# Science on Fire

They don't answer alarms, they don't slide down poles, they don't don hats and slickers. But they're firefighters nonetheless, and they recently gathered at the National Bureau of Standards (NBS) in Gaithersburg, Md., for the Fifth Annual Conference on Fire Research.

This different breed of firefighters emphasized advances in basic fire science, or the gathering of data on specific elements such as smoldering, ignition and hot gas flow. Acquired from laser studies, computers and laboratory mock-ups, these basic data eventually can be used in the development of fire-safe materials, in the design of buildings with special structural features to retard fire spread and in similar fire-fighting applications.

"For a long time, people thought that as long as they had a fire engine in town, they were doing all they could to fight fire," says Frederic B. Clarke, director of the NBS Center for Fire Research. Then, about a decade ago, he says, fire safety officials took note of the alarming fire statistics: Each year, about 12,000 Americans were killed in fires and some 300,000 more were seriously injured; in addition, an estimated $4 billion worth of property was damaged. (And these annual statistics have held fairly steady since then.) That is when fire protection engineers realized that more effective blaze battling begins with a larger pool of data on the basics of this destructive phenomenon.

One of those basics is smoldering, or burning and smoking without flaming. "Smoldering is not a well-characterized combustion process," says NBS researcher Thomas J. Ohlemiller, "but the process is one of the most significant factors involved in residential fire deaths." About 80 percent of the deaths due to fire are caused by smoke inhalation, he explains, and where there is smoke, there is not necessarily flaming — smoldering could be the culprit.

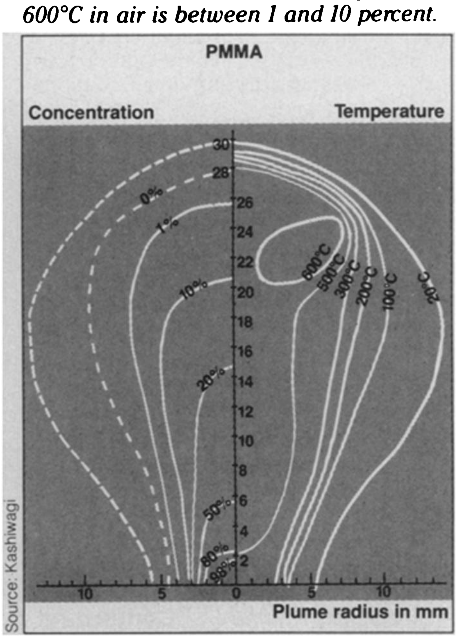
Ohlemiller has studied the smoldering of cellulosic, loose-fill insulation — an effective thermal insulator typically made from newsprint. While the flammability of this insulation is well-controlled by currently available additives, its smoldering capability is less well-controlled by the conventional smolder-retardant additive boric acid. Consequently, says Ohlemiller, when the insulation is carelessly installed and allowed to blow over heat sources such as recess light fixtures, a potential smoldering situation exists.

With an 18-centimeter-deep layer of insulation placed in a trough, Ohlemiller models such a situation in his laboratory. His "attic mock-up" also includes data-gathering gas probes and thermocouples — temperature-measuring devices. An electrical resistance heater quickly and uniformly ignites the insulation at one end of the bed, and a smolder wave sweeps slowly through the trough.

The smolder wave consists of two equally important stages — oxygen attack on the original cellulosic molecules and oxygen attack on the char left from the first stage. But boric acid, Ohlemiller discovered, "does not affect these two stages equally." While this smolder retardant does slow the heat-release rate of char oxidation (the second stage of smoldering), "Its effect on the first stage is minimal," he says. As a result, "Once smolder is initiated . . . it is always self-sustaining and continues to spread in these thick (18 cm) beds, whether the insulation is retarded or not," Ohlemiller states in the August NBS report "Smoldering Combustion Hazards of Thermal Insulation Materials." In an attic, such smoldering could create not only a smoke-generating problem, but also the potential for igniting wood materials next to it.

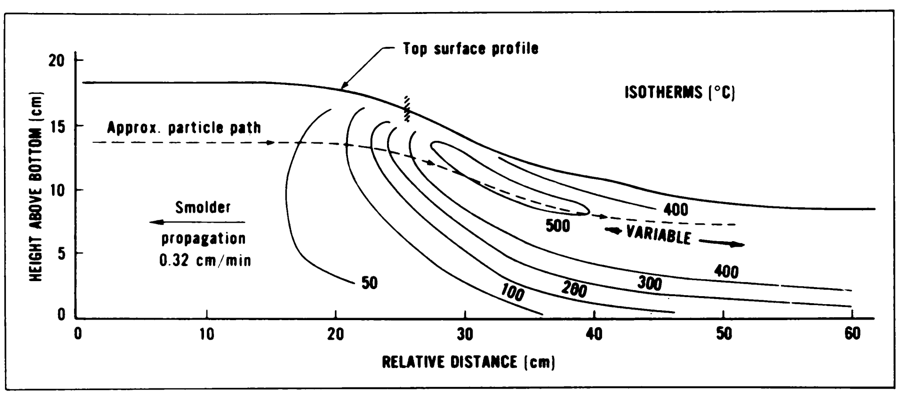
The ignition process is another area of basic fire research, and at NBS, Takashi Kashiwagi is one of the keepers of the flame. Kashiwagi combines the forces of laser holography and high-speed photography to determine the micro-chemical conditions that are necessary for the ignition of certain materials to occur.

*According to the information Kashiwagi collected 2 milliseconds before PMMA ignition, that material will ignite when the concentration of its evolved gases at 600°C in air is between 1 and 10 percent.*

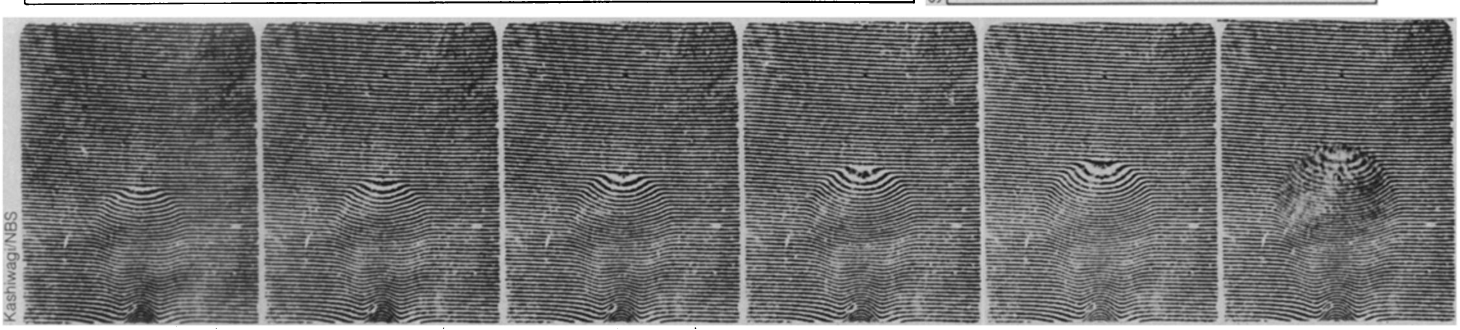



Source: Kashiwagi

*A cross-sectional diagram of a steady-state smolder wave in unretarded insulation.*




Ohlemiller/NBS



Kashiwagi/NBS

*High-speed photography records the holographic version of PMMA ignition. Straight lines indicate no gas evolution and no change in*

# Researchers probe the ABCs of fire to spell out a deeper understanding of its mode of action

BY LINDA GARMON

Thus far, Kashiwagi has investigated samples of decene ($C_{10}H_{20}$), red oak and polymethylmethacrylate (PMMA), or Plexiglas. Ignition of such materials, he says, is a function of temperature and the concentration of fuel vapor generated when samples are radiated. A $CO_2$ laser is used to radiate the samples. And because two "unknowns" (temperature and gas concentration) are sought, two different wavelengths of light — one from an argon ion (aquamarine) laser, the other from a helium-neon (red) laser — are beamed through the samples to form the hologram. When the resulting alternating aquamarine and red lines are straight, the temperature is constant and no fuel vapor is being generated. When the temperature rises and gases evolve, however, the lines begin to curve. Eventually, a darkened half-circle forms, indicating the point of ignition.

Kashiwagi records this process with high-speed (2 millisecond-per-frame) photography, and then uses the curved lines of the hologram to calculate temperature and gas concentration at the moment of ignition. Because materials far from a flame still can be ignited by a fire's radiation, Kashiwagi's detailed study of radiative ignition — to be submitted for publication in APPLIED OPTICS and COMBUSTION AND FLAME — has implications for understanding the mechanism of residential fires.

Researchers also study the stages beyond ignition in an attempt to better understand the course of residential fires. At NBS, for example, there is a model "recreation room" in the middle of what appears to be an ordinary warehouse. A folded newspaper is placed on the couch in this room and ignited with a single match. In 2 minutes, while the entire couch is engulfed in flames, the fire has not touched the rest of the fully furnished room. At the 3-minute mark, the fire suddenly takes charge of the entire room in a phenomenon called "flashover" — the "point of no return" in the evolution of a fire.

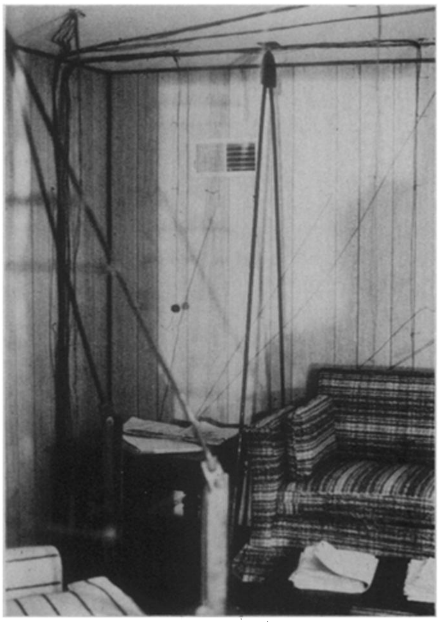
Using these dramatic full-sized room tests, researchers can obtain valuable information regarding temperature, gas flow and fire behavior in general. But these full-scale tests are difficult to perform and can cost from $10,000 to $30,000 to conduct. That is why researchers increasingly are putting fire into their computers.

Programing computers to model fire, says NBS head of such research James G. Quintiere, involves either "field" or "zone" modeling — two different mathematical strategies. Most NBS modelers use the zone approach — a method that John A. Rockett of NBS, Howard Emmons of Harvard University and Edward E. Zukoski of California Institute of Technology all independently introduced to fire research.

Zone models divide rooms into distinct homogeneous regions governed by the fire processes. They then can be used to predict, for example, the average temperature of the hot upper gas zone in a room. Leonard Y. Cooper of NBS uses this type of information to predict "safe egress," or the time available for escape before a room becomes hazardous. According to his computer program, for a 230-square-meter (2,500-square-foot) auditorium, es-

(Continued on page 222)

*Pictures of the special NBS "recreation room," the moment of "flashover" and the awesome aftermath illustrate the devastating impact of a fire.*



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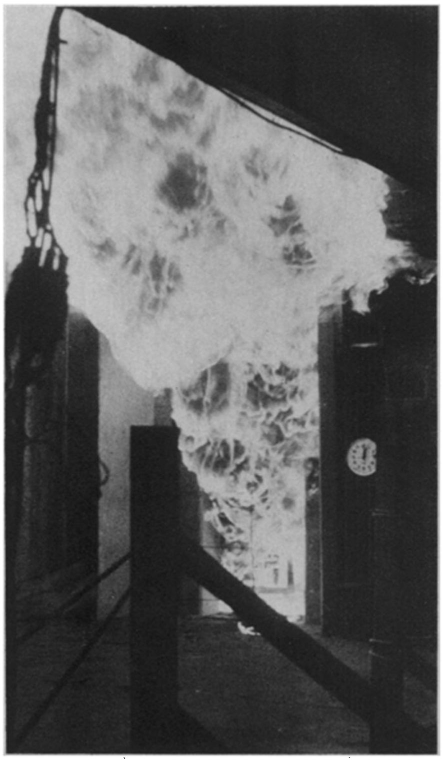
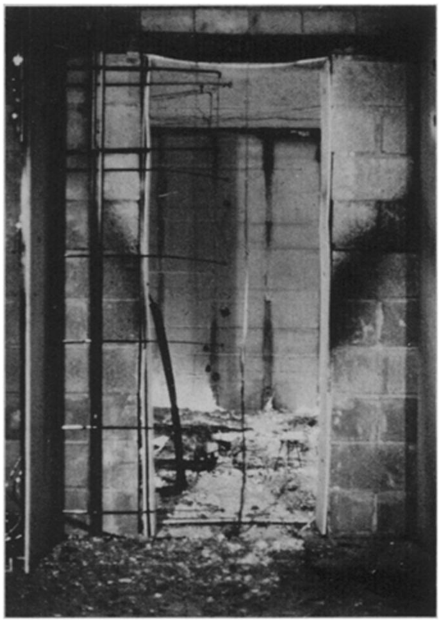
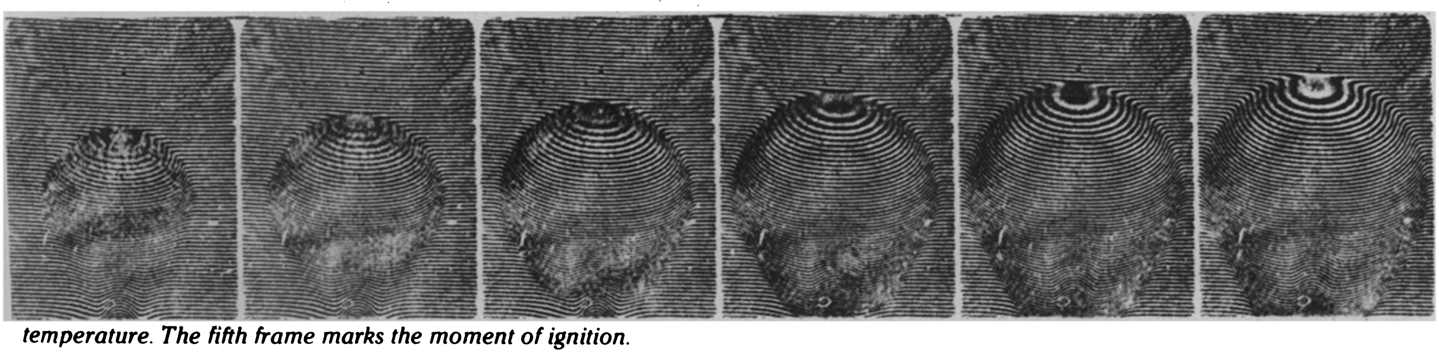






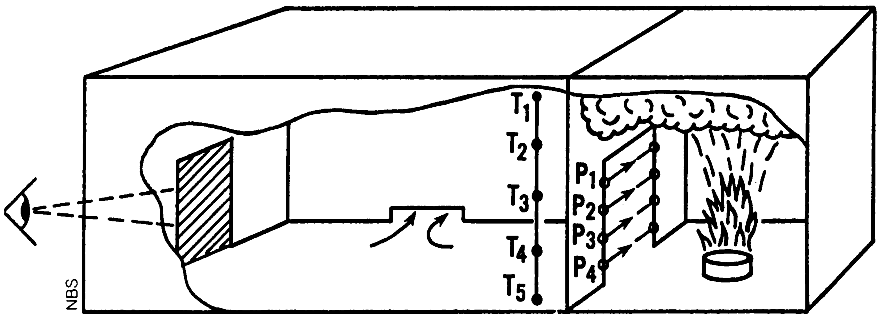
*temperature. The fifth frame marks the moment of ignition.*

NBS

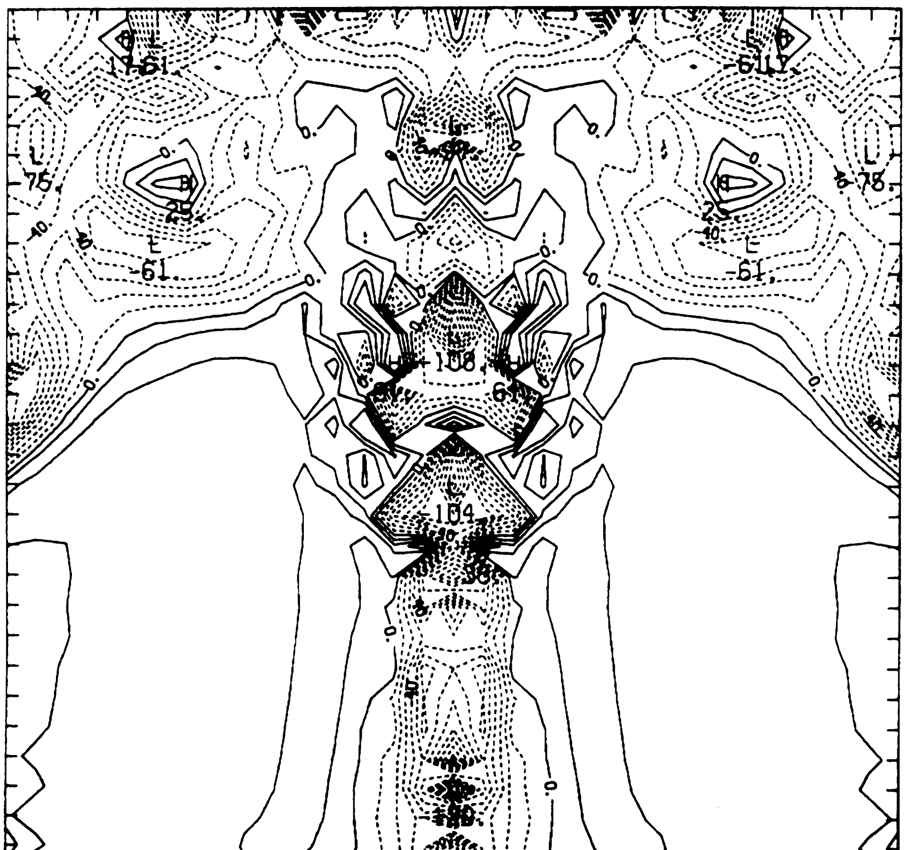
**Fire (Continued from p. 219)**
cape time is 5 to 6 minutes; for a 650-square-meter (7,000-square-foot) warehouse, it is 7 to 8 minutes; and for a 37-square-meter (400-square-foot) bedroom, it is 2 to 3 minutes.

But what if a person cannot escape? What if the fire is in a prison, for example? Then the problem is one of keeping the room safe during the fire. Cooper attacked this problem by first building four prototype cells based on those in maximum security prisons in Baltimore, Md., and Lorton, Va. He then tested a variety of doors and found that fires in cells with solid doors burn longer but at a slower rate than those with partially or fully barred doors. Next, Cooper put the data into a computer to determine how big a fan would be needed to pull smoke out of a cell block. (This system assumes there are openings at the bottom level to allow air into the cell block.) According to Cooper's program, the appropriate size ranges from one capable of moving 850 cubic meters (30,000 cubic feet) of air per minute in cells with solid doors to one capable of moving 2,000 cubic meters (70,000 cubic feet) for cells with fully open (barred) doors.

*The diagram (below) shows the arrangement of devices used to measure light intensity ($P_1$-$P_4$) and temperature ($T_1$-$T_5$) during the actual smoke-filling corridor experiment. Jones runs the same experiment on a computer (above).*




*The hot gases of this "computer fire" rise in a buoyant plume and fill the room from the top down. The lines connect points of equal temperature that, although expressed in relative units, can be converted into real units.*



Baum and Rehm/NBS

As in Cooper's prison cell computer program, most zone models simulate only single rooms. "At this point," says Quintiere, "no one has developed a program that can predict fire spread from one room to the next." However, a zone model developed by Walter Jones of NBS now can predict the spread of hot gases from one room to another.

Still, even Jones's model suffers from an affliction common to all zone models: They can produce data only in averages, not in detail. Field models, on the other hand, can provide continuous, point-by-point information over an entire space. One such model, developed by NBS researchers Ronald Rehm and Howard Baum, can differentiate between the temperature of the ceiling immediately above the fire and that farther away. This sort of information can be used to determine, for example, the most effective location for a smoke detector.

But field models also have their shortcomings — most are only two-dimensional. They can show height and width, but not breadth. They represent fires as straight lines, and as such, they can only predict theoretical fires. Only one field model — recently developed by John R. Lloyd at the University of Notre Dame in Notre Dame, Ind. — now shows three-dimensional promise.

Meanwhile, Quintiere and his colleagues are "keeping current with all the various models" and attempting to "integrate as many of their features as possible in one model." The resulting program, says Quintiere, could be used in education or training, in assessing the effect of various changes on fire-safety design and in similar fire-safety applications.

Next year, in keeping with the pattern of alternating between the basic and applied science of fire, it is these applications that will be emphasized at the NBS Annual Conference on Fire Research. "It is our intent that the distinction (between basic and applied fire research) be temporary," says Center for Fire Research Director Clarke. There already is a "gradual blurring of the borders between basic and applied work," he says.

"The laboratory scientists and the fire protection engineer don't always speak the same language, but the common vocabulary is growing," Clarke says. "Someday that language will be the same." □