CHAPTER

1

Introduction

KEY TERMS

- accidental fire, p. 2
- arson, p. 4
- combustion, p. 10
- explosion, p. 2
- fire, p. 2
- fire behavior, p. 10
- incendiary fire, p. 3
- suspicious, p. 7

OBJECTIVES

After reading this chapter, you should be able to:

- Describe the role of fire investigators in their determination of the origin, cause, and development of a fire or explosion.
- List the four major peer-reviewed publications in the field of fire investigation.
- Identify the common job performance requirements for fire investigators.
- Explain the problem of fire loss statistics in the United States and in the United Kingdom, particularly in the estimation of incendiary fires.
- Demonstrate an understanding of the role of the scientific method as it applies to fire and explosion investigations.
- Discuss the levels of confidence as they apply to expert opinions in fire and explosion investigations.
Fire Investigation

This textbook focuses on the field of fire investigation, which is the formal process of determining the origin, cause, and development of a fire or explosion. Often called origin and cause (O&C) investigation, the probe is launched after a fire or explosion is extinguished and investigators then strive to determine what circumstances caused or contributed to the incident. Due to the complex nature of the event, where fire often deforms or distorts the evidence, fire investigation is among the most difficult forensic sciences to practice. Not knowing whether the fire was intentionally set, investigators must undertake to prove or disprove any allegations or suspicions and to piece together the pre- and post-fire events. If the investigation indicates a fire was deliberately set, reasonable accidental fire causes must be evaluated and eliminated.

Fire investigators must have broad and up-to-date knowledge of topics such as fire science, fire chemistry, thermodynamics, thermometry, fire dynamics, explosion dynamics, computer fire modeling, forensic sciences, fire analysis, scientific methodology, photography, hazardous materials, building construction, gas and electricity utility systems, human behavior (related to evacuation, victims, firesetting, witnesses, and information), forensic lab analysis, failure analysis, criminal and civil law, and analytical tools.

The latest edition of Kirk’s Fire Investigation is considered the leading worldwide authoritative textbook in the field. The textbook is used both for training and as the basis for certification in many jurisdictions. A majority of the overall methodology of fire investigation relies upon Kirk’s as well as on the following three peer-reviewed sources:

- The second edition of Forensic Fire Scene Reconstruction, published in 2008, which is also considered a leading forensic textbook, serves as a “bridge textbook” that ties the concepts of fire engineering analysis to fire investigations.

NFPA 1033 identifies the professional level of job performance requirements for fire investigators. This standard specifies the minimum job performance requirements for
service as a fire investigator in both the private and public sectors. Job performance requirements for each duty are the tasks an investigator must be able to perform to successfully carry out that duty. These are summarized in Table 1-1.

Not only must fire investigators refer to and rely on these guides and standards, as well as on expert treatises, they must conduct their investigations using a systematic and scientifically guided approach. In cases of **incendiary fires** (i.e., those set intentionally to destroy), in addition to determining the origin and cause of the fire, the investigator has the added responsibility of identifying the person who set the fire and providing proof to a trier of fact. Incendiary fires represent a significant percentage of all fires and, because they are set specifically with the intent of destroying property, an inordinately high percentage of dollar losses. Finally, a majority of the fire investigators who testify as expert witnesses usually have certification in the field by one or more internationally recognized professional organizations.

### TABLE 1-1 Professional Levels of Job Performance for Fire Investigators as Cited in **NFPA 1033, 2009 Edition**

| General Requirements for a Fire Investigator | 4.1.1 Employ all elements of the scientific method as the operating analytical process  
4.1.2 Complete site safety assessments on all scenes  
4.1.3 Maintain necessary liaison with other interested professionals and entities  
4.1.4 Adhere to all applicable legal and regulatory requirements  
4.1.5 Understand the organization and operation of the investigative team and incident management system |
| Scene Examination | 4.2.1 Secure the fire ground  
4.2.2 Conduct an interior survey  
4.2.3 Interpret fire patterns  
4.2.4 Interpret and analyze fire patterns  
4.2.5 Examine and remove fire debris  
4.2.6 Reconstruct the area of origin  
4.2.7 Inspect the performance of building systems  
4.2.8 Discriminate the effects of explosions from other types of damage |
| Documenting the Scene | 4.3.1 Diagram the scene  
4.3.2 Photographically document the scene  
4.3.3 Construct investigative notes |
| Evidence Collection/Preservation | 4.4.1 Utilize proper procedures for managing victims and fatalities  
4.4.2 Locate, collect, and package evidence  
4.4.3 Select evidence for analysis  
4.4.4 Maintain a chain of custody  
4.4.5 Dispose of evidence |
| Interview | 4.5.1 Develop an interview plan  
4.5.2 Conduct interviews  
4.5.3 Evaluate interview information |
| Post-Incident Investigation | 4.6.1 Gather reports and records  
4.6.2 Evaluate the investigative file  
4.6.3 Coordinate expert resources  
4.6.4 Establish evidence as to motive and/or opportunity  
4.6.5 Formulate an opinion concerning origin, cause, or responsibility for the fire |
| Presentations | 4.7.1 Prepare a written report  
4.7.2 Express investigative findings verbally  
4.7.3 Testify during legal proceedings  
4.7.4 Conduct public informational presentations |

*Sources: NFPA 1033, 2009 Edition; S. Sklar, personal communications, 2008.*
The Fire Problem

Internationally, fire continues to be the most costly of all public safety problems today, as it has been for the past several decades. The losses in human lives and injuries due to fires and explosions continue to occur. Fire-caused property losses are far in excess of those caused by all classes of crime and rival those produced by hurricanes and earthquakes. The major issue in identifying and quantifying the fire problem is the failure to obtain accurate incident data. This problem is not limited to any single country.

FIRE STATISTICS IN THE UNITED STATES

For example, in the United States, fire incident data are collected by the U.S. Fire Administration and the National Fire Information Council using the National Fire Incident Reporting System (NFIRS) on a voluntary basis. Shrinking state budgets have often resulted in the downgrading of the priorities of fire incident data collection programs. Uniform Crime Reporting (UCR) statistics are amassed through the Federal Bureau of Investigation’s (FBI’s) National Incident Based Reporting System (NIBRS), but arson incident data are collected only when a fire or police investigator actually submits a report into NIBRS. Subsequently, arson cases go unreported when fire departments fail to pass along and fill out a separate police report on intentionally set fires.

Although the National Fire Protection Association (NFPA) collects data on fire incidents, its estimates are based on data the association receives from fire departments that respond to its National Fire Experience Survey. NFPA estimated that public fire departments in the United States responded to a total of 1,451,500 fires in 2008. Of these, an estimated 515,000 were structure fires, which represented a decrease of 2.9 percent from the number in 2007. The total monetary property loss for structure fires was $12.4 billion, an increase of 16.2 percent over the previous year’s total. The average overall loss per structure fire was $24,002, an increase of 19.7 percent from the 2007 average. Residential fires accounted for about 78.2 percent of all structure fires (estimated at 403,000), with 291,000 occurring in one- and two-family dwellings and accounting for 56.5 percent of all structure fires. In addition, in 2008 there were an estimated 236,000 vehicle fires and 594,000 “outside” fires.

No accounting can accurately reflect the loss in lives and injuries that results from fires. In 1987, the NFPA estimated that 5,810 civilians died as a result of fires, and 28,295 suffered injuries. By 1999, these losses were reduced to 3,570 deaths in structure fires (and 470 in vehicle fires) and 21,895 injured. In 2003, estimated losses were 3,925 deaths (an increase of 16 percent over 2002 losses) in structure fires and 475 in vehicle fires, with 18,125 injuries. NFPA estimates on civilian fire deaths totaled 3,320 and 16,705 civilian fire injuries in 2008, a decrease from 2007 totals of 3.2 and 5.5 percent, respectively. An estimated 2,780 civilians perished and 13,560 were injured in residential fires. Of these, 390 died and 3,975 were injured in apartment fires, and 2,365 died and 9,185 were injured in one- and two-family dwelling fires. Thus, even though the overall estimated number of fires has remained steady since 1999, injury and death rates are dropping.

During the period 1994–2007, an average of 100 firefighters died on duty each year (not including the 343 firefighters who died at the World Trade Center in 2001). There were an estimated 36,880–44,210 fireground injuries reported to U.S. firefighters per year between 2003 and 2007, reflecting a fluctuating rate of 22–27 fireground injuries per 1,000 fires per year since 1987. The National Safety Council reports that accidental fire-related burn injuries are the sixth leading cause of all accidental deaths.

In addition to these direct losses are the incalculable indirect fiscal costs. The actual dollar property losses previously listed probably represent only 10 percent of the total costs. There are inestimable losses due to lost business income, unemployment, reduced property values, and reduced tax bases as a result of nearly every major fire. In a 2005 Fire...
Protection Engineering article, Frazier estimated that the total cost of fire in the United States is on the order of $130–$250 billion per year. Personnel and equipment costs are incurred in the suppression of every fire, historic structures are lost forever, and wildland fires destroy watersheds, timber, and wildlife, which cannot be replaced at any cost.

It should be noted that virtually all U.S. fire “statistics” are only educated guesses, in the authors’ opinion. The Consumer Product Safety Commission (CPSC) once estimated that fewer than 5 percent of structure fires are even reported to authorities. Most of them were presumably too minor and resulted in no major injuries or property losses. Many state fire marshals do not forward their own statistics to NFIRS (sometimes because of staffing shortages). California, which represents more than 10 percent of the U.S. population, has not been represented in NFIRS analyses for several years. Further, without adequate training for the person checking off the boxes in NFIRS reporting forms, those responses are often no more than guesses based on first impressions and on-the-fly assessments made by incident commanders.

FIRE STATISTICS IN THE UNITED KINGDOM
The United States is not alone in the problem of fire loss. The Office of Fire and Rescue Services, Communities and Local Government (CLG) in the United Kingdom (UK) collects, maintains, and analyzes UK fire statistics. In May 2006, the CLG assumed responsibility for the fire and rescue service. Previously, responsibility had been held by different UK government departments: the Home Office; the Department for Transport, Local Government (DTLG); and the Office of the Deputy Prime Minister (ODPM).

In the United Kingdom, a total of 385,000 fires were reported in 2007, of which 77,000 (23.5 percent) were in buildings. In 2008, the number of building fires fell by 8 percent to 77,000; and the number of dwelling fires fell by 6 percent, to 51,000. The total number of fires in buildings other than dwellings (commercial premises, schools, etc.) also fell 12 percent, to 231,000. Outdoor fires totaled 186,000, and there were 44,000 road vehicle fires.

In 2003 the ODPM estimated that the average costs (property damage, health care, and lost employment) were £24,280 (approximately $47,000) per domestic fire, £58,100 (approximately $107,000) per commercial fire, and £4,670 ($8,600) per vehicle fire. The ODPM estimated that £1.1 billion ($2.03 billion) in losses were incurred from material damage and business interruption claims in the United Kingdom in 2003, but another £6.6 billion ($12.2 billion) in costs fell on society in the form of suppression costs, cleanup, environmental damage, and disruption to households.

In 2007, there were 443 fire-related deaths in the United Kingdom, a 2 percent increase from the 2006 figure. The UK study noted that a majority of fire-related deaths (greater than three quarters) occur in dwelling fires, with more fire-related deaths per 1,000 fires than in any other location.

Findings from the 2004/05 Survey of English Housing on all outbreaks of fire experienced by households in England suggested that the fire and rescue service attended approximately one fifth of all domestic fires. The explanation for this was that many of the fires recorded in that survey were minor and could be put out by someone in the home or bystanders; therefore, the fire and rescue service was not called.

ROLE OF THE FIRE INVESTIGATOR IN ACCURATELY REPORTING THE CAUSES OF FIRES
What role does the fire investigator play in this tragedy? By accurately and efficiently identifying the causes of fires, whether accidental or incendiary, investigators can make a real and substantial contribution to reducing these terrible losses. Think of the number of people who would have died had the flammability of clothing and bedding not been identified in the 1960s or had the problems with instant-on televisions not been tracked down.
in the 1970s, or with coffeemakers and portable heaters in the 1980s. What of the scores of potential victims in several large cities in the 1990s had the serial arsonists there not been identified and incarcerated? Saving lives and preventing injuries are the real reasons fire investigators spend long hours searching a fire scene or doing laboratory analysis and fire research.

The role thorough fire investigation plays in the regulatory and code-making process is also significant. Much of the progress in reducing the frequency of fires and fire deaths is due to the advances made in improving life safety and fire safety codes. Although these codes are written on the basis of the best predictive models, the only way to be sure they have the desired effect and do not create other, unanticipated risks is to document the effects of fire in code-compliant buildings and transport. In the early 1900s builders were proud of the fire-resistant buildings they had built of stone, concrete, steel, and glass. It was not until major tragedies like the Triangle Shirtwaist fire in 1911 that people realized that building contents and not just the structures were major factors in fires, and having adequate means of escape was critical to survival. Manual alarm and firefighting systems were also found to be woefully inadequate.

The Detection of Incendiary Fires

Few other investigations are as daunting as a fire scene. Because a fire scene has to be investigated before it can be established whether the crime of arson has been committed, every fire scene must be considered a possible crime scene (from the standpoint of scene security, processing, and evidence collection) until clear proof is found that the fire was accidental. As a crime scene, the typical fire scene is the antithesis of the ideal. There has been wholesale destruction of the physical material and substance of the scene, first by the fire itself and second by fire suppression and overhaul by the firefighters. Naturally, this destruction affects evidence of both accidental and incendiary causes. There has been contamination of the scene by vehicles, personnel, equipment, hoses, and large quantities of water. Scene security and control of unauthorized persons are difficult because of the attraction fire offers to the public and the press and may be further complicated by the large area involved in many fire scenes. Often, the scene investigation is carried out days or weeks after the incident, after weathering and vandals may have further compromised whatever evidence remains. Considering these negative factors, it is not surprising that police and fire personnel have often let fire investigation fall through the cracks of responsibility. As a result, it is surprising that fire causes are ever accurately determined and civil and criminal cases successfully brought to trial.

REPORTING ARSON AS A CRIME

The Uniform Crime Reports (UCR), published by the FBI of the U.S. Department of Justice, provides enlightening statistics on arson in the United States. Statistics for 2007, published in 2008, are used in this chapter. Annually, the FBI publishes Crime in the United States, which catalogs the entire crime picture of the United States. Note that a 2006 study of statistics for previous years indicates that there is a fairly constant pattern in arson statistics for past years. UCR reported in 2008 that the number of arson offenses decreased 3.6 percent compared with those reported in 2007.

The FBI’s UCR Program defines arson as

- any willful or malicious burning or attempting to burn, with or without intent to defraud,
- a dwelling house, public building, motor vehicle or aircraft, personal property of another, etc.

The FBI collects data only on the fires that through investigation were determined to have been willfully set. Fires are not included in the data collection whose cause is labeled as “suspicious” or are “unknown or undetermined.”
The FBI points out that arson rates are calculated based on data received from all law enforcement agencies that provide the UCR Program with data for 12 complete months. Unlike other national reporting systems, UCR Program data collection does not include any estimates for arson, because the degree of reporting arson offenses varies from agency to agency.

According to the 2008 UCR, 14,011 law enforcement agencies (providing 1–12 months of arson data) reported 62,807 arsons. Of those agencies, 13,980 provided expanded offense data on about 56,972 arsons. These data show that arsons involving structures (residential, storage, public, etc.) accounted for 24,750 fires, or 43.4 percent of the total number of arson offenses. Mobile property was involved in 28.9 percent of arsons, and other types of property (such as crops, timber, and fences) accounted for 27.7 percent of reported arsons.\(^{20}\) See Table 1-2 for a detailed breakdown of the 2008 statistics.

The 2008 FBI statistics showed that the average dollar loss per incident due to arson was $16,015. Arsons of industrial/manufacturing structures resulted in the highest average dollar losses (an average of $212,388 per arson incident). Regarding arson rates, the 2008 UCR data showed that nationwide, the rate of arson was 24.1 offenses for every 100,000 inhabitants in the United States.

In contrast, the NFPA statistics for 2008 estimated that arson caused 30,500 structure fires and 17,500 vehicle fires, a decrease of 6.2 percent from 2007 totals. NFPA noted in its 2008 report that in Version 5.0 of the NFIRS the classification of arson was changed to intentionally set from the previous incendiary category. NFIRS no longer carries a suspicious fire category in its reporting system.\(^{21}\)

### TABLE 1-2

<table>
<thead>
<tr>
<th>PROPERTY CLASSIFICATION</th>
<th>NUMBER OF ARSON OFFENSES</th>
<th>PERCENT DISTRIBUTION(^a)</th>
<th>PERCENT NOT IN USE</th>
<th>AVERAGE DAMAGE</th>
<th>TOTAL CLEARANCES</th>
<th>PERCENT OF ARSONS CLEARED(^b)</th>
<th>PERCENT OF CLEARANCES UNDER 18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>56,972</td>
<td>100.0</td>
<td></td>
<td>$16,015</td>
<td>10,277</td>
<td>18.0</td>
<td>37.4</td>
</tr>
<tr>
<td>Total structure:</td>
<td>24,750</td>
<td>43.4</td>
<td>19.0</td>
<td>29,701</td>
<td>5,520</td>
<td>22.3</td>
<td>35.2</td>
</tr>
<tr>
<td>Single occupancy</td>
<td>11,435</td>
<td>20.1</td>
<td>21.4</td>
<td>28,788</td>
<td>2,389</td>
<td>20.9</td>
<td>25.7</td>
</tr>
<tr>
<td>residential</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other residential</td>
<td>4,062</td>
<td>7.1</td>
<td>13.6</td>
<td>29,343</td>
<td>983</td>
<td>24.2</td>
<td>25.0</td>
</tr>
<tr>
<td>Storage</td>
<td>1,629</td>
<td>2.9</td>
<td>20.7</td>
<td>18,021</td>
<td>298</td>
<td>18.3</td>
<td>48.7</td>
</tr>
<tr>
<td>Industrial/manufacturing</td>
<td>251</td>
<td>0.4</td>
<td>22.3</td>
<td>212,388</td>
<td>48</td>
<td>19.1</td>
<td>41.7</td>
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<tr>
<td>Other commercial</td>
<td>2,331</td>
<td>4.1</td>
<td>15.7</td>
<td>55,531</td>
<td>450</td>
<td>19.3</td>
<td>28.0</td>
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<tr>
<td>Community/public</td>
<td>2,667</td>
<td>4.7</td>
<td>16.2</td>
<td>15,799</td>
<td>857</td>
<td>32.1</td>
<td>65.3</td>
</tr>
<tr>
<td>Other structure</td>
<td>2,375</td>
<td>4.2</td>
<td>21.4</td>
<td>13,668</td>
<td>495</td>
<td>20.8</td>
<td>47.1</td>
</tr>
<tr>
<td>Total mobile:</td>
<td>16,454</td>
<td>28.9</td>
<td></td>
<td>8,766</td>
<td>1,461</td>
<td>8.9</td>
<td>20.3</td>
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<tr>
<td>Motor vehicles</td>
<td>15,572</td>
<td>27.3</td>
<td></td>
<td>8,186</td>
<td>1,314</td>
<td>8.4</td>
<td>18.7</td>
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<tr>
<td>Other mobile</td>
<td>882</td>
<td>1.5</td>
<td></td>
<td>18,991</td>
<td>147</td>
<td>16.7</td>
<td>34.7</td>
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<tr>
<td>Other</td>
<td>15,768</td>
<td>27.7</td>
<td></td>
<td>2,099</td>
<td>3,296</td>
<td>20.9</td>
<td>48.7</td>
</tr>
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</table>


Note: 13,980 agencies; 2008 estimated population 250,243,947.

\(^a\)Because of rounding, the percentages may not add to 100.0.

\(^b\)Includes arsons cleared by arrest or exceptional means.
The NFPA statistics for 2008 estimated that intentionally set fires in structure fires resulted in an estimated 315 civilian deaths and $866 million in property losses, an increase of 18.2 percent in property losses over those in 2007. Deliberate vehicle fires caused $139 million in property damage, a decrease of 4.1 percent from 2007 data. These estimates are almost certainly very low, since many U.S. jurisdictions do not report arson incidents (structural or vehicular) (in the authors’ experience). Many investigators think that the total of intentionally set structure fires is closer to 40 percent. These statistics may become further compromised as departments devote larger portions of their resources to Emergency Medical Services (EMS) operations and less to fire investigation.

This is a startling contrast to the United Kingdom experience. The UK authorities (CLG) estimate that some 31 percent of structure fires in 2003 were arson caused and 26 percent in 2004/05 after an intense national campaign, and that deliberately set fires in structures and vehicles took 117 lives, caused 3,200 casualties, and cost the economy there some £2.8 billion ($5.2 billion) (including costs in anticipation of arson fires).

In the United Kingdom, the CLG report notes that “deliberately set” fires include those where deliberate ignition was identified or was “merely suspected” and recorded by the fire and rescue service as “doubtful.” “Accidental” fires included those for which the listed cause was “not known” or “unspecified.” The number of deliberate primary fires (buildings, vehicles, outdoor structures, and any involving casualties, as defined by CLG) fell for the third consecutive year, from 79,700 in 2005 to 72,600 (9 percent) in 2007. Of the 21,400 deliberate fires in buildings recorded in 2007, more than half (59 percent) occurred in buildings other than dwellings. Of these 12,600 deliberate fires in other buildings, around a third occurred in private garages or sheds. The number of “accidental fires” decreased by 6 percent, to 82,000, in 2007 from 2005 (in all major categories). Arson-caused road vehicle fires accounted for 56 percent of all deliberate fires and 68 percent of all vehicle fires in the United Kingdom in 2007.

**PROBLEMS ASSOCIATED WITH ESTIMATING INCENDIARY FIRES**

The U.S. estimates are certainly on the conservative side, since many fires are never properly investigated because of lack of time, or are misidentified inadvertently as accidental fires due to lack of experience, or intentionally to avoid the complications that arise from identifying a fire as a criminal act. These complications can range from administrative, such as requiring more investigative time or involving another public agency, to political, such as generating negative publicity about the community. The sharp contrast between the UK estimates and the NFPA estimates that only 6.1 percent of the reported structure fires were incendiary demonstrates a systematic problem with NFPA’s data gathering and statistical processing. Recent estimates (2003–2007) represent a decrease of 15.7 percent from 2002’s already low percentages (traditionally around 15 percent of all fires).

One significant reason for this decrease is that the NFIRS changed its categories in 2003, eliminating the outmoded “suspicious” causation category. Only fires that were specifically determined to be intentionally set are now reported in the “incendiary category.” In the past, estimates of half of “suspicious” and “undetermined” fires were added to the “incendiary” total. Fire investigators across the United States suspected that even the “old” percentage (15 percent) was far below the reality of actual investigations. In response to a nonscientific random survey by DeHaan, many experienced public-sector investigators estimate that 35–40 percent of all the structure fires they see (and an even higher percentage of vehicle fires) are deliberately set. Lack of evidence, lack of time and resources, and limited cooperation of other public agencies make the selection of “undetermined” or even “accidental” causation the expedient solution. These problems have recently been exacerbated by budgeting problems at all levels of state and local governments, which have forced severely curtailing or even ceasing fire investigation services in both fire and police agencies. Consequently, the decision-making process has reverted to
fire company officers who may or may not be trained or prepared to identify evidence supporting an incendiary cause.

In 2000, the National Institute of Justice published *Fire and Arson Scene Evidence: A Guide for Public Safety Personnel* for first responders in police, fire, and medical services.\(^ {27}\) It was hoped that by familiarizing these professionals with the basics of fire-related investigation and physical evidence a higher percentage of them could contribute toward successful prosecutions. With the cutbacks in public services experienced across the United States, it is not known whether this guide has been successfully employed. From the small percentages of fires actually reported as intentional via NFIRS, it would appear not.

The situation is made even more critical by the governmental agencies that find themselves unable to cope with the onslaught of criminal cases of homicide, rape, assault, and drug-related activity and decide to ignore arson as a crime. This practice is conveniently expedited by categorizing arson as a property crime so that it can be allotted reduced priority and less tactical support than the more urgent crimes against persons. It must be recognized that arson is a crime against people. It is aimed against people where they live, where they work, and where they do business or go to church. Fire is just as much a weapon as a gun, a knife, or an axe. When aimed at persons, fires may be set directly on them or, more often, set deliberately to trap the victims in a structure or vehicle. Every set fire is a crime against the personnel of fire and police agencies who are obligated to respond to and enter fires in lifesaving efforts.

Fire is a most horrendous weapon. Successful fire investigation, culminating in an accurate determination of cause, is the only way to minimize these terrible losses. Accidental fires can be prevented by the identification and elimination of hazardous products and processes or careless practices, as well as the development and enforcement of better building codes and fire safety practices. As the recent British experience with vehicle arsons has shown, incendiary fires can be reduced by recognizing them, identifying those responsible, and prosecuting them.\(^ {28}\) Sadly, many cities, large and small, in the United States have been forced to eliminate or severely reduce their investigation units, leaving line officers to do what they can “on the fly.”

With such massive losses involved, it is not surprising that fire losses are one of the most common subjects of civil litigation. Yet, for all its economic and legal importance, fire remains one of the most difficult areas of investigation. It is challenging because the destruction of the fire and, sometimes, its suppression create difficulties in reaching firm and unassailable conclusions as to the fire’s cause. It is the investigator’s responsibility not only to identify the origin and cause of the fire but to be prepared to defend those conclusions in a rational, logical manner supported by scientifically valid data. In the absence of a rational reconstruction or scientific data, conclusions cannot be substantiated, and successful prosecution for arson is virtually impossible. Civil cases, even with their reduced requisite of proof, are made more difficult to decide fairly without such scientific analysis.

From the standpoint of public safety and economic considerations, it is important that investigative methods for accurately determining the causes of fires be understood and applied to the fullest extent possible. There should be no presumption that a fire is either accidental or incendiary. It is vital that the investigator not prejudge any fire as to cause without evaluating all the collected evidence. If an investigator decides that a fire is arson before collecting any data, then only data supporting that premise are likely to be recognized and collected. As Sherlock Holmes pointed out, “It is a capital mistake to theorize before one has data. One begins to twist facts to suit theories instead of theories to suit facts.”\(^ {29}\) The same caution is necessary for those who decide that all fires are accidental, no matter what their true cause may be. Although fire has been known since prehistoric times, it is still poorly understood by many people, including some firefighters, fire investigators, and others whose services depend on such understanding.
Scientifically Based Fire Investigation

There is a natural tendency for everyone to be impressed by the magnitude and violence of the fire itself and the degree of destruction that results from a large fire. In the case of insurance investigators, this tendency is aggravated by the fact that they are expected to assess this damage and possibly pay a claim for it. For the accurate investigation of fires, this preoccupation with the magnitude and results of the fire is unfortunate. Cause, not extent, should be the investigator’s concern, and too much attention to extent will obscure and complicate the search for the origin and cause.

COMPREHENSIVE METHODOLOGIES FOR FIRE INVESTIGATION

Because of the difficulty and complexity of a complete and accurate fire investigation, and preconceptions, there is a special need for every investigator to develop a comprehensive analytical approach to the task. This analytical approach recognizes that to be a successful fire investigator, a person must understand and master numerous facets of fires, fuels, people, and investigative procedures. The investigator must really understand how a fire burns, what factors control its behavior, and that all fires do not necessarily behave in a precisely predictable fashion. Such deviations from typical or expected fire behavior must be correlated with the fire conditions and their causes established. These causes usually involve the nature of the fuel involved or the physical circumstances and environment of the fire.

One of the most important, yet often neglected, areas of fire investigation is an understanding of the fundamental properties of the fuels involved. These properties, which include the chemistry, density, thermal conductivity, and heat capacity of the fuel, determine the ignitability and flame spread characteristics of the fuel. These, in turn, control the nature of ignition as well as events that follow. These properties are determined primarily by the chemistry of the fuel, and the investigator should have a thorough knowledge of the relevant chemistry and what happens in the reaction. Different ignition sources, whether glowing, flaming, or electric arc, will affect fuels differently, and so the investigator must rely on scientific data about the interaction of such sources with the first fuel ignited to help establish whether a particular source is even competent to accomplish ignition and what time factors may be involved. The focus tends to be simply on identifying fuels in fire scenes, but ventilation factors are equally important (as without air, there won’t be much of a fire to investigate). Investigators need to document and evaluate the sizes of rooms, windows, and doors, and changes in their condition during the fire. Ventilation factors must be considered as carefully as fuel factors. The fundamental requirement for a fire is the presence of fuel (in suitable form), oxygen, and heat (in suitable quantities), all linked by a self-sustaining chemical reaction. These factors must be taken into account by investigators when evaluating every stage of a fire’s development from ignition to extinguishment. The physical principles of heat transfer and effects on surfaces must also be understood, since they are fundamental to fire spread and to the production of fire patterns on which investigators rely after the fire.

Any attorney who is involved in fire cases, whether criminal or civil, should be generally familiar with the same areas of chemistry. An attorney who has no understanding of what happens in chemical reactions and the results of those reactions will be seriously handicapped when questioning both lay and technical witnesses. Highly significant facts of the fire, which may be crucial in causing an erroneous decision in court, may not be recognized. Such knowledge can also influence the decision whether to try a case or settle it on the best available terms. Thus, it is advantageous for both the investigator and the attorney involved to have a basic understanding of the simple chemistry of fuels, fire, and combustion and the physical laws that control the production of post-fire indicators.

Because most fires investigated involve either residential or industrial structures, there is a tendency to think of fires only in those terms. This error becomes apparent when a forest or wildland fire is under investigation. Although wildland fires involve the same basic
combustion of fuel in air, the dynamics of fire spread and the analysis and interpretation of diagnostic signs of fire behavior are quite different from those for structural fires. Factors such as weather, topography, and fuel density must be assessed in such fires. Today we commonly face the problems of investigating fires in the urban/wildland interface, where houses and trees coexist. Wherever the fire is of a highly local but very specialized nature, such as a fire in an industrial facility, the investigator must carefully analyze what is found and seek technical assistance if the issues are even marginally in doubt. Such fires are increasingly common when dealing with new products or complex processes of modern technology with which even experienced investigators have no familiarity.

Explosions, closely akin to fires and sometimes accompanying them, also must be understood by investigator and attorney alike. Explosions, like fires, can be accidental or intentional in cause. The difference between a fire and an explosion may be so small as to allow confusion and may almost be a matter of definition. The interrelation and distinction between the two types of chemical events must be clearly understood so that the combined event is properly interpreted when it occurs. The explosion that accompanies a fire is usually quite different from that produced by a bomb, commercial explosive, or a premixed fuel-air mixture, although all involve the rapid exothermic oxidation of a fuel or starting material. That distinction is sometimes lost both in the investigative and legal phases of subsequent actions. The investigation of a bombing may be very different in character from that of a fire-related explosion, but both rely on systematic collection and analysis of data and careful formulation of accurate conclusions. These distinctions and comparisons are developed in greater detail in Chapter 12.

THE SCIENTIFIC APPROACH TO FIRE INVESTIGATION

The scientific approach to fire investigation to be discussed here extends not only to the review of the entire case but also to the examination of the scene, where patient, thorough, and systematic evaluation of the scene and its contents will usually pay off in information critical to the case. It must be appreciated that the destruction of some scenes is so complete due to prolonged burning that virtually nothing can be ascertained reliably from the ashes regarding the origin, cause, and development of the fire. There can be virtually no reliable interpretation of burn patterns to establish direction or duration of fire exposure. Even such scenes can yield information about the contents of the structure, which can reveal fraud. There is a curious tendency for some investigators to show an inherent bias as to cause. These investigators appear to believe that all fires have a single cause, for example, electrical appliances or smoking materials; they then expend a vigorous effort to prove that the fire had this cause, rather than spend the time seeking the true cause. Prejudgment of fire causation is as dangerous as the prejudgment of any other unexplained event or crime. It is unfortunate that this appears to be an occupational issue within many fields of investigation, but perhaps it is more noticeable in fire investigation than in other areas. Adhering to a systematic approach (which is not to say it is dogmatic) such as the one described here will minimize the unfortunate effects of such prejudicial tendencies.

There is also an inclination to extrapolate observations about fuels and combustion in small-scale fires to full-blown incidents without knowing whether they are, in fact, appropriate or accurate. It is here that the data from fire engineering and fire dynamics studies can best be applied, but only if the user is fully aware of the conditions and limitations of the information.

Applying the Scientific Method

In recent years, the term scientific method of fire investigation has been more widely introduced, sometimes to the confusion of fire investigators. The concept does not mean that a fire investigator has to be a scientist, or to analyze things in a laboratory, or to replicate...
a fire scene in a field test or computer model. It means to apply the scientific method of logical inquiry to the investigation. It is an approach most good fire investigators already apply; it simply means the investigation follows a series of logical steps.

The universally accepted methodology cited by NFPA 921 in conducting investigations into the origin and causes of fires centers on the use of the *scientific method*, which embraces sound scientific and fire protection engineering principles. NFPA 921 defines the scientific method as

the systematic pursuit of knowledge involving the recognition and formulation of a problem, the collection of data through observation and experiment, and the formulation and testing of a hypothesis.  

The basic concepts of the scientific method are simply to *observe*, *hypothesize*, *test*, and *conclude*. The scientific method is considered the best approach for conducting fire scene origin and cause determinations, analysis, and reconstruction. The process of the scientific method is that it continuously refines and explores various working hypotheses until arriving at a final expert conclusion or opinion, as illustrated in Figure 1-1.

**STEPS IN THE SCIENTIFIC METHOD**

As applied to fire investigation and reconstruction, the scientific method is a logical and iterative seven-step systematic process. Properly applied, this systematic process addresses how to correctly formulate, test, and validate a hypothesis.

As illustrated in Figure 1-1, the following is a summary of this seven-step process:

1. **Recognize the Need.** A paramount responsibility of first responders is to protect a scene until a full investigation can be started. After initial notification, the investigator should proceed to the scene as soon as possible and determine the resources needed to thoroughly conduct the investigation. It is necessary not only to determine the origin and cause of the event but to determine whether future fires, explosions, or loss of life can be prevented through new designs, codes, or enforcement strategies. In public-safety sectors, determination of the origin and cause of every fire is often a statutory requirement. In some cases, the fire investigator may be called on to establish responsibility for the fire.

2. **Define the Problem.** Devise a tentative investigative plan to preserve and protect the scene, determine the cause and nature of the loss, conduct a needs assessment, formulate and implement a strategic plan, and prepare a report. This step is usually focused on the determination of the cause and nature of the loss but may also include determining who has the primary responsibility and authority to interview witnesses, protect evidence, and review preliminary findings and documents describing the loss.

3. **Collect Data.** Facts and information about the incident are collected through direct observations, measurements, photography, evidence collection, testing, experimentation, case histories, and witness interviews. All collected data should be subject to verification of how they were legally obtained, their chain of custody, and notation as to their reliability and authoritative nature. Data collection should include the documentation of the property; construction and occupancy; fuel loading; the processing and layering of the debris and evidence as found; examination of the fire (heat and smoke) patterns; char depths and calcination; and the application of electrical arc mapping surveys where relevant.

4. **Analyze the Data.** Using inductive reasoning (which involves formulating a conclusion based on a number of observations), analyze all the data collected. The investigator relies on his or her knowledge, training, and experience in evaluating the totality of the data. This subjective approach to the analysis may include knowledge of similar loss histories (observed or obtained from references), training in and understanding of fire dynamics, fire testing experience, and experimental data. Data
Step 1 - Recognize the Need
- Respond to loss, protect scene, assess resources
- Investigate to identify conditions or persons responsible, prevent future similar losses

Step 2 - Define the Problem
- Devise and implement a tentative investigative and strategic plan
- Determine primary responsibility and authority
- Determine cause and nature of fire

Step 3 - Collect Data
- Describe, observe, and document incident
- Photograph, sketch, and collect evidence
- Conduct tests and experiments
- Interview witnesses
- Assemble historical loss histories of similar incidents

Step 4 - Analyze the Data
- Evaluate, where applicable, fire pattern damage, heat and flame vectoring, arc mapping, fire engineering analysis
- Test predictions with established scientific knowledge of fire dynamics, loss histories, fire tests, and experimental data
- Recommend changes in working hypothesis

Step 5 - Develop a Working Hypothesis
- Develop a tentative working hypothesis from data analysis
- Address causal or mathematical relationships
- Formulate and test alternative hypothesis with established scientific and fire engineering knowledge

Step 6 - Test the Working Hypothesis
- Compare hypotheses to all known facts, incidence of prior loss histories, authoritative fire test data, sound published treatises, and experiments
- Recommend collection and analysis of additional data
- Solicit peer review to identify alternative hypotheses
- Modify working hypothesis
- Eliminate all other fire causes, if possible

Step 7 - Select the Final Hypothesis
“Expert Conclusion or Opinion”
- Make authoritative conclusion as to area and point of fire origin(s), and cause
- Identify competent ignition sources
- Establish level of confidence of final hypothesis
- Prepare expert report

evaluated can include the pattern of fire damage, heat and flame vectoring, arc mapping, and fire engineering and modeling analysis.

5. **Develop a Working Hypothesis.** A hypothesis is defined as “a supposition or conjecture put forward to account for certain facts, and used as a basis for further investigation by which it may be proved or disproved.” Based on the data analysis, the investigator develops a tentative or working hypothesis to explain the fire’s origin, cause, and development that is consistent with on-scene observations, physical evidence, and testimony from witnesses. The hypothesis may address a causal mechanism or a mathematical relation (e.g., plume flame height, impact of differing fuel loads, locations of competent ignition sources, room dimensions, impact of open or closed doors and windows). Figure 1-2 shows how working hypotheses take into account a wide spectrum of factors.

6. **Test the Working Hypothesis.** Deductive reasoning involves a conclusion based on previously known facts. Using deductive reasoning, compare the working hypothesis with all other known facts, the incidence of prior loss histories, relevant fire test data, authoritative published treatises, and experiments. Use the hypothesis testing to eliminate all other reasonable origins and causes for the fire or explosion, recommend the collection and analysis of additional data, seek new information from witnesses, and develop or modify the working hypothesis. Interactively repeat steps 4, 5, and 6 until there are no discrepancies with the working hypothesis. A critical feature of hypothesis testing is to create alternative hypotheses that also can be tested. If the alternatives are in opposition to the working hypothesis, their evaluation may reveal issues that need to be addressed. By testing all hypotheses rigorously against the data, those that cannot be conclusively eliminated should still be considered viable.

The scientific process as used in fire investigation is fundamentally different from that used in other fields, because in most fire cases, the solution or final hypothesis will not be tested by burning another house, vehicle, or wildland to see if the outcome is similar. The investigator must gather adequate reliable data and apply robust, reliable analyses (usually of basic indicators of fire movement, intensity, or duration) to develop a working (primary) hypothesis. Because these findings will often be “tested” in an adversarial legal proceeding, the fire investigator is
expected to have devised and tested alternate explanations (hypotheses). The evaluation of all these hypotheses is sometimes called **abductive reasoning**. The final outcome of this process is the selection of the hypothesis that fits all available data and the rejection of all other reasonable hypotheses. When applied in medical evaluations, this process is called **differential diagnosis**. This process best describes most modern fire investigations. Even though it does not follow every sequential step of the pure “scientific method,” it is a well-recognized analytical process.

It should be noted that this application of the scientific method is not the same as that used in experimental science. There, observation of an event causes the scientist to formulate a hypothesis about a possible explanation and then design experiments to gather data (information) with the specific intent of testing or rejecting that primary hypothesis. Only if the primary hypothesis has been rejected (or shown to be incorrect) will the experimenter return to the process and create another testable scientific hypothesis. The crucial test for scientific inquiries is to use the “proven” hypothesis to predict the outcome of further tests conducted by others (demonstrating its reproducibility and reliability). In fire/explosion investigations, it is very rarely possible to re-create an event to fully test the final hypothesis.

7. **Select Final Hypothesis (Conclusion or Opinion).** An *opinion* is defined as “a belief or judgment based upon facts and logic, but without absolute proof of its truth.” When the working hypothesis is thoroughly consistent with evidence and research, it becomes a final hypothesis and can be authoritatively presented as a conclusion or opinion of the investigation.

**LEVELS OF CONFIDENCE**

Upon selection of a final hypothesis, the confidence of an expert opinion is often determined. *Levels of confidence* may also vary with the profession of the person preparing the report. For example, *fire protection engineers* apply science and engineering principles to protect people, homes, workplaces, the economy, and the environment from the devastating effects of fires. Fire protection engineers also analyze how buildings are used, how fires start and grow, and how fires affect people and property. They commonly state in their written reports that their *expert opinion* is “to a reasonable degree of engineering certainty.” Forensic opinions should be offered only at a very high level of certainty; that is, no other logical solutions offer the same level of agreement with the available data. In forensic origin and cause determination, the investigator applies scientific knowledge to re-create the path of spread of the fire, trace it back to its origin, and, there, establish the cause of the fire. Such opinions are often expressed “to a reasonable degree of scientific certainty.”

When various hypotheses about the cause of the fire or explosion are tested, if only one hypothesis fits the available data and others are conclusively eliminated, the opinion can be expressed to a reasonable degree of scientific certainty (within the limitations of the available data). All scientific conclusions are subject to continual retesting or reevaluation if new reliable data are presented. For example, early observational “data” led the ancients to believe Earth was at the center of the universe. Later data showed that belief wrong and suggested a heliocentric universe. Modern data, of course, show our entire solar system to be circulating in an enormous galaxy moving across the universe.

If two (or more) hypotheses about the origin or cause of a fire or explosion exist and neither can be demonstrated to be false, the degree of certainty or confidence is reduced to “possible” or “suspected,” and the conclusion should be “undetermined.” The posing of alternative hypotheses is in the U.S. adversarial judicial system a fair way of testing the strength or certainty of expert conclusions.

An expert opinion should be expected to withstand the challenges of a reasonable examination by peer review or through cross-examination in the courtroom, according to *NFPA 921*. Curiously, *NFPA 921* currently discusses only two levels of confidence with
with respect to opinions—probable and possible. There is no mention of a “conclusive” opinion! A “conclusive” opinion can be offered when all the available data fit the final hypothesis and all the reasonable alternatives can be tested and have been conclusively accepted or rejected. Obviously, if there is not a conclusive opinion, but the weight of available data suggests one alternative is vastly more likely than the others, a “probable” opinion can be offered. If two or more hypotheses are equally likely, then a “possible” opinion is justified.

The collection and interpretation of information, and the decision-making process, will be addressed in a later chapter of this book, but the steps presented here are what every professional fire investigator follows even when he or she does not stop and enumerate them.

**LEGAL OPINIONS REGARDING SCIENCE IN INVESTIGATION**

Some of the most significant changes in fire investigation in the last 15 years have been the result of legal interpretations of the *Daubert, Kumho Tire, Joiner,* and *Benfield* decisions (which will be discussed in some detail in Chapters 16 and 17). Today’s fire investigator must demonstrate to the court that he or she has the training and qualifications to offer an opinion about the fire, has data (information) to support that conclusion, has followed an appropriate protocol in the investigation and decision-making process, and has followed, in general, the scientific method of inquiry. A basic protocol is outlined in the NIJ Guide described earlier. More detailed protocols are discussed in *Forensic Fire Scene Reconstruction*[^35] and NFPA 921: *Guide for Fire and Explosion Investigations.*[^36] Protocols will be discussed in Chapters 7 and 8. Note that a protocol is not a cookbook with all the steps laid out in mandatory order but an outline of a systematic, comprehensive approach to scene investigation.

The complexities encountered in fire investigation are sometimes overwhelming to the investigator, but patience and adherence to fundamental scientific principles of combustion, fire behavior, and heat transfer will usually result in a reasonable and defensible diagnosis of the fire if there are sufficient reliable data. These elementary principles of combustion, fuels, and heat effects, as well as the equally important principles of scientific investigation, are the concerns of this book.

[^35]: *Forensic Fire Scene Reconstruction*
[^36]: NFPA 921: *Guide for Fire and Explosion Investigations*
Review Questions

1. Give three examples of direct costs associated with fire losses. Give three examples of indirect costs associated with fire losses.
2. What is the fundamental organizational problem that interferes with the complete investigation of fires in most communities?
3. What points of logic support the idea that arson should be considered a crime against people rather than a property crime?
4. What are some of the negative factors to overcome when investigating a fire scene?
5. List the steps an investigator might follow when using the scientific method of fire investigation.
6. Name some reasons why the reported number of incendiary fires is considerably less than the actual number that occur.

References

20. Ibid.
22. Idem.
31. NFPA 921, pt. 3.3.139; 2011, pt. 3.3.62.
33. Ibid.
34. NFPA 921, 2011, pt. 18.6
35. Icove and DeHaan, *Forensic Fire Scene Reconstruction*.