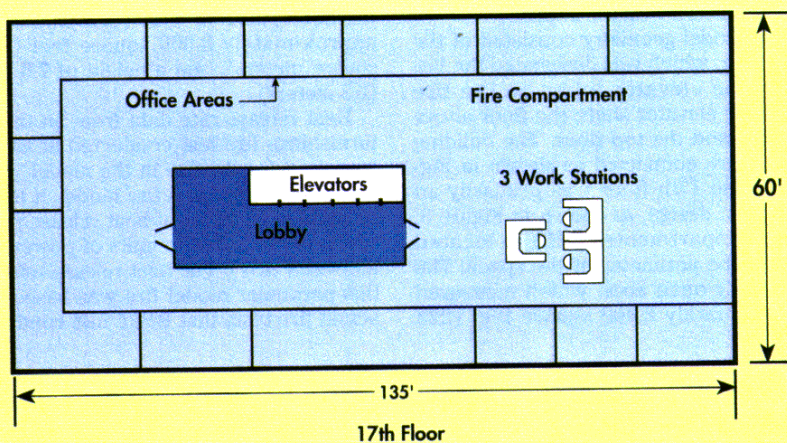
In the fight to pass the sprinkler retrofit legislation, installation costs quickly became a major obstacle. To get around that obstacle, we approached the state government with incentives in mind. We proposed providing tax incentives to owners of unsprinklered buildings to help offset the cost of retrofitting and pushed for legislation that would provide financial incentives to encourage owners of unsprinklered buildings to retrofit them with sprinkler systems.

Unfortunately, nothing substantive came of these efforts. With local elections a month away, however, the city newspaper's editorial board, an advocate of sprinkler legislation, was interviewing political candidates and publishing endorsements. The Louisville Fire Department decided that its new 21-story high-rise training building could help in the fight for sprinkler retrofit legislation. In providing the setting for a realistic training evolution, it also would be generating broad media interest.

While planning the training exercise, fire department officials discussed setting a live training fire in the building. However, we quickly abandoned that thought when we remembered past high-rise firefighting experiences. For years, the Louisville Fire Department had warned political leaders, the media, and citizens that serious high-rise fires often leave a legacy of dead occupants and firefighters. The last thing we wanted to do was prove this point. Instead, we would simulate firefighting conditions using synthetic smoke and heating the fire floor and floors above with propane heaters. This would not create the same challenges firefighters en-

**FIGURE 3**

### **Simplified Plan View of Fire Floor**



counter in a real fire, but it would not expose them to the very real dangers of fighting a high-rise fire, either.

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*To simulate a high-rise  
 fire, the fire department  
 had to determine  
 accurately the conditions  
 firefighters would  
 encounter.*  
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### **Talking to NIST**

To simulate such a fire, we needed to determine accurately the conditions firefighters would be likely to encounter so that we could evaluate the success or

failure of their efforts. Short of torching the building and initiating an actual fire attack, this posed quite a dilemma. We were unwilling to expose firefighters to the risks of an actual high-rise fire for training purposes, but we needed to predict and define the conditions they would encounter.

In search of a solution to this problem, we contacted the National Institute of Standards and Technology (NIST). NIST's Building and Fire Research Laboratory (BFRL) is a recognized leader in developing fire protection engineering methods for fire hazard analysis.<sup>4,6,7</sup> BFRL's most comprehensive set of models is HAZARD I, which is used to quantify the hazards that occupants of buildings face during fires.

Working with the Louisville Fire Department, BFRL developed an office fire scenario, based on the geometry of the

**FIGURE 6**



**Eight minutes after ignition, the test fire reached a heat release rate of 3,510 kW.**

**FIGURE 7**



**Nine minutes after ignition, the test fire reached a heat release rate of 6,710 kW.**

21-story high-rise building to be used in the training exercise. Using the data supplied, HAZARD I would provide a fire development time line we could use in conjunction with the exercise.

The model geometry consisted of the 17th floor, which was designated the fire floor; the elevator lobby on the fire floor; the elevator shaft; the floor above the fire; and the top floor. The building areas were connected as shown in Figure 2. The 17th floor was primarily an open-plan design, as shown in Figure 3, with compartmented offices located around the perimeter of the space. The remaining open area, which measured approximately 2,400 square feet (223

square meters), was chosen as the compartment of fire origin. The elevator shaft served as the vertical connection that allowed smoke to move between the floors, each of which had an area of approximately 8,000 square feet (745 square meters) and a height of 7.6 feet (2.3 meters).

Heat release rate data from an office furnishings fire test conducted at BFRL was used for the fire in the model.<sup>6</sup> If a fire is to be used in a fire model, it must be defined in terms of heat release rate, which is measured in units of power, or kilowatts (kW). The heat release rate of this particular model fire was based on actual fire tests that BFRL had conduct-

ed in office work stations.

Photographs of the fire's development are shown in Figures 4 through 7. Ten minutes after the start of a model fire, two work stations are considered to be "fully involved." To provide a perspective on the rate of fire growth, the heat release rate used in this fire model is compared to "T-squared" design fires used in NFPA 72, *National Fire Alarm Code* (see Figure 8). Household furnishings, such as sofas, easy chairs, and mattresses, are represented by "medium" to "fast" growth rate fires.

In the Louisville training building, nonrated, wood-paneled doors with windows separated the open office area from the elevator lobby on the 17th floor. The doors were assumed to remain intact during the first 5 minutes of the fire, so that smoke and heat were transmitted to the lobby only through the openings around the edges of the doors. As the temperature in the office space increased, the model assumed that the glass in the doors would fail, thus providing larger areas for hot gas movement to the rest of the building.

Hot gases could move to the floors above through the vertical elevator shafts and a heating, ventilating, and air-conditioning (HVAC) return duct. The vent from the elevator shaft to each floor was based on the area of the gaps between the elevator doors and the door frame and the area of the HVAC return duct next to the elevator bank on each floor. The model's parameters could have been varied to study the effects of mechanical ventilation, venting, and weather conditions on fire development, but these factors were not considered for this scenario.

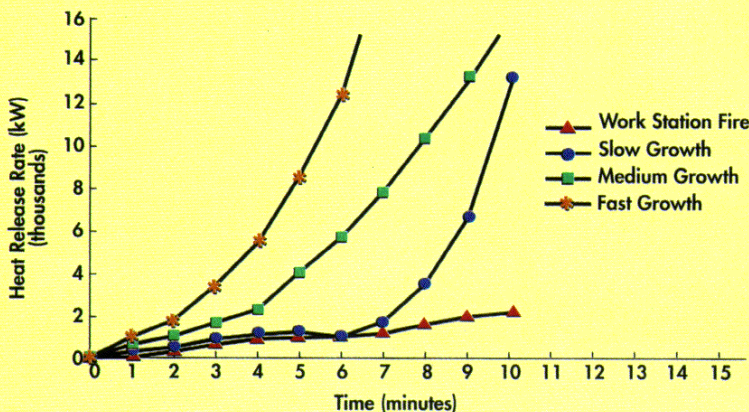
Based on the input geometry and the input fire, HAZARD I predicts smoke layer temperature, smoke layer height, and heat flux for each compartment. These can be used to evaluate the level of hazard in each compartment—that is, whether it is safe, incapacitating, or lethal. HAZARD I also predicts toxic gas concentrations, oxygen depletion, and optical density. This information has not been included here because it does not affect the outcome of the firefighter tenability analysis.

Using the data collected, BFRL modeled two cases. The first assumed an unsprinklered building, and the second considered a building with automatic sprinkler protection.

The results of the unsprinklered case show that flashover conditions of approximately 1,100°F (600°C) were reached on the fire floor approximately 9½ minutes after the fire began. Figure 9 shows the height of the smoke layer in the five different areas as it changes over time. At 9 minutes, the smoke layer

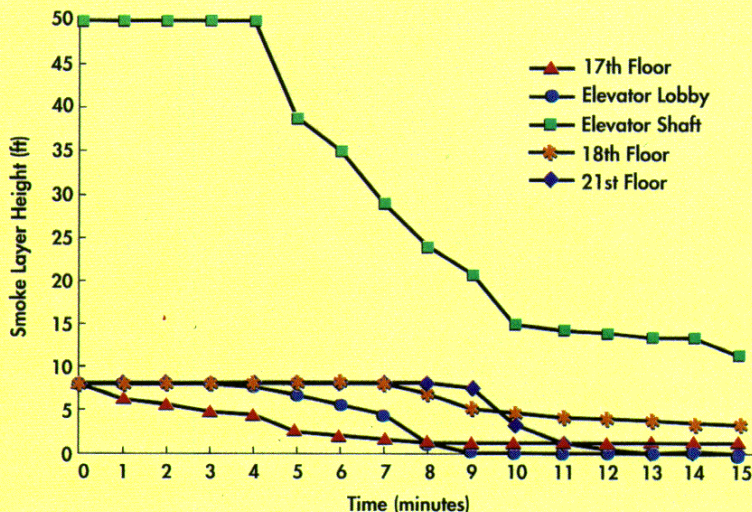
**FIGURE 8**

### Heat Release Rate Comparison Work Station vs. NFPA 72 Design Fires



**FIGURE 9**

### Smoke Layer Height



is very close to the floor in both the office area and in the elevator lobby, where the stairwell that the firefighters would use to reach the fire floor is located. As flashover approaches, exterior windows would be expected to break out, allowing more air for combustion into the fire floor and creating a path for vertical, exterior flame spread.

The heat flux measured in units of power per unit area, or  $\text{kW/m}^2$ , is shown in Figure 10. Heat flux during flashover, measured in fire tests conducted at BFRl, was found to be approximately  $25 \text{ kW/m}^2$  at floor level. This correlates well with the model's predictions. In another BFRl study, a correlation was made between the heat flux exposure from flashover and the thermal protective performance (TPP) rating of firefighters' protective clothing. The results of this study imply that protective gear with a minimum TPP of 35 would provide the firefighter with only 10 seconds of protection or less under most flashover conditions.<sup>9</sup> Given this information, a tenability limit of a 10-second exposure to flashover was used for the firefighters in this analysis. According to the model, an untenable heat flux of  $25 \text{ kW/m}^2$  is reached at approximately 9 minutes and 10 seconds into the fire on the floor of fire origin.

HAZARD I provided the fire development scenario to which the firefighters responded. The beginning of flaming combustion was defined as "time zero" for both the model and the training exercise, which was executed in exactly the same manner as an actual fire response. Firefighters were not given advance warning until the morning of the exercise. Then, an hour before the exercise was to begin, companies throughout the city were grouped in staging areas and briefed. They were told that they were being dispatched to a training fire and that all operations were to be executed as if it were an actual emergency. It was further explained that they would encounter "referees" throughout the building who would present them with specific fire rescue or related problems. Each company commander and chief officer was told to react to all situations as though they were real emergencies.

### The training exercise

At time zero, the building security guard called 911 and reported a smoke detector activation on the 17th floor. The response was dispatched 45 seconds later. Firefighters arrived at the building 3 minutes and 30 seconds after dispatch. Using the elevator lobby stairway, the first-arriving company reached the 17th floor approximately 6 minutes after arriving at the building. One minute and 20 seconds later, the first attack line was

connected to the standpipe on the 16th floor and placed in position. It took firefighters a total of 7 minutes and 20 seconds

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### *The Louisville Fire Department decided to simulate firefighting conditions using synthetic smoke and heating the fire floor and floors above with propane heaters.*

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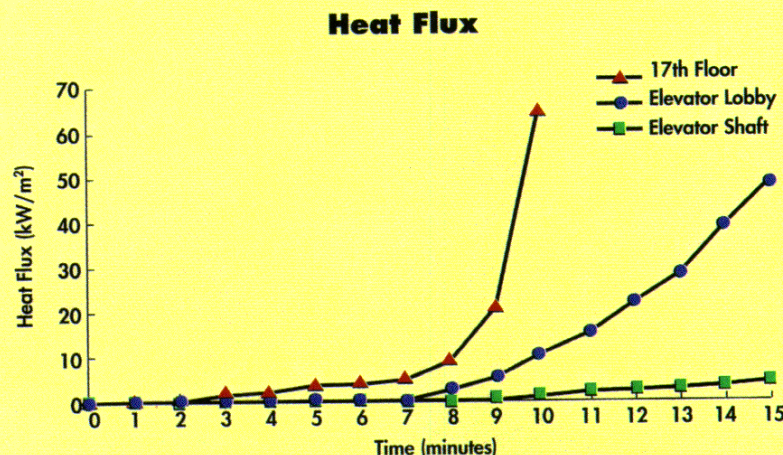
onds to ascend 17 floors in full turnout gear, carrying high-rise tools and equipment, and place an attack line in ser-

vice—an outstanding feat. Figure 11 shows a time line that compares the actions of the fire service with the development of the fire.

Unfortunately, these 7 minutes and 20 seconds, added to the 45 seconds required for dispatch and the  $3\frac{1}{2}$ -minute response time, proved to be too long. Based on the HAZARD I results, the fire floor would have reached flashover slightly more than 9 minutes after the fire was called in, more than 2 minutes before the first-in firefighters had water on their attack line.

Fire development in the First Interstate Bank Building fire was similar to that assumed here. Analysis indicates that flashover occurred approximately 11 minutes after flaming combustion began. The fire department was notified 10 minutes after the start of flaming

FIGURE 10



### The Sprinkler Algorithm

The Building and Fire Research Laboratory has developed a sprinkler fire suppression algorithm for use with sprinkler activation time models. Eight large-scale experiments were performed to determine the heat release rate (HRR) of selected office fuel packages with and without sprinklers operating. The results of these experiments were used to develop a time-dependent HRR reduction factor.

$$\text{HRR reduction factor} = e^{-0.0023t}$$

where  $t$  is the time after sprinkler activation in seconds.

The sprinkler fire suppression algo-

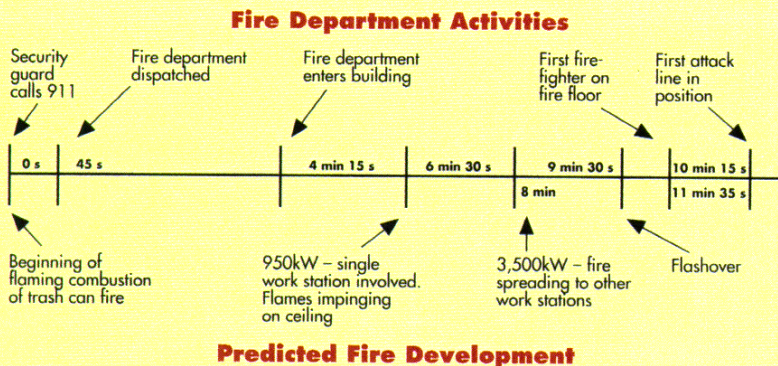
rithm consists of multiplying the HRR reduction factor by the HRR at the

time of sprinkler activation,  $\dot{Q}_{act}$ , yielding an expected upper bound to the HRR at a given time after sprinkler activation,  $\dot{Q}(t)$ , for office furnishing fires that are not heavily shielded.

$$\dot{Q}(t) = \dot{Q}_{act} e^{-0.0023t}$$

This algorithm can be thought of as a "zeroth order" fire suppression model for light hazard occupancies with a sprinkler spray density of  $0.1 \text{ gpm/ft}^2$  ( $0.07 \text{ mm/s}$ ) or greater.

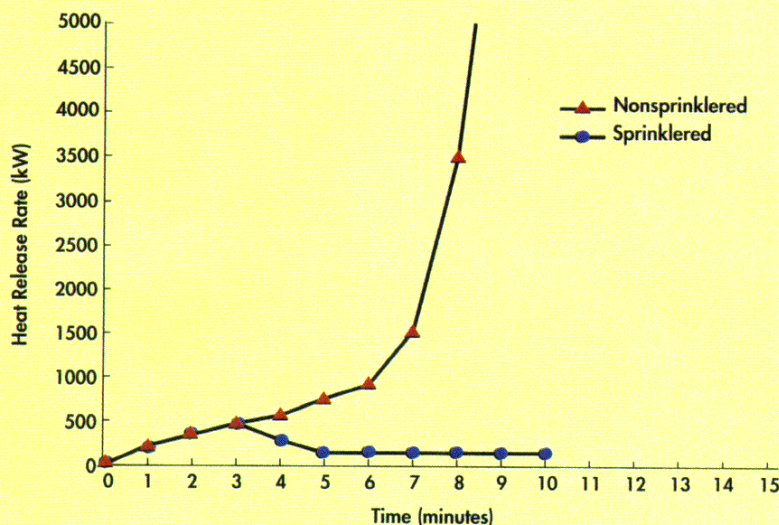
**FIGURE 11**  
Time Line Comparing Fire Department Response  
with Fire Development



short-term goal—training firefighters to fight high-rise fires—and its long-term goal—making sure that the sprinkler retrofit legislation passed. The NIST study gave us the information we needed to predict the conditions firefighters would face on the fire floor, in the elevator lobby, and on the floors above the fire without actually placing any fire-

**No matter how extensive its resources, no fire department can effectively manage a fire in an unsprinklered, open high-rise once flashover has occurred.**

**FIGURE 12**  
Heat Release Rate Comparison  
Nonsprinklered vs. Sprinklered Case



combustion, and firefighters were on the fire floor ready to mount an interior attack 20 minutes later. Considering the historical, theoretical, and empirical data, the firefighters in Louisville would have had little chance of successfully stopping the fire on the floor of origin or rescuing occupants on and above the fire floor.

The second model case assumed automatic sprinkler protection. A sprinkler with an activation temperature of 165°F (74°C) and a response time index of 100  $\text{ft}^{1/2}\text{s}^{1/2}$  (55  $\text{m}^{1/2}\text{s}^{1/2}$ ) located 10 feet from the fire would activate approximately 3 minutes after flaming combustion began. Used in conjunction with a sprinkler suppression algorithm, HAZARD I predicted that the sprinklers would pre-

vent flashover and keep conditions tenable throughout the building for individuals who were not intimate with the fire (see Figure 12).

We learned a great deal from this training exercise, and it was extremely encouraging to see how well the firefighters, both new and experienced, performed. It also was encouraging to see that the training exercise and the fire model helped prove to the public and local legislators that Louisville would benefit by mandating that the 49 non-sprinklered high-rise buildings in the city be retrofitted with automatic sprinkler systems. Legislation requiring just that passed in June 1993.

By joining forces with NIST, the Louisville Fire Department met both its

fighters at risk, providing a meaningful and safe training exercise. By using the test data and HAZARD I to transfer fire science technology to the media, to the legislators, and to the public in an understandable context, this exercise also provided the catalyst needed to pass the sprinkler retrofit ordinance in Louisville.

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