*by John J. Lentini**

§ 39:34 Introductory discussion of the science

The scientific study of fires, arsons, and explosions is unique among the forensic sciences for two reasons. First, the fire or explosion tends to destroy the very physical evidence that can be used to establish the cause, so in the case of arson, it is first necessary to prove that a crime has been committed. Second, the majority of practitioners of this "scientific" endeavor are not scientists and have little, if any, scientific training or education. While there are other forensic disciplines where technical skills learned on the job may provide adequate training, it is difficult to argue that individuals who have a limited understanding of the chemistry and physics of fire development can draw reasonable conclusions about fires. Yet, most practitioners do not possess a bachelor's degree. With the exception of fire debris chemists, who spend most of their time in the laboratory and most of their efforts on detecting minute quantities of ignitable or explosive material, the people who investigate fires and explosions acquired their experience one fire at a time, as firefighters, and later as fire investigators.

The skills and mindset required to extinguish a fire are quite different from those required to investigate a fire. Firefighters are accustomed to being given a straightforward, albeit dangerous and difficult, task and accomplishing it. The task of determining the origin and cause of fires is far more intellectually challenging than the task of extinguishing fires, and as a result, the success rate in determining the cause is often lower than the success rate in extinguishing the fire. All fires go out eventually. It is a difficult transition from firefighter to fire investigator, and in many cases, newly minted fire investigators are reluctant to call a fire "undetermined" even if that is the correct classification based on what they know. An "undetermined" call may be perceived as a failure by one not accustomed to failure.

Because the knowledge, skills, and abilities of fire investigators differ from forensic scientists in general, the literature in fire investigation is

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*John J. Lentini is a fire investigation consultant, and President of Scientific Fire Analysis, LLC of Big Pine Key, Florida. From 1978 through 2006, he managed the fire investigation division of Applied Technical Services of Marietta, Georgia. He is a fellow of the American Academy of Forensic Sciences and a Diplomate of the American Board of Criminalistics, with a specialty in fire debris analysis. He holds certificates from the National Association of Fire Investigators and the International Association of Arson Investigators. He served three terms as chairman of ASTM Committee E30, which is responsible for developing forensic science standards, and is a principal member of the National Fire Protection Association's Technical Committee on Fire Investigations, which maintains NFPA 921. Mr. Lentini has investigated more than 2000 fires, analyzed more than 20,000 samples of fire debris, and testified on more than 200 occasions. He can be contacted at mailto:scientific.fire@yahoo.com.

divided into two parts: the scientific literature and anecdotal reports of field investigators. In recent years, increasing numbers of fire protection engineers—scientifically trained individuals with a better (but still imperfect) understanding of the behavior of fire—have demonstrated an interest in fire investigation, and the literature is beginning to reflect the influence of this group. Much of the work of fire protection engineers in this area, however, is still beyond the technical grasp of the average fire or arson investigator.

Because of the extensive destruction of physical evidence, those who investigate fires in the field, known as "cause and origin investigators," rely heavily on eyewitness testimony. In its absence, or sometimes even in spite of contradictory eyewitness testimony, fire investigators commonly rely heavily on their previous experiences in analyzing small bits of evidence. Fire investigation has been likened to putting together a jigsaw puzzle, where the pieces are not just scattered but also often missing, and those that are present are frequently unrecognizable.

A fire investigator puts this puzzle together and reaches conclusions by comparing observations with expectations. The expectations have been developed from training and experience, but that training and experience may not necessarily have a solid scientific foundation. For this reason, it is imperative that before an investigator's opinion is taken seriously, the efforts taken to "calibrate" the investigator's expectations should be scrutinized. Most importantly, the presumptions that the investigator carries into each fire scene should be determined, as these presumptions will have a significant impact on the investigator's credibility as an expert.

Observations that one investigator will use to show incontrovertible evidence of an incendiary fire might be found by another investigator to be an unimportant indicator of a secondary event that occurred long after the fire started. By way of example, there are major areas of disagreement on the ability of investigators to "read" burn patterns, particularly in fires that have burned for extended periods of time. This disagreement has only increased in recent years. There is also disagreement about an investigator's ability to interpret the condition of wires as evidence of electrical arcing, which might have caused the fire or may be a result of the fire. There are numerous other chicken-and-egg problems that arise in fires, due to the destructive nature of the event.

There is reasonably good agreement among forensic scientists regarding the proper testing of physical evidence in the laboratory. Consensus standards exist for most routine tests of fire debris. Standardization of field practices, however, is still controversial, though many courts have recognized NFPA 921 (discussed in section 39:35) as the appropriate "standard" by which to judge the methodology of fire investigator.[1] One impetus for the standardization of the fire investigation field is the realization by fire investigators (and, indeed, by most forensic scientists) that standards may be the key to admissibility. Another impetus for standardization springs from efforts at certification of both laboratory and field investigators. Because examinations are required to grant certification, a standard body of knowledge from which to develop such examinations also is required. Laboratory analyst certification did not become universally available until 1993. Field investigators may obtain certification from either the International Association of Arson Investigators (IAAI) or the National Association of Fire Investigators (NAFI). Laboratory analysts may obtain certification from the American Board of Criminalistics (ABC).

The existence of standards is now recognized as a fact of life by fire investigators, and this may be one cause for the declining number of fires determined to be arson fires: fire investigators may finally be becoming more cautious.

Fire investigators are also becoming more educated. As older, "traditional" fire investigators retire, they are being replaced by younger, better-educated investigators for whom NFPA 921 (discussed below) has always been the gospel. In the artful words of Max Planck describing scientific progress, "Science advances one funeral at a time."

§ 39:35 Introductory discussion of the science—Sources—Authoritative publications

The industry standard for fire investigation is known as NFPA 921, Guide for Fire and Explosion Investigations. The National Fire Protection Association is a nonprofit organization founded in 1896 that promulgates all types of codes related to fires, including building codes, equipment specifications, guidelines for certification of individuals, and a guide for fire investigation. NFPA 921 is produced and maintained using the NFPA consensus process, which has been approved by the American National Standards Institute (ANSI). The Technical Committee on Fire Investigations, which drafted NFPA 921, consists of no more than 30 individuals, with membership strictly regulated by NFPA guidelines, including specified numbers of public officials, academics, insurance industry representatives and private experts.

The general public has the opportunity to propose changes to the standard, and to comment the Committee's disposition of proposed changes. (In general, however, only NFPA members are made aware of pending standards.) The Committee then votes on whether to accept, modify or reject the proposals from the individual submitters, some of whom may be members of the Committee. If the Committee takes any action other than

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[Section 39:34]

[1]See cases cited in § 39:9.

to accept the proposal for change, a technically valid reason must accompany the rejection or modification. The Committee's actions on proposals are then published, and the submitter (or anyone else) has the opportunity to comment on the Committee's decision. Comments are then reviewed similarly to proposals. When studying the reasons for the existence of a particular paragraph in NFPA 921 (or any NFPA document) the record of any changes can be found in the Report on Proposals or Report on Comments published by NFPA, and available at no cost from www.NFPA.org. The following paragraphs outline the major changes in the evolution of the standard.

The first edition of NFPA 921 was published in 1992. The document, which took six years to produce, was passed with no dissenting votes from Committee members.[1]

When *Modern Scientific Evidence* was first published in 1997, the industry standard for fire investigation was the 1995 edition of NFPA 921, Guide for Fire and Explosion Investigations. As a result of the receipt of more than 150 proposals for changes, the 1998 edition, which became effective in February of 1998, contained substantial changes and clarifications. The document was extensively revised in 2001 and 2004. In 2008, the chapter on fire patterns and the chapter on origin determination underwent significant revision, and the document addressed the concept of expectation bias for the first time. In 2011, the chapter on cause determination was extensively revised. To the consternation of many fire investigators, the use of "negative corpus" methodology was condemned as invalid and unscientific.

One of the more interesting changes between 1995 and 1998 was the removal of the word "misconception" from the titles of many sections. A significant portion of the fire investigation community was offended by the use of the word "misconception" in the first two editions of the Guide. Proponents of the change argued (with, it turns out, unjustified optimism) that while misconceptions might exist in a few investigators' minds, the first two editions had cleared up many of those misconceptions. In most cases, the text of the chapter section was left intact, but the title was changed. For example, the sections entitled "Misconceptions about Char" and "Misconceptions about Spalling" had their titles changed to "Interpretation of Char" and "Interpretation of Spalling." The cautions regarding the potential for misinterpretation of these two artifacts, however, remained in the text.

Another significant change between 1995 and 1998 was the removal of

[Section 39:35]

[1] Disclaimer: The author is a member of the NFPA Technical Committee on Fire Investigations, and has attempted to accurately describe the contents and appropriate interpretation of NFPA 921, Guide for Fire and Explosion Investigations. Nothing in this text, however, should be interpreted as a formal interpretation or the official position of NFPA or the Technical Committee on Fire Investigations.

the section on certainty of opinions. A consensus within the Committee developed regarding removal of these various levels of certainty. The Committee felt that the rubric had been mistakenly equated by the legal community with burdens of proof—an easy mistake to make since some of the terms and their definitions plainly adopted terminology that borrowed from and tracked legal burden of proof concepts. Whatever the intention of the fire and arson community may have been, they provide an example of how to invite (and generate) confusion. An attempt had been made to clear up the confusion between the 1992 and 1995 editions, but it was not successful. Elimination of the terminology altogether was judged to be the best available course for the subsequent edition. Many Committee members, however, felt that some expression of the "comfort level" that an investigator had with his opinion was in order. In the 2001 edition, the discussion was unchanged, but in the 2004 edition, the following text was added:

> Two levels of confidence have significance with respect to opinions:
>
> 1. Probable. This level certainty corresponds to being more likely true than not. At this level of certainty, the likelihood of the hypothesis being true is greater than fifty percent.
>
> 2. Possible. At this level of certainty the hypothesis can be demonstrated to be feasible but cannot be declared "probable." If two or more hypotheses are equally likely then the level of certainty must be "possible."[2]

The section on certainty continues to cause controversy because of language that states, "Ultimately, the decision as to the level of certainty in data collected in the investigation or of any hypothesis drawn from an analysis of the data rests with the investigator." Some have argued that this statement gives the blessing of "scientific truth" to what is merely a testable hypothesis.[3]

In the 1998 edition, the chapter on electricity and fire and the interpretation of electrical artifacts was significantly expanded and improved. A chapter was added on fuel gas systems, and a large number of references were added to the explanatory material in the appendix.

Between 1998 and 2001, the NFPA received 183 proposals for changing the NFPA 921, and over 500 comments on the Technical Committee's handling of those proposals. The level of discourse in the standards development process descended to a level commonly associated with party politics. There was a serious conflict between the old guard "arson investigators," and the proponents of the scientific method. The proponents of science prevailed.

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[2]National Fire Protection Association, Guide for Fire and Explosion Investigations (Pub. No. 921) (2011), at § 4.5.

[3]Brannigan,V. and Buc, E., "Forensic Fire Investigation: An Interface of Science, Technology and Law," proposal 921–41, NFPA 921 *Report on Proposals*, NFPA, Quincy, MA, (Sept. 2009).

The 2001 edition of NFPA 921, released in February 2001, included a rewritten chapter on vehicle fires, and new chapters on fire deaths, human behavior in fires, analytical tools (including computer assisted fire modeling), wildfire investigations and building systems. Additionally, the Guide was reorganized into three sections outlining what a fire investigator should know, how a fire investigator should conduct a routine investigation, and special topics in fire investigation.

In the 2001 edition, language was added to the section on hypothesis testing under the scientific method to allow for "cognitive" testing in addition to, or in lieu of, experimental testing. This change was made because many people in the fire investigation community misunderstood the scientific method, and believed that in order to be "scientific," it was necessary to rebuild the structure and recreate the fire, which was never the intent of the document. (Actually, this wrongheaded argument was usually advanced disingenuously by attorneys opposing the introduction of scientific methodology and resisting Daubert challenges.) Some fire investigators, however, took the new language on "cognitive" testing as a license to go back to the old ways of declaring a fire to be caused by arson or some other cause based on nothing more than their "training and experience" rather than on deductive reasoning. Consequently, for the 2004 edition, the Technical Committee on Fire Investigations added definitions of inductive reasoning and deductive reasoning, and added an explanatory appendix item to this paragraph in order to explain exactly what is meant by "cognitive testing."

Other significant additions to the 2001 edition included a discussion of spoliation of evidence, and a definition of those necessary activities that should not be considered spoliation, as well as a discussion of reasoning by process of elimination, an attempt to come to grips with the so-called "negative corpus" determination.[4]

By far the most significant controversy for the 2001 edition was a movement led by the International Association of Arson Investigators and certain insurance defense attorneys to remove any mention of the word "science" from the document. Despite the fact that the Kumho decision rendered the effect of such a change moot, the rear guard took this fight to the NFPA, and, as happened in the Supreme Court, they were roundly defeated. The Technical Committee and the NFPA as a whole continued to endorse the scientific method as the way to investigate fires. The vote was 29–0 in the Technical Committee and unanimous by a voice vote at the NFPA annual meeting. The rejection of the IAAI *amicus* brief by the Kumho court and the rejection of the proposals to eliminate science from NFPA 921 finally caused a change in the attitude in the IAAI leadership. The 2001 edition of NFPA 921 was the first officially endorsed by the President of the IAAI on behalf of his 8,000 members. The same attorneys who

[4] § 39:65.

had counseled investigators to avoid using the "S" word subsequently began advising the investigators to embrace the document and using it as a means of getting their testimony accepted by trial courts.

Compared to the technical, legal, and ideological battles that surrounded the production of the 2001 edition, the proposals to make changes in the 2004 edition were relatively minor, at least from a substantive standpoint.

The format of the 2004 edition of NFPA 921 changed, because NFPA decided to conform all of its standards to International Organization for Standards (ISO) guidelines. Additionally, the document separated the chapter on cause into two separate chapters, one dealing with the circumstances that bring together an ignition source, an oxidizer, and a fuel, and another chapter dealing with the "cause" of fire spread, injuries, deaths, and other issues that go beyond the traditional "cause" of the fire.

The chapter on legal considerations was completely rewritten and reorganized to provide more information on discovery procedures, and the impact of the Daubert decision on fire investigation. The chapter has also been reordered so that the paragraphs generally follow the temporal path of a legal case, beginning with investigative considerations, followed by the filing of a complaint or indictment, discovery, and trial.

In 2008, the concept of expectation bias was addressed for the first time. (Fire investigators are advised to avoid it.) The chapter on basic fire science was revised and clarified. The chapter on origin determination was extensively rewritten to follow the temporal flow of the scientific method. An additional chapter on marine fires was introduced. The number of proposals for changes stayed about the same as in previous years, but the number reflected the engagement of the fire investigation community, whereas earlier, many proposals reflected the rage of the old guard at being asked to embrace science.

By the 2011 edition, the number of controversies reduced. An additional caution against bias—this time there was a warning to avoid contextual bias—was introduced, partly in response to the 2009 NAS Report, "Strengthening Forensic Science in the United States: A Path Forward." A section on reviews, which specifically disparaged the use of the term "peer review" in the context of a fire investigation, was added.

The most controversial change occurred in the chapter on cause determination, which was rewritten to follow the temporal flow of the scientific method. For several editions, the Technical Committee sought to circumscribe the circumstances under which an investigator could infer an "open flame" as the ignition source. Some fire investigators continued to abuse the language on "process of elimination," which allowed such an inference where the origin was "clearly defined." The language was first placed into the 1998 edition, to allow for a determination of an open flame ignition in cases where the origin would be obvious to even an untrained person, and there were no potential sources of accidental ignition in the "clearly defined" area of origin. Investigators who applied a "creative" definition of "clearly defined origin" insisted on their ability to infer an open flame ignition even in cases of full room involvement. Finally a majority of the Technical Committee decided to insist on a stricter guideline, and specifically disparaged the use of the so-called "negative corpus" determination (discussed in section 39:65). Such determinations are made as follows: "I know where the origin is. I can find no potential source of accidental ignition there. (And I know I would find it if it were there.) Therefore, the fire must have been ignited by an open flame, which was removed from the fire scene." Continuing with this flawed logic, the investigator concludes that the fire must have been set. Further, in the absence of any obvious fuel package, the investigator concludes that the first fuel ignited must have been a flammable or combustible liquid, even in the absence of laboratory confirmation.

Such negative corpus arson determinations have served as the basis of many wrongful charges and convictions. What actually happens in these cases is that the fire investigator identifies the wrong origin. Beginning in 2008, NFPA 921 stated that when no competent ignition source is identified at the hypothesized origin, the determination of origin is subject to "increased scrutiny."[5] What that means (without putting too fine a point on it) is that "the investigator probably got the origin wrong."

As of this writing, work is underway on the 2014 edition of NFPA 921. There will no doubt be many proposals suggesting that the Committee revisit its disparagement of the negative corpus methodology. There will be a proposal to change the definition of the term "incendiary." The 2011 definition reads as follows: "A fire that is intentionally ignited under circumstances in which the person knows that the fire should not be ignited." This would seem to require that a fire investigator declare even the most obvious arson fire to be undetermined, unless he knows what was in the mind of the fire setter. The major change that will appear in the 2014 edition of NFPA 921 will be the inclusion of color photographs in the electronic edition.

The general, if grudging, acceptance of NFPA 921 as the standard of care in fire investigation is reflected in the growing number of Daubert challenges to fire investigators who fail to follow its guidance, particularly with respect to interpretation of fire scene evidence. It is the misinterpretation of fire effects and fire patterns (as opposed to incorrect procedures) that account for most of the incorrect determinations of fire origins and causes. Daubert rulings on the admissibility of fire investigation opinions almost invariably cite NFPA 921.[6] Daubert exclusions in fire litigation occur almost exclusively in civil cases. Public sector fire investigators testifying in criminal trials are generally allowed to say whatever they wish, no matter how outrageous, even though there is considerable support in law

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[5]NFPA 921, 2008, 2011 editions at 17.6.1.1.

[6]See cases cites in § 39:9.

enforcement circles for use of the scientific method as described in NFPA 921.

Indeed, support from the law enforcement community for the use of NFPA 921 as the standard of care in fire investigations began in late 1997, when the Justice Department started work on national guidelines for fire and arson scene investigation. The guidelines were modeled after the National Guidelines for Death Investigation, a research report published by the National Institute of Justice (NIJ) in December of 1997.[7] The Technical Working Group assembled by NIJ first recommended that the Justice Department simply purchase 15,000 copies of NFPA 921 and mail them to the nation's law enforcement agencies and fire departments, but this suggestion was not adopted. Work on the national guidelines continued for three more years, culminating in the publication of a finished pamphlet in June 2000. These national guidelines recommend a general procedure for the handling of fire and arson scenes, and specifically direct responsible officials to find a fire investigator capable of conducting a scientific scene inspection according to the recommendations of NFPA 921. While the term "standard of care" does not appear in the Justice Department document, it does say the following about NFPA 921: "It has become a benchmark for the training and expertise of everyone who purports to be an expert in the origin and cause determination of fires."[8]

A similar guide was published at the same time dealing with the responses to explosion or bombing scenes.[9]

Most fire investigators will, on cross-examination, concede that NFPA 921 represents the industry standard for the conduct of fire investigations although some may argue that it is "only a guide." These words, "only a guide," suggest that somewhere in the investigation, the investigator has elected not to accept the proffered guidance.

The most important concept embodied in NFPA 921 is the recognition that fire investigation must be based upon the scientific method.[10] This may seem obvious, but until recently, fire investigators based their conclusions upon their "technical knowledge" gained through training, and experience. The existence of NFPA 921 makes it more difficult for the investigator to rely solely upon anecdotal experience. As stated by the Joiner court, "nothing in either Daubert or the Federal Rules of Evidence requires a district court to admit opinion evidence which is connected to

[7]National Medicolegal Review Panel, National Guidelines for Death Investigation (NCJ 167568) (1997).

[8]Technical Working Group on Fire/Arson Scene Investigation, USDOJ, Fire and Arson Scene Evidence: A Guide for Public Safety Personnel (Jun. 2000), available at http://www.ojp.usdoj.gov/nij/scidocs2000.htm.

[9]Technical Working Group for Bombing Scene Investigation, USDOJ, A Guide for Explosion and Bombing Scene Investigation (Jun. 2000), available at http://www.ojp.usdoj.gov/nij/scidocs2000.htm.

[10]National Fire Protection Association, Guide for Fire and Explosion Investigations (Pub. No. 921) (2011), at § 1.3.2.

existing data only by the *ipse dixit* of the expert." This ruling disappointed many fire investigators, but it has had a salutary effect on the practice of fire investigation.

Even before the publication of NFPA 921, NFPA published a document known as NFPA 1033, *Standard for Professional Qualifications for Fire Investigator*. This document described in general terms the knowledge, skills and abilities required to do the job. The document changed for the first 20 years of its existence. The 2003 edition made reference to the guidance of NFPA 921 as a source of requisite knowledge, but a truly substantive change occurred with the publication of the 2009 edition. In its own words, the Technical Committee on Fire Investigator Professional Qualifications "included more specific Requisite Knowledge statements to various JPRs (Job Performance Requirements)." The specific language reads as follows:

> 1.3.8* The investigator shall have and maintain at a minimum an up-to-date basic knowledge of the following topics beyond the high school level at a post-secondary education level:
> (1) Fire science
> (2) Fire chemistry
> (3) Thermodynamics
> (4) Thermometry
> (5) Fire dynamics
> (6) Explosion dynamics
> (7) Computer fire modeling
> (8) Fire investigation
> (9) Fire analysis
> (10) Fire investigation methodology
> (11) Fire investigation technology
> (12) Hazardous materials
> (13) Failure analysis and analytical tools[11]

It is an unfortunate fact that most fire investigators do not possess this knowledge at any level, much less "beyond the high school level at a post-secondary education level." This new requirement has led to Daubert challenges based not only on methodology, but also on qualifications. A fire investigator who cannot explain the combustion of hydrogen in air to form water vapor, or who does not know the chemical formula for methane (CH_4) is unlikely to be able to persuade a court that he has any knowledge of fire chemistry. Many fire investigators are unable to define some of the terms in the above list, much less explain them.

It should be noted that unlike NFPA 921, NFPA 1033 is a *standard*, rather than a guide. In NFPA parlance, this means that the document is

[11] National Fire Protection Association, Standard for Professional Qualifications for Fire Investigator (Pub. No. 1033) (2009), at § 1.3.8.

suitable for adoption into law, and in some jurisdictions, the standard is the law.

There exist a few other authoritative sources or learned texts in the field. The fundamental science may be found in two textbooks: the *Ignition Handbook* by Vytenis Babrauskas,[12] and *Principles of Fire Behavior* by James Quintiere.[13] The *Ignition Handbook* is the most heavily researched and annotated text on the subject, and the publisher is capable of providing all or nearly all of the articles cited. Dr. Quintiere's book provides explanations of fire behavior that are accessible even to non-scientists.

With respect to actual fire investigation procedures, Kirk's Fire Investigation[14] explains most of the aspects of fire investigation that a typical investigator is likely to encounter. Paul Kirk, perhaps the most respected forensic scientist of the 20th century,[15] authored the first edition of this book in 1969[16] and it was the standard reference text for over a decade. To appreciate the changes and improvements in the understanding of fire dynamics and fire investigation that have occurred since 1969, a review and comparison of the successive editions of this book is useful. This popular reference text on fire investigation came out in its seventh edition in 2011.

As with most "standard" texts, *Kirk's Fire Investigation*, while moving the profession gradually forward, defines where the current consensus is rather than leading the way. The evolution of the thinking of mainstream fire investigators can, in fact, be followed by reviewing the changes in *Kirk's Fire Investigation* through its seven editions, as it gradually embraces a more rigorous approach, and finally, though belatedly, disposes of some of the myths and misconceptions that appeared in earlier editions.

A second fire investigation text that most fire investigators will recognize as authoritative is this author's own text, *Scientific Protocols for Fire Investigation*, published by CRC Press in 2006. As the first fire investigation text published in full color, it was well regarded by the fire investigation profession. The second edition is due to be published in 2012. Further commentary on this text can be found in the reviews at amazon.com.

§ 39:36 Introductory discussion of the science—Sources—Periodical literature

There are several periodicals to which fire investigators may subscribe, and the reliability of the information in these periodicals varies widely. *Fire Technology*, a peer-reviewed journal, usually deals with highly techni-

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[12] Babrauskas, V., Ignition Handbook, Fire Science Publishers, Issaquah, WA, (2003).

[13] Quintiere, J., Principles of Fire Behavior, Delmar Publishing, Clifton Park, NY, (1997).

[14] DeHaan, J., and Icove, D., Kirk's Fire Investigation (7th ed. 2011).

[15] Paul Kirk was the forensic scientist who successfully explained the flaws in the case of Ohio vs. Sam Sheppard.

[16] Paul Kirk, Fire Investigation (1969).

cal aspects of fire behavior, such as computer modeling, the behavior of large liquid pool fires, or the response of fire protection systems. Fire investigation articles appear occasionally in *Fire Technology*, as fire protection engineers publish results of test fires that may (or may not) validate computer models.

The most widely read fire investigation publication is *The Fire & Arson Investigator*, the official publication of the International Association of Arson Investigators. Publication in this journal may reflect a thorough peer review (for the more technical articles) or simply editorial review (for news reports or "op-ed" pieces). Peer review began only in 1996. The IAAI Board of Directors, until then, elected to publish more of a newsletter than a scientific journal, in the belief that everyone is entitled to their own opinion and that the exclusion of articles, even highly technical scientific articles, because of the objections of peer reviewers was equivalent to "censorship." The introduction of peer review to *The Fire and Arson Investigator* has not been without its difficulties. Some reviewers report that, while they have made comments and suggestions for changes to technical articles, the articles were eventually published in their original form.

Fire Findings, an independent publication based in St. Joseph, Michigan, published topical articles on fire investigation, but unfortunately, ceased publication in 2010. While not strictly peer-reviewed, it was generally worth reading. Issues contained directions to resources, reports of experiments, and explanations of how things work. Each issue also contained a section on product recalls, book reviews, a report on a particular type of fire (for instance, neon sign fires), and a discussion of some part of NFPA 921. The back issues of this publication contain many oft-cited articles.

The National Association of Fire Investigators publishes a quarterly newsletter that usually contains at least one peer-reviewed article. The international symposium on fire investigation (ISFI) occurs every two years, and the proceedings of that symposium are generally worth reading, and contain articles on the cutting edge of fire investigation.

The *Journal of Forensic Sciences* and *Forensic Science International* both publish articles on fire investigation, though heavily weighted toward the laboratory analysis of fire debris, as opposed to fire scene investigation.

The internet is gaining popularity as a resource for fire investigators. Particularly useful sites include CFI Trainer, an online training center, and an independent forum for fire investigators, http://www.forumworld.com/arson-investigations, where fire investigators exchange information (and sometimes barbs). Information about Daubert challenges to fire investigators (and all experts in any discipline) can be found in the subscription-based website www.Dauberttracker.com. This site reports on hundreds of challenges to fire investigators.

A recent development in fire investigator training has demonstrated the potential for dramatically improving the quality of fire investigations. The

IAAI, funded by the Department of Homeland Security's Assistance to Firefighters Grant Program and working with the Bureau of Alcohol, Tobacco, Firearms and Explosives, the Insurance Committee for Arson Control and NIST, now offers, at no cost, training modules of interest to both fire investigators and the attorneys who employ them. This training is available at http://www.cfitrainer.net. As of August 2011, more than 35 modules were available on the application of Daubert to fire investigations, an introduction to fire dynamics and fire modeling (in terms understandable to lay audiences), the Scientific Method in Fire Investigations, and recent advances in the understanding of the role of ventilation in the production of fire patterns, discussed in section 39:48.

§ 39:37 Introductory discussion of the science—Field investigations

Just as the type of evidence examined and the type of people examining the evidence differ from the field to the laboratory, the approach to the scientific analysis of fire behavior often differs radically between the field and the laboratory.

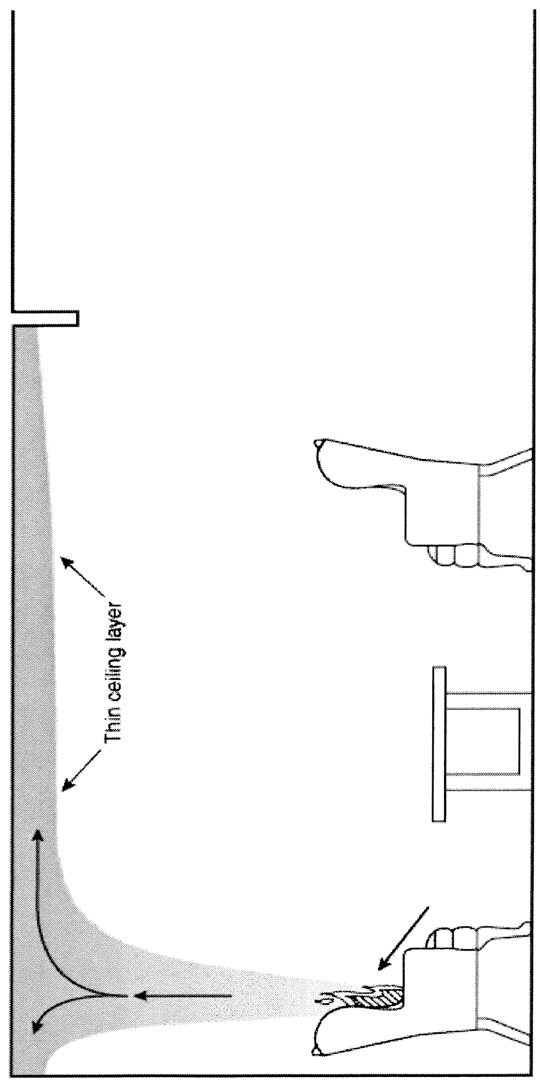
§ 39:38 Introductory discussion of the science—Field investigations—Test burns

During the 1970s and 1980s, the Center for Fire Research at the National Bureau of Standards, now known as the National Institute of Standards and Technology (NIST), conducted hundreds of excellent test burns, and characterized the behavior of fire up to the point of *flashover*. Flashover is a transitional phase in compartment fires in which temperatures rise to a level sufficient to cause ignition of all exposed combustible items in the compartment. This behavior of fires is foreign to most people, whose familiarity with fire is based on experience with "free burning," exterior fires, such as campfires and trash fires. Fires confined by a structure (compartment fires) behave in an entirely different manner. Most structure fires will eventually achieve flashover, unless there is intervention by firefighters or unless there is an unusual occurrence that allows the release of the fire gases, thus preventing the heat build-up.

The time until flashover varies, depending on the size of the structure and the type of fuels involved. It can take as little as two minutes or as long as fifteen minutes, or never occur at all if the fire is quenched

In a typical flashover scenario, an item of burning fuel, typically a piece of furniture, releases heat and smoke into the room, but in its early stages, the fire is unaffected by the room itself. This is known as the "free-burning" stage, and the behavior of the fire at this stage is relatively simple and easily explained (heat rises). When the fire begins to interact with its enclosure, its behavior becomes much more complex. As the fire progresses, a layer of hot gases forms at the ceiling, and gradually banks down, becoming thicker and more charged with energy. Once the gas layer reaches a temperature of approximately 1100F, the radiant heat coming from the gas layer is sufficient to ignite common combustibles.[1]

Figure A



[Section 39:38]

[1]National Fire Protection Association, Guide for Fire and Explosion Investigations (Pub. No. 921) (2011), at § 5.10.2.

Figure B

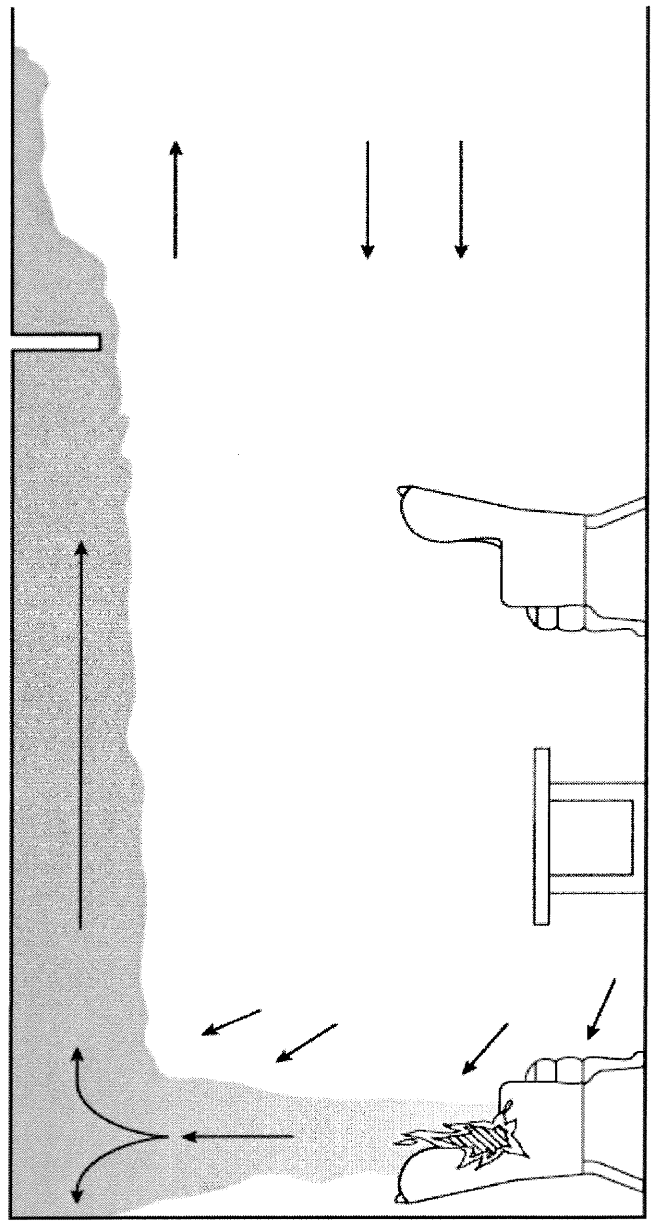


Figure C

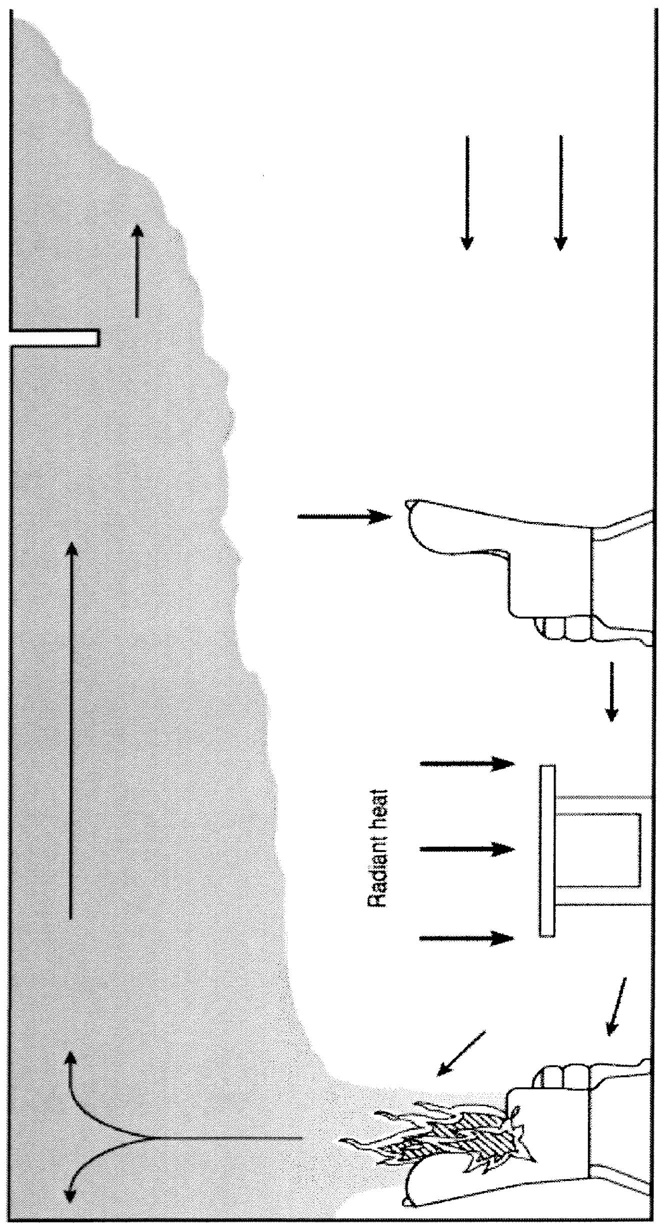


Figure D

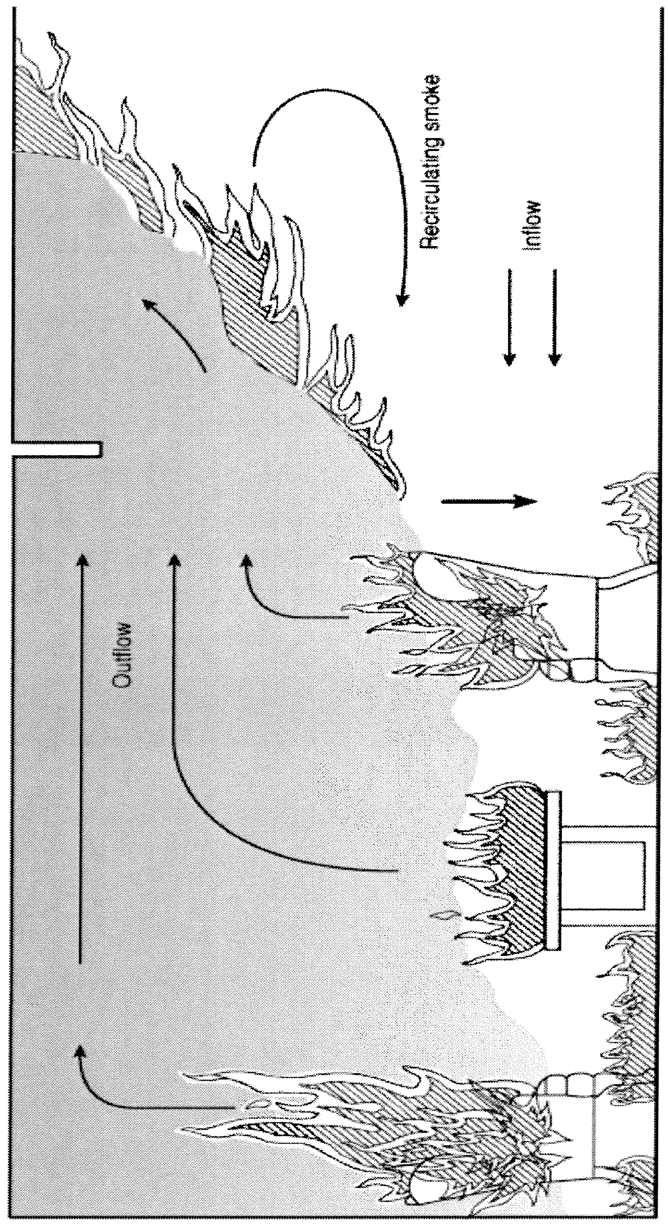
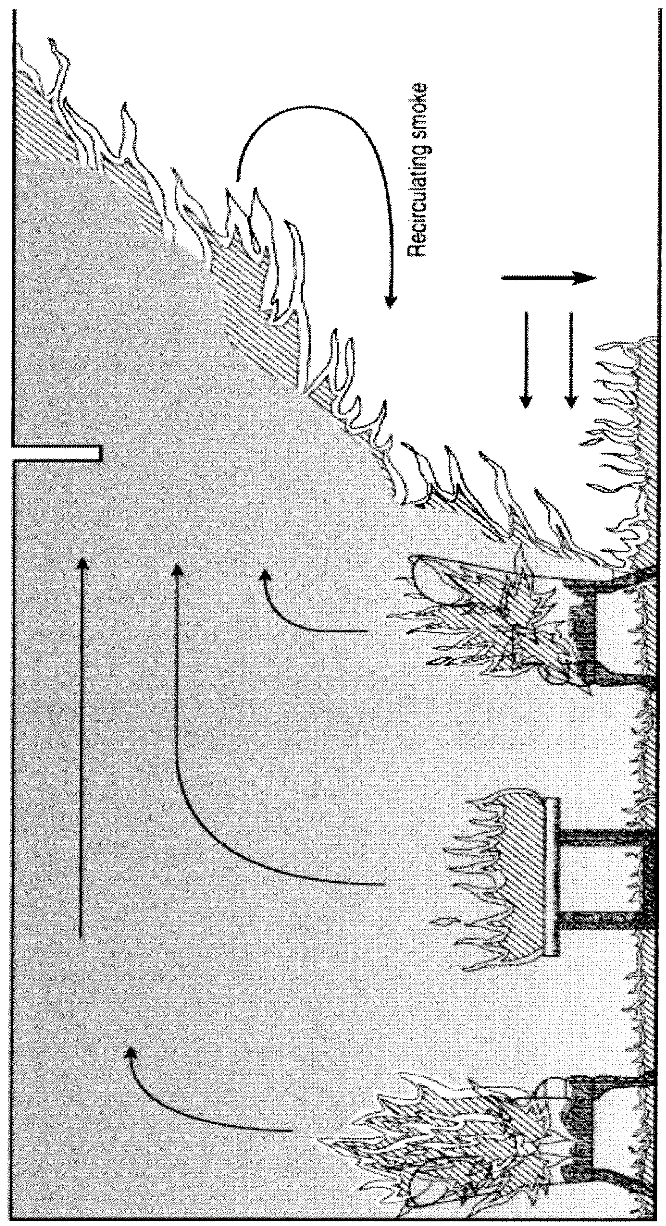


Figure E



Prior to flashover, the fire can be described as “a fire in a room.” After flashover, the fire is more accurately described as “a room on fire.” Flashover is actually a transition point, not an end point, and the damage that results from flashover is actually the result of *full room involvement* rather than the result of the flashover itself. Prior to flashover, the fire increases in size as more fuel is involved, and is said to be a “fuel-controlled” fire. Once flashover occurs, all of the exposed fuel is already involved, so the growth of the fire is controlled by the amount of oxygen available. The fire is said to be “ventilation-controlled.”

The research conducted at NBS and NIST in the 1970s and 1980s was designed to characterize the behavior of materials up to the point of flashover, for purposes of improving the safety of structures and contents. Of the hundreds of fires conducted, none of the scenes were examined to document the aftermath, so from that era, there are almost no data from scientifically conducted test burns that give the field investigator any clues about what type of “burn patterns” remain behind after flashover has been achieved.

Other test burns take place on a regular basis, and are usually conducted at weekend seminars sponsored by local chapters of the International Association of Arson Investigators (IAAI). The reproducibility, and therefore, the validity of these tests varies widely from test to test, depending on the knowledge and dedication of the test organizers. Many of these “burn exercises” are conducted merely to familiarize new investigators with what an ignitable liquid pour pattern looks like (how to recognize arson), and to provide extinguishment exercises for fire crews.[2] The vast majority of burn exercises conducted over the years have been performed with these limited goals in mind. This approach has resulted in many trainees getting a one-sided view of fire investigation, which has unfortunately been passed on to each successive generation of investigators.

As a result of criticism of this practice, fire investigation groups are now beginning to try to simulate accidental fires, and to collect more data from the fires they set. A properly instrumented test burn may have as many as two hundred thermocouples and several radiometers collecting data. A typical test burn conducted by professional fire investigators has fewer than ten thermocouples and no radiometers. The behavior of the fire is usually recorded on videotape.

Two types of test burns have been attempted. The vast majority of test burns are set up to test one or more hypotheses about the general behavior of fire. If the test burn is narrowly focused in terms of the questions it seeks to answer, it is possible for useful information to be derived. Frequently, however, because structures that are available to burn are a rare resource, multiple burns are scheduled for the same structure, so the

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[2] National Fire Protection Association, Standard on Live Fire Training Evolutions in Structures (Pub. No. 1403) (2002).

validity of subsequent tests is questionable.

The second type of test burn aims to reconstruct a particular fire, even though it is generally accepted that no two fires are alike, and an exact reconstruction is impossible. A simple change, such as leaving an interior door open when it should be closed, can drastically affect the development of a fire. About the best that can be hoped for is to reasonably reproduce a fire in a single compartment. This requires an exact match of interior finish and furnishings, something that is difficult to ascertain after a severe fire. Because of the time and enormous expense ($10,000-$100,000) involved in full-scale test burns, they are usually conducted only when there have been multiple deaths or when the damages are in the millions of dollars.

The United States Fire Administration (USFA) released a report on the study of fire patterns in July 1997.[3] The Fire Pattern Research Committee conducted ten full-scale fire tests, four at NIST headquarters in Gaithersburg, Maryland, two in residences in Florence, Alabama, and four in residences in Santa Ana, California. All of the test fires were instrumented and recorded, and the results of the tests are presented in a 210-page report. Many of the concepts, investigative systems, dynamics of pattern production, and pattern analysis concepts put forward in NFPA 921 were confirmed by the testing. Several of the "old fire investigators' tales" and fire investigation misconceptions that are repudiated in NFPA 921 were likewise shown to be unsubstantiated by the testing.

The "old investigators' tales" whose repudiation was confirmed by this testing included:

* wide V's versus narrow V's (which were erroneously thought to reflect the "speed of a fire")

* crazing of window glass (which was erroneously thought to indicate rapid heating—it actually indicates rapid cooling—a much less significant phenomenon)

* char blisters and speed of fire (large, shiny blisters were thought to indicate a rapid fire, while small flat blisters were thought to indicate a slower fire, when, in fact, there is no scientific basis for such an interpretation)

* window sooting/staining (formerly thought to signify the type of fuel that had burned, but now understood to be of little value in determining the fuel type)

* color of smoke and flame (often thought to be indicative of the type of fuel that was burning, but easily misinterpreted in light of the large number of petroleum-based products found in common household items)

Throughout the ten test burns, it became apparent that a major factor in fire pattern development, namely ventilation, was the least understood.

[3] Federal Emergency Management Agency, U.S. Fire Administration, USFA Fire Burn Pattern Tests-Program for the Study of Fire Patterns (FA 178) (Jul. 1997).

The study concluded that much more research needs to be directed at studying the effects of ventilation on the development of fire patterns. Funding for such tests, however, is difficult to obtain.

§ 39:39 Introductory discussion of the science—Field investigations—Errors in origin determinations

In 2005, a group of certified fire investigators from the Bureau of Alcohol Tobacco and Firearms (ATF) designed an experiment that mirrored similar experiments that had been conducted (but not documented) at the Federal Law Enforcement Training Center in Glynnco, GA.

These investigators set up two rooms, simple 12 by 14 foot bedrooms, lit each of them on fire, and allowed them to burn for about two minutes after they flashed over. They then asked 53 participants in a Las Vegas IAAI-sponsored fire investigation seminar to walk through the burned compartments and to write down the quadrant in which they believed the fire had originated. In the first compartment, three participants identified the correct quadrant. When the exercise was repeated on the second compartment, three different participants identified the correct quadrant.

These results caused much consternation in the fire investigation community because one commonly used methodology equated the fire's origin with the area of lowest and deepest char, and that methodological approach was proven wrong. In fact, the poor results should not have surprised anyone. Carman reports that in the undocumented tests at Glynnco, the success rate was 8 to 10%.[1] To be sure, the participants in the Las Vegas tests were not allowed to interview witnesses, nor were they allowed to shovel any of the debris or perform any of the other activities besides the visual observation that typically take place at a fire scene. Moreover, the qualifications of some of the participants were found to be less than stellar, and some people were taking part in the experiment just to familiarize themselves with fire investigative procedures.

Nevertheless, no matter how many explanations for the low success rate were offered, the fact remains that the number of correct origin determinations was three. Reducing the denominator (the total number of "experienced" participants) might raise the percentage of correct answers to 10% or even 20%, but it is important to remember that 25% is the percentage of correct answers that would be expected if all of the participants had been blind, and simply guessed in which of the four quadrants the fire began.

In an attempt to understand what was going on, Carman and his collaborators at ATF re-created the test fires at the ATF Fire Research Laboratory in Ammendale, MD, and modeled the results using computational

[Section 39:39]

[1]Carman, S., "Improving the Understanding of Post-Flashover Fire Behavior," Proceedings of the 3rd International Symposium on Fire Investigations Science and Technology (ISFI). Available at http://www.carmanfireinvestigations.com.

fluid dynamics (FDS and Smokeview). What emerged from these studies was a better, but certainly not complete, understanding of the effects of ventilation in post-flashover fires. The results of these studies have now been incorporated into two very well produced training modules, available at no cost at CFITrainer.net.[2]

Specifically, when the fire undergoes flashover, it is said to make the transition from a fire in a room to a room on fire. Prior to flashover, a fire grows by involving more fuel. Once flashover occurs, all of the fuel that can be involved is involved, and the fire can only grow where it has sufficient ventilation. As stated earlier, the fire is said to have made the transition from a "fuel-controlled" fire to a "ventilation-controlled" fire.

Among many problems with determining the wrong origin is that *the ignition source will not be found there.* Finding an origin without an accidental ignition source will lead investigators who don't understand what is going on to conclude that somebody must have placed some fuel at that origin and ignited it with an open flame. If there is an irregular burn pattern on the carpet in that area, even in the absence of a positive laboratory report, the investigator will almost certainly conclude that the fire was intentionally set using a flammable liquid. Many investigators have made errors using this kind of "negative corpus" determination (discussed more in section 39:65). Finding the correct origin is the key to a correct fire cause determination, and is the most difficult part of the investigation of a fully involved compartment fire.

In 2007, ATF agents refined and repeated the Las Vegas experiment, this time in Oklahoma City. They set up three burn cells, with identical fuel and identical ventilation, but different points of origin. The cells were allowed to burn for 30 seconds beyond flashover, 70 seconds beyond flashover, and 180 seconds beyond flashover. To put these times in context, the best fire departments in big cities *might* have a three-minute response time. If they are not called until someone sees the fire venting out the window (a sign of flashover) the chances of them extinguishing the fire with less than three minutes of post-flashover burning are practically zero. The results of the Oklahoma City experiment validated the data from Las Vegas obtained two years earlier. Further, it became clear that the longer the fire was allowed to burn after flashover, the less likely the fire investigators were to correctly identify the quadrant of origin. The results of the Oklahoma City experiment are shown in Table 1.

Table 1. Results of 3 burn cell tests conducted to measure fire investigators' ability to determine the correct quadrant of origin.[3]

[2] http://www.cfitrainer.net, "Post-Flashover Fires." http://www.cfitrainer.net, "A Ventilation-Focused Approach to the Impact of Building Structures and Systems on Fire Development."

[3] Heenan, D., "History of the Post-Flashover Ventilation Study," Presentation to the California Conference of Arson

Post-flashover burning time	# of responses	# Correct	% Correct
30 seconds	70	59	84
70 seconds	64	44	69
180 seconds	53	13	25

There were, apparently, six investigators who ruled the origin "undetermined" based on the fact that they did not turn in a response for the 70-second post-flashover fire, and 17 investigators who declined to select a quadrant of origin when the fire had burned for 3 minutes beyond flashover.

Of those 53 investigators who did respond, twenty-five percent (25%) got the quadrant of origin correct. While this is a better result than the 6% obtained in Las Vegas, again it was *no better than would be expected if the investigators had chosen the quadrant of origin at random*. Further, there are those who would argue that 69% correct or even 84% correct are low numbers, when one is using those determinations to either send people to prison, or to deny them coverage under their homeowner's policy.

What these results show is a failure of the infrastructure for training fire investigators. Exercises conducted at fire investigation seminars historically have used short-lived fires, extinguished before flashover, to help investigators "recognize arson." This kind of training is no longer acceptable. What these results also show is that fire investigators *and the people who hire them* need to be prepared to accept the reality that sometimes the best answer that can be obtained is "undetermined," if either an accidental or an incendiary call is not supported by conclusive evidence.

§ 39:40 Introductory discussion of the science—Field investigations—Uncertainty in measurement

Based on a combination of fundamental properties as well as the results from experimental fires, fire protection engineers have been able to formulate numerical equations (known as "hand models"), and computer models that predict fire behavior. These models were originally designed for calculating how many sprinkler heads should be required in a room, or how far the exits should be from a particular point. Some of these models are now routinely applied to fire investigation.

When designing a sprinkler system, an uncertainty of plus or minus 30% is considered a good result, because it is possible to simply overdesign the system and install twice as many sprinkler heads as the equation suggests are necessary. When trying to re-create a historical event such as a

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Investigators, San Luis Obispo, CA, November 9, 2010.

fire, however, uncertainties can be very problematic. There are some model outputs that exactly match the progress of a fire, but such precision exists only in cases in which the fires in question were caught on videotape. Multiple iterations of the model allowed the output of the model to match the fire. But if video were available in unknown fires, modeling would hardly be necessary.

Recent research conducted by Daniel Madrzykowski at the National Institute of Standards and Technology[1] attempted to quantify some of the uncertainties inherent in the equations and models. The first thing he noticed was that the oxygen consumption calorimeter, which measures radiant heat flux and other important properties of the fire itself, has a measurement uncertainty of plus or minus 11%. Madrzykowski burned simple known fuels, natural gas, gasoline, and polyurethane foam, and measured flame height, flame width, and the area of the patterns produced by these flames. Even for the simplest of fuels, there was a 25% uncertainty in flame width, and a 33% uncertainty in the fire pattern area. For polyurethane foam, there was a 50% uncertainty in flame height, and a 57% uncertainty in fire pattern area.

The take-away message from these experiments is that equations and models should be used with the greatest caution when attempting to apply them to a fire investigation.

Madrzykowski's work supports work done at the Nuclear Regulatory Commission by Salley et al., in 2007,[2] which compared measurements from test fires with predictions generated by different kinds of models. The NRC researchers found deviations of up to 60% between the predictions and the measured results.

§ 39:41 Introductory discussion of the science—Field investigations—Accelerant detecting canines

In the early 1980s, the Bureau of Alcohol, Tobacco & Firearms and the Connecticut State Police pioneered the use of "accelerant detecting canines (ADCs)". While the name itself is a misnomer (dogs can only detect ignitable liquid residues—they can't tell us whether the liquid was used as an accelerant) this practice has spread as its efficacy has become more apparent.[1] One of the central problems in fire investigation, particularly in

[Section 39:40]

[1]Madrzykowski, D., Fire Fire Pattern Repeatability: A Laboratory Study On Gypsum Wallboard. Proceedings of the 4th International Symposium on Fire Investigation Science and Technology, Columbia, MD, (2010).

[2]Salley, M., et al., "Verification and Validation—How to Determine the Accuracy of Fire Models," *Fire Protection Engineering*, Issue No. 34, Spring 2007, pp. 34–44.

[Section 39:41]

[1]Melissa F. Smith, Evidentiary Issues Surrounding Accelerants Detected by Canines, Proceedings of the Annual Meeting of the American Bar Association (Aug. 9, 1993); Kurz et al., Evaluation of Canines for Accelerant Detection at Fire Scenes, 39 J.

arson investigation, is the location of suitable samples for submission to a laboratory so that hypotheses about the presence of ignitable liquids can be tested. Because most ignitable liquids have an odor, it is surprising that it took as long as it did until the concept of accelerant detecting canines was explored. The canines have the ability to improve the efficiency of a fire investigation, by indicating the location of the ignitable liquid residue and decreasing the frequency of the submission of negative samples to the laboratory, thus saving an enormous amount of resources. Like many scientific advances, however, the law has allowed unjustified excesses with regard to the science, and there are now individuals testifying as to the presence of ignitable liquids at a fire scene based on "alerts" from their canines, even though the laboratory has failed to confirm the indication. Given that there have been few scientific studies and even fewer published research papers on the subject of canine proficiency, this is a disturbing trend.[2] Most scientists in the fire investigation field hold that unless there is a positive laboratory analysis to confirm a canine alert, the alert is not useful in determining the cause of the fire, and is, therefore, irrelevant, both to the fire investigator and to the trier of fact.[3]

This widely held view has subsequently been codified in NFPA 921, as discussed below. Because of concern over some misguided court decisions that allowed the testimony of dog handlers regarding unconfirmed alerts, the NFPA passed a "Tentative Interim Amendment" (TIA) to its 1995 edition of the Guide for Fire and Explosion Investigations, fearing that if they waited to voice their concerns until the 1998 edition of the document, the rapidly developing law on the subject would be difficult or impossible to change. Consequently, the Technical Committee on Fire Investigations declared (and the NFPA Standards Council agreed) that a "judicial emergency" existed. The TIA stated that the only legitimate uses for a canine were the selection of samples that had a higher probability of testing positive, and the establishment of probable cause for a warrant to search further. The TIA echoed the concerns expressed by the IAAI Forensic Science Committee, and was carried forward into future editions of NFPA 921.[4]

As a result of the publication of the TIA, most judges began to follow the guidance of the fire investigation community, and excluded evidence of unconfirmed alerts. In a murder case in Georgia, a conviction was overturned because the trial judge allowed testimony about unconfirmed

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Forensic Sci. 1528 (1994); George Dabdoub et al., Accelerant Detection Canines and the Laboratory, Proceedings of the Annual Meeting of the American Academy of Forensic Sciences 19, (1995).

[2] *State v. Buller*, 517 N.W.2d 711 (Iowa 1994).

[3] IAAI Forensic Science Committee, Position on Accelerant Detection Canines (adopted Sep. 1994), 45 Fire & Arson Investigator 22 (1994).

[4] See National Fire Protection Association, Guide for Fire and Explosion Investigations (Pub. No. 921) (2004), at § 16.5.

alerts into evidence.[5] There have been several notable exceptions, however, as discussed in the preceding section, in which courts have ignored the near unanimous advice of the scientific community, and allowed dog handlers to testify about their dogs' "alerts," even when laboratory testing failed to confirm them.[6]

The utility of canines as a tool for detecting ignitable liquid residues (ILR) was introduced at a meeting of the American Academy of Forensic Sciences in the late 1980s when Maddie, the first operational ADC, was brought to a meeting for a demonstration. Six crime laboratory directors were selected from the audience and asked to stand on a stage. One of them had a drop of gasoline placed on his shoe, and when Maddie came into the hall, she immediately alerted on the appropriate shoe. One astute crime laboratory director asked his colleague to hand him the shoe and brought it up to his nose at which point he exclaimed "I can smell that!" In fact, the true value of accelerant detection canines is not so much in the sensitivity of their noses, but in their willingness to spend their entire day sniffing the floor of a 4,000 sq. ft. fire scene, something that the average fire investigator is not willing to do.

§ 39:42 Introductory discussion of the science—Field investigations—Sniffers

Dogs were preceded into fire scenes by electronic sniffers, devices that had been developed to detect combustible gases in mines and in utility installations. These devices, while useful in eliminating negative samples, are widely believed to be prone to providing false positive alerts. A positive alert by an electronic sniffer is generally not accepted as an indication of the presence of ignitable liquids.

Commercially available electronic sniffers generally incorporate detection devices similar to those used on gas chromatographs. The simplest sniffers use thermal conductivity detectors. Flame ionization, photo ionization and solid-state models have been used. The more complex detectors are sometimes unable to withstand the harsh conditions of the fire scene environment. Solid-state units with comparison modules, sold by Pragmatics, are probably the most popular unit in use today.

§ 39:43 Introductory discussion of the science—Field investigations—Visual observation of accelerant pour patterns

One of the central controversies in arson investigation revolves around an investigator's ability to recognize damage caused by burning accelerants on the basis of observation of visual appearance alone. Since its first

[5] *Carr v. State*, 267 Ga. 701, 482 S.E.2d 314 (1997).

[6] See e.g., *Yell v. Com.*, 242 S.W.3d 331 (Ky. 2007); see also § 39:26.

edition in 1992, NFPA 921 has warned against this practice, with successive editions containing still stronger admonitions. An "obvious pour pattern" may exist in a fire that has not become fully involved, but once flashover has occurred, the rules for interpreting damage change. Fire patterns that look like, but are not, accelerant induced patterns are a common occurrence in fully developed compartment fires. Even in fires that are not fully developed, the interpretation of fire patterns by visual observation alone can be problematic. The Justice Department reported on a series of test burns, conducted by Anthony Putorti at NIST in 2001. Putorti's goal was to characterize the appearance of floor surfaces on which he had started fires using 250–1000 ml of gasoline or kerosene. Many of the patterns produced did not live up to the expectations of many investigators. This was particularly true of the fires set on nonporous surfaces. Additionally, Putorti had difficulty in achieving self-sustained combustion of kerosene, because of its low volatility.[1]

§ 39:44 Introductory discussion of the science—Laboratory analysis—Classification of petroleum products

Most of the people with science degrees who are interested in the study of fires conduct their investigations in the laboratory, where they examine samples brought to them by field investigators. Because it is based on fundamental principles of chemical analysis, laboratory analysis of fire debris is one area of forensic science where there is a near consensus on methodology and terminology.[1] Because of this consensus, there has been a considerable amount of research published on the characterization of ignitable liquid residues recovered from fire debris. Much of the credit for this general consensus goes to the International Association of Arson Investigators Forensic Science Committee and ASTM Committee E30 on Forensic Sciences, which publishes Standard Test Methods for the separation and identification of ignitable liquid residues.[2]

The gas chromatograph (GC) historically has been the primary instrument used in the identification of petroleum-based hydrocarbon liquids, which are the most commonly used accelerants (discussed also in 39:70). An identification not based at least in part on GC is probably invalid. Gas chromatographic techniques that are significantly at variance with the ASTM standards have a lower likelihood of being valid.

As is the case with many of the forensic sciences, the identification is

[Section 39:43]

[1]Anthony Putorti, Flammable and Combustible Liquid Spill/Burn Patterns (March 2001) (NCJ Number 186-634), available online at www.ncjrs.org.

[Section 39:44]

[1]U.S. DOJ, Forensic Sciences: Review of Status and Needs (Feb. 1999), at 40, available at http://www.ncjrs.org/pdffiles1/173412.pdf.

[2]ASTM International; ASTM International, Standard Test Method for Ignitable Liquid Residues in Extracts from Samples of Fire Debris by Gas Chromatography/Mass Spectrometry (Pub. No. E1618) (2010).

based on pattern recognition and pattern matching. The "pattern" arises because petroleum distillates are complex mixtures of up to five hundred different compounds. There is, for example, no such entity as a "gasoline molecule." Gasoline and most petroleum distillates are resolved by the chromatographic column into separate compounds, usually in ascending order by boiling point or molecular weight. (Lighter compounds pass through the chromatographic column more quickly than heavier compounds.) The laboratory analyst comes to recognize the patterns produced by particular classes of petroleum products, and the "match" is made by overlaying the chromatogram from the sample extract onto the chromatogram of a known standard. This comparison can be made on a computer screen, but the traditional method involves laying one paper chart over another on a light box.

There is some room for subjective judgment in this pattern matching, and it is for this reason that the use of mass spectrometry, coupled with gas chromatography, is now the generally accepted methodology (see discussion in 39:70). The standard test method using gas chromatography alone was relegated to "historical" status by ASTM in 2009. While gas chromatography produces a pattern of peaks, the mass spectrometer is capable of identifying the compounds that produce the peaks. With gas chromatography, it may be possible to confuse patterns produced by background materials with patterns of petroleum-based liquids. This is less likely to happen when gas chromatography-mass spectrometry (GC-MS) is used, because there is much less guesswork about the identity of the compounds causing the peaks on the chart. Caution is still required, however, because a piece of carpeting (or any combustible solid) pyrolyzing in the process of combustion may produce compounds that also are found in petroleum distillates. Thus, ASTM E1618 advises analysts that merely *detecting* benzene, toluene, and xylenes, or higher molecular weight aromatics is not sufficient for identifying gasoline. The relative concentrations of all of the compounds of interest must be such that *a recognizable pattern is produced*.

The forensic analysis of ignitable liquid residues thus differs significantly from "identifications" made by environmental scientists, for whom quantifying benzene, toluene and xylene equates to quantifying gasoline. The forensic analysis of ignitable liquids also differs significantly from the forensic analysis of drugs, where detection, not pattern recognition, is the analytical question. Fire debris analysis conducted by drug chemists or environmental chemists is worthy of increased scrutiny, because the specific skill sets required for fire debris analysis are different.

Proficiency tests, manufactured by Collaborative Testing Services (CTS) and sponsored by the American Society of Crime Laboratory Directors (ASCLD), revealed that the error rate for laboratories using gas chromatography alone is significantly higher (50 to 100% higher) than laboratories using GC-MS.[3] These same CTS studies show a decreasing reliance on GC alone (at least among CTS subscribers—arguably the better laboratories in the field). It was a recognition of the advantages of GC-MS over GC alone that caused the deletion of ASTM E1387 from the current book of ASTM standards.

§ 39:45 Introductory discussion of the science—Laboratory analysis—Identification (individualization) of petroleum products

Considerable work has been done regarding the individualization of ignitable liquids in order to tie a suspect to a source. Matching of gasolines has been demonstrated, but as a fire progresses and the gasoline becomes more evaporated, the identification becomes more difficult. In 1987, Mann was able to correctly identify the source of fresh gasoline based on the relative concentrations of light hydrocarbons.[1] Recent work by Dolan and Ritacco demonstrates that it is possible to make successful comparisons, or at least exclusions, of gasoline samples that have weathered to more than fifty percent.[2] This identification is carried out by analyzing pairs of minor components that have very similar boiling points, and thus are equally affected by evaporation. Both Mann and Dolan and Ritacco used a 60-meter column and conventional gas chromatography-mass spectrometry.

A somewhat simpler approach, using an analysis of polynuclear aromatic hydrocarbons (PAHs) has been reported by Sandercock and Du Pasquier in a three-part series published in 2003 and 2004. The instrumentation required no special setup beyond what is ordinarily used for routine fire debris analysis. The PAH ratios do not change significantly upon evaporation and seem to be a characteristic imparted by the refinery.[3]

A new technique, which is in use in the United Kingdom, is said to be capable of not only comparing gasolines, but determining their manufacturer based on the characterization of additive packages using highly sophisticated time-of-flight mass spectrometry. These additives are not volatile, and are said to remain even after all of the volatile materials in a sample have evaporated. Because of privatization of the forensic sciences

[3]Collaborative Testing Services, Flammables Analysis Report No. 9716 (1998); Collaborative Testing Services, Flammables Analysis Report No. 9816 (1999); Collaborative Testing Services, Flammables Analysis Report No. 99–536 (2000).

[Section 39:45]

[1]Mann, Comparison of Automotive Gasolines using Capillary Gas Chromatography: I Comparison Methodology, 32 J. Forensic Sci. 606 (1987).

[2]J. Dolan and C. Ritacco, Gasoline Comparisons by Gas Chromatography/Mass Spectrometry Utilizing an Automated Approach to Data Analysis, Proceedings of the American Academy of Forensic Sciences Annual Meeting, Atlanta, Georgia (Feb. 16, 2002), at 62.

[3]Sandercock, M., and Du Pasquier, E. (2004b). Chemical fingerprinting of gasoline: 3.Comparison of unevaporated automotive gasoline samples from Australia and New Zealand. *Forensic Sci. Int.*, 140:71–77.

in the U.K., however, the one laboratory that claims the capability of performing it has not yet published this technique.[4]

Individualization of petroleum distillates other than gasolines has not been extensively studied, due mainly to the difficulty of the task. Unless there is some unusual compound dissolved in the petroleum distillate, identification is generally regarded as difficult, but exclusions are possible.

Recent studies by environmental chemists, attempting to measure the age or source of petroleum discharges, have identified several classes of higher molecular weight compounds, more likely to survive a fire, which can be used for individualization. Considerable additional work is required before this technology will be applicable to fire debris analysis.[5]

With the enormous financial incentives related to the identification of responsible parties in environmental cases, the field of environmental forensics has moved forward in ways that indicate that the day is soon arriving when it will be possible for petroleum products to be linked to a particular source. *Introduction to Environmental Forensics*[6] goes into great detail about the chemical "fingerprinting" of hydrocarbons, and the scientific theory that makes such fingerprinting possible. New techniques to accomplish this task include two-dimensional gas chromatography, high-resolution mass spectrometry and isotope ratio mass spectrometry. While generally too expensive to be used routinely in ordinary fire cases (and usually the question of individualization does not present itself) these techniques promise to assist in the individualization of even highly weathered residues such as those found at fire scenes.

One technique that allows for the elimination of a suspect source relies on the comparison of the average molecular weight of the residue from the fire with the suspected source. Evaporation of an ignitable liquid under fire conditions is an irreversible, one-directional phenomenon. When exposed to heat, the more volatile (lower molecular weight) compounds in the liquid vaporize before the less volatile compounds, leaving the resulting residue relatively richer in the higher molecular weight compounds. Thus, the average molecular weight of the residue (which can be evaluated by examining the "carbon number range") is necessarily higher in the fire-exposed residue than in the container from which it was poured. If the liquid in the suspected source container exhibits a lower average molecular weight than the residue, it may be the true source. If, on the other hand, the liquid in the suspected source container exhibits a higher molecular weight than the residue, it can be positively eliminated as the source, even though it contains the same class of ignitable liquid.

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[4]Rebecca Pepler, Petrol Branding, Presentation at Gardner Associates International Fire and Arson Investigator Conference (June 29, 2005).

[5]S. A. Stout & A.D. Uhler, Chemical "Fingerprinting" of Highly Weathered Petroleum Products, Proceedings of the American Academy of Forensic Sciences (Feb. 2000).

[6]Brian L. Murphy and Robert D. Morrison, Introduction To Environmental Forensics (2002).

§ 39:46 Areas of scientific agreement and disagreement—Field investigations

There are few fields where the ability of experts to disagree after viewing the same evidence is more of a problem than in fire investigation. Because a fire destroys so much of the physical evidence, it is a rare fire that can be examined by more than one expert and yet have only one conclusion reached about it. Generally, the more severe the fire, the less likely two individuals are to agree as to its cause. Certainly, the more thorough the investigation and the more information actually collected, the more likely these individuals are to be able to agree as to the cause of a fire.

Some opinions are a cause for particular concern. When the fire investigator opines that the artifacts he sees are the result of the burning of an ignitable liquid, and the laboratory analysis fails to confirm the presence of ignitable liquid residue, additional scrutiny of the investigator's methodology is warranted. This is especially true if the investigator bases his interpretation on one or more of the many discredited myths about fire investigation. These myths were first collected, described, and published by the Aerospace Corp., working under contract to the Law Enforcement Assistance Administration in 1977.[1] Misconceptions include the following:

Alligatoring effect (checking of charred wood, giving it the appearance of alligator skin): Large rolling blisters were believed to indicate rapid intense heat, while small flat alligatoring suggested long, low heat.

Crazing of glass (formation of irregular cracks in glass due to rapid intense heat): attributed to possible fire accelerant.

Depth of char (depth of burning of wood): used to determine length of burn and thereby purportedly locate the point of origin of the fire.

Line of demarcation (boundary between charred and uncharred material): On floors or rugs, a puddle-shaped line of demarcation was believed to indicate a liquid fire accelerant. In the cross-section of wood, a sharp distinct line of demarcation was believed to indicate a rapid, intense fire.

Sagged furniture springs: Because of the heat required for furniture springs to collapse from their own weight (1150F) and because of the insulating effect of the upholstery, sagged springs were believed to be possible only in either a fire originating inside the cushions (as from a cigarette rolling between the cushions) or an external fire intensified by a fire accelerant.

Spalling (breaking off of pieces of the surface of concrete, cement or brick due to intense heat): Brown stains around the spall were believed

[Section 39:46]

[1]Aerospace Corp., Arson and Arson Investigation: Survey and Assessment (USDOJ, National Institute of Law Enforcement and Criminal Justice, 1977), at 87.

to indicate the use of a fire accelerant.

In addition to the misconceptions listed in the LEAA report, the following myths have also been widely promulgated:

Fire load: Knowing the energy content (as opposed to the energy release rate) of the fuels in a structure was believed to allow an investigator to calculate the damage that a "normal" fire should produce in a given time frame.

Low burning and holes in the floor: Because heat rises, it was widely believed that burning on the floor, particularly under furniture, indicated an origin on the floor.

V-pattern angle: The angle of a V-pattern was supposed to indicate the speed of the fire.

Time and temperature: By estimating the speed of a fire, or establishing the temperature achieved by a fire, it was believed that an investigator could determine whether it was accelerated.[2]

The authors of the LEAA publication, to their credit, acknowledged that the burn indicators listed had not been scientifically validated, and urged a series of experiments to test their reliability. They further urged the production of a handbook after the tests were run.

Unfortunately, no tests were run, but a handbook was published anyway. Using information provided by the U.S. Fire Academy, no less an authority then the U.S. National Bureau of Standards, published a collection of old wives' tales in 1980.[3] Given the undisputed authority of the NBS, these myths were widely cited in the fire investigation literature.

Despite the fact that no one now employed at The National Fire Academy or at NIST (the successor to NBS) still believes the myths, neither agency has yet "officially" repudiated the misinformation that they promulgated. This is particularly disturbing in the case of the NFA, because nearly all public sector fire investigators, and especially the senior members of the profession were trained (or mis-trained) at the NFA. The NFA has stopped teaching myths, but as of 2011, the misguided 1980 *Handbook* could still be downloaded from the NIST website.

§ 39:47 Areas of scientific agreement and disagreement—Field investigations—The behavior of fire

With respect to the behavior of fire, all investigators will agree that there is a fire triangle consisting of heat, fuel, and oxygen. Some investigators will expand the triangle into three dimensions, and describe a fire tetrahedron, the fourth point of which is a sustained chemical reaction.[1]

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[2]See John J. Lentini, The Mythology of Fire Investigation, in *Scientific Protocols for Fire Investigation* (2006).

[3]Francis Brannigan et al. (eds.), Fire Investigation Handbook (1980).

[Section 39:47]

[1]National Fire Protection Association,

Fire investigators will all agree that heat rises, and that the primary means of fire spread are conduction, convection, and radiation.

When they actually begin to describe how a *particular* fire spread, however, many fire investigators ignore everything but convection, that is, the phenomenon that causes warm air to rise. This phenomenon also causes a fire to spread out in a "V" shaped pattern until it reaches an obstruction. Thus, seeking the bottom of the "V" shaped burn pattern should lead one to the origin.[2]

Unfortunately, this indication of a fire's origin is useful only when the fire is extinguished prior to achieving total room involvement. Once a fire has progressed beyond a certain point, items that were located near the top of the room catch fire and fall down, causing secondary ignitions, and additional "V" shaped burn patterns.[3] These may be falsely interpreted as evidence of a second point of origin. Since everyone agrees that with limited exceptions, an accidental fire can begin in only one place, multiple points of origin are generally considered to be an indicator of arson.

There is considerable disagreement in the fire investigation community, however, about the ability of fire investigators to credibly determine multiple origins when the fires have burned together. Some fire investigators insist that they have the ability to determine multiple points of origin even if a room has flashed over. They do this by looking at holes in the floor, and because holes in the floor represent "low burns," these are equated with multiple origins. NFPA 921 advises the investigator to be wary of numerous conditions that could result in "apparent" multiple origins.[4]

Low burns are also taken (or mistaken) as an indication of the presence of ignitable liquids. Because heat rises and fire burns up, the presence of a low burn is sometimes taken as an indication that there was "something" on the floor that held the fire down. While ignitable liquids will accomplish this task, radiation is even more effective at burning floors. If total room involvement has been achieved, there is no reason for a floor not to be burned.[5] The failure to take into account the effects of radiation may be a result of a general lack of understanding of this common and important means of heat transfer.[6]

When the floor is burned, there is a tendency on the part of some fire investigators to believe that, unless it has burned in a perfectly uniform

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Guide for Fire and Explosion Investigations (Pub. No. 921) (2004), at § 5.1.2.

[2]National Fire Protection Association, Guide for Fire and Explosion Investigations (Pub. No. 921) (2004), at § 6.6.2.5.

[3]National Fire Protection Association, Guide for Fire and Explosion Investigations (Pub. No. 921) (2004), at § 22.2.1.

[4]National Fire Protection Association, Guide for Fire and Explosion Investigations (Pub. No. 921) (2004), at § 22.2.1.2.

[5]National Fire Protection Association, Guide for Fire and Explosion Investigations (Pub. No. 921) (2004), at § 6.19.1.

[6]John D. DeHaan, Kirk's Fire Investigation 36 (5th ed. 2003).

manner, radiation can be ruled out as the cause of the low burning. This is based on the misperception of flashover as being a uniform phenomenon.[7] Actually, the uniformity of the flashover event breaks down within the first few seconds. Additionally, most synthetic floor coverings have a tendency to tear open during a fire, thus leaving parts of the floor exposed and other parts of the floor covered. The alternating exposed and covered areas can result in the production of patterns, particularly on combustible surfaces, which look remarkably like patterns that people associate with flammable liquids.[8] This is a fact that is not yet accepted by many fire investigators, but the exposure of these misperceptions has led to several well-publicized reversals of convictions.[9] The current edition of NFPA 921 contains several photographs of what one would expect to be a flammable liquid pour pattern, but which were actually created by radiation alone.[10]

The series of test burns conducted under the auspices of the USFA, discussed above, has generated much interesting data, but there has not been unanimous agreement on the correct interpretation of those data. The NFPA Technical Committee on Fire Investigations received several comments critical of the series of tests when it proposed citing the final test report in NFPA 921.[11] Many of these criticisms cited the "incomplete" nature of the data, because funds ran out before all of the proposed tests could be completed. These arguments really did not focus on the quality or the interpretation of the data. Other, more legitimate, criticisms of the report focused on its conclusions about the cause of certain types of burn patterns, believed to have been caused by unique ventilation parameters, and on the suggestion of the report's authors that much meaningful information could be gleaned from the depth of the "calcination" (the whitening and softening of the wallboard due to dehydration) of gypsum wallboard.

§ 39:48 Areas of scientific agreement and disagreement—Field investigations—Ventilation controlled fires

In follow-up studies after the origin determination experiments described in 39:39, ATF scientists modeled what was happening in the fires that caused so much confusion. What they learned was that at the point of flashover, when all exposed combustible fuels ignite almost simultaneously, the fire uses up most of the oxygen in the room. The point where the fire originated may have a poor oxygen supply, and thus not burn as vigorously as other points within the room. The models clearly show that it is

[7] Barker Davie, Flashover, 11 Nat'l Fire & Arson Rep. 1 (1993).

[8] National Fire Protection Association, Guide for Fire and Explosion Investigations (Pub. No. 921) (2004), at § 6.17.8.2.5.

[9] State v. Knapp, No. CR 78779 (Superior Ct. of Arizona, Maricopa County, Feb. 11, 1987); State v. Girdler, No. 9809 (Superior Ct. of Arizona, Maricopa County, Jan. 3, 1991).

[10] National Fire Protection Association, Guide for Fire and Explosion Investigations (Pub. No. 921) (2004), at § 6.17.8.2.

[11] Technical Committee Documentation, NFPA, Report on Proposals for the Fall, 2000, Meeting, at www.nfpa.org.

the absence of oxygen that causes the fire to vitiate (go out). Flames typically cannot exist if the oxygen content of the air is lower than 12%. In fully involved compartments, the oxygen content away from points of ventilation falls well below that.

Once flashover has occurred, the space inside the compartment is filled with vaporized but unburned fuel. That fuel can only burn when it has air. This is why fully involved fires may seem to be coming from darkened interiors, and only flame once the heavy smoke reaches the outside. As was suggested by the 1977 tests, ventilation plays a very important role in the production of post-fire artifacts. Fire investigators who do not understand ventilation will not understand the fire.

After the catastrophic Oakland fire of 1991, Lentini, Smith, and Henderson conducted a study to determine the validity of the "indicators of arson." They studied copper, steel, and glass in fifty of the 3,000 houses that had been burned to completion. Most of the houses exhibited multiple "indicators" of arson, even though they are known to have burned in an accidental fire.[1]

§ 39:49 Areas of scientific agreement and disagreement—Field investigations—The appearance of accelerant induced damage

Scientists at the Building and Fire Research Laboratory (BFRL) at NIST conducted a series of tests to identify the characteristics of flammable and combustible liquid burn patterns on horizontal surfaces.[1] The findings reveal several interesting facts about the resulting patterns, including that:

* the spill area can be predicted from fuel quantity
* the quantity of gasoline spilled can be determined by the burn pattern area on nonporous flooring such as carpet
* the heat release rates of spilled liquids on carpeted surfaces are approximately equal to the steady heat release rate of the equivalent diameter pool fires, but on nonporous surfaces the heat release rates are much lower
* on carpeted surfaces, a "donut" pattern frequently results when ignitable liquid burns on the carpet

The study also found that significant quantities of the fuel were present after extinguishment on carpeted fires because the carpet melted and protected the unburned liquids. On nonporous surfaces, some of the burn

[Section 39:48]

[1]John J. Lentini et al., Baseline Characteristics of Residential Structures Which Have Burned to Completion: The Oakland Experience, 28 Fire Technology 195 (1992).

[Section 39:49]

[1]Putorti, A. Flammable and Combustible Liquid Spill/Burn Patterns (NCJ Number 186–634) (March 2001), available online at www.ncjrs.org.

patterns look remarkably *unlike* those typically expected from a flammable liquid pour. It turns out that radiation from burning solids can create "puddle-shaped" patterns when no liquids are present. A photograph of such a puddle shaped pattern was added to NFPA 921 as a caution to fire investigators against "over interpreting" (a euphemism for misinterpreting) the burn patterns that they see on floors.

The NIST study also determined that heavy petroleum distillates such as kerosene make poor accelerants. On nonporous surfaces, the experimenters had difficulty keeping kerosene burning.

§ 39:50 Areas of scientific agreement and disagreement—Field investigations—Accidental fires

Even though 90% or more of all fires are accidents, the vast majority of fire scene investigators receive their training as "arson investigators." Accidental fires frequently result in civil litigation. The trend toward subrogation in the insurance industry picked up considerable strength in the late 1980s and shows no signs of abating. Thus, arson investigators are now called upon to determine accidental causes, with an eye toward pinning the blame on a manufacturer, or a provider of a service, or anyone other than the named insured. Competent investigators have the good sense to call in the appropriate engineering discipline once they have determined that a particular device is located at the origin. Most engineers are unable to determine the origin of a fire, and most fire investigators are unable to independently determine the cause of failure of an appliance or system. It should be noted, however, that the possession of a degree in electrical engineering is no guarantee that the engineer knows anything about burned appliances and systems, as that is not a subject learned in engineering school. Evaluating electrical sources of ignition requires skill that can only come from experience.

§ 39:51 Areas of scientific agreement and disagreement—Field investigations—Electrical activity

Given the billions of connections and millions of megawatts flowing through them at any given time, it is truly amazing that there are so few electrical fires, amounting to less than 5% of structure fires. Most of these are the result of loose connections.[1]

Fire investigators generally agree that the electrical system can be used as a fire detector, in that the first point on an energized electrical circuit that is compromised by a fire is likely to be the first and only point on that

[Section 39:51]

[1]John J. Lentini, Electrical Fires, in Scientific Protocols For Fire Investigation (2006).

circuit where arcing occurs.[2] There is some disagreement, however, about the characterization of arcing. There are many fires where one investigator will point to a piece of melted copper and identify it as evidence of arcing, while another investigator will look at the same piece and state that the copper was heated above its melting point (1981F). The determination as to whether a bead of melted copper was caused by electrical or thermal activity can usually be resolved through an examination by a practiced investigator.[3] The essential test for determining whether the copper was melted by electrical or thermal activity is the existence of a sharp line of demarcation between a localized area of melting and unmelted wire.

Some studies have been conducted on the examination of arc beads, to determine whether they were created in an atmosphere full of smoke or in a smoke-free atmosphere. The, thus far unproved, theory is that if the arc was created toward the beginning of the fire, it might have been the cause of the fire.[4] The ability to determine the elemental content of the atmosphere at the time an arc bead was created, however, has not been repeatedly demonstrated, and the significance of the atmospheric chemistry is a subject of debate.[5] Arcing occurs in almost all fires, and almost all arcing events are the result of a fire, rather than the cause of it. The search for the "primary" arc, however, has resulted in many disagreements among fire investigators and electrical engineers. The fact is that electrical arcing is not responsible for a large number of fires, but an arc can be shown to be a competent ignition source, although the typical arc lasts less than a hundredth of a second. Thus electrical arcs are often mistakenly blamed for causing fires.[6] Electricity does cause fires, but almost all electrical fires are caused by "series arcs." These arcs occur when the electrical current is traveling in its intended path, but encounters a loose connection. When the current jumps across that connection, it generates local temperatures sufficiently high to ignite surrounding combustibles. Series arcs typically can last for hours or days. Ground fault arcs, where the current moves out of its intended path, are frequently extinguished in one cycle (1/60th of a second) or less. Thus, the utility of looking for evidence of a "primary" arc is questionable, at best. The analytical technique required for this "test," auger electron microscopy, is quite expensive, and is unlikely to be encountered in routine cases.

In addition to "arcing," other electrical sources are frequently cited, correctly or incorrectly, as the cause of a fire. Heat producing appliances (portable space heaters and kitchen ranges) are the most frequent causes of

[2]Richard Underwood & John J. Lentini, Appliance Fires: Determining Responsibility, 7 Nat'l Fire & Arson Report 1 (1989).

[3]Bernard Beland, Examination of Electrical Conductors Following a Fire, 16 Fire Tech. 252 (1980).

[4]Anderson, Surface Analysis of Electrical Arc Residues in Fire Investigation, 34 J. Forensic Sci. 633 (1989).

[5]Bernard Beland, Examination of Arc Beads, 44 Fire & Arson Investigator, Jun. 1994, at 20.

[6]John D. DeHaan, Kirk's Fire Investigation at 335 (5th ed. 2003).

fires started with electrical energy.[7] Ballasts from fluorescent lights are probably the most frequently falsely accused electrical devices. When we consider the millions of these devices in use, it is not hard to imagine that there will be a ballast found within ten feet of the origin of almost any commercial fire. If a fluorescent light ballast truly has caused a fire, it will likely have a hole melted in the ballast case.

Electronic equipment such as computers, stereo systems, and televisions often are blamed for fires. In fact, television sets manufactured in the early 1970s were responsible for a very large number of fires. But by 1993, the Consumer Product Safety Commission (CPSC) estimated that incidence had fallen to 0.4% of all residential fires, or 2100 incidents annually, causing 30 deaths.[8]

Recent work on the evaluation of low voltage devices causing fires has occasioned reconsideration of the potential of some devices to cause fires. As a result of manufacturers turning to "environmentally friendly" solders for printed circuit boards (PCBs), the potential for these devices to cause fires has increased dramatically.[9] Fires have even been reported in television remote controls operating at three volts if the PCB becomes contaminated with a conductive substance such as salt water.

Each proposed electrical fire cause deserves careful evaluation. Some "indicators" of electrical causation, like some indicators of arson, have been studied and shown to be less valid than previously thought. Oversized fuses or breakers, unless very much larger than required, are generally incapable of supplying sufficient current to overheat a circuit. A 30-amp fuse or breaker located in a panel where there should be a 20-amp fuse or breaker is interesting, but almost certainly meaningless. Research has shown that large excesses of current, three to four times the designed load, are necessary to cause a dangerous situation.[10] The condition of insulation on a cable may yield some information about overcurrent, particularly if the insulation has melted loose from the conductor. A comparison must be made with a similar unheated wire, however, to determine the original "tightness" of the insulation. The lack of loose insulation does not rule out overcurrent.[11] Overcurrent in branch circuit wiring, however, is not a frequent cause of fires. Sometimes, overcurrent causes undersized extension cords to overheat.

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[7] National Fire Protection Association, Major Causes of Home Structure Fires, 2005–2009, (2011).

[8] John D. DeHaan, Kirk's Fire Investigation at 271 (4th ed. 1997) and at 340 (5th ed. 2002).

[9] Vicars, R. et al., "Low Voltage The Incompetent Ignition Source Dispelling The Myth," Proceedings of the 4th International Symposium on Fire Investigations Science and Technology (ISFI), NAFI, Sarasota, FL, 2010.

[10] Ferrino, J.L, "An Investigation of Fire Phenomena in Residential Electrical Wiring and Connections," M Sc. Thesis, Department of Fire Protection Engineering, University of Maryland, 2002, page 34.

[11] John D. DeHaan, Kirk's Fire Investigation at 271 (4th ed. 1997) and at 340 (5th ed. 2002).

The most frequently encountered problem in the examination of electrical evidence is one of cause and effect. Did the wire short and start the fire, or did the fire burn the insulation and cause the wire to short? Almost always it is the latter, because arcs are such short-lived events.

The laboratory examination of an appliance suspected of causing a fire will usually allow for a definitive ruling out of whether the appliance was the cause. An essential component of such a laboratory examination is the acquisition of an exemplar product. A detailed description of the procedures for examining various types of appliances suspected of causing fires may be found in *Scientific Protocols for Fire Investigation*.[12]

§ 39:52 Areas of scientific agreement and disagreement—Field investigations—Cause and effect

The same type of chicken-and-egg, or cause and effect, argument applies to other systems found in buildings as well. The gas system, for instance, is frequently compromised by a fire, resulting in leaks observed during and after the fire. It is the goal of the fire investigator to determine whether the leak existed before the fire. This is often a more difficult question than the science is capable of resolving, particularly if the leak occurs in a combustible line. Metallurgists can be of some assistance in determining the reason for a fracture, and can sometimes tell whether the metal broke while it was hot or cold.

The compromise of electrical and fuel systems by fire, and the confusion that it creates, is even more evident in vehicle fires. As a general rule, fire investigators will agree that, while fires can start in the engine compartment and move to the passenger compartment, the reverse is seldom true. Some of the early fire investigation literature pertaining to vehicles suggested that almost all vehicle fires were intentionally set, as all of the fires contained certain "indicators" of excessive heat.[1] These texts are now generally regarded as incorrect, as it has been shown that regardless of ignition method, the temperature achieved by a vehicle fire will approach 2000F, resulting in buckling and warping of body panels, melting and flowing of window glass, and a loss of seat spring temper. Thus, the intensity and duration of a vehicle fire cannot be interpreted as indicating or not indicating the presence of accelerants.[2]

In a structure fire, an investigator who can narrow down the origin to a three-by-three foot square is considered a hero. In a vehicle fire, a three by three foot square is the starting point, and unless the exact cause can be determined, the fire investigator fears being seen as a failure. Thus,

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[12] John J. Lentini, Evaluation of Ignition Sources, in Scientific Protocols For Fire Investigation (2006).

[Section 39:52]

[1] National Automobile Theft Bureau, Manual for Investigation of Vehicle Fires (1986).

[2] John D. DeHaan, Kirk's Fire Investigation 287 (5th ed. 2003).

frequently investigators will seize upon a burned fuel line or an arced electrical wire as the cause of a fire, when the evidence argues equally that the observed "causative" phenomenon is actually an effect.

Since 2004, it has been accepted that a determination of the compartment of origin (engine compartment versus passenger compartment) can be made by observing burn patterns on the exterior surfaces of the car. These so-called *radial burn patterns* indicate the direction of fire movement.[3]

A special case of vehicle fire can usually be determined without even looking at the vehicle. This is the case where a vehicle is reported stolen and recovered burned. It requires no special training to conclude that it is unlikely to have sustained an accidental fire right after it was stolen.

§ 39:53 Areas of scientific agreement and disagreement—Field investigations—Black holes

Perhaps no type of fire is more difficult than the "black hole," a structure fire in which everything is reduced to ashes. Despite the difficulties of these investigations, fire investigators have been known to claim the ability to detect multiple origins in completely consumed structures, or to state, based on "indicators," that a fire burned "hotter than normal" or "faster than normal."[1]

The studies done by the Center for Fire Research have tended to put to rest the diagnosis of "faster than normal." If a piece of upholstered furniture is ignited, it can bring a room to total involvement in less than five minutes. Flashover times of 3 to 5 minutes are not unusual in residential room fire tests and even shorter times to flashover have been observed in nonaccelerated room fires.[2] Once flashover occurs in a particular room, extension into nearby rooms can be exceedingly rapid, involving entire houses in as little as ten minutes.

The editors of *Fire Findings* explored the reliability of witnesses who report on the speed of a fire. Such reports are generally unreliable.[3] *Fire Findings* offers a videotape entitled "What Witnesses Don't See" that describes the event preceding a fire's detection. Often, witnesses only notice a fire when it breaks out a window, a sign that flashover has just occurred. The witnesses to the event have no clue as to when the fire started. Eyewitnesses reporting a rapid rate of fire growth should not be

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[3]National Fire Protection Association, Guide for Fire and Explosion Investigations (Pub. No. 921) (2004), at § 25.8.

[Section 39:53]

[1]Lentini, J., "A Calculated Arson," *The Fire and Arson Investigator*, Vol. 49, No. 3, April 1999.

[2]National Fire Protection Association, Guide for Fire and Explosion Investigations (Pub. No. 921) (2011), at § 5.10.4.6.

[3]Jack Sanderson, Fire Timing Test Results: Fires May Only Appear to Spread Rapidly, 3 Fire Findings 1 (1995).

construed as data supporting an incendiary fire cause.[4]

The fire that burns "hotter than normal" has, in the past, been identified by examination of the metals and other noncombustible materials within a structure, in order to get a handle on the temperature that the fire achieved. In 1969, Kirk advised noting melted metals because:

> The investigator may use this fact to his advantage in many instances, because of the differences in effective temperatures between simple wood fires and those in which extraneous fuel, such as accelerant, is present.[5]

Contrast this advice with DeHaan, Kirk's successor:

> While such melted metals cannot and should not be used as proof that the fire was incendiary, the fire investigator should note their presence, extent and distribution. Such information can be of help in establishing differences between normally fueled and ventilated accidental fires and those produced by enhanced draft conditions or unusual fuel loads from accelerants in incendiary fires.[6]

While DeHaan recognizes the importance of ventilation, he still maintains that unusual temperatures may be caused by enhanced draft conditions *or* unusual fuel loads while the data only support the former. Nonetheless, the modern text of Kirk's at least recognizes what blacksmiths and metallurgists have known for millennia: increased ventilation—not a change in fuel—causes increased temperatures. Despite this knowledge, fire investigators continue to rely on the presence of melted copper to indicate a "hotter than normal" (therefore accelerated) fire. This is particularly true of fires when the melting is found at floor level.

Melted steel was considered to be even more indicative of a "hotter than normal" fire. Steel has a melting temperature of 2100–2700F, depending on its elemental content. Multiple areas in a structure that exhibit melted steel have been considered as indications of the use of ignitable liquids to accelerate a fire.

Actually, it has been demonstrated that the flame temperature above a burning pool of ignitable liquid is no greater than the flame temperature of a well-ventilated wood fire.[7] The purpose of an accelerant is to make the fire burn faster, by involving more materials sooner than they would be otherwise involved. These fires *do not burn at higher temperatures*. The *rate* of heat release is higher in an accelerated fire, as the BTUs or joules are released over a shorter period of time. The *temperature* of the fire, however, and its ability to melt items such as steel and copper, is actually no different from that of an unaccelerated fire.

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[4] National Fire Protection Association, Guide for Fire and Explosion Investigations (Pub. No. 921) (2011), at § 5.10.1.4.

[5] Paul Kirk, Fire Investigation 145 (1969).

[6] John D. DeHaan, Kirk's Fire Investigation, at 173 (4th ed. 1997) and at 218 (5th ed. 2002).

[7] Richard Henderson & George Lightsey, Theoretical Combustion Temperature, Nat'l Fire & Arson Report (1985).

Although the concept of an accelerated fire burning hotter than an unaccelerated fire is an appealing notion, like many of the other myths in fire investigation it is easily disproved. Again, the purpose of an accelerant is to involve materials sooner. Consider a birthday candle. We can use a thermocouple to measure the temperature of the candle. If we light ten candles, the energy released by the burning candles will be 10 times higher, but the temperature of the individual candle flames will be exactly the same. Since it was first published in 1992, NFPA 921 has contained an admonition that wood fires and gasoline fires burn at essentially the same temperature, but to this day there are "arson investigators" who don't acknowledge this simple truth.

§ 39:54 Areas of scientific agreement and disagreement—Field investigations—"Melted" steel

Metallurgical laboratory analysis conducted as a follow-up to the Oakland study revealed that it is not possible to determine by visual inspection alone whether a piece of steel, particularly a low mass piece of steel such as a bedspring, has melted or merely oxidized. This distinction can only be made by microscopic examination of a polished cross-section of the metal. Thus, steel that had been characterized as "melting," at temperatures of up to 2700F, may have actually been exposed to temperatures no higher than 1300F for a long period of time, and assumed an appearance that was wrongly interpreted as melting.[1]

§ 39:55 Areas of scientific agreement and disagreement—Field investigations—Crazed glass

Glass is another material that changes as a result of exposure to the heat of a fire. Many texts have referred to the crazing of glass as an indication of rapid heating, and one widely circulated handbook went so far as to state that crazed glass was an indicator of nearby accelerants.[1] Crazed glass was used as an important "indicator" in the trial of Ray Girdler, whose conviction was later overturned based on new scientific evidence.[2] Experiments conducted after the Oakland fire study revealed that no amount of rapid heating would cause crazing, but that rapid cooling, caused by the application of a water spray, would cause crazing in all

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[Section 39:54]

[1] John J. Lentini et al., Baseline Characteristics of Residential Structures Which Have Burned to Completion: The Oakland Experience, 28 Fire Technology 195 (1992).

[Section 39:55]

[1] John Barracato, Burning, A Guide to Fire Investigation, AETNA Casualty and Surety Company (1986).

[2] State v. Girdler, No. 9809 (Superior Ct. of Arizona, Maricopa County, Jan. 3, 1991).

cases, whether the glass was heated rapidly or slowly.[3] Crazed glass is meaningless in determining the cause of a fire. Investigators who cite crazed glass as an indicator of an incendiary fire should be easily discredited.

§ 39:56 Areas of scientific agreement and disagreement—Field investigations—Concrete spalling

Spalling is the explosive breaking of concrete, caused by the application of heat. This phenomenon has been the subject of more rhetoric, and probably less research, than most of the other issues in fire investigation. It is one of the most misunderstood and improperly used evidentiary features in the field,[1] and was the basis of an unfortunate case in Alabama that resulted in a record punitive damage award against the insurance company, which presented spalling as evidence of incendiary origin. In that case, the fire had reduced a two-story house to a pile of rubble about a foot deep on top of the concrete slab basement floor. The fire investigator (the second one hired by the insurance company) cleared off a narrow area about ten feet in length and discovered that the floor was spalled. He then declared that a "trail of spalling" existed, and was incontrovertible proof of an incendiary fire. Despite the fact that the defendant's investigator found that the entire slab was spalled, this "trail" evidence was presented, resulting in the court rendering and the supreme court endorsing the following characterization: "The presentation of [the investigator's] testimony borders upon the perpetration of a fraud upon this court."[2]

There is an "old school," which holds that concrete spalling is an indication of the presence of ignitable liquids, as well as a cadre of scientists (none of whom have published in a peer reviewed journal) who hold that it is impossible for a flammable liquid to cause spalling.[3] In the middle are the vast majority of fire investigators, who believe that spalling is just another facet of the "burn pattern," which may or may not indicate the presence of an ignitable liquid, depending on the situation. Most fire investigators have seen containers of ignitable liquids that have spilled their contents onto a concrete floor, and in the exact place where the liquid was located, spalling has occurred. The extrapolation of this anecdotal experience to all fires is, of course, an error. There have been no documented experiments in which a flammable liquid caused concrete to spall. When one considers the behavior of flammable liquids, one is led to the conclusion that as long as there is liquid on the concrete, the surface of the concrete

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[3]Lentini, Behavior of Glass at Elevated Temperatures, 37 J. Forensic Sci. 1358 (1992).

[Section 39:56]

[1]National Fire Protection Association, Guide for Fire and Explosion Investigations (Pub. No. 921) (2004), at § 6.6.2.

[2]*United Services Auto. Ass'n v. Wade*, 544 So. 2d 906, 909, (Ala. 1989).

[3]Dennis Canfield, Causes of Spalling Concrete at Elevated Temperatures, 34 *Fire & Arson Investigator*, Jun. 1984, at 22.

cannot exceed the boiling point of the liquid. Thus, the liquid actually protects the concrete from spalling.

§ 39:57 Areas of scientific agreement and disagreement—Field investigations—Colors of smoke and fire

Other indicators of unusual fire behavior that have fallen by the wayside include the color of smoke and the color of the flame. When these indicators first were promulgated by the teachers of fire investigation, they were considerably more valid than they are today. Wood and cotton products tend to produce a gray to white smoke, and burn with a yellow flame. Petroleum based products, such as most common ignitable liquids, burn with sooty orange flames and produce large quantities of black smoke. In the past, it was thus possible to reach conclusions about what was burning, particularly in the early stages of a fire. In the modern structure, however, a large portion of the interior finish and furnishings consists of petroleum-based products in the form of plastic films, foams and fibers. A burning couch is just as likely to produce thick black smoke as is a burning pool of gasoline or kerosene.

Once again, it is useful to contrast Kirk in 1969 with DeHaan in 1991 and later. According to Kirk, "The presence of much black smoke, especially in the early stages of building a fire, is highly indicative of the presence and burning of a highly carbonaceous material, typical of many fire accelerants."[1] DeHaan, on the other hand, advises, "The combustion of [such] polymers contributes largely to the formation of greasy or sticky dense soot found at many fire scenes, and is responsible for the dense black smoke more frequently noted during the early stages of structure fires."[2] Not only is smoke color an unreliable discriminator between normal and abnormal fuels, it has lately been found that even ordinary wood fires can produce black smoke in the low oxygen conditions that exist following flashover.[3]

§ 39:58 Areas of scientific agreement and disagreement—Field investigations—Low temperature ignition

Under ordinary circumstances, solid materials, particularly wood, will not ignite unless they are heated to their ignition temperature. The theory of low temperature ignition proposes that prolonged exposure to a source of energy that does not raise wood to its ignition temperature, but to some temperature tens or hundreds of degrees below that ignition temperature, will cause the ignition temperature to decrease. At some point, the theory

[Section 39:57]

[1]Paul Kirk, Fire Investigation 61 (1969).

[2]John D. DeHaan, Kirk's Fire Investigation 111 (5th ed. 2002).

[3]National Fire Protection Association, Guide for Fire and Explosion Investigations (Pub. No. 921) (2004), at § 5.6.7.

goes, the wood is transformed into "pyrophoric carbon," which is subject to ignition at lower temperatures. This theory has it origins in the observation of wood members ignited by high-pressure steam pipes in industrial settings. There are reported cases of ignition by steam pipes in residential settings as well. The temperature of the steam pipes is allegedly well known, and below the ignition temperature of wood. Therefore, the theory goes, prolonged exposure to the low temperature has caused a reduction in the ignition point of the wood. This was the theory advanced by a group of investigators in the case of *Truck Insurance Exch. v. MagneTek*.[1] In that case, however, the investigators proposed that the ignition source was not a steam pipe, but a fluorescent light ballast operating at approximately 325F. Further, the ballast was insulated from the wood target fuel by a layer of gypsum drywall.

The phenomenon of low temperature ignition is also known as "pyrophoria." This phenomenon was studied by Cuzzilo[2] and has been reported on extensively by Babrauskas[3] who takes issue with the appellate court in the *Truck* case.[4]

Cuzzilo claims that his research has proven the pyrophoria hypothesis to be false. Babrauskas argues that there are simply too many reported cases of low temperature ignition to ascribe to poor fire investigation. Babrauskas admits that there is no scientific theory underpinning low temperature ignition, at least not one that we understand now. He compares this lack of scientific theory to the lack of a geological theory as to why Mt. St. Helens exploded on May 18, 1980, instead of May 15. Essentially he says, "We know it happens but we don't know why." Scientists generally eschew this kind of thinking, and since Daubert, courts do as well.

The scientific controversy has directed much attention to the possibility of low temperature ignition, and this has resulted in more, not fewer, determinations that low temperature ignitions took place. In some situations, the results are similar to what happens when a fire investigator is unable to find an ignition source and determines the fire to be incendiary. In the industrial situation where arson is eliminated, low temperature ignition is the next obvious suspect.

In an instance of the court not truly understanding the science upon which it was ruling, the *Magnetek* court conflated the concept of pyrophoria with the concept of "pyrolysis" (the perfectly legitimate description of the endothermic breaking of chemical bonds that occurs when fuel is heated

[Section 39:58]

[1] *Truck Ins. Exchange v. MagneTek, Inc.*, 360 F.3d 1206, Prod. Liab. Rep. (CCH) P 16918, 63 Fed. R. Evid. Serv. 948 (10th Cir. 2004).

[2] Bernard Cuzzillo, Pyrophoria (unpublished manuscript) University of California, Berkley (1997).

[3] Vytenis Babrauskas, Ignition Handbook, SFPE (2004), at 955.

[4] Vytenis Babrauskas, Truck Insurance v. MagneTek: Lesson to be Learned Concerning Presentation of Scientific Information, 55 Fire & Arson Investigator 9 (Oct. 2004).

prior to ignition).

§ 39:59 Areas of scientific agreement and disagreement—Field investigations—Computer modeling

As a result of years of research conducted at the Center for Fire Research, several computer programs have been developed to predict the spread of a fire, given certain assumptions.[1] If certain facts are known about the configuration of the compartments and fuel packages in a building, a model can predict how a fire can behave and the model's predictions can be compared with fire patterns and witness observations. Fire modeling is a way to test hypotheses, and to answer questions about which factors might have affected the growth and development of a fire. Because the fire models were developed at taxpayer expense, these models are free and becoming quite popular. All of the models available from NIST[2] come with a disclaimer similar to the one that accompanies Fire Dynamics Simulator:

> The US Department of Commerce makes no warranty, expressed or implied, to users of the Fire Dynamics Simulator (FDS), and accepts no responsibility for its use. Users of FDS assume sole responsibility under Federal law for determining the appropriateness of its use in any particular application; for any conclusions drawn from the results of its use; and for any actions taken or not taken as a result of analyses performed using these tools.
>
> Users are warned that FDS is intended for use only by those competent in the fields of fluid dynamics, thermodynamics, combustion, and heat transfer, and is intended only to supplement the informed judgment of the qualified user. The software package is a computer model that may or may not have predictive capability when applied to a specific set of factual circumstances. Lack of accurate predictions by the model could lead to erroneous conclusions with regard to fire safety. All results should be evaluated by an informed user.[3]

There are currently two types of computer modeling programs for fires: zone models and field models. A zone model divides each compartment into an upper zone and a lower zone, and predicts the conditions in each zone as a function of time. Zone models are useful for situations where a rough approximation will do, and have been used to closely predict, for instance, when flashover will occur, given a specific fire on a specific fuel package. A proficient modeler can run zone models in a few hours on a personal computer. A typical zone model assumes that every part of the zone is uniform with respect to temperature and smoke concentration. Consequently, while the model may be able to predict when any sprinkler head might activate, it will be less reliable in predicting the activation of a particular sprinkler head.

[Section 39:59]

[1] Harold Nelson, FPETOOL Users Guide (NIST Pub. No. 4439) (1990).

[2] http://www.bfrl.nist.gov.

[3] Kevin McGrattan and Glenn Forney, Fire Dynamics Simulator (Version 4) User's Guide (NIST Special Publication 1019) (Feb. 2005).

Field models (also known as computational fluid dynamics or CFD models) are much more complicated. They divide each compartment into thousands or tens of thousands of small volumes, and calculate the fire's progress through each volume. This makes the field models much more precise, but they are much more difficult to work with compared to zone models. In the recent past, a multi-compartment field model required days or weeks of mainframe computer time, but now it can be run on reasonably fast personal computers, although the model may still take days or weeks to process.

The information required for both field and zone models is the same. A good description of the required inputs, as well as the limitations of computer models, was added to NFPA 921 in 2001.

As in other areas of fire investigation, two experts provided with the same program can plug in different assumptions and reach different conclusions about the spread of a fire. This is because of the large number of variables that affect the fire's behavior. Although computer modeling has been touted as a method for testing an investigator's hypothesis, the vast majority of computer models that are likely to be presented to a jury will simply demonstrate, but not prove, the expert's opinion.

Because of their ability to graphically present the growth of a fire, computer models are becoming commonplace in fire litigation. It is necessary to distinguish whether an expert is presenting a simulation or an animation. Animations are used to demonstrate what an expert thinks happened, while a simulation is the actual output of the model. Formerly, the output of models was numbers or graphs. The development of a program called Smokeview by engineers at NIST[4] now allows for computational fluid dynamics models as well as zone models to be presented graphically on a 3D CAD drawing of a building. These make powerful exhibits, but need to be checked carefully against the facts. As with any computer program, and as described above, the rule "garbage in, garbage out" still applies.

The issue of false precision is one that plagues the fire investigation profession. When fire protection engineers conduct experiments and plot the results, they generally do so on logarithmic paper, meaning that they are measuring orders of magnitude. The equations that fall out of these plots, however, can be reported with as many as four significant figures in some of the coefficients. Fire protection engineers know that these numbers exhibit much greater precision than the underlying data will support. Unfortunately, fire investigators may not appreciate that limitation. A model that predicts flashover in a compartment to take place at 4.98 MW really means "somewhere between 4 and 6 MW, or in that ballpark." The traditional meaning of 4.98 is "a number between 4.975 and 4.985."

[4]Glenn P. Forney 5 User's Guide for Smokeview Version 5—A Tool for Visualizing Fire Dynamics Simulation Data (NIST Special Publication 1017–1) (Dec. 2010).

Computer models are meant to "bound" the parameters that might be expected in a given fire if all of the assumptions built into the models are correct. The results of various correlations are not to be averaged, but this has happened, with disastrous results.[5]

It is possible now for fire investigators to download a program called "CFI Calculator," an excellent program for showing the relationships between building conditions and the requirements for flashover. Like the NIST models, CFI Calculator comes with its own disclaimer, which reads as follows: "Users are warned that CFI Calculator and the CFI Calculator Users Guide is intended for use only by those competent in the field of heat transfer, combustion and fire science, and is intended only to supplement the informed judgment of the qualified user. This calculator may or may not have predictive capability when applied to a specific set of factual circumstances."[6]

§ 39:60 Areas of scientific agreement and disagreement—Field investigations—Fatal fires

Fires that involve fatalities are more likely to become the subject of civil or criminal litigation than fires that cause only property damage. The methodology of investigating a fatal fire is exactly the same as the methodology involved in investigating a property fire, except that there is one important piece of evidence provided in the fatal fire: the body or bodies. In those cases where the victim dies at the scene, the body can provide invaluable information as to the condition of the atmosphere at the time of death.

A careful forensic autopsy and toxicology including carboxyhemoglobin (COHb), blood alcohol and drug readings are imperative for a proper understating of what occurred. Low carbon monoxide content in a victim's blood suggests that they were rapidly overcome by heat, and died from burn injuries, rather than smoke inhalation, the most common cause of fire death. Really low carbon monoxide readings—less than 5% for non-smokers, less than 10% for smokers—suggest that the victim's death preceded the fire. Higher carbon monoxide concentrations (around 50%), on the other hand, suggest exposure to a gradual build-up of smoke. Still higher levels of CO suggest brief exposure to very high concentrations of toxic smoke. Such exposures are typical of victims found some distance from the origin of a fire. Those proximate to the originating fire are unlikely to be still breathing by the time the fire produces high concentrations of CO. Combustion products of ventilation controlled fires include high levels

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[5]John J. Lentini, "Progress" in Fire Investigation: Moving from Witchcraft and Folklore to the Misuse of Models and the Abuse of Science," 4th International Symposium on Fire Investigations Science and Technology, September 28, 2010, Columbia, MD.

[6]Schaal, R., CFI Calculator Users Guide, available at CFITrainer.net.

of carbon monoxide.[1]

Low carbon monoxide (CO) concentrations have been interpreted by fire investigators as indicating arson, rather than an accidental fire.[2] The problem with this indication is that, like fire damage itself, carbon monoxide poisoning is a result of both the intensity of the exposure (carbon monoxide concentration) and the duration of the exposure. Exposure to a high concentration for a short period of time may result in the same carboxyhemoglobin level as exposure to a low concentration for a long time. For instance, exposure to a concentration of 0.05% CO (500 parts per million) for two to three hours will result in a COHb level of 30%. The same result is achieved by exposure to a concentration of 1% CO (10,000 parts per million) for one to five minutes. Of course, a COHb concentration of zero is an indication that the victim was not breathing and indicates that death preceded the fire. An excellent review of carbon monoxide data compilations has been published by Gordon Nelson.[3]

The effects of incineration can lead to mischaracterization of the events leading up to the victim's death. Muscle contraction caused by exposure to heat results in a "pugilistic pose," which has led investigators to see the victim as fighting off an assailant. This is a misconception.[4] Other artifacts of incineration include neck contusions, which have been interpreted as evidence of strangulation, and skull fractures, caused by the expansion of cranial contents, which have been misinterpreted as evidence of bludgeoning. High COHb levels have been misconstrued as evidence of accelerants.[5] The knowledge and experience of the medical examiner with burn victims should be carefully scrutinized before allowing these sorts of conclusions to be put into evidence unchallenged.

§ 39:61 Areas of scientific agreement and disagreement—Field investigations—Explosions

Procedures for investigating an explosion are similar to those used for fire investigations. A more detailed examination of the surrounding area is

[Section 39:60]

[1] National Fire Protection Association, Guide for Fire and Explosion Investigations (Pub. No. 921) (2011), at § 5.3.2.

[2] See e.g., Pennsylvania v. Han Tak Lee (Court of Common Pleas of Monroe County, 43rd Judicial District, No. 577 Criminal, 1989), testimony of Robert Jones. The Third Circuit reversed this trial court's denial of a habeas corpus petition for discovery and an evidentiary hearing based upon developments in arson science. *Han Tak Lee v. Glunt*, 667 F.3d 397 (3d Cir. 2012).

[3] G.L. Nelson, Carbon Monoxide and Fire Toxicity: A Review and Analysis of Recent Work, 34 Fire Technology 39 (1998).

[4] National Fire Protection Association, Guide for Fire and Explosion Investigations (Pub. No. 921) (2011), at § 23.3.2.

[5] State v. Girdler, No. 9809 (Superior Ct. of Arizona, Maricopa County, Jan. 3, 1991). A detailed description of all of the misconceptions in this case can be found in Lentini, Scientific Protocols for Fire Investigation, Sources of Error in Fire Investigation (2006).

generally required, particularly in the case of chemical explosions.[1]

Historically, explosions have been difficult to define because there are several types of explosions, some of which are difficult to distinguish from rapid combustion. For this discussion, let us describe an explosion as an event having the following four characteristics: high pressure gas, confinement or restriction of the pressure, rapid production or release of the pressure, and change or damage to the confining or restricting structure or vessel.

Two major types of explosions may occur: mechanical explosions, such as steam boiler explosions, and chemical explosions, which encompass combustion explosions and the detonation of high explosives.

In a mechanical explosion, no chemical or combustion reaction is necessary, although mechanical explosions caused by boiling liquid and expanding vapor (BLEVE) frequently happen as a result of heating a sealed container of liquid in a fire. If the liquid is flammable, a chemical explosion may follow the mechanical explosion.

Chemical explosions may be caused by the sudden ignition of dusts, gas/air mixtures, or vapor/air mixtures. (A vapor is the gas phase of a substance that is a liquid at room temperature.) These are known as combustion explosions. An explosion in a cloud of smoke from a pre-existing fire is known as a backdraft. Most of the explosions described so far are accidental in nature. Explosions fueled by chemicals whose primary function is to explode are more likely intentional.

All explosions, whether mechanical or chemical, are grouped into two categories: low order and high order. Low order explosions are characterized by a widespread "seat" or no "seat," and by the movement of large objects for short distances. High order explosions are characterized by a well-defined "seat," where the energy of the explosion creates a shattering effect, and typically a crater. High order explosions tend to project small objects for long distances.

Determination of the origin or epicenter of an explosion is carried out by searching the perimeter of the scene, locating and documenting projected debris, and developing force vector diagrams. This task may be complicated by secondary explosions, which appear to have more than one "origin." Once the origin is observed, conclusions can be drawn about the type of fuel involved and, if necessary, samples selected for laboratory analysis.

While the types of materials involved in commercial or industrial explosions are too numerous to cover in this chapter, the potential fuels for residential explosions are very limited. Unless the explosion is a backdraft, easily recognized by the smoke staining on the projected objects, the potential sources of fuel are limited to natural and LP gas, and flammable

[Section 39:61]

[1]National Fire Protection Association, Guide for Fire and Explosion Investigations (Pub. No. 921) (2011), at § 21.1.8.

liquid vapors.

NFPA 921 contains an excellent discussion of the techniques of explosion investigation, and a 2000 National Institute of Justice guide dealing with the responsibilities of responders to explosion or bombing scenes contains much useful information.[2]

§ 39:62 Areas of scientific agreement and disagreement—Field investigations—Smoke detectors

According to statistics compiled by the National Fire Protection Association, residential fire deaths in the United States have dropped from a high of 6,015 in 1978 to 3,010 in 2009.[1] The National Smoke Detector Project—a joint project among the Consumer Product Safety Commission, the Congressional Fire Services Institute, the U.S. Fire Administration, and the National Fire Protection Association—issued a major report in October 1994 on the use of home smoke detectors, and characterized the home smoke detector as the fire safety success story of the decade. According to the 1994 report, smoke detectors cut the risk of dying in a home fire by roughly 40%. In the ten years ending in 1995, the death rate from fires in homes with a smoke detector present was 45% lower than the death rate from fires in homes with no smoke detector present.[2]

Of course, once technology comes into being that can save lives, certain failures of that technology become occasions for tort litigation.[3] The National Smoke Detector Project study found that nearly all of the smoke detectors that failed to operate did so because their batteries were either dead or disconnected. Some research, however, has indicated that for certain types of smoldering fires, the most common type of detector, the ionization detector, did not respond as quickly to the large particles generated by smoldering fires as a different type of detector, the photoelectric detector.[4] The general consensus of the scientific community involved in smoke detector research, and the vast majority of the literature,[5] however, supports the proposition that the differences in response time are not significant with respect to smoldering fires, and the ionization detector's faster response to the more immediately dangerous flaming fire makes it the detector of choice. In recent litigation, smoke detector manufacturers

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[2]Technical Working Group for Bombing Scene Investigation, USDOJ, A Guide for Explosion and Bombing Scene Investigation (Jun. 2000), available at http://www.ojp.ussdoj.gov/nij/scidocs2000.htm.

[Section 39:62]

[1]Fast Facts, http://www.nfpa.org.

[2]Consumer Product Safety Commission, Smoke Detector Operability Survey: Report on Findings (1994).

[3]See Grady, Why Are People Negligent? Technology, Nondurable Precautions, and the Medical Malpractice Explosion, 82 Nw. U.L. Rev. 293 (1988).

[4]R.G. Bill, The Response of Smoke Detectors to Smoldering-started Fires in a Hotel Occupancy (Factory Mutual Research, Norwood, MA) (1988).

[5]R. Bukowski & N. Jason (eds.), Int'l Fire Detection Bibliography 1975–1990 (NIST 4661, Building and Fire Research Laboratory, Gaithersburg, MD) (1991).

have been sued for failing to incorporate a photoelectric detector in their smoke alarms, and the plaintiffs have had some success.[6]

Most smoke detectors use a small amount of radioactive material to ionize particles of air in the detection chamber. The ionized air conducts a very small current between a pair of electrodes. The presence of small particles of smoke in the ionization chamber interferes with this passage of current and triggers an alarm. In photoelectric detection chambers, there is a light emitting device and a light-detecting device. The light-emitting device is aimed away from the detection device, but the presence of smoke particles causes light to be reflected to the detection device, which sets off the alarm. Photoelectric detectors are not as sensitive to particles smaller than one micron (characteristic of flaming fires) as are ionization detectors. Ionization detectors are not as sensitive to particles larger than one micron (characteristic of smoldering fires) as are photoelectric detectors. All fires produce a wide range of particle sizes, and both types of detectors have been evaluated and found to provide adequate warning.[7] It is possible to build a smoke alarm that utilizes both types of detectors, and the argument has been advanced that alarms that incorporate only ionization detectors are therefore dangerous and defective. Unfortunately, when the smoke detector manufacturers put combination units on the store shelves, they stayed there. Consumers seem to be motivated largely by cost in the selection of smoke alarms. Litigation surrounding smoke detector design is likely to continue, but as of this writing, there have been few appellate decisions on the subject.

Recent work by Worrell et al.[8] describes ways of determining whether smoke detectors sounded during a fire. This involves looking for a ring of agglomerated soot particles on the hole in the center of the horn. The techniques described work well in fires in which soot-producing material, such as polyurethane, are involved, and not so well in fires fueled by paper and other materials that produce white or gray smoke. In the presence of black smoke, determinations could generally be made. In the past, smoke patterns known as Chlandi figures have been cited, without the benefit of any research, as an indication that the vibrating disc of a smoke detector has sounded, and the absence of such figures, which can theoretically take the shape of concentric rings, a wagon wheel, or variations of the two, could be used as an indication that a smoke detector did not sound. This

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[6] See, e.g., Gordon v. BRK Brands, Inc., No 992–0771 (Circuit Ct. of the City of St. Louis, July, 1999) (settled after a $50 million verdict) or *Mercer v. Pittway Corp.*, 616 N.W.2d 602, Prod. Liab. Rep. (CCH) P 15925 (Iowa 2000) ($16.9 million trial verdict for compensatory and punitive damages, reversed in part and remanded for new trial).

[7] Ionization Versus Photoelectric: Choosing the Right Smoke Detector, 30 Building Official & Code Admin., Nov./Dec. 1996, at 17.

[8] C.L. Worrell et al., Effect of Smoke Source and Horn Configuration on Enhanced Deposition, Acoustic Agglomeration, and Chlandi Figures in Smoke Detectors, 39 Fire Technology 309 (Oct. 2003).

particular hypothesis has failed to gain any acceptance, and Worrell et al. seem to disprove the hypothesis. Once a smoke alarm has been significantly damaged by fire, the telltale ring of agglomerated soot particles around the horn may no longer be visible.

§ 39:63 Areas of scientific agreement and disagreement—Field investigations—Stolen autos recovered burned

This common scenario requires almost no investigation to determine that the fire was intentionally set. The chance that a vehicle happened to catch fire accidentally after it was stolen is almost not worth considering. The question in cases such as this is not whether the car was set on fire, but who did it. If an insurance company can prove that it was their insured that set the fire, or arranged the theft and fire, the company can avoid payment. Historically, this has been difficult to prove.

A new technique, bearing some resemblance to traditional toolmark analysis, purports to be able to determine the "last key used" to move a vehicle. This technique has no support in the relevant scientific community of firearms and toolmark examiners, but has nonetheless proven popular with insurers, and has been admitted over Daubert objections in several jurisdictions. Challenges are rare because the stakes are usually too low to support the involvement of adverse experts to refute the claim of the "forensic locksmith."

The proponents of this technique submitted a proposal to the NFPA to include it as a tool for vehicle fire investigations, but the Technical Committee rejected the proposal because there was no scientific evidence supporting the validity of the technique.[1]

§ 39:64 Areas of scientific agreement and disagreement—Field investigations—Presumption of accidental cause

Because the investigator making an arson case frequently lacks scientific training, the presumptions that individual carries into a fire scene should be closely scrutinized. Just as the assumptions that are plugged into a computer model can affect the outcome of the analysis, so can the assumptions that a fire investigator carries into a fire scene affect the outcome of the investigation.

Because of the large amount of evidence destroyed in a fire, it is possible to "prove" almost any fire scene to be the result of arson, if one is bent on doing so. This idea is conveyed by DeHaan: "If an investigator decides that a fire is arson before collecting any data, then only data supporting that

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[Section 39:63]

[1]See Technical Committee Documentation, NFPA, Report on Comments for the Fall, 2000, Meeting.

premise are likely to be recognized and collected."[1] DeHaan, of course, was inspired by Holmes (Sherlock not Oliver Wendell), who stated, "It is a capital mistake to theorize before one has data. Insensibly, one begins to twist facts to suit theories, instead of theories to suit facts."[2]

Many fire investigators will state that they carry no presumptions into a fire scene with them, and rely on an objective evaluation of the evidence to reach their conclusions. NFPA 921 urges upon investigators the scientific method of hypothesis development and hypothesis testing. The question is: Should there be a hypothesis before all of the evidence has been observed? It could be argued that the proper presumption to carry into a fire scene is a presumption of accidental cause, i.e., all fires are presumed accidental until proven otherwise. Such a presumption mirrors the presumption of innocence accorded to individuals. Many states[3] have codified this presumption of accidental or providential cause into the standard jury charge for arson, but whether codified in a particular jurisdiction or not, the fire investigator who fails to apply the presumption of accidental cause to all fires will eventually make an erroneous declaration of arson.

The error will result from a misinterpretation of circumstantial evidence. In nearly every fire case, it is circumstantial evidence that allows the cause of the fire to be deduced. Likewise, in nearly every arson case, the *corpus delicti* is proven by circumstantial evidence, and the jury is read the standard circumstantial evidence charge. Mr. Holmes described the perils of circumstantial evidence in *The Boscombe Valley Mystery*:

> Circumstantial evidence is a very tricky thing. It may seem to point very straight to one thing, but if you shift your own point of view a little, you may find it pointing in an equally uncompromising manner to something entirely different.[4]

In many instances, if there is one survivor of a fire, particularly a fatal fire, and the fire is determined to have been the result of arson, then only one conclusion can be reached—the survivor did it. This is because, in the investigator's "opinion," the survivor's account of events, which typically describes an accidental fire, is "impossible," and therefore, the survivor is lying. This is exactly what happened to Ray Girdler. Judge James Sult, who presided over the first trial and sentenced Girdler to life in prison, wrote in his opinion ordering a new trial:

> The newly discovered evidence would probably change the verdict upon a retrial of this case. Several considerations support this finding: . . . At the trial of the case, the State claimed, based on then understood fire investiga-

[Section 39:64]

[1] John D. DeHaan, Kirk's Fire Investigation 5 (6th ed. 2007).

[2] Arthur Conan Doyle, A Scandal in Bohemia, in The Annotated Sherlock Holmes (William S. Baring-Gould ed., 1967).

[3] AR, GA, HI, IN, MD, MI, MO, MT, NE, NC, OR, PA, TN, TX, VT, VA, WA, WV.

[4] Arthur Conan Doyle, The Boscombe Valley Mystery, in The Annotated Sherlock Holmes (William S. Baring-Gould ed., 1967).

> tion evidence, that Mr. Girdler's account of the fire was impossible and, therefore, false. The new evidence shows that Mr. Girdler's observations of the fire are consistent with a flashover fire of innocent origin.[5]

If the state's investigator had the proper scientific approach to fire investigation, or even admitted the possibility that an explanation other than burning flammable liquids (none were detected in laboratory analysis) existed, the erroneous conviction, which cost Ray Girdler eight years in prison, might have been avoided.

Ray Girdler's experience is unfortunately not unique. A 2006 review of expert testimony in two Texas death penalty cases from 1986 and 1992 revealed that the evidence used to obtain the convictions had no value in helping the Court understand how the fires actually started. In one case, the defendant was freed after 17 years on death row. In the second case, the defendant was executed.[6] These cases were investigated by the Texas Forensic Science Commission, which hired a nationally known fire expert, Dr. Craig Beyler, to examine the evidence. He found that the methodology used by the fire investigators in both cases were more like the methods of mystics and psychics than scientists.[7] The Forensic Science Committee issued a report in April 2010, which made recommendations for studying past arson convictions based on bad science, and improving current methods.[8]

§ 39:65 Areas of scientific agreement and disagreement—Field investigations—The "negative corpus"

Since the advent of scientifically based fire investigation, one of the thorniest issues for fire investigators has been the determination of fire cause when the evidence has either burned up or been taken from the scene by the fire setter. "Negative corpus," short for negative *corpus delicti*, is fire investigator shorthand for the determination that a fire was incendiary based on the lack of evidence of an accidental cause. Such determinations come from investigators who fail to heed Carl Sagan's warning, "Absence of evidence is not evidence of absence." The proponents of scientific fire investigation have generally held "negative corpus" determinations in low regard, but that has not prevented their introduction into evidence. The case of *Michigan Millers Mutual Insurance Corp. v.*

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[5] State v. Girdler, No. 9809 (Superior Ct. of Arizona, Maricopa County, Jan. 3, 1991); see also *State v. Girdler*, 138 Ariz. 482, 675 P.2d 1301 (1983) (en banc) (original opinion upholding conviction).

[6] Arson Review Committee, Report on the Peer Review of the Expert Testimony in the Cases of State of Texas v. Cameron Todd Willingham and State of Texas v. Ernest Ray Willis (2006), available at www.innocenceproject.org.

[7] Craig Beyler, Analysis of the Fire Investigation Methods and Procedures Used in the Criminal Arson Cases Against Ernest Ray Willis and Cameron Todd Willingham, Report to the Texas Forensic Science Commission, August 17, 2009.

[8] Report of the Texas Forensic Science Commission, Willingham/Willis Investigation, April 15, 2011.

Benfield[1] was a classic "negative corpus" determination. When fire investigators testify that a fire was intentionally set, "the elimination of all potential accidental causes" is frequently added to other evidence of incendiary activity.

The NFPA Technical Committee on Fire Investigations struggled with the concept of "negative corpus" for several years. Despite the lack of a demonstrable ignition source, many fires can be stated to have been set based on the absence of any other possibilities. The Committee's challenge was to limit the abuse of the negative corpus determination, and to put legitimate determinations of incendiary activity into the context of the scientific method. The result of the Committee's work, first published in the 2001 edition of NFPA 921 is as follows:

> Process of Elimination. Any determination of fire cause should be based on evidence rather than on the absence of evidence; however, when the origin of a fire is clearly defined, it is occasionally possible to make a credible determination regarding the cause of the fire, even when there is no physical evidence of that cause available. This may be accomplished through the credible elimination of all other potential causes, provided that the remaining cause is consistent with all known facts.
>
> For example, an investigator may properly conclude that the ignition source came from an open flame even if the device producing the open flame is not found at the scene. This conclusion may be properly reached as long as the analysis producing the conclusion follows the Scientific Method as discussed in Chapter 2.
>
> "Elimination," which actually involves the testing and rejection of alternate hypotheses, becomes more difficult as the degree of destruction in the compartment of origin increases, and is not possible in many cases. Any time an investigator proposes the elimination of a particular system or appliance as the ignition source, the investigator should be able to explain how the appearance or condition of that system or appliance would be different than what is observed, if that system or appliance were the cause of the fire.
>
> There are times when such differences do not exist, for example, when a heat producing device ignites combustibles that are placed too close to it, the device itself may appear no different than if something else were the ignition source.
>
> The "elimination of all accidental causes" to reach a conclusion that a fire was incendiary is a finding that can rarely be scientifically justified using only physical data; however, the "elimination of all causes other than the application of an open flame" is a finding that may be justified in limited circumstances, where the area of origin is clearly defined and all other potential heat sources at the origin can be examined and credibly eliminated. It is recognized that in cases where a fire is ignited by the application of an open flame, there may be no evidence of the ignition source remaining. Other evidence, such as that listed in § 22.3, which may not be related to combustion, may allow for a determination that a fire was incendiary. (This last sentence was removed

[Section 39:65]

[1] *Michigan Millers Mut. Ins. Corp. v. Benfield*, 140 F.3d 915, 49 Fed. R. Evid. Serv. 549 (11th Cir. 1998).

from the 2008 edition of NFPA 921.)

In a determination of an accidental cause, the same precautions regarding "elimination" of other causes should be carefully considered.

Note that nowhere in the above quotation does the term "negative corpus" appear.

The above language represents a compromise between the presumption of accidental cause and the knowledge that in many cases, particularly where the ignition source is an open flame, incendiary fires may leave behind little physical evidence of their cause.[2] As with many other additions of compromise language, this section of NFPA 921 has been the subject of some misconstruction. The term "clearly defined" was not itself clearly defined. What the Committee meant by "clearly defined" was an area of origin that even an untrained person could easily discern. Abuses of this language have occurred when the clear definition of the area of origin existed only in the mind of the investigator.

In the 2011 edition of NFPA 921, the Technical Committee on Fire Investigations finally decided to deal with the problem of negative corpus determinations. Much to the concern of fire litigators and fire investigators, the following language was inserted.

18.6.5* Inappropriate Use of the Process of Elimination. The process of determining the ignition source for a fire, by eliminating all ignition sources found, known, or believed to have been present in the area of origin, and then claiming such methodology is proof of an ignition source for which there is no evidence of its existence, is referred to by some investigators as "negative corpus." Negative corpus has typically been used in classifying fires as incendiary, although the process has also been used to characterize fires classified as accidental. This process is not consistent with the Scientific Method, is inappropriate, and should not be used because it generates un-testable hypotheses, and may result in incorrect determinations of the ignition source and first fuel ignited. Any hypothesis formulated for the causal factors (e.g., first fuel, ignition source, and ignition sequence), must be based on facts. Those facts are derived from evidence, observations, calculations, experiments, and the laws of science. Speculative information cannot be included in the analysis.

18.6.5.1 Cause Undetermined. In the circumstance where all hypothesized fire causes have been eliminated and the investigator is left with no hypothesis that is evidenced by the facts of the investigation, the only choice for the investigator is to opine that the fire cause, or specific causal factors, remains undetermined. It is improper to base hypotheses on the absence of any supportive evidence *(see 11.5.2, Types of Evidence)*. That is, it is improper to opine a specific ignition source that has no evidence to support it even though all other hypothesized sources were eliminated.

The Committee still felt it was possible to infer a cause in certain circumstances where there was no physical evidence; the problem they encountered was when there was no evidence at all. The language in the follow-

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[2] National Fire Protection Association, Guide for Fire and Explosion Investigations (Pub. No. 921) (2004), at § 18.2.

ing paragraph allows for a determination by inference in the absence of physical evidence.

> **18.4.4.3** There are times when there is no physical evidence of the ignition source found at the origin, but where an ignition sequence can logically be inferred using other data. Any determination of fire cause should be based on evidence rather than on the absence of evidence; however, there are limited circumstances when the ignition source cannot be identified, but the ignition sequence can logically be inferred. This inference may be arrived at through the testing of alternate hypotheses involving potential ignition sequences, provided that the conclusion regarding the remaining ignition sequence is consistent with all known facts *(see Basic Methodology chapter)*. The following are examples of situations that lend themselves to formulating an ignition scenario when the ignition source is not found during the examination of the fire scene. The list is not exclusive and the fire investigator is cautioned not to hypothesize an ignition sequence without data that logically supports the hypothesis.
>
> **(A)** Diffuse fuel explosions and flash fires.
>
> **(B)** When an ignitable liquid residue (confirmed by laboratory analysis) is found at one or more locations within the fire scene and its presence at that location(s) does not have an innocent explanation. *(See Incendiary Fires chapter)*.
>
> **(C)** When there are multiple fires *(See Incendiary Fires chapter)*.
>
> **(D)** When trailers are observed *(See Incendiary Fires chapter)*.
>
> **(E)** The fire was observed or recorded at or near the time of inception or before it spread to a secondary fuel.

Once again, there was more compromise involved, but the committee seems to be moving strongly in the direction of science based investigations.

Computer modeling has lately started to be used in "negative corpus" cases. The investigator posits "hypotheses" even though no evidence supports them. These "hypotheses" are then run through the model and the scenario that provides the "best fit" with the post-file artifacts is declared the winner. Thus the model is used to manufacture "data." Because computer modelers are highly skilled and highly educated, courts should be wary of being hoodwinked.[3]

§ 39:66 Areas of scientific agreement and disagreement—Field investigations—Certainty of opinions

Few legal issues other than the cause of fires rely so heavily on the opinion of the investigator. Even in the case of explosions, which may be equally destructive or more destructive than fires, the fact that an explosion occurred drastically limits the number of potential causes.

Fire investigators have grappled with the question of certainty for years, raising such questions as whether an investigator's "comfort level" with

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[3] See, e.g., *Louisiana v. Hypes*, Criminal Docket No. 265,037 (9th Judicial Cir., Rapides Parish, Jun. 27, 2006).

his opinion should be stronger in a criminal case than in a civil case. On cross examination, many investigators will admit that they are not infallible, yet nevertheless go on to assert that there is no other possible explanation for their observations than what they have offered.

The uncertainty about certainty has generated much discussion in the fire investigation community, as illustrated by the discussion in the previous edition of this chapter. Because it seemed impossible to separate a codification of "comfort level" from legal burdens of proof, the Technical Committee on Fire Investigations voted in 1998 to remove the discussion about levels of certainty from the document. As discussed previously, the concepts of probable and possible were added back into the document in the 2004 edition.

In the 2011 edition, guidance about levels of certainty has been removed from the cause chapter and placed in the basic methodology chapter, so that the requirement to think about the level of certainty applies to all opinions, not just those involving the cause of the fire.[1]

§ 39:67 Areas of scientific agreement and disagreement—Field investigations—Conflicting opinions

There is a curious notion in the fire investigation community that every fire investigator is entitled to his own opinion about the cause of a fire. There is even a tacit recognition of the possibility of investigators reaching different conclusions after making the same observations of the same fire scene in the International Association of Arson Investigators Code of Ethics, which includes the rule, "I will remember always that I am a truth seeker, not a case maker."[1]

Unfortunately, due to the lack of scientific training in the discipline, many investigators do not understand the difference between a "personal" opinion and a "professional" opinion. Certainly, very few investigators will grant their physicians the right to make a misdiagnosis based on their observation and interpretation of a set of symptoms. If two doctors disagree on a diagnosis, the doctors regard it as their duty to cooperate and attempt to reach the correct conclusion. They would be uncomfortable knowing that one of them was wrong if they did not do so. Such cooperation in the search for the truth, particularly when arson is alleged, is so far a relatively rare occurrence in fire investigations. Fire investigators with differing views most often leave it up to the trier of fact to decide who is right, even though the legal fact finder is likely to be even less knowledgeable about the substance of the expert testimony than either investigator.

[Section 39:66]

[1]National Fire Protection Association, Guide for Fire and Explosion Investigations (Pub. No. 921) (2011), at § 4.5.

[Section 39:67]

[1]International Association of Arson Investigators, IAAI Code of Ethics (1949).

With the growing acceptance of NFPA 921 as the standard of care in fire investigation, some investigators are learning to accommodate the standard without really changing the way they do business.

A curious circular logic seems to be gaining currency with respect to the "elimination" of particular causes of fire. The fire investigator first determines the point of origin, sometimes with arresting specificity, even in rooms that have gone well beyond flashover and have been completely involved in fire for tens of minutes. Recall that in such compartments, it is difficult, if not impossible to determine what burned first; it is possible to determine only what burned the most. This frequently has nothing to do with the origin of the fire; but, upon declaring a particular point to be the origin of the fire, the fire investigator then states that he has "eliminated" everything on the north side of the room because he has "determined" that the origin is at the south side of the room. In this way, it is possible to avoid examining just about anything, but still be in a position to state that even without the examination, a particular system or appliance has been eliminated.[2]

Some fire investigators continue to follow the "Emperor's New Clothes" school of reporting, by showing a photograph and stating that there are "obvious pour patterns" in the photograph, when all anyone, even another fire investigator, can see is a burned surface. There is a frequent overuse of the words "clear" and "obvious." If the artifact that the investigator is pointing at is neither clear nor obvious to an untrained individual, the investigator should be challenged.

§ 39:68 Areas of scientific agreement and disagreement—Laboratory analysis

Unlike the field investigation of fires, there are considerably more areas of agreement and fewer areas of disagreement in the laboratory analysis of fire debris, and since the early 1990s, a near consensus has developed in the scientific community regarding the proper techniques to be applied to samples of fire debris in which it is suspected that ignitable liquid residues are contained. Two chemists, looking at the same data from a fire debris sample, are more likely to agree on its interpretation than are two field investigators looking at the same fire scene, but disagreements still occur, and these are usually due to one of the chemists failing to follow industry standards.

§ 39:69 Areas of scientific agreement and disagreement—Laboratory analysis—Conflicting opinions—Standard methods of sample preparation

The industry standard for the laboratory analysis of fire debris is

[2]See the discussion of error in origin determinations at § 39:39.

embodied in ASTM E1618, Standard Test Method for Identification of Ignitable Liquid Residues in Extracts from Samples of Fire Debris by Gas Chromatography-Mass Spectrometry.[1] It is agreed almost unanimously in the forensic science community that gas chromatography is an essential requirement for the identification of common petroleum-based products. Gas chromatography-mass spectrometry and gas chromatography-infrared spectrophotometry, known as "hybrid" or "hyphenated" techniques, provide more information, but are basically more sophisticated versions of gas chromatography. Gas chromatography has been the accepted method of analyzing petroleum products since the 1960s, but there have been considerable improvements in the field. These improvements and variations on the technique of gas chromatography are reported in peer-reviewed journals such as the Journal of Forensic Sciences, Science and Justice, Analytical Chemistry, and others.

ASTM's Committee E30 on Forensic Sciences voted in 2009 to allow its first fire debris analysis standard, ASTM E1387, to expire, thereby relegating it to historical status. The Committee believes that the only proper test for ILR is gas chromatography-mass spectrometry, as set forth in ASTM E1618.

There have also been numerous improvements in sample preparation techniques over the years. These improvements are also likely to be documented in the literature, and all of the commonly used sample preparation techniques are described in ASTM standards.

Headspace analysis (ASTM E1388) is the simplest of the sample preparation techniques. This method is rapid, but not highly reproducible, and not highly sensitive to the heavier hydrocarbons such as those found in diesel fuel. The sample is warmed and a syringe is used to withdraw a small volume of the air above the sample, known as the headspace. This headspace is then injected directly into the gas chromatograph.[2]

Steam distillation (ASTM E1385) is a classical technique, which relies on the immiscibility of oil and water. A visible oily liquid can be separated from the sample and then diluted or injected directly into the gas chromatograph. This technique is time consuming, and is not sensitive to very low concentrations of ignitable liquids, which are often all that remains in fire debris samples. When applied to a sufficiently concentrated sample, the visible liquid that the technique produces can make a very convincing exhibit.[3] When the jury can actually see the recovered liquid, and perhaps smell it and watch it burn, they will not likely feel the need

[Section 39:69]

[1] §§ 39:44 & 39:45.

[2] ASTM International, Standard Practice for Sampling of Headspace Vapors from Fire Debris Samples (Pub. No. E1388) (2010).

[3] ASTM International, Historical Standard Practice for Separation and Concentration of Ignitable Liquid Residues from Fire Debris Samples by Steam Distillation (Pub No. E1385) (2001).

to understand the intricacies of gas chromatography-mass spectrometry. Steam distillation has so many disadvantages for routine samples that it has also been allowed to expire. It is now a "historical standard."

Solvent extraction (ASTM E1386) is another classical technique which is highly sensitive, but which has the disadvantage of dissolving materials other than the ignitable liquid residues of interest. It is also expensive, dangerous, and destructive of evidence. This is a technique best applied to very small samples and to the problem of determining what was inside a now empty container.[4]

Headspace concentration techniques (ASTM E1412 and E1413) employ an adsorbent to trap volatile materials present in the headspace above a warmed sample. These adsorption/elution techniques are highly sensitive, highly reproducible, and the passive headspace concentration technique is both simple to use and essentially nondestructive of evidence. The sample can be analyzed repeatedly, by different laboratories, if necessary, and the carbon strips used in the analysis can be archived and repeatedly retested. Because of its simplicity and non-destructive nature, passive headspace concentration has become the "method of choice" in modern forensic science laboratories.[5]

All of the above sample preparation techniques are scientifically valid. Sample size, ignitable liquid concentration, and the analyst's experience and preference will determine which method of separation is selected. Regardless of separation technique, the only analytical method currently recognized as valid is gas chromatography-mass spectrometry.

§ 39:70 Areas of scientific agreement and disagreement—Laboratory analysis—Conflicting opinions—Classification of ignitable liquids

Beginning in 1982, fire debris chemists used a numbered "petroleum distillate classification system" to characterize petroleum products found in fire debris samples.[1] Classes 1 through 5 described light petroleum distillates, gasoline, medium petroleum distillates, kerosene, and diesel fuel. New products coming to the market in the 1980s and 1990s led to the addition of a new class, Class 0, which was initially entitled "Miscellaneous Products," and then was broken down into Classes 0.1, 0.2, etc., to describe the newer products. Eventually, the miscellaneous sub-classes outnumbered the traditional classes, and it was the decision of ASTM Committee

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[4] ASTM International, Standard Practice for Separation and Concentration of Ignitable Liquid Residues from Fire Debris Samples by Solvent Extraction (Pub. No. E1386) (2010).

[5] ASTM International, Standard Practice for Separation and Concentration of Ignitable Liquid Residues from Fire Debris Samples by Passive Headspace Concentration (Pub. No. E1412) (2007).

[Section 39:70]

[1] AA Notes, 6 Arson Analysis Newsletter (Systems Engineering Associates, Columbus, OH) (1982).

E30 on Forensic Sciences to restructure the classification system in 2001,[2] doing away with the class numbers, and relying instead on the class name. Under the new system, for example, gasoline is simply called gasoline, rather than a "Class 2 petroleum product."

Distinctions within any one of these classes are very difficult, and often impossible.[3] Once an ignitable liquid has been exposed to a fire, its character changes to the extent that its source is very difficult to identify. Some work has indicated that source identification is possible if a sample is less than 30% evaporated (i.e., at least 70% of the original weight remains). There are times, however, when ignitable liquids are mixed, producing a unique pattern that can conceivably be identified with a source. There also exist occasions when it is possible to unequivocally eliminate a suspected source of an ignitable liquid residue.

There exist "chemometric" methods for comparing sources. These involve quantifying the signals from compounds that are very similar in terms of volatility, so there is little effect from evaporation on the ratio between the two.[4] Another method to examine identity of source involves quantifying the polynuclear aromatic hydrocarbons in the sample.[5]

The exposure of a petroleum distillate to a fire results in its evaporation, with the lower boiling point compounds being preferentially evaporated over the higher boiling point compounds. This results in an increase in the average molecular weight of the mixture. Thus, when a suspected source of ignitable liquid exhibits a higher average molecular weight than the fire-exposed residue, the source can be unequivocally eliminated.

It is generally recognized that it is not possible to distinguish whether a sample has been exposed to a fire or to room temperature evaporation. A sample of petroleum distillate that has burned to 50% of its original volume or weight will give a gas chromatographic pattern that is indistinguishable from a sample that has evaporated to that point.

§ 39:71 Areas of scientific agreement and disagreement—Laboratory analysis—Conflicting opinions—Detection of explosives

[2] ASTM International Standard Test Method for Ignitable Liquid Residues in Extracts from Fire Debris by Gas Chromatography-Mass Spectrometry (Pub. No. E1618) (2001).

[3] ASTM International; ASTM International, Standard Test Method for Ignitable Liquid Residues in Extracts from Samples of Fire Debris by Gas Chromatography/Mass Spectrometry (Pub. No. E1618) (2010).

[4] J. Dolan and C. Ritacco, Gasoline Comparisons by Gas Chromatography/Mass Spectrometry Utilizing an Automated Approach to Data Analysis, Proceedings of the American Academy of Forensic Sciences Annual Meeting, Atlanta, Georgia (Feb. 16, 2002), at 62.

[5] Sandercock, M., and Du Pasquier, E. (2004b). Chemical fingerprinting of gasoline: 3.Comparison of unevaporated automotive gasoline samples from Australia and New Zealand. *Forensic Sci. Int.*, 140:71–77.

As with fire investigations, explosion investigations are divided into two disciplines, field analysis and laboratory analysis. Because of the relative rarity of explosion incidents (compared to fire incidents) and because bombing incidents are exclusively criminal, scientists that regularly deal with the detection and identification of explosives are almost exclusively concentrated in law enforcement laboratories, particularly federal laboratories like the FBI and ATFE. Most private laboratories have only primitive explosive detection capabilities, and most state and local government laboratories are not much better equipped. Techniques for explosive detection and identification appear in the literature, but few laboratories are capable of replicating the published analyses. Techniques used by explosive chemists are as varied as the explosives themselves. The following are techniques used in the federal laboratories on a routine basis: thin layer chromatography, gas chromatography, gas chromatography-mass spectrometry with chemical ionization, infrared spectrophotometry, high performance liquid chromatography, energy dispersive x-ray analysis, x-ray diffraction, and capillary electrophoresis.[1]

As in the analysis of petroleum distillates in fire debris, the critical first step in the analysis of explosive residue is the separation of the residue from the debris. The salts that are the products of the explosive reaction are removed from the debris by a cold water extraction, while the unreacted or partially reacted residue of the explosive itself is removed using an organic solvent. These concentrated extracts are then analyzed using one, or often several, of the techniques listed above.

For explosions caused by fuels other than chemicals designed to explode, gas chromatography is the usual method of analysis. Gasoline, the most common fuel for explosive vapor/air mixtures, is detected as described previously. Gas chromatography is required to detect ethane, and higher molecular weight gases, which are found in natural gas, but not in sewer gas. Odorization of natural and LP gases is frequently an issue in explosion cases. The National Fuel Gas Code requires that consumer fuel gases be odorized so that they are detectable at a concentration of one-fifth of the lower explosive limit. Quantitation of the odorant level may be accomplished by gas chromatography or through an "odor panel," five people with an unimpaired sense of smell. Reagent tubes can also be used to detect the ethyl mercaptan or thiophane used to odorize fuel gases.

As reflected in many YouTube entries, "recreational" bombs seem to be gaining in popularity. These can be simple devices such as a 2 L soft drink bottle with water and carbon dioxide in the form of dry ice, or slightly

[Section 39:71]

[1]For a discussion of the analysis of explosive devices, see Thurman, J.T., in Explosions: Scene Investigation, in Encyclopedia of Forensic Sciences, Jamieson, A., and Moenssens, A., editors, Wiley 2008.1019. For a discussion of the analysis of explosive residues, see Oxley, J., and Marshall, M., in Laboratory Analysis of Explosion Debris, in Encyclopedia of Forensic Sciences, Jamieson, A., and Moenssens, A., editors, Wiley 2008. 1028.

more complicated bombs involving acids and metals, which produces hydrogen. Juveniles experimenting with explosives may find themselves charged with major felony violations of antiterrorism statutes. It is frequently difficult to find a non-government scientist willing to examine such devices, and even in the event that they are actually harmless, a defense expert will generally decline to re-create the device for fear of being arrested for possession of it.

§ 39:72 Future directions

The laboratory analysis of fire debris is about as "settled" as any forensic science is ever likely to be. The gas chromatograph-mass spectrometer can provide almost total characterization of complex mixtures to allow for unequivocal identification of the petroleum products that are likely to be used as accelerants. The techniques of sample preparation have reached the practical limit of what is desirable to detect. More sensitive levels of detection increase the risk of identifying ignitable liquid residues that are part of the normal background.[1] The simplicity of the techniques available to achieve current levels of detection provides little impetus to improve the techniques. The impetus in the field is now to improve the quality of work done by laboratories that have yet to adopt techniques that are generally recognized as valid. Laboratories that fail to follow these minimum standards can expect to see their results challenged frequently and more vigorously.

With the lack of a frontier, more laboratory scientists are stepping out into the field, and applying their scientific skills to the understanding of the behavior of fire. The National Fire Protection Association (NFPA) and the National Institute of Standards and Technology (NIST) are both considering avenues to repeat the experiments of the 1970s and 80s, but this time, to also study the aftermath and not just the fire itself. Numerous test burns should be recorded in the next few years, and the information that comes out of them should greatly improve the quality of field fire investigation work.

As more canines are brought into the field of accelerant detection, a body of knowledge, including peer-reviewed research, is likely to come into being. The use of accelerant detecting canines may free up large amounts of fire investigators' time, allowing overworked state and local officials to concentrate on those fire scenes most likely to result in prosecutable arson cases.

Computer modeling is likely to assume a much larger role in the future, particularly as data are produced from more test burns. These data can be used to validate a model's predictions. As with any new technique, the potential for error or abuse is present. Determinations that rely heavily on

[Section 39:72]

[1] Lentini et al., The petroleum-laced background, 45 J. Forensic Sci. 968 (2000).

modeling should be carefully challenged. If a mathematical or computer model is required to prove a claim of arson, it is a weak case indeed. It is questionable whether a technology based on tests with a 30% or greater uncertainty is useful in forensic analyses.

Certification of field investigators by the International Association of Arson Investigators or by the National Association of Fire Investigators is becoming more common. Neither certification program guarantees the competence of the witness or the correctness of their findings, but the programs do serve a useful purpose in encouraging the fire investigation community to identify some areas of agreement and to study areas of disagreement. Many states require fire investigators to be licensed as private investigators, but in most cases these requirements only serve to restrain trade and raise revenue. Kentucky is the first state to require that private investigators that conduct fire and arson investigations be certified by either IAAI or NAFI.

Certification of laboratory analysts through the American Board of Criminalistics began only in 1994, and there is now a significant cadre of certified fire debris chemists. The 2009 NAS report, Strengthening Forensic Science in the United States: A Path Forward, advocates mandatory certification for all forensic scientists, though the profession, citing the costs, has been slow to respond.

As more scientists leave the laboratory to do field research in the area of fire behavior, the understanding of fire behavior is likely to improve, and the quality of fire investigations is likely to benefit from the application of a scientist's natural skepticism to the outdated or unsupported beliefs held by many field investigators.

In 2002, the Bureau of Alcohol, Tobacco and Firearms and Explosives opened up a world-class research facility in Ammendale, Maryland, designed to conduct experiments to improve the understanding of fires. Unfortunately, there has been very little research out of that laboratory as it has been taken over by the Department of Justice and turned into a crime lab. Almost all of the staff work to support prosecutions, and because they are working on ongoing cases, very little of what they have learned can be published. Some new research is taking place as a result of the 2009 NAS report.

While there are still far too many cases of erroneous fire analyses, the profession is moving incrementally toward a more accurate "calibration" of expectations. Training available over the internet from CFI trainer has the capacity to rapidly improve the level of knowledge in the field, but only if the field chooses to take advantage of this resource.

The entry of fire protection engineers (FPEs) into the fire investigation business is a hopeful sign. These highly educated scientists and engineers are bringing a new level of rigor to the field, which can only improve the quality of analyses. Individuals and organizations that formerly ignored or even looked down upon the contribution of these engineers are beginning to appreciate what they have to offer.

The process of fire investigation continues to improve, though the vast majority of practitioners still possess no formal education in chemistry and physics, despite the fact that society asks them to make sophisticated decisions concerning exactly those subjects. The strengthening of the requirements of the NFPA 1033 standard will, one way or another, cause fire investigators to become more educated. Challenges based on a lack of qualifications are likely to increase. If the courts can bring themselves to follow the requirements of Rule 702, the quality of work will likewise increase as a result.

APPENDIX 39A

Glossary

Accelerant. An agent, often an ignitable liquid, used to initiate or speed the spread of fire.

Adsorption/elution. A method of concentrating ignitable liquid vapors onto an active surface, usually a small (10 × 10 mm) square of carbon impregnated polytetrafluoroethylene (PTFE) tape, or c-strip. Once the vapors are trapped on the active surface, they are removed (eluted) by placing the c-strip in a solvent. The resulting solution in the analyzed by GC-MS.

Arc. A luminous electric discharge across a gap. If the arc generates sufficient energy, an arc bead may be formed. An arc bead is a round globule of re-solidified metal at the point on an electrical conductor where the arc occurred.

Area of Origin. The room or area where a fire began. While "area" of origin is a common term of art, the fire occurs in three-dimensional space, and this term actually means "volume" of origin. *(See also Point of Origin.)*

Capillary Electrophoresis. An analytical separation technique, which utilizes electric charge to separate and analyze sub-milligram quantities of chemical substances. Capillary Electrophoresis is useful in many types of analytical chemistry, including the detection of explosives and gunshot residues.

Cause. The circumstances, conditions, or agencies that brought about or resulted in the fire or explosion incident, damage to property resulting from the fire or explosion incident, or bodily injury or loss of life resulting from the fire or explosion incident.

Compartment Fire. Any fire that occurs inside an enclosure. Once a fire has progressed beyond the initial free-burning stage, it interacts with the floors, walls, and ceilings of the enclosure and behaves differently from a free-burning fire.

Flashover. A transition phase in the development of a compartment fire in which surfaces exposed to thermal radiation reach ignition temperature more or less simultaneously and fire spreads rapidly throughout the space.

Fuel-controlled fire. A fire in which the heat release rate and growth rate are controlled by the characteristics of the fuel, such as quantity and geometry, and in which adequate air for combustion is available.

Gas Chromatography (GC). An analytical method for separating and identifying mixtures of compounds. A compound's solubility in a stationary phase versus its solubility in a mobile phase allows separation of similar compounds due to subtle differences in physical or chemical properties. Most gas chromatography performed on ignitable liquid residues relies on differences in boiling points to effect the separation. GC is the fundamental first step in the analysis of any ignitable liquid residue. The output of the GC is known as a chromatogram. GC must be coupled with mass spectrometry (MS) in order to meet currently accepted standards.

Headspace. The volume of air above a sample of debris in a container.

Infrared Spectrophotometry (IR). An analytical method that measures the absorbance of radiation having a wavelength slightly longer than the wavelength of visible light. This method is used to characterize the functional groups present in a sample, and is frequently applied to polymers and drugs. The utility of IR is limited in ignitable liquid residue analysis because most ignitable liquids are mixtures, and infrared spectrophotometry requires pure or nearly pure compounds in order to yield meaningful data. The output of the IR spectrophotomer is known as an absorbance spectrum.

Mass Spectrometry (MS). An analytical method that begins with the breaking up of the compounds of interest by the application of chemical or electrical energy, followed by a measurement of the size and number of ions produced in the ionization step. Like other spectral techniques, mass spectrometry requires pure compounds in order to yield meaningful data. The purification for most mass spectral analysis is accomplished via gas chromatography. Typically, the MS is attached to the output side of a gas chromatograph (GC-MS) column. The output of the mass spectrometer is known as a mass spectrum.

Odorization. The addition of small concentrations of substances to a fuel gas in order to make it detectable by smell. The two common fuel gases, natural gas and LP gas, have no odor. Odorants such as ethyl mercaptan or thiophane must be added to fuel gases in order to make them detectable at a concentration not over one-fifth of the lower limit of flammability.

Point of Origin. The exact physical location in three-dimensional space where a heat source and a fuel come in contact with each other and a fire begins.

Radiometer. A collection of thermocouples encased in a solid conductive metal jacket (e.g., copper), which is cooled by water. By measuring the voltage difference between the thermocouples exposed to the fire and the thermocouples exposed to the water, and taking into account the surface area of the case, the radiative flux in watts per square centimeter (or kilowatts per square meter) can be measured directly.

Thermocouple. A device consisting of two dissimilar metal wires, which convert heat energy into electrical energy. A voltage-measuring device is attached to the wires and the temperature at the junction of the wires can be calculated. This is usually accomplished electronically, and the thermocouple readout, known as a pyrometer, reads directly in F or C.

Thin Layer Chromatography (TLC). A chemical analytical procedure, which separates compounds by their solubility in a solvent, and the tenacity by which these compounds adsorb (adhere) to a thin sheet of silica gel (or other absorbing substance) spread out on a glass plate. Once separated, the spots of analyte can be further characterized by exposure to a developing agent, which causes the spots to change color. As in all chromatographic analyses, a comparison is made between a known substance and an unknown substance. TLC may be used for the separation of drugs and explosives, and also for the characterization of dyes in automotive gasoline.

Ventilation-controlled fire. A fire in which the heat release rate or growth is controlled by the amount of air available to the fire. Nearly all fully involved compartments contain a ventilation-controlled fire.

APPENDIX 39B

National Research Council Comments*

ANALYSIS OF EXPLOSIVES EVIDENCE AND FIRE DEBRIS

Explosives evidence encompasses a wide range of materials from unburned, unconsumed powders, liquids, and slurries, to fragments of an explosive device, to objects in the immediate vicinity of an explosion thought to contain residue from the explosive. A typical analytical approach would be to identify the components and construction of an explosive device and conduct an analysis of any unconsumed explosives and residues. In addition to the analysis and identification of low and high explosives, chemical reaction bottle bombs are also analyzed. The scene of an explosion can require special investigative attention. What may appear to be a small piece of scrap metal could in fact be an important piece of the device that caused the explosion. The very nature of an explosion has a direct impact on the quality of evidence recovered. Pristine devices or device fragments, or appreciable amounts of unconsumed explosive material, should not be expected.

Analyses

Generally speaking, laboratories will not accept devices until they have been rendered safe. Examiners involved with the analysis of explosives evidence in the laboratory typically have an extensive scientific background, because the methods used entail a large amount of chemistry and instrumentation. The Technical Working Group for Fire and Explosives (TWGFEX), a group of fire debris and explosives examiners, suggests that an explosives examiner be required to possess a bachelor's degree in a natural or applied science, with recommended coursework in chemistry and instrumental analysis.[1] The group also recommends that the examiner complete a training program that includes the analysis of low and high explosives, instruction in the use of instrumentation used in routine analyses, the construction of explosive devices, and participation in a postblast investigation course. Although there is no official certification program for explosives examiners, TWGFEX has devised a suggested train-

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*This Appendix contains an excerpt from Strengthening Forensic Science in the United States: A Path Forward, which has been reprinted with permission from the National Academies Press, Copyright 2009, National Academy of Sciences.

[1] TWGFEX Explosive Examiners Job Description. Available at http://ncfs.ucf.edu/twgfex/documents.html.

ing guide. The guide is divided into seven modules, each with a reading list, practical exercises, and methods of evaluation.[2] To ensure that examiners maintain a level of competency, proficiency testing (internal or external) is required by ASCLD/LAB once per calendar year.[3]

The ultimate goal of an explosives examination is the identification of the explosive material used, whether it is through the analysis of an intact material or of the residue left behind when the material explodes. Intact material lends itself to being more easily identified. The individual components of postblast residue may often be identified (e.g., potassium chloride and potassium sulfate). The training and experience of examiners allows them to deduce what types of explosive material were originally present from possible combinations of explosive materials.

Whether it is a low explosive or high explosive, the analysis of an intact explosive material follows a procedure that begins with a macroscopic and microscopic examination of the material, followed by a burn test, when appropriate. The results of the initial observations will dictate how the rest of the analysis will proceed. Typically it will involve the use of instrumentation that provides both elemental and structural information about the material, such as X-ray diffraction, scanning electron microscope-energy dispersive X-ray analysis, or infrared spectroscopy. TWGFEX has devised guidelines for the analysis of intact explosives that categorize the instruments that can be used based on the level of information they provide.[4] The information gathered, if sufficient, can be useful in identifying the material.

The analysis of postblast explosive residues begins much like the analysis of intact explosives, with the macroscopic and microscopic analysis of the evidence submitted (whether it is an expended device, fragments of a device, or debris from near the site of the explosion). If no intact explosive material is found, a sequence of extracts may be used to capture any organic and/or inorganic residues present. These extracts are then analyzed employing the same instrumentation used for intact explosives. However, the results produced differ in their specificity, and it is here that the training and expertise of the examiner plays a large role. To interpret the results properly, the examiner must have knowledge of the composition of explosives and the reaction products that form when they explode. Interpretation can be further complicated by the presence of contaminants

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[2] TWGFEX Training Guide for Explosives Analysis Training. Available at http://ncfs.ucf.edu/twgfex/Documents.html.

[3] American Society of Crime Laboratory Directors International. 2006. *Supplemental Requirements for the Accreditation of Forensic Science Testing Laboratories*, p. 20. See www.ascld-lab.org/international/indexinternational.html.

[4] TWGFEX Recommended Guidelines for Forensic Identification of Intact Explosives. Available at http://ncfs.ucf.edu/twgfex/documents.html.

from, for example, the device or soil.[5]

Examination conclusions for postblast residues range from "the residue present was consistent with an explosive material" to "the residue is only indicative of an explosive" to "no explosive residues were present." TWGFEX recently has developed a set of guidelines for the analysis of postblast explosive residues,[6] but has yet to make any recommendations for report wording.

The examination of fire debris not associated with explosions often aims to determine whether an accelerant was used. To assess the effects of an accelerant, one might design an experiment, under a range of conditions (e.g., wind speed, temperature, presence/absence of other chemicals) with two groups: one in which materials are burned in the presence of an accelerant ("treatment") and one with no accelerant ("control"). The measured outcomes on the burned materials might be measures that characterize the damage patterns (e.g., depth of char, size of bubbles on surfaces). Differences in the ranges of these measurements from the materials in the two groups (treatment versus control) suggest a hypothesis about the effects of an accelerant. Following this exploration, one should design validation studies to confirm that these measures do indeed characterize the differences in materials treated or untreated with an accelerant.

Summary Assessment

The scientific foundations exist to support the analysis of explosions, because such analysis is based primarily on well-established chemistry. As part of the laboratory work, an analyst often will try to reconstruct the bomb, which introduces procedural complications, but not scientific ones.

By contrast, much more research is needed on the natural variability of burn patterns and damage characteristics and how they are affected by the presence of various accelerants. Despite the paucity of research, some arson investigators continue to make determinations about whether or not a particular fire was set. However, according to testimony presented to the committee,[7] many of the rules of thumb that are typically assumed to indicate that an accelerant was used (e.g., "alligatoring" of wood, specific char patterns) have been shown not to be true.[8] Experiments should be designed to put arson investigations on a more solid scientific footing.

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[5] C.R. Midkiff. 2002. Arson and explosive investigation. In: R. Saferstein (ed.). *Forensic Science Handbook*. Vol. 1, 2nd ed. Upper Saddle River, NJ: Prentice Hall.

[6] TWGFEX Recommended Guidelines for Forensic Identification of Post-Blast Explosive Residues. Available at http://ncfs.ucf.edu/twgfex/action_items.html.

[7] J. Lentini. Scientific Fire Analysis, LLC. Presentation to the committee. April 23, 2007. Available at http://sites.nationalacademies.org/PGA/stl/forensic_science/.

[8] NFPA 921 Guide for Explosion and Fire Investigations, 2008 Edition. Quincy, MA: National Fire Protection Association.