ISSN 1041-9489

SAFETY BRIEF

December 1991 Volume 7, No. 2

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Fire and Explosion Investigations – A Historical and Hysterical Perspective

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Abstract

This is the first of a series of Fire/Explosion Safety Briefs introducing engineering and science into fire/explosion investigations. Just as the "magic" of alchemy preceded the science of chemistry, so has a large body of cause-and-effect mythology developed in fire investigation. These myths, which have been given the name "Old Fire Investigators' Tales" or OFITs, are described and the lack of validity of common OFITs is discussed.

With the use of engineering analysis supplemented by experimental data, we can replace those OFITs and provide the forensic engineer with new tools for identifying the origin and cause of fires and, often even more important, the cause of the resultant fire loss. Computer-aided fire models, heat transfer calculations and other engineering analyses can often be used to establish or validate possible causes, failure of protective devices and adequacy of fire protection features. Data to support these analyses should be obtained from government agencies and from private organizations experienced in fire research and experimentation. Data from demonstration fires or inexperienced "testers" should be avoided.

INTRODUCTION

The introduction of modern technology into fire and explosion investigations is the subject of this first of the Fire/Explosion Series Safety Briefs. Part 1, "Science, Art or Sorcery," concerns fire investigation mythology and unacceptable methods. Part 2, "Engineering and Scientific Tools," describes the application of analytical and experimental tools to fire and explosion investigation. Future Safety Briefs will include: Electrical Fire Causes (How electricity can and cannot cause a fire); Floor Surface Burning, Its Real Significance; Real Ignition and Fire Temperatures; and a Glossary of Forensic Fire Terminology.

Correct and reliable determination of the cause of fire and explosions is very important for fire/explosion prevention and when there is litigation after a loss. In addition to determining the cause of the fire or explosion, it is often equally important to determine the cause of the loss, which can be quite distinct from the cause of the fire or explosion.

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PART 1: SCIENCE, ART OR SORCERY?

Fire and explosion investigations have developed from a flawed art into a science as a result of new analytical techniques supported by extensive scientific data. Until recent years, almost all fire and explosion investigations were performed as an art. Many conclusions were based on a mythology developed over years of after-the-fact observations and assumptions as to the cause of what was observed. Cause and origin were commonly determined using methodologies which a 1977 Law Enforcement Assistance Administration (LEAA) report (10) characterized as having "little or no scientific testing" and "no published material in the scientific literature to substantiate their validity."

The 1977 LEAA study identified the fact that there was no scientific basis for techniques commonly used to determine cause and origin of fires. What was not explicitly stated was that even then there was engineering and scientific data that proved many of these techniques erroneous. Some of the investigative methods described depended on violations of the laws of chemistry, physics, and heat transfer. Many fire investigators still persist in using and teaching methods and myths which have been proven invalid.

In the past, the qualifications of investigators have been judged on the basis of how many fires they had investigated, regardless of whether they understood the chemistry, physics and heat transfer of fire phenomena. This is like saying that eating a lot of cakes and pies makes one a good cook. Seeing and participating in after-the-fact results do not teach the process needed to achieve the observed results. The eating experience makes you fat, not a good cook. After-the-fact fire investigations alone do not make experts in origin and cause.

A qualified investigator should understand fire phenomena and the chemistry and physics of fire, have experimental fire knowledge, and have observed fires and post-fire scenes. Many fire-cause determination courses are taught at the technician level and directed toward fire and police personnel, some of whom have not even had high school physics or chemistry courses. At times, the course instructor

Double, double, toil and trouble; Liquid burn and concrete bubble.
Dark black smoke with red orange flame; Softened glass will fix the blame.
Round about the cauldron go; In this fire, myths will grow.

may not have the scientific knowledge needed to understand how fires start and spread. Both instructor and student may be completely unfamiliar with the basic principles of ignition such as: critical surface temperatures for piloted and auto-ignition; the scenario, time and configuration specificity of ignition temperatures; critical radiant flux; and other basic parameters.

The start and behavior of fires is an interdisciplinary topic which requires knowledge often not even taught in engineering schools. The typical college engineering curriculum contains nothing related to the cause of fires. Those engineering curricula which lack both organic chemistry and heat transfer courses can leave an engineer poorly equipped even to learn fire cause determination. Information on course programs that are available at both the technician and engineering levels can be obtained from the Fire Science and Technology Educators Section of the National Fire Protection Association and from the Society of Fire Protection Engineers.

Fire investigation myths have developed in a manner analogous to the development of other myths. A cause-and-effect relationship was assigned to post-fire observations and to fire behavior. Persons developing and accepting the cause-effect correlation often had little understanding of the chemistry, physics and heat transfer of fire. In addition, prior to the late 1950's, little engineering and scientific work had been performed on structural fire phenomena. Many of these myths appear rational under narrow scrutiny, but resemble the flat-earth concept. That concept seems valid as long as you do not look too far nor expect the myth to conform to basic physical laws. Fire investigation myths die hard. Many investigators do not read the engineering and scientific fire literature. In addition, there are many who do not want to admit that their mythological-based testimony has caused serious injustices when insurance companies have denied legitimate claims or when innocent people have been sent to prison.

Old Fire Investigators' Tales, OFITs, is the term we have assigned to elements of this mythology. Many investigators still depend on OFITs even though they violate basic laws of chemistry, physics and heat transfer. OFITs retain common credibility because of the number of persons still depending on them. For example, a conviction in a recent capital arson case was obtained with OFIT evidence that violated the laws of physics and heat transfer. In addition, some OFITs have a semblance of credibility because they appear correct under specific fire scenarios.

Certain fire investigator training has been based on OFITs and other unscientific principles. For example, many investigators have been taught that there are four modes of heat transfer–convection conduction, radiation and "direct flame contact." The world's engineering and scientific community recognizes only convection, conduction and radiation. Direct flame contact is a form of convective heat transfer. Those who believe direct flame contact is another form of heat transfer do not understand what flame is. From a heat transfer standpoint, flames are hot gases in motion; their luminescence is the result of incandescent particles, principally carbon.

COMMON OFITs

Some of the more common Old Fire Investigators' Tales are described below, followed by referenced discussions of their flaws. Additional OFITs will be discussed in future Safety Briefs.

OFIT:
"V burn patterns show the point of origin."

A "V" pattern is a signature of a fire plume on a vertical surface and indicates that there was burning at the base of the plume (17, 48). Such a pattern reveals nothing about whether this was the origin or whether it occurred later in the fire. When a fire starts near a vertical surface, such as a wall, it often produces a "V" pattern signature. This residual pattern may be the result of one or a combination of things such as paint damage, corrosion, char, deposits of carbon (soot), calcination of gypsum, surface burning, etc. If the fire were extinguished before room flashover, the "V" pattern likely will be still distinguishable. The presence, however, of the "V" pattern alone will not indicate whether that is the point of origin or whether the fire spread from another point, e.g. from an item in the center of the room to the item by the wall that produced the "V" pattern. If a fire has developed to flashover or substantial room involvement, however, post-fire observations can reveal multiple, single or no "V" patterns and give no indication of their significance.

OFIT:
"The low burn point is the fire's origin."

This is another OFIT which requires suspension of the laws of gravity, physics, and heat transfer. Scientific methods show that fires spread downward in several ways through falldown of burning debris, melt drip properties of polymers, and radiant heat. If this OFIT were valid, a fire starting in an attic or an upper floor would never damage lower floors. Anyone who still believes that is ignoring the fact that burning debris will drop down and ignite combustibles. They should read of the vast destruction in World War II caused by fires burning down after being started on upper floors by incendiary bombs. (4)

OFIT:
"Char depth of wood indicates time of burning."

The char depth of wood depends on many parameters in addition to burning time. One of the important parameters is fire environment. Burning rate of wood can vary by a factor of ten, depending on whether it is burning freely or burning in a fully developed room fire. Burning rate also depends on the moisture content, type of wood and dimensions of the burning wood (4, 17).

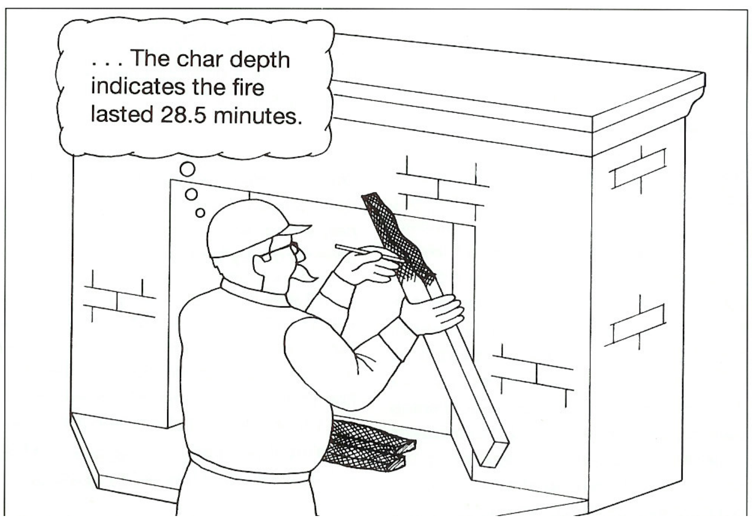
OFIT:
"The area of greatest fire damage is the point of origin."

The logic behind this OFIT is that the fire burns longest at the point of origin and therefore that is where the most damage occurs. This OFIT has an initial appearance of respectability because it is correct in very simplistic fire scenarios; however, the more combustibles available to burn and the larger the fire, the more irrational this OFIT becomes. Factors that determine the local fire damage include: the amount of material available to burn at that point; the heat release rate of that material; the size, construction, loading, and interior finish of the space in which the material is burning; the ventilation history and what fire suppression activities have been performed and when. The above factors establish the duration and temperature of the fire and the susceptibility of that location to fire damage. It is purely coincidental when the area of greatest damage also corresponds to the point of origin.

OFIT:
"Floor surface burn pattern indicates the use of an accelerant."

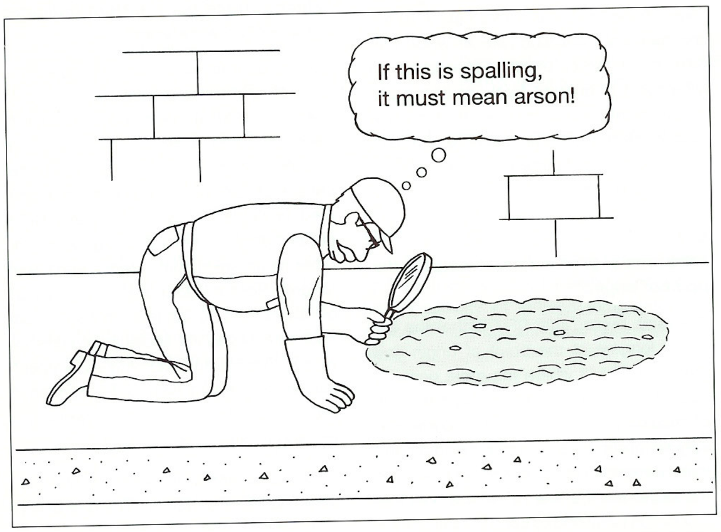
This is another OFIT which ignores the laws of physics and heat transfer; however, it has an appearance of credibility because some accelerants ignite some flooring. Of course, there are many other causes of floor burning. This myth is covered in detail in Campbell's 1982 NFPA paper (13). As a general rule, gasoline and other flammable liquids are the least likely to ignite floor surfaces and generally burn off too quickly to ignite such non-porous floor surfaces as tile, linoleum and finished wood. Floor surface burning is commonly caused by radiant heat or by burning of ordinary combustibles such as wood, paper and plastic on the surface.

Accelerants are effective in igniting contents, not floor surfaces. The one excep-



tion is stairways which have both horizontal and vertical surfaces. These can be ignited by accelerants and may cause a "trench effect" fire spread in which the flame plume tends to follow the slope of the stairs instead of rising vertically. This fire movement phenomenon was first identified after the London King's Cross subway station fire (20). Additional investigation is still needed to establish the application of the trench effect phenomena to multiple flights of combustible stairs.

OFIT:
"Spalling of a concrete floor indicates the use of an accelerant".



This OFIT is so strongly espoused by some that an investigators' association newsletter even repudiated a paper by a professor who had conducted tests showing this OFIT was not true.

Spalling of concrete can be caused by vaporization of water in the concrete which "blows" out solid pieces and can be caused by heat from any fire. It requires that the concrete below the surface be heated above the boiling point of water. When a liquid is burning on any surface, the temperature of the surface cannot exceed the boiling point of the liquid. Since water boils above the boiling point of flammable liquid compounds, the temperature of the concrete under the liquid cannot be hot enough to cause spalling. Burning of a high-boiling-point combustible liquid on concrete might cause spalling, but combustible liquids spilled on concrete are difficult to ignite (33, 45).

Spalling can also be used to describe the breaking off of pieces of concrete, stone or masonry as a result of differential thermal expansion. When one part of a construction element is significantly hotter than another part, the resultant differences in thermally expanded dimensions produce stresses sometimes sufficient to break off pieces. This differential thermal expansion can occur as a result of rapid heating during a fire or cooling by water during fire extinguishment. Differential thermal expansion stresses are also developed in composite structures when one material has a different coefficient of expansion than another.

OFIT:
"Electric arcs and sparks produced at normal household voltage will ignite paper, wood, wire insulation, plastic and other ordinary combustibles."

These arcs and sparks can ignite gasoline vapors but typically do not ignite ordinary combustibles. Beaded wires and other wire damage are commonly caused by the fire rather than a cause of the fire. (7, 8. 18. 19). A complete and documented discussion of electrical fire causes will be the subject of a future Fire Safety Brief.

OFIT:
"The condition of the springs in furniture after a fire indicates whether it was a smoldering-cigarette ignition or a fast developing (accelerated) fire."

This OFIT has numerous flaws. Anyone with rudimentary knowledge of metallurgy knows the basic premise is false; anyone knowledgeable in fire phenomena knows the interpretation is false. Recent tests conducted by the Federal Bureau of Investigation should completely bury this tale (49).

OFIT: "Fires seek oxygen"

This OFIT is based upon a faulty interpretation of how fire sometimes spreads. Fire gases are governed by the same laws of physics as any other fluid. Fire plume dynamics are well described in the scientific literature (17, 48). Combustion produces heated fire gases which are lighter than the surrounding air. Their normal movement is upward until they are deflected by a barrier such as a ceiling. Moving fire gases entrain air causing the plume to expand in an inverted cone configuration. Oxygen in air entrained near the base of the plume mixes with pyrolysates and participates in combustion. When the fire plume is deflected by a ceiling or other barrier, it moves outward and entrains additional air from below.

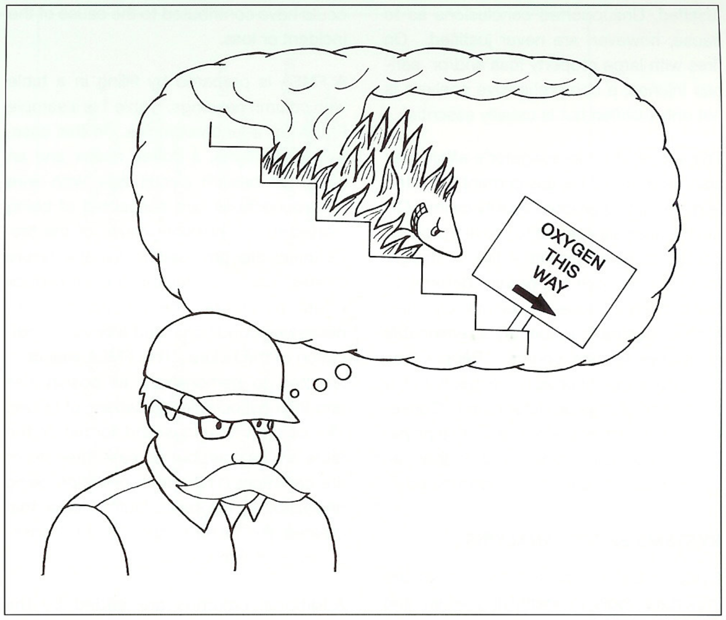
When a fire room is ventilated through a single door or window, pressure differences which are the result of the buoyancy of hot gases result in cool air going through the bottom of the door (or window) and part of it participating in combustion. Hot fire gases are discharged out the top of the opening. When these hot fire gases are not completely burned, they may mix with air outside the fire space and continue flaming combustion.

Observations of the results of these plume dynamics could lead one to believe the fire sought oxygen when it was actually moving according to basic physical laws. When there are multiple openings or ventilation in a fire area, fire gas movement is more complex and it may or may not appear to be seeking oxygen. A fire may also appear to be seeking oxygen when it does not spread into an oxygen deficient space. Hot fire gases will still flow as determined by plume dynamics, but if a space is deficient in oxygen, fire will not propagate into that space.

A fire may or may not move in the direction of a supply of oxygen. When it coincidentally moves that way it is following basic physical laws, it is not seeking oxygen.

OFIT:
"Window glass condition is indicative of fire development"

The condition and appearance of window glass after a fire is a common clue. Clean glass versus heavily sooted glass or glass which has broken into small pieces or into large shards have been used as *de facto* evidence of particular fire phenomena. Little consideration is given to the age, type or condition of the glass, type and geometry of the frame, fire growth rate, temperature differential or convection currents (26, 29). Used carefully and with support by other fire scene patterns, the condition of the glass may provide data and support a cause-and-origin hypothesis, but it is not conclusive evidence.



PART 2:
ENGINEERING & SCIENTIFIC TOOLS

Mathematical modeling supplemented by experimental data provides the forensic engineer with new tools for identifying or verifying the cause and origin of a fire and, often even more important, the cause of a resultant fire loss. Even when the cause and origin of a fire is not at issue, it is often possible and important to establish the cause of loss.

The 1983 edition of the National Fire Protection Association's *Manual on Investigation of Fires of Electrical Origin (NFPA 907M) (37)* stated that, "A clue by itself is not sufficient to classify a fire as electrical. A clue must be validated by proving the necessary physical cause and conditions were present. If clues cannot be validated, the fire cause should not be listed as electrical. The physical clues in a fire scene may be created by a hostile fire of other than electrical origin."

The validation of clues is a prudent practice that should be applied before identifying the cause of any fire or fire loss. If clues cannot be validated by proving the necessary physical cause and conditions were present, then those clues should not be used as the basis for determining the cause. The tools and databases available to assist in determining the cause of a fire or fire loss have greatly expanded in recent years. Engineering analysis in fire and explosion investigations has become very practical with the use of personal computers. There is a vast amount of experimental information available to the investigator which can be used to support or provide input for analyses. Computer-aided fire models, heat transfer calculations and other engineering analyses can often be used to establish or validate:

- Whether a particular cause, origin and ignited fuel coincides with the known fire development history and conditions existing before the fire;
- Whether a suspected ignition source could have generated and maintained sufficient energy or temperature to start this fire;
- Whether protective devices such as sprinklers or smoke detectors did operate or should have operated;
- Whether a protective device would have prevented the injuries or reduced the property damage; and
- Whether a suspected or alleged gas leak or chemical reaction could have caused the fire/explosion that occurred.

The scope of this discussion emphasizes models and analyses that can be exercised using state-of-the-art microcomputers. Both public domain and custom analyses are described together with source references. The type of models and analytical tools to be discussed include:

1. Systems Safety Analysis;
2. Heat Transfer Modeling;
3. Gas Concentration Modeling;
4. Thermodynamic Chemical Equilibrium Analysis;
5. Hydraulic Modeling of Sprinklers & Water Supply; and
6. Fire Modeling.

These analytical and experimental tools are currently available; however, whether an investigator uses such tools depends on the particular incident and the practical purpose of the investigation. The effort that can be justified in the investigation depends on the scope of the investigtor's assignment and generally on the magnitude of the loss. If the total loss is relatively small, a comprehensive analysis of the cause of either the fire or the loss is rarely

Note: part 2 has 14 pages and is not included here