Forensic Sci Rev 31:37–44
Jan. 2019

Fire Investigation:
Historical Perspective and Recent Developments

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1042-7201/31-1/Jan. 2019/37–44/$12.00 •

Fire Investigation: Historical Perspective and Recent Developments

REFERENCE: Lentini JJ: Fire investigation: Historical perspective and recent developments; *Forensic Sci Rev* 31:37; 2019.

ABSTRACT: As a forensic science, fire investigation involves a wide variety of disciplines and thus attracts an equally wide variety of practitioners. These range from fire protection engineers who may only occasionally engage in forensic work to law enforcement officers, laboratory chemists, metallurgists, and materials engineers. This breadth of practice has resulted in a checkered history, which only relatively recently has given science a full-throated embrace. Because of the stakes involved, fires provide a rich source of material for litigation, both civil and criminal. This conceptual review provides a brief history from the standpoint of a practitioner who has witnessed and sometimes precipitated the changes that have taken place since 1974. Highlights include the debunking of many misconceptions about fire behavior and a general (though not always uninterrupted) movement toward making fire investigation more scientifically accurate through the development of best practices.

KEYWORDS: Arson, Cameron Todd Willingham, fire investigation, ignitable liquid residues (ILR), Lime Street fire, NFPA, Oakland fire, standards.

INTRODUCTION

As a forensic science discipline, fire investigation is one of the broadest, in that it encompasses so many different academic and investigative fields. Fire investigators, if they are to understand their role properly, need to be conversant in chemistry, physics, fluid dynamics, fire dynamics, developments in data collection and analysis, and the use of science to answer questions of interest to the legal system. To say that fire investigation has undergone dramatic changes in the last few decades would be a major understatement. It becomes difficult to identify a place to start, as change has been stretched out over so many years and seems to be accelerating.

A wide-ranging and richly annotated review of the discipline was released in 2017 by the American Association for the Advancement of Science (AAAS), entitled "Forensic Science Assessments: A Quality and Gap Analysis. Report 1: Fire Investigation" [1]. This gap analysis was intended to be applied to 10 forensic disciplines, but only two have been released so far: fire investigation and latent fingerprint examination. The Fire Investigation Report and its "plain language" summary may be found at: *https://www.aaas.org/resources/fire-investigation*.

I. FIRE SCENE INVESTIGATION WENT OFF THE RAILS EARLY ON

To put the changes in fire investigation science into historical perspective, a convenient starting point is the 1977 report by the Law Enforcement Assistance Administration (LEAA), the predecessor to the National Institute of Justice (NIJ), entitled "Arson and Arson Investigation: Survey and Assessment" [3]. The 144-page study may be found at: *https://www.ncjrs.gov/pdffiles1/Digitization/147389NCJRS.pdf*.

In that assessment, the authors described several well-known "burn indicators" but stated, "Although burn indicators are widely used to establish the causes of fires, they have received little or no scientific testing." The study authors recommended "that a program of carefully planned scientific experiments be conducted to establish the reliability of currently used burn indicators" and "a handbook based on the results of the testing program should be prepared for field use by arson investigators".

Three years later, the handbook called for in the 1977 report was published by the most respected scientific and engineering body on the planet, the US National Bureau of Standards (NBS; National Institute of Standards and Technology, or NIST, since 1988) [4]. Unfortunately, the scientific studies recommended in the survey had not been conducted. The NBS handbook editors were advised by two members of the National Fire Academy staff, and in Chapter 1 they repeated most of the myths that have been used to incorrectly determine that a fire burned faster or hotter than normal. The text refers to "hot" fires and a "rapid buildup of heat", which were generally interpreted by investigators as indicative of the use of liquid accelerants.

The indicators that could allegedly be used to determine whether a fire was a "slowly developing" one or a "rapidly developing" one were listed as follows [4]:

- **Alligatoring of wood.** Slow fires produce relatively flat alligatoring. Fast fires produced humpback, shiny alligatoring.
- **Spalling of concrete.** An indication of intense high-heat fire.
- **Fire patterns.** A wide-angle or diffuse V pattern generally

indicates the slowly developing fire. A narrow sharply defined V pattern generally indicates a rapidly developing hot fire.

- **Glass effects.** Crazed or irregular pieces of glass with light smoke deposits indicate a rapid buildup of heat.
- **Floor damage.** Based on the premise that floors seldom receive damage similar to that of ceilings, even in the case of a total burnout, floors can develop patterns that give the appearance of flammable liquids.

In the decades following the publication of this NBS handbook, numerous authors of fire investigation texts felt very comfortable citing the work of NBS, and the literature of the discipline became well and truly contaminated. The indicators of arson were also cited in hundreds, if not thousands, of reports where the investigators found indicators of arson even though the fires were accidental.

Developing along a parallel track was the discipline of fire protection engineering, in which analysts used quantitative data from test fires to develop hypotheses about fire behavior, rather than the subjective and speculative data used by fire scene investigators. In the early 1980s, much groundbreaking work was conducted at the Center for Fire Research at NBS, including the invention of the oxygen consumption calorimeter, and the beginnings of computer fire modeling. Prior to the 1980s, there was insufficient computing power available to run the multiple simultaneous differential equations used to describe fires.

II. FIRE DEBRIS ANALYSIS FOLLOWED A DIFFERENT PATH

In an almost completely divorced discipline development, fire debris analysts learned how to detect smaller and smaller quantities of ignitable liquid residues (ILR) in samples of fire debris to the point where it became possible to detect the medium petroleum distillate solvent applied in a flooring coating 25 years prior to the fire in question [18]. Because of its solid foundations in analytical chemistry, fire debris analysis was able to make rapid progress during the 1980s and 1990s to the point where in February 1999 the Office of Law Enforcement Standards at NIST (formerly NBS) was able to declare, "Fire debris analysis is a subdiscipline of trace analysis that is in good standing because there is sufficient published work on the analysis and interpretation of the material involved. Standard guides for the examination and interpretation of chemical residues in fire debris have been published through the consensus process of ASTM Committee E30 on Forensic Science" [12].

In 2009, the National Academy of Sciences (NAS) report entitled "Strengthening Forensic Science in the United States: A Path Forward" reached a similar conclusion about fire debris analysis [29] and in 2017, the AAAS report [1], while identifying some promising areas for new research, reached the following conclusion: "The working group believes the ASTM standard test methods for extraction, separation, and analysis of ILRs are sufficiently developed and mature and there is no reason for operational laboratories not to use the methods. All forensic practitioners should be made aware of these methods, should have access to them, and should be required to follow them if their analyses are to be admitted by courts."

The author has made extensive studies of fire investigations that have gone awry, but usually it is the field investigators rather than the laboratory investigators who are led astray by ambiguous evidence. This is not to say that mistakes don't happen in fire debris analysis. They do, and when they do, they can have a devastating impact simply because of the much greater credibility afforded to the laboratory analysis of fire debris than the on-site analysis of fire patterns, which are viewed these days (deservedly so) with considerably more skepticism. Because of the different paths taken by fire scene inspection and fire debris analysis, we will leave further discussion of developments in fire debris analysis for another day.

III. THE NEED FOR SCIENCE

The complex nature of fire demands that it be approached scientifically, and the history of science and the history of fire are inextricably intertwined. As one of the original four "elements", fire received a lot of attention from scientists of the 16th through the 20th centuries. Beginning in the second half of the 20th century, however, science seems to have fallen out of favor among fire investigators. In the mid-1990s, the International Association of Arson Investigators (IAAI) went so far as to sponsor an amicus brief urging the 11th Circuit and then the Supreme Court to treat fire investigation as a "less scientific" discipline, and not require it be subject to a "strict *Daubert* inquiry" [5].

Even as the publication of myths about fire behavior was undermining the discipline, the National Fire Protection Association (NFPA) was setting the stage for the remedy of this problem. First suggested to the NFPA Standards Council in 1979 [27], a project on fire investigation was approved and a Technical Committee was appointed in 1985 [28] to develop a "Guide for Fire and Explosion Investigations". It required over seven years for the Technical Committee to publish the first edition of NFPA 921 [24]. By following the development of changes in this document, which is updated on a three-year schedule, one can follow the progress of fire investigation and the gradual undoing of the mythology from the 1970s and '80s.

To state that NFPA 921 was not uniformly embraced by the fire investigation profession would be a gross understatement. Investigators who had no scientific education felt that the document was threatening their livelihood, and individuals who had sent people to prison based on now-discredited "indicators" simply chose denial. It was dogged persistence by the 921 Technical Committee that allowed 921 to continue to evolve in the face of tremendous opposition, which finally diminished as the older investigators retired and newer investigators understood that a scientific approach would be a fact of life if they wanted to stay in fire investigation. There was a brief period of time when a case from the 11th Circuit known as *Benfield* stated that fire investigators who claimed to be "fire scientists" would be subject to a *Daubert* inquiry, but investigators who relied only on "experience" could avoid such scrutiny [22]. The 11th Circuit badly misread the Supreme Court's intent in *Daubert*, and it was clarified with the *Kumho* decision in 1999. To the extent that investigators wanted to be less scientific, they would get more scrutiny, not less. There was still a rear-guard action that took place in 2000 prior to the issuance of the 2001 edition [20] of NFPA 921. Hundreds of proposals were received to excise the word "science" from NFPA 921. Fortunately, the proponents of science were able to overcome this regressive movement.

Throughout the 1990s, the principal message of NFPA 921 was that fires should be investigated scientifically, and that all of the evidence available indicates that accidental fires are capable of producing artifacts that look remarkably like the artifacts produced by an intentionally set fire. This was first demonstrated in 1990, when a re-creation of a multiple fatality fire in Jacksonville, FL, produced artifacts that were remarkably similar to those artifacts that fire investigators had used to declare the fire to have been intentionally set. This exercise, known as the Lime Street fire, made a significant impression on the fire investigation community, although there was still considerable pushback [30]. Later on, the Oakland Hills fire in 1991 destroyed more than 3,000 homes, which provided a "baseline" showing what can happen in a known accidental fire. The investigators collected data from 50 of the residences at the periphery of the fire, and found "indicators of arson" in nearly all of them [21].

Research following the Oakland study further undermined the validity of indicators such as crazed glass and melted metals. Eventually, it became clear that accelerated fires and accidental fires burn at the same temperature, and that it is the amount of oxygen available that determines a fire's intensity. (Blacksmiths have known this for millennia.) The results of the Oakland survey and the laboratory experiments testing the validity of the indicators studied were recorded in a 30-minute video available at: *http://www.firescientist.com/multimedia.php*.

These new findings were eventually incorporated into NFPA 921, sometimes over the objections of investigators who preferred to rely on "traditional indicators". By the time the Supreme Court ruled against the "less scientific" approach embraced in the IAAI *amicus* brief [17], fire investigators were just about ready to accept that they would have to rely more on science than on "art". The year 2000 can be stated to be the turning point when NFPA 921 became "generally accepted" in the relevant scientific community.

IV. 2000: A TURNING POINT

It was in 2000 that the US Department of Justice (DOJ) released its research report entitled "Fire and Arson Scene Evidence: A Guide for Public Safety Personnel" [32]. This document advocated the use of NFPA 921 methodology whenever a fire was suspected of being intentionally set, and in all cases of large property losses and fatalities. Also in 2000, the IAAI formally endorsed the adoption of NFPA 921.

At about the same time that the Innocence Project was using DNA to exonerate wrongfully convicted citizens, NFPA 921 was being used for a similar purpose in cases of arson. Fire investigation did not enjoy a good reputation during this period of time, but it can be argued that the fire investigation profession, as a whole, was actually more willing to admit to problems than practitioners of other forensic science disciplines, many of which suffered from the same lack of fundamental scientific underpinning.

The reputation of fire investigation sank about as low as possible in 2009, when the story of Cameron Todd Willingham became a major news item. David Grann's "Trial by Fire" article in *The New Yorker* [15] set the context, while a report by the Innocence Project laid out the technical problems with the case [2]. What made the case so famous is that Willingham was executed in 2004 for setting a fire that happened just before Christmas in 1991. The NIJ symposium in 2010 featured a session entitled "Rising From The Ashes: What Have We Learned from the Case Of Cameron Todd Willingham?" The seminar is available at: *https://www.youtube.com/watch?v=b-AqqPtVSgU*.

Two movies that have been made about the Willingham case, "Incendiary" (2011) [23] and "Trial by Fire" (2018) [14], are available. PBS's *Frontline* also presented the case in a documentary called "Death by Fire" in 2010 [10], and in a followup episode in 2014 [11]. The Frontline episode is available at: *http://www.pbs.org/wgbh/pages/frontline/death-by-fire*.

The Texas Forensic Science Commission (FSC) issued a report on its investigation into the Willingham matter, a review that took several years to complete. Without ruling on Willingham's guilt or innocence, it found that "flawed science" had been used to convict him. In April 2011, it issued 17 recommendations, all of which were adopted by the new Texas Fire Marshal. The FSC report [33] is available at: *http://www.txcourts.gov/media/1440974/09-01-final-report-willingham-willis-investigation-20110415-with-addendum-20111028.pdf*.

V. FIRE SUCKS THE OXYGEN OUT OF THE ROOM

While most of the 1990s were spent trying to persuade investigators that some artifacts were not what they had been led to believe, the focus more recently has been on trying to educate investigators about the importance of ventilation.

For more than a decade, attendees at the Bureau of Alcohol, Tobacco and Firearms (ATF) advanced arson school started the course with a review of a test fire scene that had been set up prior to their arrival. The attendees were asked to identify the quadrant of origin based on their reading of fire patterns. Origin determination is supposedly the core competence of fire investigators. The results of these exercises, while never published, were dismal. Accuracy of the origin determination was less than 10%. In 2005, a group of ATF fire investigators brought the exercise out into the open at a seminar in Las Vegas. Two rooms were set up like bedrooms and burned. The 53 attendees at this seminar were then asked to determine the quadrant in which the fire had originated based on reading fire patterns. In the first of these exercises, only 3 of the 53 correctly identified the quadrant of origin. (This is fewer correct answers than would be expected if the quadrant had been selected at random.) In the second room, a different three investigators correctly identified the quadrant of origin.

When word of this experiment got out, there was much scrambling and much criticism. The experiment was repeated in 2007 in Oklahoma City with three different fires and 70 investigators. The results were not much more encouraging. In a fire that burned for 30 seconds in a fully involved condition, 84% of the 70 investigators were able to correctly identify the quadrant of origin. When the fire burned for 70 seconds in a fully involved condition, 6 investigators declined to select the quadrant, but of the 64 who did, only 49% correctly identified the quadrant of origin. When the fire was allowed to burn in a fully involved condition for 3 minutes, 17 investigators called the origin undetermined but of the 53 who picked a quadrant, the percent of correct determinations dropped to 25%, no better than random chance.

ATF Special Agent Steven Carman published these results in 2008, and the world of fire investigation has not been the same since [6]. Carman went on to study the effect of elevation of the origin, only to learn that the "z-factor" adds a whole new level of complexity [7]. When we consider that the most common cause of fires is cooking, we realize that an elevated origin is more likely than a floor-level origin.

Ventilation is what determines the appearance of fire patterns in any compartment that has burned in a fully involved condition for more than a few minutes. There has never been a controlled experiment where the validity of origin determination by reading fire patterns has been demonstrated if the fire burns for more than 3 minutes. Fire investigators may bristle at this statement, demanding proof that their "science" is not valid. Science works the other way around. It is up to the proponents of a method to demonstrate its validity.

In 2013, Andrew Cox, another ATF special agent, published a technique for taking ventilation into account, called "origin matrix analysis" [9]. Using this technique, investigators are asked to determine which fire patterns were the result of ventilation, for example, from a nearby open door or window, or an open door directly across the room from a pattern of interest. If the investigator can determine that ventilation played a role in the production of the pattern, then the most likely conclusion to be reached is that the pattern was not produced until such time as the fire became "ventilation controlled". Fire investigators are looking for the *first* pattern created by the fire, not one created after the fire has undergone flashover when the room has become fully involved.

Additional current research on the importance of ventilation is being conducted at Underwriters Laboratories' Fire Safety Research Institute (FSRI). Early results show that temperatures in fully involved compartments move in near-perfect alignment with the oxygen concentration. When the fire reaches flashover, it consumes much of the oxygen available and temperatures immediately begin to drop [20].

This new understanding of the role of ventilation in the production of fire patterns has taken the last 10 years to percolate down through the ranks of fire investigators, and there are still many who believe that they are capable of reading fire patterns even in fires that have burned for 10 or 20 minutes in a fully involved condition or in fires where the wall covering has been completely consumed.

What this new understanding of the role of ventilation has caused is an increase in the number of undetermined fires. It is, after all, better to say "I don't know" than to pick the wrong origin and then the wrong cause.

VI. THE FUTURE PARADIGM: STANDARDIZATION, CERTIFICATION, AND ACCREDITATION

Regulation of fire investigation (or any forensic science discipline) is unlikely to come about through legislation. Until there are standards accepted by the practitioners, not much else is likely to happen.

General Awareness

In 2004, the American Bar Association House of Delegates, representing the ultimate consumers of the work product of all forensic scientists (including fire investigators), passed the following resolution [13]:

> RESOLVED, That the American Bar Association urges federal, state, local and territorial governments to reduce the risk of convicting the innocent, while increasing the likelihood of convicting the guilty, by adopting the following principles:
>
> 1. Crime laboratories and medical examiner offices should be accredited, examiners should be certified, and procedures should be standardized and published to ensure the validity, reliability, and timely analysis of forensic evidence.
>
> 2. Crime laboratories and medical examiner offices should be adequately funded.
>
> 3. The appointment of defense experts for indigent defendants should be required whenever reasonably necessary to the defense.
>
> 4. Training in forensic science for attorneys should be made available at minimal cost to ensure adequate representation for both the public and defendants.
>
> 5. Counsel should have competence in the relevant area or consult with those who do where forensic evidence is essential in a case.

In February 2009, the NAS, through its Committee on Identifying the Needs of the Forensic Science Community, echoed the ABA resolution when it called for:

1. Mandatory accreditation of medical examiners offices and crime laboratories;
2. Mandatory certification of all forensic scientists; and
3. Mandatory implementation of standard methods of analysis and reporting.

As a result of the 2009 NAS report [29], the DOJ and NIST entered into a memorandum of understanding to set up an organization to deal with the problem of standards, and to bring some uniformity to the approach to reforming forensic science.

Almost 10 years after the NAS report, there is still no mandatory accreditation, certification, or standard methodology in any forensic science, other than that tied directly to federal funding. But there is movement in the right direction.

Efforts in the Fire Investigation Science Community

NFPA 921 has been accepted by so many courts that its acceptance as the standard of care in fire investigation is now routine. Most fire investigators, when asked, will admit that NFPA 921 represents the standard of care, and investigators who deviate significantly from NFPA 921 risk having their testimony excluded.

Certification of fire investigators first became available in 1986 through the IAAI [16], but fewer than a third of the current practitioners hold a certification. The IAAI states that it bases its certification programs and all of its training on both NFPA 921 and NFPA 1033, *Standard for Professional Qualifications for Fire Investigator*. There are many certified and noncertified fire investigators who claim to meet the requirements of NFPA 1033, but in many cases that is wishful thinking.

In 2009, NFPA 1033 was amended to include a list of subject-matter areas in which a fire investigator was expected to be knowledgeable beyond the high school level [25]. Although only a high school diploma or GED is required by NFPA 1033, many of the subjects in this mandatory list of knowledge areas are not taught in high school.

When facing a qualifications challenge (as opposed to a methodology challenge), a surprising number of fire investigators are unable to describe the basic units of energy or power, or describe the difference between energy and power. Many investigators are shockingly ignorant of even the most basic combustion reactions such as those of hydrogen or methane. There have been few actual exclusions of (alleged) experts because of such embarrassing shortcomings. The usual result when such gaps are exposed is a settlement or dismissal.

The IAAI bases all of its certifications and training on NFPA 921 and NFPA 1033, and operates a website known as *CFItrainer.net* that provides enough information for most fire investigators to clear the low bar set by NFPA 1033.

Most fire investigators do not possess science degrees and many have no formal scientific training. This seems to go against the recommendation for a "culture strongly rooted in science" that the NAS report called for [29].

Caudill [8], moving toward a more practical approach to "expertise" as opposed to "science", has suggested for forensic science in general a model more like that used in the medical profession. There are many biomedical researchers who never treat patients, and many clinicians who do not conduct research, and laboratory technicians who perform medical procedures, yet the profession holds together. Caudill describes two kinds of experts: (a) the "contributory" experts who conduct basic research and validate new methods; and (b) the "interactional" experts, who understand what is valid, without ever themselves conducting a validation. These interactional experts, with sufficient exposure to the underlying science, could reach valid conclusions indistinguishable from those reached by the PhD researcher, and may be more adept at doing so.

Having worked in the fire investigation field for more than 40 years, the author has met numerous qualified fire investigators who took the time to learn the fundamental science and to keep up with developments in the field. There is no reason that such individuals could not be a model for the entire field.

In 2014, the Organization of Scientific Area Committees (OSAC) established a Subcommittee on Fire and Explosion Investigations, which is meant to work in concert with standards development organizations, primarily NFPA, to improve the validity of the standards governing fire investigation including NFPA 921, *Guide for Fire and Explosion Investigations,* and NFPA 1033, *Standard for Professional Qualifications for Fire Investigator*. These were the first two standards added to the OSAC Registry. (As of October 1, 2018, there were only 12 standards on the registry [31].) NFPA 921 and NFPA 1033 can provide the underpinning for both a standard approach to fire investigation and the basis for a certification program.

The OSAC subcommittee recognized the lack of any existing standards for accreditation, and seeing this need, has persuaded NFPA to open a new project to standardize the operation of fire investigation units (FIUs) [26]. Thus, fire investigation may one day realize the goal set forward by the 2009 NAS report [29] that forensic science should be conducted by certified individuals following standard methods and working in accredited organizations. The new NFPA project on standardization of the operation of FIUs will provide a standard that will be capable of supporting a move toward accreditation. Accreditation in fire investigation is almost unheard of. Only two units had been accredited to *ISO/IEC 17020: 2012 Conformity Assessment — Requirements for the Operation of Various Types of Bodies Performing Inspection* by the end of 2017. Without a national standard on how to operate an FIU, these organizations had to start from scratch by writing their own quality assurance and procedure manuals. It is hoped that the production of the new NFPA standard will facilitate other organizations becoming accredited.

Working in concert with NFPA, the OSAC Subcommittee (on Fire and Explosion Investigations) has proposed amendments to both NFPA 921 and NFPA 1033 in its October 2, 2018, meeting [19]. The new FIU Technical Committee is expected to be established by the end of 2018, but it is unlikely to have a deliverable standard before 2021. The OSAC Subcommittee is also working on a much more comprehensive "Strategic Vision" for fire investigation, which was being reviewed as this article went to press. Stay tuned.

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Mr. Lentini began his career in the Georgia Bureau of Investigation Division of Forensic Sciences (Decatur, GA) where he analyzed all kinds of trace evidence, and specialized in fire debris analysis. He entered the private sector in 1978 offering both fire scene inspections and laboratory analysis of fire debris, serving as the manager of fire investigations at Applied Technical Services (Marietta, GA) through 2006, when he opened his current consultancy. Mr. Lentini has been very active in standards development organizations, including both the National Fire Protection Association (Quincy, MA) and ASTM International (West Conshohocken, PA). His research has resulted in significant contributions to the literature in both fire debris analysis and interpretation of fire scene artifacts.

Mr. Lentini is certified by the American Board of Criminalistics (General Criminalistics) and by the International Association of Arson Investigators (Certified Fire Investigator). He is the author of *Scientific Protocols for Fire Investigation*, now in its third edition (CRC Press: Boca Raton, FL; 2018). In addition to offering training and fire litigation consulting, he is active in many professional organizations, including the American Academy of Forensic Sciences, and is a charter member of the Organization of Scientific Area Committees for Forensic Science's Subcommittee on Fire and Explosion Investigations (*https://www.nist.gov/topics/forensic-science/fire-and-explosion-investigation-subcommittee*).