Fire Research: Providing New Tools for Fire Investigation

DAN MADRZYKOWSKI–Imagine arriving at a fire scene. You examine the area, working your way to the room of fire origin. As you survey the burned out room, something doesn't add up. The heavy burn pattern on the wall and the ceiling is remote from the apparent spill pattern on the floor.

After taking digital images of the room and loading them into your strap-on portable computer, you can "stitch" the separate images together to form a virtual fire room. Assigning a reference dimension to your image allows the computer to develop an input file for a mathematical fire simulation. You continue to define your digital image and add data, defining surfaces so that the computer model attaches values, such as ignition temperature or heat release rate per unit area to each.

Next, identify the openings to the doorways, HVAC vents or windows to complete the geometry of the model. Trace the demarcation lines of thermal damage on the image. Finally, define an ignition source, place the ignition fire and press the submit button.

The satellite modem sends your input fire to a remote computing site and the model is analyzed. A series of potential solutions to your problem are downloaded to your portable computer for you to watch. The fire simulations help you visualize what may have happened, which may lead to a "best fit" scenario or guide you in continuing your investigation. Sounds farfetched? Even impossible?

Research is currently underway that could deliver this type of technology within the decade. Researchers at the National Institute of Standards and Technology, Building and Fire Research Laboratory are working with the U.S. Fire Administration (USFA), the Bureau of Alcohol, Tobacco and Firearms (ATF) and the U.S. Department of Justice (DoJ) to provide a more scientific basis for the investigation of fire. This article will provide an overview of where the state of the art research is and where it may lead us.

Science vs. Arson

Arson is one of the top causes of fires and fire deaths in the United States. The annual direct dollar losses from arson are approximately $3.6 billion dollars[1]. As previously discussed in the pages of Fire Chief by Professor Vincent Brannigan, fire investigators will have to work differently if their expert testimony is to be admissible in court[2,3]. Because of the Daubert and the Kumho Tire decisions, expert testimony must be technically defensible.

In other words, if something cannot be proven based on scientific principles or recreated in an experiment, then it may not be admissible as evidence in court. Coupled with the estimate that only 2 percent of set fires lead to conviction, the fire investigation community is looking to improve their capabilities by building a better scientific foundation for their use [4].

Knowledge built on technically defensible data is only one part of what is needed to successfully investigate a fire scene. A well-trained and well-equipped investigator is critical to the process. To that end, efforts have also been undertaken to provide high quality fire investigation training to a wide audience. In addition, research and field-testing is being conducted to develop state of the art hardware for investigators.

Computer Based Training

A standardized, state of the art, fire investigation training package was the goal of the public-private partnership that developed interFIRE VR. The Bureau of Alcohol, Tobacco and Firearms (ATF) spearheaded the partnership that included the United States Fire Administration (USFA), the National Fire Protection Association (NFPA), and the American Re-Insurance Company. Experts from the International Association of Arson Investigators, the National Institute of Standards and Technology, and the law firm of Butler, Burnette and Pappas also contributed to the development of the material for the training package.

InterFIRE VR is a CD-ROM based interactive training program that was developed using the latest in pc-based virtual reality technology to present lessons of best practices in fire investigation. The program has three work sections, which include a series of video clip based tutorials, a reference file, and the "scenario."

The tutorial section provides training segments on topic areas such as preparing for the investigation, collecting evidence, documenting the scene, interviewing witnesses, and preparing for the trial.

The reference file section provides information on a broad range of topics including; arson prevention, evidence preservation, trial preparation, forensic accounting, and fire modeling to list a few.

The "scenario section" allows the user to "respond to a call" and conduct an investigation from start to finish. The user must document the scene, collect evidence, submit evidence for lab analysis, interview witnesses and present the case. The program even provides the option of working with a canine team to assist in case. The "team approach" to fire investigation is emphasized to demonstrate how using all of your available resources can yield a more thorough and timely investigation.

In addition, the house fire used in the scenario was filmed and instrumented by the National Institute of Standards and Technology, for interFIRE VR users that want to use a computer fire model on the case. They can compare their model predictions with the temperature data given in [5].

To view updated information related to interFIRE VR and fire investigation in general visit the interFIRE website at www.interfire.org. Copies of interFIRE VR can also be ordered from the website. Members of the fire service obtaining a copy for their department may contact the USFA for a copy of interFIRE VR.

Arson Intervention and Mitigation Strategy (AIMS)

AIMS is a joint project of the U.S. Fire Administration and the U.S. Tennessee Valley Authority Police[6]. The objective of the project is to enhance fire investigation by: standardizing the process of scene documentation, increasing the communications and data transfer capability of investigators at the scene, and providing electronic references and computer fire modeling capability to investigators.

The program supports a field investigators need to collect, record, and document information or images to simplify case information management. The system also enables rapid data exchange to allow for on-scene interaction with persons remote from the fire site.

The hardware and software core of the AIMS project is called the Transportable Rapid Information Package or TRIP. The hardware consists of a laptop computer that is integrated with a GPS receiver, color printer, document scanner, evidence label printer, digital cameras (still and video), cell phone and wireless LAN capabilities.

tion from the National Fire Incident Repository System (NFIRS), FBI Uniform Crime Incident Reports (UCR) or provide remote access to reference materials or to fire libraries such as the Fire Research Information Service at NIST.

Table 1. TRIP Functional Capabilities

	Functional Elements
Basic Virtual Office Unit	Laptop configured with color scanner, printer, and Microsoft Professional Office software tools
Fire Reports	Field data collection of information needed for NFIRS, NIBRS, and fire modeling
Interviews	Written field witness interviews using prompted questions.
Evidence Collection	Photography by digital and video cameras, printing of evidence labels
Fire Scene Diagramming	Computer-assisted drafting of building floor plans and fire scene.
Mapping and Global	Plotting the fire scene location on a digital map using GPS positioning system (GPS)
CD-ROM Library	Retrieval of fire reports, NFPA fire codes, and NFIRS data profiles and NIST models
Network Conferencing	Wireless network with other TRIP units with video desktop conferencing
Telecommunications	Cellular and pager communications, faxing of reports from scene

Table 2. Technological Assessment Matrix

Major Goals	Current Practices	Current Challenges	TRIP Phase 1 Solutions
Case Management	Non-standard approach to scene	Reliance on NFPA 921 and 1033	Template-based scene exams
Incident Reporting Systems	Complete Separate NFIRS and NIBRS forms	Reduce reporting duplication	Collect data, print NFIRS and NIBRS reports
Fire Investigation Unit Management	Cases assigned and closed as needed	Develop case solvability scoring	Incorporate case solvability factors
Litigation and Prosecutive Support	Cases based on written files	Automate case	Case-based search and retrieval of data
Investigative efficiency and productivity	Case assignments by call out	Measure efficiency	Time-motion studies

(Tables courtesy of Kenneth Kuntz, USFA, FEMA)

TRIP can be used to process and distribute information, data and images from the fire scene or it can be used to retrieve informa-

The functional capabilities of the TRIP are summarized in Table 1. The technological improvements to the fire investigation and case information management are summarized in Table 2.

Fire Investigation Research

While the training and applied research and development efforts listed above can increase investigators' skills and enhance their field capabilities, the field of fire investigation has another underlying weakness. There is the lack of a comprehensive body of data or knowledge to which fire investigators can refer. Needs in this area include an appropriate understanding of fire dynamics, real world ignition thresholds, effects of ignition sources, heat release rate and flame spread data for a wide variety of commercial products and material assemblies and the generation of fire patterns to name a few.

A limited amount of work has been started by a variety of federal agencies to address the research needs of the fire investigation community. Summaries of these research programs are given below.

USFA Fire Burn Pattern Tests

USFA in conjunction with NIST conducted a series of full-scale fire experiments study the development of fire patterns[7]. The experiments were conducted in rooms constructed in a laboratory as well as in rooms in residential structures. Different fuel loads were used during the course of the study. The experiments were designed by a committee of fire investigators, and the post fire analysis was conducted by a team of seasoned fire investigators. Many patterns were produced and documented during the course of experiments. It was documented that fire patterns are influenced by a variety of variables. The report identified two parameters that had a major influence on the resulting fire patterns, ventilation and flashover. The results from this report have provided the direction for further fire pattern study.

NIJ Full Scale Room Burn Pattern Study

The Building and Fire Research Laboratory and the Office of Law Enforcement Standards at NIST under the sponsorship of NIJ conducted a series of experiments with the University of Maryland, Maryland Fire & Rescue Institute [8]. These experiments focused on a single room configuration with a similar set of furnishings used in each experiment. Four experiments were conducted. Two replicate experiments were ignited with a small flame on an upholstered chair. The other two experiments used a 0.95 L (1 qt) spill of gasoline on the floor of the room as the first item ignited. In the first two experiments, un-accelerated ignition, flashover occurred at approximately 5 minutes and 40 seconds in both experiments. The experiments that used the gasoline ignition reached flashover conditions at approximately 1 minute and 15 seconds. In all of the experiments fire suppression was started approximately 3 minutes after flashover began.

The temperature and heat flux time measurements were conducted for each experiment and are provided in the report. In two of the experiments, oxygen, carbon dioxide and carbon monoxide measurements were also made. In addition, the rooms and furnishings were studied and photographed after each experiment. Comparisons between the replicate experiments yielded many similarities in the data, in the burn patterns and in the condition of articles in the burn rooms such as "pulled light bulbs". The evidence suggests that light bulbs pull in the direction of the greatest heat, but not necessarily toward the fire's origin.

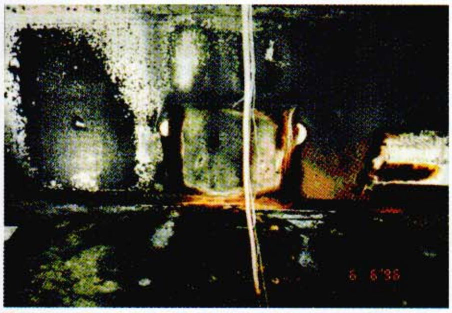

Figure 1. Back wall of chair ignition experiment.

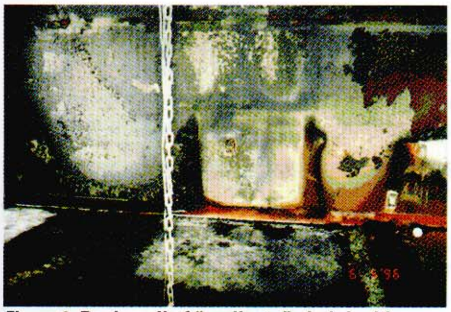

Figure 2. Back wall of "replicate" chair ignition experiment.

Unfortunately for investigators, the "replicate" experiments also produced some significant differences in the "severity of burning, the locations of patterns, and the types of patterns present"[8]. A comparative example can be seen in figures 1 and 2. The figures show a photograph of the back wall for each of the small flame ignition experiments. The outline of the upholstered chair that was ignited can be seen in the center of each wall. The outline of the bed can be seen to the right of the chair. With the exception of the burn patterns on the wall above location of the chair, the walls yield significantly different patterns. Fire patterns, therefore, may not be such reliable indicators as many fire investigators believe.

As in the USFA research, ventilation seems to be the prime cause of the difference in fire behavior within the rooms that led to the different burn patterns. Based on the results of these studies, further research has been started to decouple the phenomena that occur in full-scale room fires in order to gain a better understanding of fire pattern development.

Liquid Fuel Spill/ Burn Pattern Study

NIST has conducted a study examining gasoline spills and the burn patterns caused by them[9]. NIJ sponsored the first phase of the study, which measured the physical size of the spill relative to the amount of gasoline spilled. Several types of floor covering were used in the experiments; vinyl tile, wood parquet, dense loop polyolefin carpeting and cut pile nylon carpeting. The floors had no walls around them, to eliminate compartmentation effects and were positioned under a smoke hood instrumented to measure heat release rate. After the initial spill pattern measurements were made, the spills were ignited. The resulting burn patterns were measured and heat release rates were determined. A photograph of one of the experiments is provided in figure 3.

Figure 3. Burn pattern fire experiment conducted under fire products calorimeter.

The results from this report provide fire investigators with a means to predict the quantity of spilled gasoline needed to produce a burn pattern of a given size on number of common flooring materials. Heat release rate data for each experiment is provided for use in fire model calculations.

In each of the carpeted floor experiments, a "doughnut" pattern remained where quantities of gasoline were present. This phenomenon, which results from the liquid accelerant actually protecting the carpet, is consistent with the experience of many fire investigators.

Additional liquid burn pattern experiments are being planned in buildings of opportunity. The experiments conducted at NIST will be repeated in rooms to examine the effects of the compartment and then the additional effects on the floor pattern of furnishings in the room. These experiments sponsored by NIJ and USFA are scheduled for completion later this year.

Fire Simulations

Computer fire models have been used by fire investigators for many years. Typically these have been relatively simple numerical correlations or "zone models" such as ASET-B, FPETool, or FAST. These models can be used to calculate a characteristic temperature for the hot gas layer in a room and define the position of the hot gas layer height.

Recently a new model has been developed and issued by NIST called the Fire Dynamics Simulator (FDS). This is a computational fluid dynamics (CFD) model. A CFD model requires that the room or building of interest be divided into small rectangular control volumes or computational cells. The model computes the temperature, velocity, pressure and species concentration of gas in each cell, based on the conservation laws of mass, momentum, energy, and species, to model the movement of fire gases. FDS utilizes material properties of the furnishings, walls, floors and ceilings to simulate fire growth and spread. A complete description of the FDS model can be found in reference[10].

A second program, called Smokeview, is a scientific visualization program that was developed to display the results of an FDS model simulation, see figure 4. Results can be displayed as snapshots or as two or three dimensional animations[11]. Both of these programs are available for free at www.fire.nist.gov.

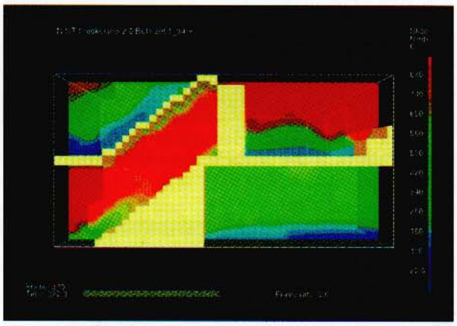

Figure 4. Smokeview animation representing the output from a Fire Dynamics Simulator model. Gas temperatures are shown.

The Fire Safety Engineering Division at NIST recently used these programs to assist the District of Columbia Fire and Emergency Medical Services Department Reconstruction Committee in examining the fire dynamics of an incident that claimed the lives of two firefighters and burned other firefighters[12]. The FDS model was developed using the building geometry, material thermal properties, and an approximate time line of the fire department actions. The model outputs were checked against physical damage from the fire scene and information from the Reconstruction Committee. The committee used the model to examine the best representation of the fire as it occurred as well as a fire simulation with different ventilation. The presentation of these simulations is available from the NIST on CD-ROM or available for downloading at www.fire.nist.gov.

While this use of this technology is just beginning, with further research and validation, FDS and Smokeview may be able to recreate fire patterns, thus providing the investigator with valuable information on the development and spread of the fire in question, see figure 5. Work is on going to take the use of the models in this direction. The simulations also have the potential to be used as training tools to demonstrate fire dynamics effects.

Into the future

The federal government has begun to increase the amount of fire research aimed at fire investigation by funding the creation of the ATF Fire Research Laboratory. While the laboratory will not be completed until 2002, some of the ATF laboratory staff are already in place and working with Building and Fire Research Laboratory staff at NIST under a co-operative agreement.

As one can see, a number of activities are occurring in the field of fire investigation and the tools that fire investigators have to do their job are increasing. Perhaps the scenario that was presented in the opening paragraph is not as far away as we might think.

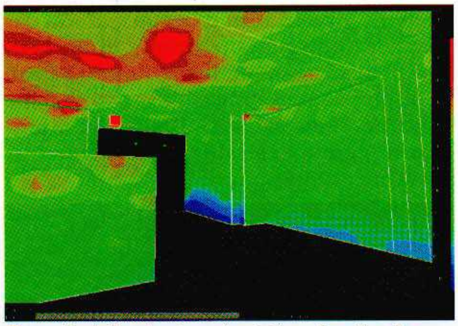

Figure 5. A Smokeview simulation showing the temperatures of the walls in room with a fire.

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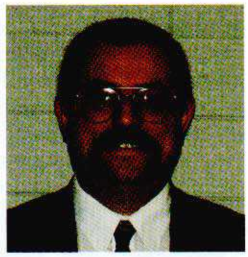
About the Author



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