RELIABILITY OF FIRE TESTS AND COMPUTER MODELING IN FIRE SCENE RECONSTRUCTION – PART II

In this paper some of the concepts discussed in Part I will be illustrated using case investigation examples. Use of calculated values, spreadsheets, scale models, “bench”-scale fire tests, and full-scale fire tests can all play a role in the accurate reconstruction of a fire or explosion or the exploration of various scenarios posed during an investigation.

Case Study 1: Exploding Gas Cans

It is often suggested that vapors emanating from a fuel tank or gas container sustained ignition within and exploded in a massive, engulfing fireball (1). An examination of the basic physical processes involved shows that the vapor pressure and temperature of the fuel and the flammability range of that fuel will determine the ignitability of vapors in the container. Once the fuel involved is identified, the vapor pressure curve of that fuel can be calculated or found in spreadsheet data. The temperature to which the fuel is exposed can be estimated from the scene investigation. As the curve in Figure 1 shows, at any normal temperature (between –20 and 40°C), the saturation vapor pressure of pentane (the major component in fresh automotive gasoline) is well above the upper flammability limit (UFL) of that fuel (noted by the upper dashed line in Figure 1). At any temperature above ~0°C, hexane, the main ingredient in Coleman© type camping fuels, will be above its UFL and therefore not ignitable in a closed container where the vapors have formed an equilibrium concentration. Firefighters know that vehicle tanks rarely explode in a fire but will support a plume of flame around the filler cap, overflow vent, or wherever vapors can escape and mix with surrounding air to be diluted into their flammability range.

To test the theoretical (calculated) concept, empirical testing of plastic fuel containers filled with gasoline was conducted in cooperation with the New Zealand Police Service. A 20 liter (5 gal.) HDPE container full of gasoline was rocked about with a loose cap so that gasoline spilled from the front and pooled around the cap (Figure 2). On ignition the spilled gasoline on the side of the can burned off in seconds, not even scorching the label. The pool around the cap burned for some seconds, igniting the plume of vapors coming from the loose cap. This fire was a small clear flame about 5” (12 cm) high, as in Figure 3. The plastic cap eventually melted into the container (with burning, molten droplets of plastic falling into the gasoline below). As the opening increased in area, and heat was absorbed by the gasoline, the plume got larger, but there was no propagation into the can to cause an explosion. In these tests eventually the entire top of the can melted or burned away, exposing the entire horizontal surface of the gasoline (see Figure 4). The maximum size of the fire is controlled by the area of the pool exposed multiplied by an experimentally determined kW/area factor. For gasoline, that is around 1800 – 2000 kW/m^2. For a typical 20 liter (5 gal.) container 15” x 15” (0.38 m x 0.38 m)in size, this means a maximum fire of about 400 kW. Estimates of the HRR of these tests based on plume height reveal a maximum fire of ~150 kW (seen in Figure 4), the reduction being due to the “lip” of plastic around the pool, reducing entrainment efficiency. Even when the test was conducted with a “flat style,” 20 l container half full lying on its side with no cap, there was no explosion. In that test the upper side of the reclining can melted away over a period of minutes (Figures 5-7). Eventually the plastic containers fail as the gasoline overflows from expansion, and a very large pool fire results.

Case Study 2: Fatal Smoke and Thermal Injuries in a Room Remote from the Fire

An elderly man was found unconscious by firefighters in his smoke- and steam-filled upstairs bedroom after a deliberately-set trash fire in the stairwell had been extinguished. He was found face up in bed wearing only underclothes and suffering from first- and second-degree burns of his face, arms, and legs. As a result of smoke inhalation complicated by emphysema and thermal burns, he died some hours after the fire. The fire was limited to the stairwell leading to the bedroom as represented in Figures 8 and 9. It was set in a “cascade” of paper trash on the steps reaching nearly to floor level on one side of the stairs. The size of the fire was estimated from the height of the thermal impact area on the wall of the stairwell where the paint was destroyed. Allowing for the wall factor in flame height calculations ($Z_f = .17\ (KQ)^{2/5}$ where K = 2), the maximum heat release rate of the fire was estimated to be 500 kW(2). Using the Zukoski equation (or FPETOOL), the mass “generation” rate of smoke can be calculated:

$$m_p = 0.065\ Q^{1/3}\ Y^{5/3}$$

where the mass rate is in kg/s, Q is the total heat release rate (kW), and Y is the vertical distance from the virtual point source of the fire to the bottom of the layer (m). Due to the change in elevation, the entrainment of air into the buoyant plume can proceed at maximum rate (filling the hall above). As the upper hall fills, Y changes from a maximum of 5 m to 2.5 m so the m_p varies from 7.5 to 2.4 Kg/s. Assuming a maximum density of 1.2 Kg/m^3 (at room temperature), the filling rate varies from 10 to 3 m^3/s. From the dimensions of the hall (20’ x 8’ x 35” – 6.1 x 2.44 x 0.9 m) (13.2 m^3) any rooms open to it (determined from the scene indicators to be a bathroom (12.7 m^3)), the rate at which the hall fills with smoke can be calculated (Figure 10). Within 10 s a 500 kW fire will basically fill the hall and bathroom. With the bedroom door partly open, the buoyancy will push substantial quantities of hot smoke into the room (Figure 11). The temperature of a ceiling jet can also be calculated for these conditions. From Quintiere’s data (Figure 12), it can be seen that a hot gas layer of 200°C would produce radiant heat fluxes of 2-3kW/m^2 at floor level (3). These fluxes are enough to induce second degree burns to exposed skin while inducing only modest damage to painted walls (and softening plastic objects like clocks immersed in it). Given the time factors of the fire and rescue estimated from physical evidence and witness statements, the total duration of exposure was about 15 min. The burn injuries and smoke injuries suffered by the victim were found to be entirely consistent with the conditions as predicted by the calculations.

Case Study 3: Burning Bodies – Lab-Scale Tests and Mathematical Calculations

In this case (and similar cases) the issue was whether the duration of a fire fueled by the combustion of a human cadaver can be estimated using published test data and mathematical calculations. Test data revealed several important properties of such fires: they are only sustained as a flame, never as a smoldering fire; clothing, bedding or other cellulosic materials that can char and act as a rigid, porous wick are necessary; the size of the fire is controlled by the area of “wick” involved (4). If we can estimate the heat release rate of the fire, knowing the heat of combustion of the fuel, we can calculate the mass loss rate (rate of fuel consumption). In the case in Figure 12, the body was found beneath roadside shrubbery burning with small flames at about 8:00 a.m. There is published data on tests of human and pork fat and tissue that reveals that the effective heat of combustion of subcutaneous fat is approximately 32 kJ/g and that, while skin and connective tissue will char and burn, the fat represents the only fuel that will readily support combustion. Because this body was found beneath shrubbery, as in Figure 13, the size of the maximum fire plume can be determined. The zone of shriveled leaves (indicating temperatures of 100˚C (or above) was 2.1 m high, while the zone of charred leaves (indicating temperatures of 400˚ – 450˚C) extended 0.6 – 0.8 m above the ground (as in Figure 14). Using a spreadsheet or plume height calculations (such as $T_o - T_\infty - 21.6\ Q^{2/3}\ Z^{-5/2}$), we find that a fire with a maximum HRR of 100 kW produces those temperatures at those heights. It has to be kept in mind that there will be substantial growth and decay periods for this fire (no ignitable liquids were detected, and the first fuel ignited was thought to be the cotton blanket in which the body was wrapped). The 100 kW represents a peak HRR, not a continuous rate. Animal carcass tests showed that a fire of 30 kW to 125 kW can be sustained by the body fat rendering down into the porous char of clothing, bedding or carpet (5). If such a fire drops much below 30 kW (30 kJ/s), it is unlikely to be self-sustaining as a flaming fire. To sustain a fire of 30 – 100 kW, the mass loss rate (given a ΔH_c of ~32 kJ/g) would be 1 – 3 g/s (3.6 – 10.8 Kg/hr – 2 – 24 lbs/hr). Based on ante-mortem and post-mortem weights, the body here was estimated to have lost ~28 Kg (62 lb). Allowing for fluid losses and growth/decay times, the duration of the fire was estimated to be 3 – 6 hours. This meant the fire had to have been ignited no later than 2:00 a.m., a conclusion that corroborated the statement of a participant. The accused was found guilty of the murder.

Case Study 4: Cubicles

Cubicles, purpose-built enclosures replicating furnished rooms in full or nearly full scale, can be used to simulate a variety of rooms. If the cubicle is built under a suitably large calorimetry hood, the heat release of the room fire can be measured continuously and accurately as the fire grows, stabilizes, and decays. The test shown in Figures 15 – 17 was conducted in the Large Burn Hall of the Fire Research Station at Garston, England (6). The fire was ignited in newspapers in a wastebasket in the right rear. Figure 15 shows the fire growing at approximately 8 minutes as furnishings ignite progressively (the sofa on the right is made using fire-retardant fabrics to meet current U.K. standards). At 10.75 min. the room achieved flashover conditions (Figure 16) and then proceeded into decay (Figure 17 at 16 min.). The heat release curve in Figure 18 shows the prolonged incipient fire stage (total HRR of 100 – 200 kW), the ignition of the non-flame-retardant or treated curtains at 7 min. (producing 2 MW), ignition of the hot smoke layer (2.7 MW), and flashover at 10.75 min. (5.2 MW). Due to the prolonged growth phase much of the fuel had been consumed prior to flashover, so the fire's maximum HRR was limited by fuel, not by ventilation. (The ventilation limit was calculated to be on the order of 10 MW.) The decay period was marked by the delayed ignition of a quantity of draperies inside the wooden cabinet on the left side.

Cubicle tests allow for direct observation of the production of indicators and fire patterns (as well as those produced by ventilation or suppression activities). In the cubicle test in Figure 19, the fire was started on top of a single bed in the right rear corner. The bed and an armchair (in the left rear corner) and the carpet and pad on the floor constituted the fuel load in the room. The fire on the bed grew over a 16 min. period until the HRR was sufficient to trigger flashover in the room. Post-flashover burning in the room consumed the exposed carpet and pad beneath and burned through the ½" plywood floor in less than 5 min. Air drawn into the lower portion of the door enhanced the combustion of floor, framework, and furniture in the vicinity of the door (right front corner). Tests in similar cubicles observed using an InfraMetrics thermal imaging video camera revealed the extreme turbulence and high temperatures produced in the doorway of a post-flashover room fire (7). The thermal images in Figure 21 show the same non-accelerated fire 20 s apart (some 20 min. after ignition of bedding). The temperatures near the floor are on the order of 1800˚F (1000˚C), and the highest temperature zones are moving rapidly and chaotically due to the turbulence of the incoming air.

Cubicle tests allow easy observation of suppression effects such as the scouring of soot off a wall by a nozzle-spray (Figure 21) or ventilation effects (such as those in Figure 22). In that later case the fire had progressed to flashover and the observation window in the rear corner shattered due to thermal shock. The air drawn in caused a high temperature flame zone to form and burn the soot and paper off the drywall nearby. Without that broken window, that area would have been in an oxygen-deficient zone of the fire.

Case Study 5: Full-Scale Tests

In complex fires, especially those involving fatalities, it is sometimes necessary to duplicate the actual structure in a full-scale test. In this case a two-story, all-wood, hollow-frame structure suffered an extensive fire that involved the front half of the first floor, most of the top floor, and heavily damaged the open stairwell in between (Figure 23) (8). The bodies of two adults and four children were found upstairs. An adult (husband of one victim) and one child escaped without injury. They described a rapidly-growing fire in the living room sofa that engulfed the room and spread upstairs, trapping the others. The original investigation revealed burn patterns on the floors and partial failures of walls and ceilings did not match the placement of fuel packages (furniture). There was extensive post-flashover burning due to delayed alarm and response (isolated area of town) that obscured many indicators. Lab results originally indicated the presence of an ignitable liquid in floor debris. The evaluation of a death penalty arson-murder case against the husband prompted the State's Attorney to seek additional information. Re-testing of the physical evidence demonstrated original lab results were erroneous; there were only pyrolysis products, no detectable ignitable liquids. Proof of a deliberately-set fire then rested on fire patterns alone.

The discovery of a nearly identical house next door (Figure 24), abandoned and slated for demolition, permitted an evaluation of the structure, especially the walls and ceilings. By comparison, it was discovered that the burned house had been repaired with a variety of methods, producing an unpredictable response to fire insult. (Some areas of walls and ceilings were only a single thickness of ⅜" drywall; others were two layers of drywall; others yet more drywall over plaster and lath.)

It was decided to use the "new" structure for two tests to establish how fires (accelerated and non-accelerated) spread, how long it would take to trap occupants upstairs, and what fire patterns would be produced. The house was fitted with new windows and walls and ceilings repaired, and then refurnished to match the original house as closely as possible (Figures 25 and 26). A thermocouple tree was prepared for the living room and other thermocouples recorded temperatures in the hall, stairwell and upstairs. Gases were sampled in the stairwell and upstairs bedroom door. Video cameras inside and outside monitored development of smoke and fire from various vantage points (Figure 27). The first fire, set on the living room sofa with only a match (Figure 28), produced a fire that went to flashover in about 4 minutes and produced unsurvivable conditions at the bedroom door just 4½ minutes after ignition (Figure 29). That fire was extinguished, windows and walls replaced, and new furniture and carpet installed. The second fire was ignited using gasoline in the living room and at the base of the stairs in the hall. That fire would have trapped victims upstairs in about 2½ minutes. The burn patterns produced by the first (non-accelerated) fire were indistinguishable from the patterns observed in the original house, and the mechanisms for producing them could be identified by the observation (direct and by video) of the developing fire. These factors (and a fresh examination of some other evidence) led the prosecutor to drop the charges against the husband as there was no irrefutable proof of the incendiary nature of the fire.

Case Study 6: Van Fire

In this case a camper-style van fully engulfed in flames was observed by a witness (9). Upon extinguishment the badly burned body of an adult female was found in the cargo area of the van. Her companion said he and the decedent were sleeping on the floor of the van, and he awoke to find the van filling with dense smoke. He said he attempted to awaken his friend, but she was non-responsive. He reportedly found the doors locked and escaped by ramming a rear door window with his head and crawling out. He reported the doors were locked, and he could not rescue her as the fire grew inside the van. The van was nearly gutted before suppression about 30 minutes after being seen alight by the witness (Figure 30). The van had been parked since the previous evening, and no vehicle systems were involved (fuel still in tank, components normal). The victim was young, healthy, and unimpaired by drugs or alcohol. She had a 41% COHb saturation. The right half of the body had been reduced to ashes and bone fragments, obscuring some potential evidence of assault (as in Figure 31). There was no blood or ignitable liquid residue found on the carpet beneath the body.

The survivor had a coating of soot on his face, arms and hands, fresh abrasions to the scalp at the top of his head, broken glass in his hair, longitudinal abrasions on his lower legs, and singed hair at the top of his head, but no singed facial hair (Figure 32). His blood was not taken until several hours after the fire but still had elevated COHb levels (but no alcohol or significant drug levels). The investigators concluded that the fire had to be deliberate and that a flammable liquid would be the only means by which such an intense fire could occur. The survivor was charged with murder. The negative lab report, absence of singed facial hair or burns on the survivor, soot deposits and injuries of the survivor, and elevated (but not fatal) COHb saturation in the victim all created doubt and prompted the prosecutor to seek a second opinion.

Analysis of the incident was aided by extensive photos and retention of the van and its contents. The van contained a considerable quantity of boxes and bags of clothing, food, and camping supplies (as in Figure 33) in addition to its standard upholstery and built-in wooden storage lockers (for tools). That all represented a significant fuel load. The style of van provided a large number of windows that would fail as a fire inside progressed (Figure 34). Using the ventilation limit calculation in FPETOOL, the maximum fire size was calculated to be over 3 MW once all the windows had failed. Given the quantity of fuel and the availability of oxygen via the windows, it was hypothesized that a flaming fire started accidentally inside the van could produce the observed damage to the van, injuries, toxicology results, and damage to the victim’s body without the use of accelerants.

To test this hypothesis a nearly identical van was obtained with the same interior and size (Figure 35). A vent was cut in one side that could be opened during the fire to create a total ventilation area equivalent to failure of all the original van’s windows. A thermocouple was installed near the center of the cargo compartment and a single thermocouple placed near a rear door window. The fuel load of the original vehicle was approximated with the same type (clothing and containers) and arrangement, simulating the same total surface area (which controls the maximum heat release rate) (Figure 36). The same total mass could not be replicated (affecting only the duration of the fire). The fire test was videotaped and thermocouple readings recorded. The fire was started with a match to paper and the doors and windows closed. The interior became untenable (T > 100˚C, heavy smoke in upper layer) at 3.5 min., at which time the escape of the survivor was simulated by breaking the one rear-door window. The fire grew to flashover at approximately 7 min. (windows failing between 6 and 8 min.) (Figure 37). As seen in Figure 38, maximum ceiling temperature reached 1100˚C (2000˚F). Rapid onset of decay occurred as the fuel exhausted quickly. Temperatures in excess of those of a commercial crematorium (800˚C) existed for over 10 min. of the 30 min. test.

Conclusions:

1. The statements of the survivor were credible.
2. Injuries and physical evidence of the survivor were consistent.
3. Conditions inside the van were more severe than in a cremation (and would have done similar damage if prolonged by more fuel).
4. No accelerant was needed.
5. Damage to the body and toxicological findings of the victim were all consistent with a non-accelerated fire.
6. There was no irrefutable evidence of deliberate ignition, and all charges were dropped before trial.

Case Study 7: Scale-Model Tests

In 1998 a fire in a crowded disco in Gothenburg, Sweden, killed 63 and injured over 200 attendees (10). The disco was on the second floor of a converted industrial building with only two stairwell exits (one of which was blocked by heavy smoke and fire) coming into the dance area. The smoke spread rapidly when a stairwell door was opened, and shortly after fire spread across the still-trapped party-goers. A massive joint investigation was undertaken by police and fire officials and fire engineers at SP (Sweden's equivalent of NIST) and Lund University. The scene investigation revealed that the first fuel ignited was the stack of chairs piled on a landing of one stairwell and that the lower entry door to the stairs was left open (Figure 39). Lab tests of similar chairs showed ignition had to be deliberate (open flame), not an accidental smoldering cigarette, and recorded the fire growth and HRR characteristics of such stacks. With that as input data, SP created a 1:4 scale model of the building to study smoke and fire movement. Not all factors in fire behavior scale in the same way as the linear dimensions of a scale model. The Froude number (the relationship of inertial to gravity forces) is used to validate scaling factors such as ventilation area, radiant heat, flow velocities, and even time.

Even the thermal properties of structural materials were scaled in this exacting study. Modeling the masonry stairwells, for instance, required finding a material whose thermal properties mimicked concrete and brick on a 1:4 scale. A calcium silica board was found to match. The smoke tests were conducted some 14 times to study the movement of smoke with variations in door position and timing. The model results were compared to witness statements (from inside and outside the club), scene observations and evidence, and the results of CFD modeling carried out by Lund University (11). It was discovered that the combustibility of the floor covering in the disco contributed to the spread of fire once the hot gases from the stairwell were admitted into the main hall (Figure 40). All test results used together showed that the stack of chairs on the stairwell landing were ignited by direct open flame some 15 min. before the upper door was opened and that the spread of the fire from that point was due to normal ventilation and smoke flows and the ignitability of fuels already present (and not to the use of an accelerant).

Case Study 8: Modeling Corroborates Fire Pattern Interpretation

FDS modeling was conducted by Dr. David Icove as part of an arson-murder investigation originally with the intent of studying the tenability of the fire on a witness/suspect. An early-morning fire destroyed the one-bedroom apartment leaving a male victim dead in his recliner chair in the living room. Post-mortem tests revealed he died of natural causes prior to the fire. The victim’s wife claimed she had awakened to find the chair already well alight, attempted to douse the fire with a pitcher of water and attempted several times to call 9-1-1. She eventually fled the apartment to find a telephone elsewhere. By the time fire crews arrived, the fire had exited the apartment and engulfed the adjacent landing and stairs, trapping a family of four in the apartment above. Scene investigation left no doubt that the fire started in the recliner (with the body in it). Lab tests revealed that a dropped cigarette was not capable of igniting the recliner material, but a dropped match was a competent ignition source. (Due to the decedent’s medical condition, he was not physically capable of lighting a paper match, so he always used a disposable butane lighter.

A large-scale test using a duplicate recliner, bedding, and a large pig carcass was recorded via videotape, with that data used as the input fire for the model. FDS (using Smokeview) predicted burn patterns on the walls and ceiling nearest the recliner (as in Figure 41) that matched scene observations. This confirmed the reported location of the recliner. Smokeview also showed the development of heat horizons in the living room and adjacent rooms that corroborated heat patterns at the scene (see Figure 42). The predicted time of development of the hot smoke layer indicated that the wife could not have been in the room doing the things she said she was and suffer no burns, heat or significant smoke inhalation injuries. While the test results were referred to during testimony as one of the means by which the investigators’ recreations were corroborated, the data itself or the graphic representation was not introduced as evidence.

Case Study 9: Firefighter Deaths in a Structure Fire-Testing Hypotheses

Three Pittsburgh firefighters died during the suppression of an arson-caused fire in a four-story building in 1995. They apparently became lost in the heavy smoke and died from inhalation of combustion products. This fire was one of several excellent studies NIST has published regarding application of FDS to complex fire reconstructions. The NIST study addressed the reconstruction of the fire, retracing its path of development and evaluating an ignition on the bottom floor (a flammable-liquid accelerated fire) (12). Two the firefighters had similar COHb saturations (44 and 49%), while the third had a COHb saturation of only 10%. This discrepancy suggested different mechanisms (or activities) were involved. Christensen and Icove addressed the hypothesis that two of the firefighters were using “buddy breathing” fro one air bottle and were exposed to different combustion gases and that affected their survival (C&I, JFS). The COHb saturation in blood is generally governed by the Stewart relationship (for slow to moderate concentrations of CO in air):

$$\mathrm{COHb} = (3.317 \times 10^{-5})\,(\mathrm{CO})^{1.038}\,(\mathrm{RMV})\,t$$

where COHb is in % saturation in blood, CO is carbon monoxide concentration in ppm, RMV is the respiratory minute volume in liters per minute, and t is the exposure time in minutes.

Therefore, if we know the COHb saturation and can estimate the CO concentration and RMV of the victim, we can estimate exposure time. The RMV is dependent on the sex, age, and physical activity of the individual. For male firefighters during maximum physical exertion, the rate has been measured to be approximately 70 liters per minute.

Using FDS the fire was modeled based on floor plans and sketches derived from a technical report produced by the Federal Emergency Management Agency (13). The starting fire was “simulated” using a gasoline pool fire of some 700 kW HRR. Since CO concentration was the product of interest, a vertical “slice” through the structure using Smokeview allowed the monitoring of CO heights and concentrations. The slice through the family room (see Figure 43) in which the firefighters were found predicted that at the time the firefighters reported they were apparently running low (27 minutes into the event), the CO concentration was about 3600 ppm. For exposure time to reach 47% COHb, that firefighter would be breathing CO-laden air for 4 – 5 min. (or longer if fresh air were inhaled periodically). This indicated that while a heroic gesture, sharing a mask is futile because exposure to toxic combustion gases while transferring the facemask resulted in fatal (or likely fatal) CO concentrations. The third firefighter apparently died from oxygen deprivation as his air bottle was depleted and his mask remained in place. This study illustrates the potential value for advanced fire modeling to evaluate various elements of a fire scene (not simply fire growth).

Case Study 10: Evaluation of Two Competing Scenarios in a Fatal Fire

An early-morning fire in a two-story residence resulted in the smoke inhalation deaths of two elderly and partially disabled residents. An adult son who reported the fire escaped, reportedly after attempting an unsuccessful rescue. He described finding his parents in a found floor family room attempting to deal with a fire on a sofa. While he called 9-1-1, he assumed his parents escaped the rapidly-growing fire. The fire gutted the family room, and fire damage extended into an adjacent kitchen and hallway. Fire patterns in the room of origin lead original investigators to believe the fire had been started with a pour of gasoline across the room while the parents were in an upstairs bedroom. The investigator did not appreciate the effects of cross-ventilation in a post-flashover room fire nor the fuel contributions made by the modern furniture and thin wall paneling on one wall (adjacent to one sofa). Defense investigators assessed the fuel load and ventilation in the room and estimated that a fire started in a sofa could result in flashover in the room in just a few minutes, overwhelming room occupants. Jason Sutula modeled the house using FDS with "starting fires" of both accelerated and non-accelerated (flame on furniture) types (14). The heat release curves and Smokeview images showed that an accelerated fire in the family room would grow so quickly that the victims or the survivor would not survive long enough to reach their final locations (see Figure 44). FDS showed that fire growth would be at a slow, progressive rate if furniture were ignited, and the flames and smoke from the accidental fire would more closely agree with the physical and testimonial evidence (as in Figure 45). Those predictions, accompanies by data from cubicle tests, eventually convinced the prosecutor that the suggested arson using flammable liquids was not provable or even possible.

Conclusion

It is hoped that these case studies will help illustrate some of the key elements emphasized in Part I. Lab-scale, reduced-scale, and full-scale tests can all play a role in accurate reconstructions and provide critical data (such as "input" or initial fire growth curves) in support of computer models. Similarly, mathematical methods, from computer models to simple calculations, can aid the investigator in testing hypotheses in scientific fire investigation.

Dr. John D. DeHaan
June 18, 2004