NFPA 921
Guide for Fire and Explosion Investigations

1998 Edition

National Fire Protection Association, 1 Batterymarch Park, PO Box 9101, Quincy, MA 02269-9101
An International Codes and Standards Organization

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This edition of NFPA 921, *Guide for Fire and Explosion Investigations,* was prepared by the Technical Committee on Fire Investigations and acted on by the National Fire Protection Association, Inc., at its Fall Meeting held November 17–19, 1997, in Kansas City, MO. It was issued by the Standards Council on January 16, 1998, with an effective date of February 6, 1998, and supersedes all previous editions.

Changes other than editorial are indicated by a vertical rule in the margin of the pages on which they appear. These lines are included as an aid to the user in identifying changes from the previous edition.

This edition of NFPA 921 was approved as an American National Standard on April 2, 1998.

Origin and Development of NFPA 921

NFPA 921, *Guide for Fire and Explosion Investigations,* was developed by the Technical Committee on Fire Investigations to assist in improving the fire investigation process and the quality of information on fires resulting from the investigative process. The guide is intended for use by both public sector employees who have statutory responsibility for fire investigation and private sector persons conducting investigations for insurance companies or litigation purposes. The goal of the Committee is to provide guidance to investigators that is based on accepted scientific principles or scientific research.

The first edition of the document, issued by the Association in 1992, focused largely on the determination of origin and cause of fires and explosions involving structures. The second edition of the document included revised chapters on the collection and handling of physical evidence, safety, and explosions. NFPA 907M, *Manual for the Determination of Electrical Fire Causes,* was withdrawn as an individual document and was integrated with revisions into this document as a separate chapter. Elements of NFPA 907M that relate to other chapters of this document were relocated appropriately. New chapters dealing with the investigation of motor vehicle fires, management of major investigations, incendiary fires, and appliances were added.

The third edition of the document includes a new chapter on fuel gas systems in buildings and the impact of fuel gases on fire and explosion investigations (Chapter 19). The chapter on electricity and fire (Chapter 14) was rewritten to improve organization, clarify terminology, and add references. In the chapter on fire patterns (Chapter 4), several sections were revised. Other revisions were made in Chapter 9 in the subject of preservation of the fire scene and physical evidence. This edition also includes new text regarding ignitible liquid detection canine/handler teams.

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This list represents the membership at the time the Committee was balloted on the text of this edition. Since that time, changes in membership may have occurred. A key to classifications is found at the back of this document

NOTE: Membership on a committee shall not in and of itself constitute an endorsement of the Association or any document developed by the committee on which the member serves.

Committee Scope: This Committee shall have primary responsibility for documents relating to techniques to be used in investigating fires, and equipment and facilities designed to assist or be used in developing or verifying data needed by fire investigators in the determination of the origin and development of hostile fires.

Contents

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NOTICE: An asterisk (*) following the number or letter designating a paragraph indicates that explanatory material on the paragraph can be found in Appendix A.

Information on referenced publications can be found in Chapter 20 and Appendix B.

Chapter 1 Administration

1-1 Scope. This document is designed to assist individuals who are charged with the responsibility of investigating and analyzing fire and explosion incidents and rendering opinions as to the origin, cause, responsibility, or prevention of such incidents.

1-2 Purpose. The purpose of this document is to establish guidelines and recommendations for the safe and systematic investigation or analysis of fire and explosion incidents. Fire investigation or analysis and the accurate listing of causes is fundamental to the protection of lives and property from the threat of hostile fire or explosions. It is through an efficient and accurate determination of the cause and responsibility that future fire incidents can be avoided.

Proper fire origin and cause determination are also essential for the meaningful compilation of fire statistics. Accurate statistics form part of the basis of fire prevention codes, standards, and training.

This document is designed to produce a systematic, working framework or outline by which effective fire investigation and origin and cause analysis can be accomplished. It contains specific procedures to assist in the investigation of fires and explosions. These procedures represent the consensus judgment of the committee on a system that, if followed, can be expected to lead to sound conclusions with supporting evidence. Deviations from these procedures, however, are not necessarily wrong or inferior but need to be justified.

As every fire and explosion incident is in some way different and unique from any other, this document is not designed to encompass all the necessary components of a complete investigation or analysis of any one case.

Not every portion of this document may be applicable to every fire or explosion incident. It is up to investigators (depending on their responsibility, as well as the purpose and scope of their investigation) to apply the appropriate recommended procedures in this guide to a particular incident.

In addition, it is recognized that time and resource limitations or existing policies may limit the degree to which the recommendations in this document will be applied in a given investigation. This document has been developed as a model for the advancement of fire investigation technology.

1-3 Definitions.

Absolute Temperature. A temperature measured in degrees Kelvin (K) or degrees Rankine (R). Zero is the lowest possible temperature, 273°K corresponds to 0°C, and 460°R corresponds to 0°F. °K = °C + 273 and °R = °F + 460.

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

Accident. An unplanned event that interrupts an activity and sometimes causes injury or damage. A chance occurrence arising from unknown causes; an unexpected happening due to carelessness, ignorance, and the like.

Ambient. Someone's or something's surroundings, especially as they pertain to the local environment. For example, ambient air and ambient temperature.

Ampacity. The current, in amperes (A), that a conductor can carry continuously under the conditions of use without exceeding its temperature rating.

Ampere. The unit of electrical current represented by the symbol *I*.

Approved.* Acceptable to the authority having jurisdiction.

Arc. A high-temperature luminous electric discharge across a gap.

Arcing Through Char. Arcing associated with a matrix of charred material (e.g., charred conductor insulation) that acts as a semiconductive medium.

Area of Origin. The room or area where the fire began. *(See also Point of Origin.)*

Arrow Pattern. A fire pattern displayed on the cross section of a burned wooden structural member.

Arson. The crime of maliciously and intentionally, or recklessly, starting a fire or causing an explosion. Precise legal definitions vary among jurisdictions, wherein it is defined by statutes and judicial decisions.

Autoignition. Initiation of combustion by heat but without a spark or flame.

Autoignition Temperature. The lowest temperature at which a combustible material ignites in air without a spark or flame.

Backdraft. An explosion resulting from the sudden introduction of air (i.e., oxygen) into a confined space containing oxygen-deficient superheated products of incomplete combustion.

Bead. A rounded globule of resolidified metal at the end of the remains of an electrical conductor that was caused by arcing and is characterized by a sharp line of demarcation between the melted and unmelted conductor surfaces.

Blast Pressure Front. The expanding leading edge of an explosion reaction that separates a major difference in pressure between normal ambient pressure ahead of the front and potentially damaging high pressure at and behind the front.

BLEVE. Boiling liquid expanding vapor explosion.

British Thermal Unit (Btu). The quantity of heat required to raise the temperature of one pound of water 1°F at the pressure of 1 atmosphere and temperature of 60°F.

Burning Rate. See Heat Release Rate.

Cause. The circumstances, conditions, or agencies that bring together a fuel, ignition source, and oxidizer (such as air or oxygen) resulting in a fire or a combustion explosion.

Ceiling Layer. A buoyant layer of hot gases and smoke produced by a fire in a compartment.

Char. Carbonaceous material that has been burned and has a blackened appearance.

Char Blisters. Convex segments of carbonized material separated by cracks or crevasses that form on the surface of char, forming on materials such as wood as the result of pyrolysis or burning.

Clean Burn. A fire pattern on surfaces where soot has been burned away.

Code.* A standard that is an extensive compilation of provisions covering broad subject matter or that is suitable for adoption into law independently of other codes and standards.

Combustible. Capable of burning, generally in air under normal conditions of ambient temperature and pressure, unless otherwise specified. Combustion can occur in cases where an oxidizer other than the oxygen in air is present (e.g., chlorine, fluorine, or chemicals containing oxygen in their structure).

Combustible Gas Indicator. An instrument that samples air and indicates whether there are combustible vapors present. Some units may indicate the percentage of the lower explosive limit of the air/gas mixture.

Combustible Liquid. A liquid having a flash point at or above 100°F (37.8°C). *(See also Flammable Liquid.)*

Combustion Products. Heat, gases, solid particulates, and liquid aerosols produced by burning.

Conduction. Heat transfer to another body or within a body by direct contact.

Convection. Heat transfer by circulation within a medium, such as a gas or a liquid.

Deflagration. A combustion reaction in which the velocity of the reaction front through the unreacted fuel medium is less than the speed of sound.

Detection. (a) Sensing the existence of a fire especially by a detector from one or more products of the fire, such as smoke, heat, ionized particles, infrared radiation, and the like. (b) The act or process of discovering and locating a fire.

Detonation. A reaction in which the velocity of the reaction front through the unreacted fuel medium is equal to or greater than the speed of sound.

Drop Down. The spread of fire by the dropping or falling of burning materials. Synonymous with “Fall Down.”

Entrain. To pull along with or after.

Explosion. The sudden conversion of potential energy (chemical or mechanical) into kinetic energy with the production and release of gases under pressure, or the release of gas under pressure. These high-pressure gases then do mechanical work such as moving, changing, or shattering nearby materials.

Explosive. Any chemical compound, mixture, or device that functions by explosion.

Explosive Material. Any material that can act as fuel for an explosion.

Exposed Surface. The side of a structural assembly or object that is directly exposed to the fire.

Extinguish. To cause to cease burning.

Failure. Distortion, breakage, deterioration, or other fault in an item, component, system, assembly, or structure that results in unsatisfactory performance of the function for which it was designed.

Failure Analysis. A logical, systematic examination of an item, component, assembly, or structure and its place and function within a system conducted in order to identify and analyze the probability, causes, and consequences of potential and real failures.

Fall Down. See Drop Down.

Finish Rating. The time in minutes, determined under specific laboratory conditions, at which the stud or joist in contact with the exposed protective membrane in a protected combustible assembly reaches an average temperature rise of 250°F (121°C) or an individual temperature rise of 325°F (163°C) as measured behind the protective membrane nearest the fire on the plane of the wood.

Fire. A rapid oxidation process with the evolution of light and heat in varying intensities.

Fire Analysis. The process of determining the origin, cause, development, and responsibility as well as the failure analysis of a fire or explosion.

Fire Cause. See Cause.

Fire Investigation. The process of determining the origin, cause, and development of a fire or explosion.

Fire Propagation. See Fire Spread.

Fire Scene Reconstruction. The process of recreating the physical scene during fire scene analysis through the removal of debris and the replacement of contents or structural elements in their pre-fire positions.

Fire Spread. The movement of fire from one place to another.

Flame. The luminous portion of burning gases or vapors.

Flame Front. The leading edge of burning gases of a combustion reaction.

Flameover. The condition where unburned fuel (pyrolysate) from the originating fire has accumulated in the ceiling layer to a sufficient concentration (i.e., at or above the lower flammable limit) that it ignites and burns. This can occur without ignition and prior to the ignition of other fuels separate from the origin.

Flammable. Capable of burning with a flame.

Flammable Limit. The upper or lower concentration limits at a specified temperature and pressure of a flammable gas or a vapor of an ignitible liquid and air, expressed as a percentage of fuel by volume that can be ignited.

Flammable Liquid. A liquid having a flash point below 100°F (37.8°C) (tag closed cup) and having a vapor pressure not exceeding 40 psia (2068 mm Hg) at 100°F (37.8°C). *(See also Combustible Liquid.)*

Flash Fire. A fire that spreads rapidly through a diffuse fuel, such as dust, gas, or the vapors of an ignitible liquid, without the production of damaging pressure.

Flash Point of a Liquid. The lowest temperature of a liquid, as determined by specific laboratory tests, at which the liquid gives off vapors at a sufficient rate to support a momentary flame across its surface.

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

Forensic. Legal; pertaining to courts of law.

Fuel. A material that yields heat through combustion.

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.

Fuel Gas. Natural gas, manufactured gas, LP-Gas, and similar gases commonly used for commercial or residential purposes such as heating, cooling, or cooking.

Fuel Load. The total quantity of combustible contents of a building, space, or fire area, including interior finish and trim, expressed in heat units or the equivalent weight in wood.

Gas. The physical state of a substance that has no shape or volume of its own and will expand to take the shape and volume of the container or enclosure it occupies.

Glowing Combustion. Luminous burning of solid material without a visible flame.

Ground Fault. A current that flows outside the normal circuit path, such as (a) through the equipment grounding conductor, (b) through conductive material other than the electrical system ground (metal water or plumbing pipes, etc.), (c) through a person, or (d) through a combination of these ground return paths.

Guide. A document that is advisory or informative in nature and that contains only nonmandatory provisions. A guide may contain mandatory statements such as when a guide can be used, but the document as a whole is not suitable for adoption into law.

Hazard. Any arrangement of materials and heat sources that presents the potential for harm, such as personal injury or ignition of combustibles.

Heat. A form of energy characterized by vibration of molecules and capable of initiating and supporting chemical changes and changes of state.

Heat Flux. The measure of the rate of heat transfer to a surface. Heat flux is expressed in kilowatts/m^2, kilojoules/m^2/sec, or Btu/ft^2/sec.

Heat of Ignition. The heat energy that brings about ignition. Heat energy comes in various forms and usually from a specific object or source. Therefore, the heat of ignition is divided into two parts: (a) equipment involved in ignition and (b) form of heat of ignition.

Heat Release Rate (HRR). The rate at which heat energy is generated by burning. The heat release rate of a fuel is related to its chemistry, physical form, and availability of oxidant and is ordinarily expressed as Btu/sec or kilowatts (kW).

High Explosive. A material that is capable of sustaining a reaction front that moves through the unreacted material at a speed equal to or greater than that of sound in that medium [typically 3300 ft/sec (1000 m/sec)]; a material capable of sustaining a detonation. *(See also Detonation.)*

High-Order Explosion. A rapid pressure rise or high-force explosion characterized by a shattering effect on the confining structure or container and long missile distances.

Ignitible Liquid. Any liquid or the liquid phase of any material that is capable of fueling a fire, including a flammable liquid, combustible liquid, or any other material that can be liquefied and burned.

Ignition. The process of initiating self-sustained combustion.

Ignition Energy. The quantity of heat energy that should be absorbed by a substance to ignite and burn.

Ignition Temperature. Minimum temperature a substance should attain in order to ignite under specific test conditions. Reported values are obtained under specific test conditions and may not reflect a measurement at the substance's surface. Ignition by application of a pilot flame above the heated surface is referred to as pilot ignition temperature. Ignition without a pilot energy source has been referred to as autoignition temperature, self-ignition temperature, or spontaneous ignition temperature. The ignition temperature determined in a standard test is normally lower than the ignition temperature in an actual fire scenario.

Ignition Time. The time between the application of an ignition source to a material and the onset of self-sustained combustion.

Isochar. A line on a diagram connecting points of equal char depth.

Kilowatt. A measurement of energy release rate.

Kindling Temperature. See Ignition Temperature.

Low Explosive. An explosive that has a reaction velocity of less than 3300 ft/sec (1000 m/sec).

Low-Order Explosion. A slow rate of pressure rise or low-force explosion characterized by a pushing or dislodging effect on the confining structure or container and short missile distances.

Material First Ignited. The fuel that is first set on fire by the heat of ignition. To be meaningful, both a type of material and a form of material should be identified.

Noncombustible Material. A material that, in the form in which it is used and under the condition anticipated, will not ignite, burn, support combustion, or release flammable vapors when subjected to fire or heat. Also called incombustible material (not preferred).

Nonflammable. (a) Not readily capable of burning with a flame. (b) Not liable to ignite and burn when exposed to flame. Its antonym is *flammable*.

Ohm. The unit of electrical resistance represented by the symbol *R*. A single ohm is the resistance between two points of a conductor when a constant difference of potential of one volt between these two points produces in this conductor a current of one ampere.

Origin. See Point of Origin or Area of Origin.

Overcurrent. Any current in excess of the rated current of equipment or the ampacity of a conductor. It may result from an overload *(see definition)*, short circuit, or ground fault.

Overload. Operation of equipment in excess of normal, full-load rating or of a conductor in excess of rated ampacity, which, when it persists for a sufficient length of time, would cause damage or dangerous overheating. A fault, such as a short circuit or ground fault, is not an overload. *(See also Overcurrent.)*

Oxygen Deficiency. Insufficiency of oxygen to support combustion. *(See also Ventilation-Controlled Fire.)*

Piloted Ignition Temperature. See Ignition Temperature.

Plastic. Any of a wide range of natural or synthetic organic materials of high molecular weight that can be formed by pressure, heat, extrusion, and other methods into desired shapes. Plastics are usually made from resins, polymers, cellulose derivatives, caseins, and proteins. The principal types are thermosetting and thermoplastic.

Plume. The column of hot gases, flames, and smoke rising above a fire. Also called convection column, thermal updraft, or thermal column.

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

Premixed Flame. A flame for which the fuel and oxidizer are mixed prior to combustion, as in a laboratory Bunsen burner or a gas cooking range. Propagation of the flame is governed by the interaction between flow rate, transport processes, and chemical reaction.

Preservation. Application or use of measures to prevent damage, change or alteration, or deterioration.

Products of Combustion. See Combustion Products.

Proximate Cause. The cause that directly produces the effect without the intervention of any other cause.

Pyrolysis. The transformation of a compound into one or more other substances by heat alone. Pyrolysis often precedes combustion.

Radiant Heat. Heat energy carried by electromagnetic waves longer than light waves and shorter than radio waves. Radiant heat (electromagnetic radiation) increases the sensible temperature of any substance capable of absorbing the radiation, especially solid and opaque objects.

Radiation. Heat transfer by way of electromagnetic energy.

Rate of Heat Release. See Heat Release Rate.

Recommended Practice. A document that is similar in content and structure to a code or standard but that contains only nonmandatory provisions using the word "should" to indicate recommendations in the body of the text.

Rekindle. A return to flaming combustion after apparent but incomplete extinguishment.

Risk. (a) The degree of peril; the possible harm that might occur. (b) The statistical probability or quantitative estimate of the frequency or severity of injury or loss.

Rollover. See Flameover.

Scientific Method. 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.

Seat of Explosion. A craterlike indentation created at the point of origin of an explosion.

Seated Explosion. An explosion with a highly localized point of origin, such as a crater.

Secondary Explosion. Any subsequent explosion resulting from an initial explosion.

Self-Heating. The result of exothermic reactions, occurring spontaneously in some materials under certain conditions, whereby heat is liberated at a rate sufficient to raise the temperature of the material.

Self-Ignition. Ignition resulting from self-heating. Synonymous with spontaneous ignition.

Self-Ignition Temperature. The minimum temperature at which the self-heating properties of a material lead to ignition.

Short Circuit. An abnormal connection of low resistance between normal circuit conductors where the resistance is normally much greater. This is an overcurrent situation but it is not an overload.

Smoke. An airborne particulate product of incomplete combustion suspended in gases, vapors, or solid and liquid aerosols.

Smoke Condensate. The condensed residue of suspended vapors and liquid products of incomplete combustion.

Smoke Explosion. See Backdraft.

Smoldering. Combustion without flame, usually with incandescence and smoke.

Soot. Black particles of carbon produced in a flame.

Spalling. Chipping or pitting of concrete or masonry surfaces.

Spark. A small, incandescent particle.

Spark, Electric. A small incandescent particle created by some arcs.

Spontaneous Heating. Process whereby a material increases in temperature without drawing heat from its surroundings. The process results from oxidation often aided by bacterial action where agricultural products are involved.

Spontaneous Ignition. Initiation of combustion of a material by an internal chemical or biological reaction that has produced sufficient heat to ignite the material.

Standard. A document, the main text of which contains only mandatory provisions using the word "shall" to indicate requirements and which is in a form generally suitable for mandatory reference by another standard or code or for adoption into law. Nonmandatory provisions shall be located in an appendix, footnote, or fine-print note and are not to be considered a part of the requirements of a standard.

Suppression. The sum of all the work done to extinguish a fire from the time of its discovery.

Target Fuel. A fuel that is subject to ignition by thermal radiation such as from a flame or a hot gas layer.

Temperature. The intensity of sensible heat of a body as measured by a thermometer or similar instrument. The lowest possible temperature is absolute zero on the Kelvin temperature scale (–273° on the Celsius scale). At absolute zero it is impossible for a body to release any energy.

Thermal Column. See Plume.

Thermal Expansion. The proportional increase in length, volume, or superficial area of a body with rise in temperature. The amount of this increase per degree temperature, called the coefficient of thermal expansion, is different for different substances.

Thermal Inertia. The properties of a material that characterize its rate of surface temperature rise when exposed to heat. Thermal inertia is related to the product of the material's thermal conductivity *(k)*, its density (rho, or ρ), and its heat capacity *(c)*.

Thermoplastic. Plastic materials that soften and melt under exposure to heat and can reach a flowable state.

Thermoset Plastics. Plastic materials that are hardened into a permanent shape in the manufacturing process and are not commonly subject to softening when heated. Typically forms char in a fire.

Time Line. Graphical representation of the events in the fire incident displayed in chronological order.

Upper Layer. See Ceiling Layer.

Vapor. The gas phase of a substance, particularly of those that are normally liquids or solids at ordinary temperatures. *(See also Gas.)*

Vapor Density. The ratio of the average molecular weight of a given volume of gas or vapor to the average molecular weight of an equal volume of air at the same temperature and pressure.

Vector. An arrow used in a fire scene drawing to show the direction of heat, smoke, or flame flow.

Vent. An opening for the passage of, or dissipation of, fluids, such as gases, fumes, smoke, and the like.

Ventilation. (a) Circulation of air in any space by natural wind or convection or by fans blowing air into or exhausting air out of a building. (b) A fire-fighting operation of removing smoke and heat from the structure by opening windows and doors or making holes in the roof.

Ventilation-Controlled Fire. A fire in which the heat release rate or growth is controlled by the amount of air available to the fire.

Venting. The escape of smoke and heat through openings in a building.

Volt (V). The unit of electrical pressure (electromotive force) represented by the symbol *E*. The difference in potential required to make a current of one ampere flow through a resistance of one ohm.

Watt (W). The unit of power, or rate of work. This is equal to one joule per second, or the rate of work represented by a current of one ampere under the potential of one volt.

1-4* Units of Measure. Metric units of measurement in this standard are in accordance with the modernized metric system known as the International System of Units (SI). The unit of liter is outside of but recognized by SI and is commonly used in international fire protection.

1 in. = 2.54 cm

1 ft = 0.3048 m

1 ft^2 = 0.09290 m^2

1 ft^3= 7.481 gal

1 ft^3= 0.02832 m^3

1 U.S. gal = 3.785 L

1 lb = 0.4536 kg

1 oz (weight) = 28.35 g

1 ft/sec = 0.3048 m/sec

1 lb/ft^3 = 16.02 kg/m^3

1 gpm = 0.06308 L/sec

1 atmosphere = pressure exerted by 760 millimeters of mercury of standard density at 0°C, 14.7 lb/in.^{2} (101.3 kPa)

1 Btu/sec = 1.055 Kw

1 Btu = 1055 J

1 kw = 0.949 Btu/sec

1 in. w.c. = 248.8 Pa = .036 psi

1 psi = 27.7 in. water column

Chapter 2 Basic Methodology

2-1 Nature of Fire Investigations. A fire or explosion investigation is a complex endeavor involving both art and science. The compilation of factual data, as well as an analysis of those facts, should be accomplished objectively and truthfully. The basic methodology of the fire investigation should rely on the use of a systematic approach and attention to all relevant details. The use of a systematic approach often will uncover new factual data for analysis, which may require previous conclusions to be reevaluated. With a few exceptions, the proper methodology for a fire or explosion investigation is to first determine and establish the origin(s), then investigate the cause: What circumstances, conditions, or agencies caused the ignition source, fuel, and oxidant to come together?

2-2 Systematic Approach. The systematic approach recommended is that of the scientific method, which is used in the physical sciences. This method provides for the organizational and analytical process so desirable and necessary in a successful fire investigation.

2-3 Relating Fire Investigation to the Scientific Method. The scientific method *(see Figure 2-3)* is a principal of inquiry that forms a basis for legitimate scientific and engineering processes, including fire incident investigation.

The scientific method is applied using the following six steps.

2-3.1 Recognize the Need. First, one should determine that a problem exists. In this case a fire or explosion has occurred and the cause should be determined and listed so that future, similar incidents can be prevented.

2-3.2 Define the Problem. Having determined that a problem exists, the investigator or analyst should define in what manner the problem can be solved. In this case, a proper origin and cause investigation should be conducted. This is done by an examination of the scene and by a combination of other data collection methods, such as the review of previously conducted investigations of the incident, the interviewing of witnesses or other knowledgeable persons, and the results of scientific testing.

2-3.3 Collect Data. Facts about the fire incident are now collected. This is done by observation, experiment, or other direct data gathering means. This is called empirical data because it is based on observation or experience and is capable of being verified.

2-3.4 Analyze the Data (Inductive Reasoning). All of the collected and observed information is analyzed by inductive reasoning. This is the process in which the total body of empirical data collected is carefully examined in the light of the investigator's knowledge, training, and experience. Subjective or speculative information cannot be included in the analysis, only facts that can be clearly proven by observation or experiment.

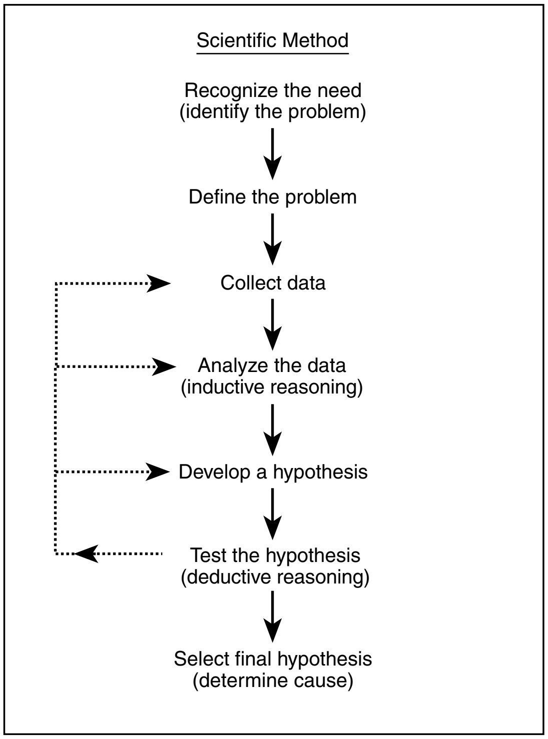


Figure 2-3 Use of the scientific method.

2-3.5 Develop a Hypothesis. Based on the data analysis, the investigator should now produce a hypothesis or group of hypotheses to explain the origin and cause of the fire or explosion incident. This hypothesis should be based solely on the empirical data that the investigator has collected.

2-3.6 Test the Hypothesis (Deductive Reasoning). All other reasonable origins and causes should be eliminated. The investigator does not have a truly provable hypothesis unless it can stand the test of careful and serious challenge. This is done by the principle of deductive reasoning, in which the investigator compares his or her hypothesis to all known facts. If the hypothesis cannot withstand an examination by deductive reasoning, it should be discarded as not provable and a new hypothesis tested. This may include the collection of new data or the reanalysis of existing data. This process needs to be continued until all feasible hypotheses have been tested. Otherwise the fire cause should be listed as "undetermined."

2-3.6.1 Presumption of Cause. Until data have been collected, no specific hypothesis can be reasonably formed or treated. All fires, however, should be approached by the investigator without presumption.

2-4 Basic Method of a Fire Investigation. Using the scientific method in most fire or explosion incidents should involve the following five major steps from inception through final analysis.

2-4.1 Receiving the Assignment. The investigator should be notified of the incident, what his or her role will be, and what he or she is to accomplish. For example, the investigator should know if he or she is expected to determine the origin, cause, and responsibility; produce a written or oral report; prepare for criminal or civil litigation; make suggestions for code enforcement, code promulgation, or changes; make suggestions to manufacturers, industry associations, or government agency action; or determine some other results.

2-4.2 Preparing for the Investigation. The investigator should marshal his or her forces and resources and plan the conduct of the investigation. Preplanning at this stage can greatly increase the efficiency and therefore the chances for success of the overall investigation. Estimating what tools, equipment, and personnel (both laborers and experts) will be needed can make the initial scene investigation, as well as subsequent investigative examinations and analyses, go more smoothly and be more productive.

2-4.3 Conducting the Investigation. The investigator should conduct an examination of the scene, if it is available, and collect data necessary to the analysis. The actual investigation may take and include different steps and procedures, and these will be determined by the purpose of the investigation assignment. These steps and procedures are described in detail elsewhere in the document. A typical fire or explosion investigation may include all or some of the following: a scene inspection; scene documentation through photography and diagramming; evidence recognition, documentation, and preservation; witness interviews; review and analysis of the investigations of others; and identification and collection of data or information from other appropriate sources.

It is during this phase of the investigation that the data necessary for the analysis of the incident will be collected.

2-4.4 Collecting and Preserving Evidence. Valuable physical evidence should be recognized, properly collected, and preserved for further testing and evaluation or courtroom presentation.

2-4.5 Analyzing the Incident. All collected and available data should be analyzed using the principles of the scientific method. An incident scenario or failure analysis should be described, explaining the origin, cause, fire spread, and responsibility for the incident. Conclusions should be drawn according to the principles expressed in this guide.

2-5 Reporting Procedure. The reporting procedure may take many written or oral forms, depending on the specific responsibility of the investigator. Pertinent information should be reported in a proper form and forum to help prevent recurrence.

Chapter 3 Basic Fire Science

3-1 Chemistry of Combustion. The fire investigator should have a basic understanding of combustion principles and be able to use them to help in interpretation of evidence at the fire scene and in the development of conclusions regarding the origin and cause of the fire.

The body of knowledge associated with combustion and fire would easily fill several textbooks. The discussion presented in this section should be considered as introductory. The user of this guide is urged to consult the technical literature for additional details.

3-1.1 Fire Tetrahedron. The combustion reaction can be characterized by four components: the fuel, the oxidizing agent, heat, and an uninhibited chemical chain reaction. These four components have been classically symbolized by a four-sided solid geometric form called a tetrahedron *(see Figure 3-1.1)*. Fires can be prevented or suppressed by controlling or removing one or more of the sides of the tetrahedron.

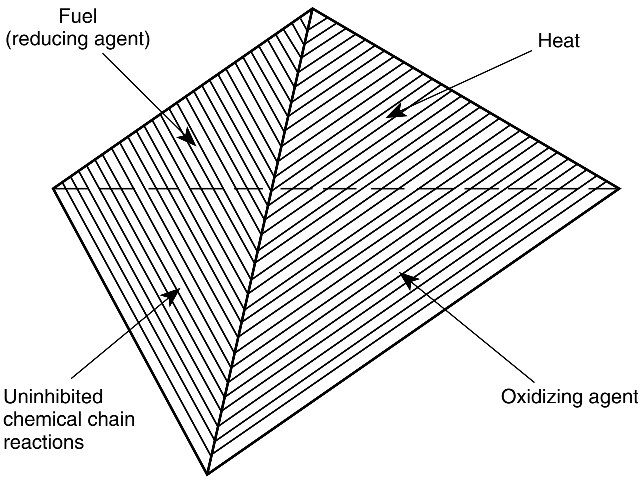


Figure 3-1.1 Fire tetrahedron.

3-1.1.1 Fuel. A fuel is any substance that can undergo combustion. The majority of fuels encountered are organic and contain carbon and combinations of hydrogen and oxygen in varying ratios. In some cases, nitrogen will be present; examples include wood, plastics, gasoline, alcohol, and natural gas. Inorganic fuels contain no carbon and include combustible metals, such as magnesium or sodium. All matter can exist in one of three phases: solid, liquid, or gas. The phase of a given material depends on the temperature and pressure and can change as conditions vary. If cold enough, carbon dioxide, for example, can exist as a solid (dry ice). The normal phase of a material is that which exists at standard conditions of temperature [21°C (70°F)] and pressure [14.7 psi (101.6 kPa) or 1 atmosphere at sea level].

Combustion of a solid or liquid fuel takes place above the fuel surface in a region of vapors created by heating the fuel surface. The heat can come from the ambient conditions, from the presence of an ignition source, or from exposure to an existing fire. The application of heat causes vapors or pyrolysis products to be released into the atmosphere where they can burn if in the proper mixture with air and if a competent ignition source is present. Ignition is discussed in Section 3-3.

Some solid materials can undergo a charring reaction where oxygen reacts directly with solid material. Charring can be the initial or the final stage of burning. Sometimes charring combustion breaks into flame; on other occasions charring continues through the total course of events.

Gaseous fuels do not require vaporization or pyrolysis before combustion can occur. Only the proper mixture with air and an ignition source are needed.

The form of a solid or liquid fuel is an important factor in its ignition and burning rate. For example, a fine wood dust ignites easier and burns faster than a block of wood. Some flammable liquids, such as diesel oil, are difficult to ignite in a pool but can ignite readily and burn rapidly when in the form of a fine spray or mist.

For the purposes of the following discussion, the term *fuel* is used to describe vapors and gases rather than solids.

3-1.1.2* Oxidizing Agent. In most fire situations, the oxidizing agent is the oxygen in the earth's atmosphere. Fire can occur in the absence of atmospheric oxygen when fuels are mixed with chemical oxidizers. Many chemical oxidizers contain readily released oxygen. Ammonium nitrate fertilizer (NH_4NO_3), potassium nitrate (KNO_3), and hydrogen peroxide (H_2O_2) are examples.

Normal air contains 21 percent oxygen. In oxygen-enriched atmospheres, such as in areas where medical oxygen is in use or in high-pressure diving or medical chambers, combustion is greatly accelerated. Materials that resist ignition or burn slowly in air can burn vigorously when additional oxygen is present. Combustion can be initiated in atmospheres containing very low percentages of oxygen, depending on the fuel involved. As the temperature of the environment increases, the oxygen requirements are further reduced. While flaming combustion can occur at concentrations as low as 14 to 16 percent oxygen in air at room temperatures of 70°F (21°C), flaming combustion can continue at close to 0 percent oxygen under post-flashover temperature conditions. Also, smoldering combustion once initiated can continue in a low-oxygen environment even when the surrounding environment is at a relatively low temperature. The hotter the environment, the less oxygen is required. This later condition is why wood and other materials can continue to be consumed even though the fire is in a closed compartment with low oxygen content. Fuels that are enveloped in a layer of hot, oxygen-depleted combustion products in the upper portion of a room can also be consumed.

It should be noted that certain gases can form flammable mixtures in atmospheres other than air or oxygen. One example is a mixture of hydrogen and chlorine gas.

For combustion to take place, the fuel vapor or gas and the oxidizer should be mixed in the correct ratio. In the case of solids and liquids, the pyrolysis products or vapors disperse from the fuel surface and mix with the air. As the distance from the fuel source increases, the concentration of the vapors and pyrolysis products decreases. The same process acts to reduce the concentration of a gas as the distance from the source increases.

Fuel burns only when the fuel/air ratio is within certain limits known as the flammable (explosive) limits. In cases where fuels can form flammable mixtures with air, there is a minimum concentration of vapor in air below which propagation of flame does not occur. This is called the lower flammable limit. There is also a maximum concentration above which flame will not propagate called the upper flammable limit. These limits are generally expressed in terms of percentage by volume of vapor or gas in air.

The flammable limits reported are usually corrected to a temperature of 32°F (0°C) and 1 atmosphere. Increases in temperature and pressure result in reduced lower flammable limits possibly below 1 percent and increased upper flammable limits. Upper limits for some fuels can approach 100 percent at high temperatures. A decrease in temperature and pressure will have the opposite effect. Caution should be exercised when using the values for flammability limits found in the literature. The reported values are often based on a single experimental apparatus that does not necessarily account for conditions found in practice.

The range of mixtures between the lower and upper limits is called the flammable (explosive) range. For example, the lower limit of flammability of gasoline at ordinary temperatures and pressures is 1.4 percent, and the upper limit is 7.6 percent. All concentrations by volume falling between 1.4 and 7.6 percent will be in the flammable (explosive) range. All other factors being equal, the wider the flammable range, the greater the likelihood of the mixture coming in contact with an ignition source and thus the greater the hazard of the fuel. Acetylene, with a flammable range between 2.5 and 100 percent, and hydrogen, with a range from 4 to 75 percent, are considered very dangerous and very likely to be ignited when released.

Every fuel/air mixture has an optimum ratio at which point the combustion will be most efficient. This occurs at or near the mixture known by chemists as the stoichiometric ratio. When the amount of air is in balance with the amount of fuel (i.e., after burning there is neither unused fuel nor unused air), the burning is referred to as stoichiometric. This condition rarely occurs in fires except in certain types of gas fires. *(See Chapter 13.)*

Fires usually have either an excess of air or an excess of fuel. When there is an excess of air, the fire is considered to be fuel controlled. When there is more fuel present than air, a condition that occurs frequently in well-developed room or compartment fires, the fire is considered to be ventilation controlled.

In a fuel-controlled compartment fire, all the burning will take place within the compartment and the products of combustion will be much the same as burning the same material in the open. In a ventilation-controlled compartment fire, the combustion inside the compartment will be incomplete. The burning rate will be limited by the amount of air entering the compartment. This condition will result in unburned fuel and other products of incomplete combustion leaving the compartment and spreading to adjacent spaces. Ventilation-controlled fires can produce massive amounts of carbon monoxide.

If the gases immediately vent out a window or into an area where sufficient oxygen is present, they will ignite and burn when the gases are above their ignition temperatures. If the venting is into an area where the fire has caused the atmosphere to be deficient in oxygen, such as a thick layer of smoke in an adjacent room, it is likely that flame extension in that direction will cease, although the gases can be hot enough to cause charring and extensive heat damage.

3-1.1.3 Heat. The heat component of the tetrahedron represents heat energy above the minimum level necessary to release fuel vapors and cause ignition. Heat is commonly defined in terms of intensity or heating rate (Btu/sec or kilowatts) or as the total heat energy received over time (Btu or kilojoules). In a fire, heat produces fuel vapors, causes ignition, and promotes fire growth and flame spread by maintaining a continuous cycle of fuel production and ignition.

3-1.1.4 Uninhibited Chemical Chain Reaction. Combustion is a complex set of chemical reactions that results in the rapid oxidation of a fuel producing heat, light, and a variety of chemical by-products. Slow oxidation, such as rust or the yellowing of newspaper, produces heat so slowly that combustion does not occur. Self-sustained combustion occurs when sufficient excess heat from the exothermic reaction radiates back to the fuel to produce vapors and cause ignition in the absence of the original ignition source. For a detailed discussion of ignition, see Section 3-3.

Combustion of solids can occur by two mechanisms: flaming and smoldering. Flaming combustion takes place in the gas or vapor phase of a fuel. With solid and liquid fuels, this is above the surface. Smoldering is a surface-burning phenomenon with solid fuels and involves a lower rate of heat release and no visible flame. Smoldering fires frequently make a transition to flaming after sufficient total energy has been produced or when airflow is present to speed up the combustion rate.

3-2 Heat Transfer. The transfer of heat is a major factor in fires and has an effect on ignition, growth, spread, decay (reduction in energy output), and extinction. Heat transfer is also responsible for much of the physical evidence used by investigators in attempting to establish a fire's origin and cause.

It is important to distinguish between heat and temperature. Temperature is a measure that expresses the degree of molecular activity of a material compared to a reference point such as the freezing point of water. Heat is the energy that is needed to maintain or change the temperature of an object. When heat energy is transferred to an object, the temperature increases. When heat is transferred away, the temperature decreases.

In a fire situation, heat is always transferred from the high-temperature mass to the low-temperature mass. Heat transfer is measured in terms of energy flow per unit of time (Btu/sec or kilowatts). The greater the temperature difference between the objects, the more energy is transferred per unit of time and the higher the heat transfer rate is. Temperature can be compared to the pressure in a fire hose and heat or energy transfer to the waterflow in gallons per minute.

Heat transfer is accomplished by three mechanisms: conduction, convection, and radiation. All three play a role in the investigation of a fire, and an understanding of each is necessary.

3-2.1 Conduction. Conduction is the form of heat transfer that takes place within solids when one portion of an object is heated. Energy is transferred from the heated area to the unheated area at a rate dependent on the difference in temperature and the physical properties of the material. The properties are the thermal conductivity (k), the density (ρ), and the heat capacity (c). The heat capacity (specific heat) of a material is a measure of the amount of heat necessary to raise its temperature (Btu/lb/degree of temperature rise).

If thermal conductivity (k) is high, the rate of heat transfer through the material is high. Metals have high thermal conductivities (k), while plastics or glass have low thermal conductivity (k) values. Other properties (k and c) being equal, high-density (ρ) materials conduct heat faster than low-density materials. This is why low-density materials make good insulators. Similarly, materials with a high heat capacity (c) require more energy to raise the temperature than materials with low heat capacity values.

Generally, conduction heat transfer is considered between two points with the energy source at a constant temperature. The other point will increase to some steady temperature lower than that of the source. This condition is known as steady state. Once steady state is reached, thermal conductivity (k) is the dominant heat transfer property. In the growing stages of a fire, temperatures are continuously changing, resulting in changing rates of heat transfer. During this period, all three properties — thermal conductivity (k), density (ρ), and heat capacity (c) — play a role. Taken together, these properties are commonly called the thermal inertia of a material and are expressed in terms of k, ρ, c. Table 3-2.1 provides data for some common materials.

The impact of the thermal inertia on the rise in temperature in a space or on the material in it is not constant through the duration of a fire. Eventually, as the materials involved reach a constant temperature, the effects of density (ρ) and heat capacity (c) become insignificant relative to thermal conductivity. Therefore, thermal inertia of a material is most important at the initiation and early stages of a fire (pre-flashover).

Table 3-2.1 Thermal Properties of Selected Materials

Material	Thermal Conductivity (*k*) (W/m × K)	Density (ρ) (kg/m³)	Heat Capacity (c_p) (J/kg × K)
Copper	387	8940	380
Concrete	0.8–1.4	1900–2300	880
Gypsum plaster	0.48	1440	840
Oak	0.17	800	2380
Pine (yellow)	0.14	640	2850
Polyethylene	0.35	940	1900
Polystyrene (rigid)	0.11	1100	1200
Polyvinylchloride	0.16	1400	1050
Polyurethane[a]	0.034	20	1400

[a]Typical values, properties vary.
Source: From Drysdale, *An Introduction to Fire Dynamics,* p. 36.

Conduction of heat into a material as it affects its surface temperature is an important aspect of ignition. Thermal inertia is an important factor in how fast the surface temperature will rise. The lower the thermal inertia of the material, the faster the surface temperature will rise. Conduction is also a mechanism of fire spread. Heat conducted through a metal wall or along a pipe or metal beam can cause ignition of combustibles in contact with the heated metals. Conduction through metal fasteners such as nails, nail plates, or bolts can result in fire spread or structural failure.

3-2.2 Convection. Convection is the transfer of heat energy by the movement of heated liquids or gases from the source of heat to a cooler part of the environment.

Heat is transferred by convection to a solid when hot gases pass over cooler surfaces. The rate of heat transfer to the solid is a function of the temperature difference, the surface area exposed to the hot gas, and the velocity of the hot gas. The higher the velocity of the gas, the greater the rate of convective transfer.

In the early history of a fire, convection plays a major role in moving the hot gases from the fire to the upper portions of the room of origin and throughout the building. As the room temperatures rise with the approach of flashover, convection continues, but the role of radiation increases rapidly and becomes the dominant heat transfer mechanism. See 3-5.3.2 for a discussion of the development of flashover. Even after flashover, convection can be an important mechanism in the spread of smoke, hot gases, and unburned fuels throughout a building. This can spread the fire or toxic or damaging products of combustion to remote areas.

3-2.3 Radiation. Radiation is the transfer of heat energy from a hot surface to a cooler surface by electromagnetic waves without an intervening medium. For example, the heat energy from the sun is radiated to earth through the vacuum of space. Radiant energy can be transferred only by line-of-sight and will be reduced or blocked by intervening materials. Intervening materials do not necessarily block all radiant heat. For example, radiant heat is reduced on the order of 50 percent by some glazing materials.

The rate of radiant heat transfer is strongly related to a difference in the fourth power of the absolute temperature of the radiator and the target. At high temperatures, small increases in the temperature difference result in a massive increase in the radiant energy transfer. Doubling the absolute temperature of the hotter item without changing the temperature of the colder item results in a 16-fold increase in radiation between the two objects. *(See Figure 3-2.3.)*

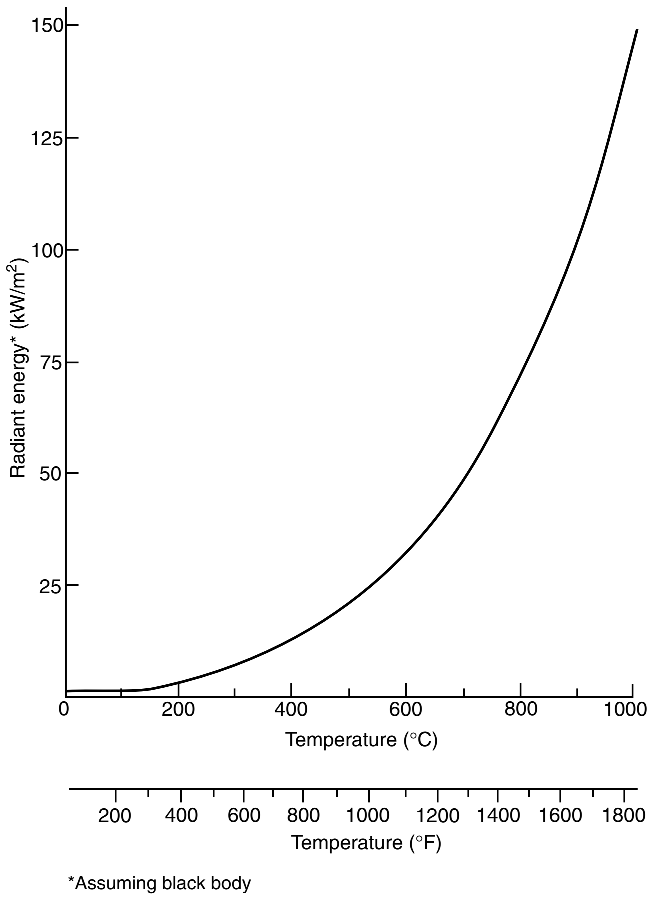


Figure 3-2.3 Relation of radiation to temperature.

The rate of heat transfer is also strongly affected by the distance between the radiator and the target. As the distance increases, the amount of energy falling on a unit of area falls off in a manner that is related to both the size of the radiating source and the distance to the target.

3-3* Ignition. In order for most materials to be ignited they should be in a gaseous or vapor state. A few materials may burn directly in a solid state or glowing form of combustion including some forms of carbon and magnesium. These gases or vapors should then be present in the atmosphere in sufficient quantity to form a flammable mixture. Liquids with flash points below ambient temperatures do not require additional heat to produce a flammable mixture. The fuel vapors produced should then be raised to their ignition temperature. The time and energy required for ignition to occur is a function of the energy of the ignition source, the thermal inertia *(k,* ρ*, c)* of the fuel, and the minimum ignition energy required by that fuel and the geometry of the fuel. If the fuel is to reach its ignition temperature, the rate of heat transfer to the fuel should be greater than the conduction of heat into or through the fuel and the losses due to radiation and convection. Table 3-3 shows the temperature of selected ignition sources. A few materials, such as cigarettes, upholstered furniture, sawdust, and cellulosic insulation, are permeable and readily allow air infiltration. These materials can burn as solid phase combustion, known as smoldering. This is a flameless form of combustion whose principal heat source is char oxidation. Smoldering is hazardous, as it produces more toxic compounds than flaming combustion per unit mass burned, and it provides a chance for flaming combustion from a heat source too weak to directly produce flame.

Table 3-3 Reported Burning and Sparking Temperatures of Selected Ignition Sources

	Temperature	
Source	**°F**	**°C**
Flames		
Benzene[a]	1690	920
Gasoline[a]	1879	1026
JP-4[b]	1700	927
Kerosene[a]	1814	990
Methanol[a]	2190	1200
Wood[c]	1880	1027
Embers[d]		
Cigarette (puffing)	1520–1670	830–910
Cigarette (free burn)	930–1300	500–700
Mechanical sparks[e]		
Steel tool	2550	1400
Copper-nickel alloy	570	300

[a]From Drysdale, *An Introduction to Fire Dynamics.*
[b]From Hagglund and Persson, *The Heat Radiation from Petroleum Fires.*
[c]From Hagglund and Persson, *An Experimental Study of the Radiation from Wood Flames.*
[d]From Krasny, *Cigarette Ignition of Soft Furnishings — A Literature Review with Commentary.*
[e]From NFPA *Fire Protection Handbook,* 15th edition, 1981, p. 4–167.

The term *smoldering* is sometimes inappropriately used to describe a nonflaming response of a solid fuel to an external heat flux. Solid fuels, such as wood, when subjected to a sufficient heat flux, will degrade, gasify, and release vapors. There usually is little or no oxidation involved in this gasification process, and thus it is endothermic. This is more appropriately referred to as forced pyrolysis, and not smoldering.

3-3.1 Ignition of Solid Fuels. For solid fuels to burn with a flame, the substance should either be melted and vaporized (like thermoplastics) or be pyrolyzed into gases or vapors (i.e., wood or thermoset plastic). In both examples, heat must be supplied to the fuel to generate the vapors.

High-density materials of the same generic type (woods, plastics) conduct energy away from the area of the ignition source more rapidly than low-density materials, which act as insulators and allow the energy to remain at the surface. For example, given the same ignition source, oak takes longer to ignite than a soft pine. Low-density foam plastic, on the other hand, ignites more quickly than high-density plastic.

The amount of surface area for a given mass (surface area to mass ratio) also affects the quantity of energy necessary for ignition. It is relatively easy to ignite one pound of thin pine shavings with a match, while ignition of a one-pound solid block of wood with the same match is very unlikely.

Because of the higher surface area to mass ratio, corners of combustible materials are more easily burned than flat surfaces. Table 3-3.1 shows the time for pilot ignition of wood exposed to varying temperatures.

Caution is needed in using Table 3-3.1, as the times and temperatures given are for ignition with a pilot flame. These are good estimates for ignition of wood by an existing fire. These temperatures are not to be used to estimate the temperature necessary for the first item to ignite. The absence of the pilot flame requires that the fuel vapors of the first item ignited be heated to their autoignition temperature. In *An Introduction to Fire Dynamics,* Dougal Drysdale reports two temperatures for wood to autoignite or spontaneously ignite. These are heating by radiation, 600°C (1112°F), and heating by conduction, 490°C (914°F).

For spontaneous ignition to occur as a result of radiative heat transfer, the volatiles released from the surface should be hot enough to produce a flammable mixture above its autoignition temperature when it mixes with unheated air. With convective heating on the other hand, the air is already at a high temperature and the volatiles need not be as hot.

Figure 3-3.1(a) illustrates the relationship between ignition energy and time to ignition for thin and thick materials. When exposed to their ignition temperature, thin materials ignite faster than thick materials (e.g., paper vs. plywood). *[See Figure 3-3.1(b).]*

3-3.2 Ignition of Liquids. In order for the vapors of a liquid to form an ignitible mixture, the liquid should be at or above its flash point. The flash point of a liquid is the lowest temperature at which it gives off sufficient vapor to support a momentary flame across its surface based on an appropriate ASTM test method. The value of the flash point may vary depending on the type of test used. Even though most of a liquid may be slightly below its flash point, an ignition source can create a locally heated area sufficient to result in ignition.

Atomized liquids or mists (those having a high surface area to mass ratio) can be more easily ignited than the same liquid in the bulk form. In the case of sprays, ignition can often occur at ambient temperatures below the published flash point of the bulk liquid provided the liquid is heated above its flash point and ignition temperature at the heat source.

3-3.3 Ignition of Gases. Combustible substances in the gaseous state have extremely low mass and require the least amount of energy for ignition.

3-3.4 Ignition Properties of Materials. Table 3-3.4 provides ignition property data for selected solids, liquids, and gases.

3-3.5 Self-Heating and Self-Ignition. Self-heating is the process whereby a material increases in temperature without drawing heat from its surroundings. Self-heating of a material to its ignition temperature results in self-ignition.

Most organic materials capable of combining with oxygen will oxidize at some critical temperature with the evolution of heat. Generally, self-heating and self-ignition are most commonly encountered in organic materials such as animal and vegetable solids and oils.

Table 3-3.1 Time Required to Ignite Wood Specimens

Wood $1^1/_4$ in. × $1^1/_4$ in. × 4 in. (32 mm × 32 mm × 102 mm)	No Ignition in 40 Min °F	No Ignition in 40 Min °C	Exposure Before Ignition, by Pilot Flame, Minutes 356°F (180°C)	392°F (200°C)	437°F (225°C)	482°F (250°C)	572°F (300°C)	662°F (350°C)	752°F (400°C)
Long leaf pine	315	157	14.3	11.8	8.7	6.0	2.3	1.4	0.5
Red oak	315	157	20.0	13.3	8.1	4.7	1.6	1.2	0.5
Tamarack	334	167	29.9	14.5	9.0	6.0	2.3	0.8	0.5
Western larch	315	157	30.8	25.0	17.0	9.5	3.5	1.5	0.5
Noble fir	369	187	—	—	15.8	9.3	2.3	1.2	0.3
Eastern hemlock	356	180	—	13.3	7.2	4.0	2.2	1.2	0.3
Redwood	315	157	28.5	18.5	10.4	6.0	1.9	0.8	0.3
Sitka spruce	315	157	40.0	19.6	8.3	5.3	2.1	1.0	0.3
Basswood	334	167	—	14.5	9.6	6.0	1.6	1.2	0.3

Source: From NFPA *Fire Protection Handbook*, 18th edition, 1997, p. 4–29.

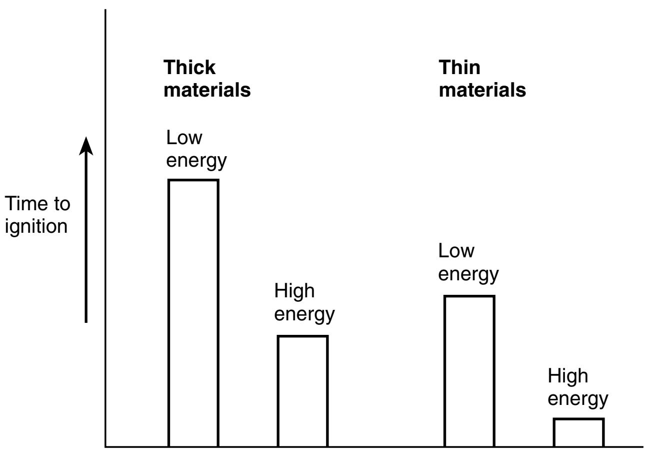


Figure 3-3.1(a) Relationship of energy source to ignition time for thick and thin materials.

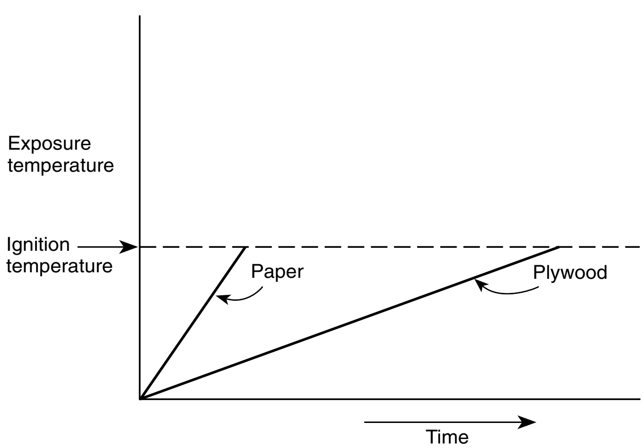


Figure 3-3.1(b) Relationship of material thickness to ignition time when exposed to ignition temperature.

Self-heating and self-ignition of materials such as motor or lubricating oils does not occur. Certain inorganic materials, such as metal powders, may undergo self-heating and self-ignition under isolated conditions.

There are three factors that control or influence the occurrence of self-heating and self-ignition:

(a) The rate of heat generation

(b) The effects of ventilation

(c) The insulating effects of the material's immediate surroundings

The rate of heat generation is slow. In order for self-ignition to occur, the rate of heat generation by the material undergoing self-heating should be faster than the rate at which the heat is being dissipated or transferred to its immediate surroundings. When the temperature of the self-heating material increases, the elevated temperatures result in an increase in the rate of heat generation. In all cases, however, the initial temperature of the pile can affect its ability to self-heat. Occasionally, products have been stacked while warm, resulting in self-heating that would not otherwise have occurred.

The effects of ventilation are also significant. In order for self-ignition to occur, sufficient air should be available to permit oxidation but not so much that the heat is carried away by convection as rapidly as it is being generated. As such, the material should be sufficiently porous to allow for oxygen to permeate through the mass to the point of combustion, and the material should also char.

A rag saturated with linseed oil, for example, that might self-heat and self-ignite when crumpled at the bottom of a wastebasket, would not be expected to do so if hung on a clothesline where effects of ventilation through air movement would dissipate the heat faster than it is being generated.

Closely related to the effects of ventilation is the insulating effect of the material's immediate surroundings. The crumpled rag saturated with linseed oil at the bottom of a wastebasket is insulated by both the rag itself and the wastebasket. This insulating effect results in the heat being retained within the material and not being as quickly dissipated to the material's immediate surroundings. In a large pile of material, the pile itself may provide enough insulation to allow self-heating in the core of the pile.

Table 3-3.4 Ignition Properties of Selected Materials

Material	Ignition Temperature °F	Ignition Temperature °C	Minimum Radiant Flux (kW/m²)	Energy Required (kJ/m²)	Minimum Ignition Energy (mJ)
Solids					
Polyethylene[a]	910	488	19	1500–5100	—
Polystyrene[a]	1063	573	29	1300–6400	—
Polyurethane (flexible)[a]	852–1074	456–579	16–30	150–770	—
PVC[a]	945	507	21	3320	—
Soft wood[b]	608–660	320–350	—	—	—
Hard wood[b]	595–740	313–393	—	—	—
Dusts (cloud)[c]					
Aluminum	1130	610	—	—	10
Coal	1346	730	—	—	100
Grain	805	430	—	—	30
Liquids[d]					
Acetone	869	465	—	—	1.15[e]
Benzene	928	498	—	—	0.22[e]
Ethanol	685	363	—	—	—
Gasoline (100 oct)	853	456	—	—	—
Kerosene	410	210	—	—	—
Methanol	867	464	—	—	0.14[e]
Methyl ethyl ketone	759	404	—	—	0.53[e]
Toluene	896	480	—	—	2.5[f]
Gases[d]					
Acetylene	581	305	—	—	0.02[e]
Methane	999	537	—	—	0.28[e]
Natural gas	900–1170	482–632	—	—	0.30[f]
Propane	842	450	—	—	0.25[e]

[a]From NFPA *Fire Protection Handbook*, 17th edition, 1991, Table A-6.
[b]From NFPA *Fire Protection Handbook*, 17th edition, 1991, p. 3–25.
[c]From NFPA *Fire Protection Handbook*, 16th edition, 1986, Table 5-9A.
[d]Ignition temperatures from NFPA 325, *Guide to Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids*, 1994.
[e]From the SFPE *Handbook of Fire Protection Engineering*, Table 2-5.2, 1988.
[f]From NFPA *Fire Protection Handbook*, 15th edition, 1981, Table 11-3B.

Because of the many possible combinations of these controlling or influencing factors, it is difficult to predict with any certainty when a material will self-heat. Table 3-3.5 lists a few materials subject to self-heating. A more complete list is found in Table A-10 of the *Fire Protection Handbook*, 18th edition. Omission of any material does not necessarily indicate that it is not subject to self-heating.

3-4 Fuel Load. The term *fuel load* has been used in the past to indicate the potential severity of a fire and has been expressed in terms of Btu (British thermal unit) or pounds of fuel per square foot of floor area. The Btus were expressed in wood equivalent based on 8000 Btu per pound. The fuel load was determined by weighing the fuel in a room and converting the weight of plastic to pounds of wood using 16,000 Btu per pound as the value for plastic (one pound of plastic equals two pounds of wood). The total Btus (or pounds of fuel) were divided by the area of the room floor. While this approach can be a measure of the total heat available if all the fuel burns, it does not depict how fast the fire will develop once the fire starts. The speed of development of a fire determined from witness statements is often used as evidence of an incendiary fire if the fire "grew faster than would be expected given the fuel load present."

Table 3-3.5 Some Materials Subject to Spontaneous Ignition

Material	Tendency
Charcoal	High
Fish meal	High
Linseed oiled rags	High
Brewing grains	Moderate
Foam rubber	Moderate
Hay	Moderate
Manure	Moderate
Wool wastes	Moderate
Bailed rags	Variable (low to moderate)
Sawdust	Possible
Grain	Low

Source: From the *Fire Protection Handbook,* 18th edition, 1997, p. A-15.

Total fuel load in the room has no bearing on the rate of growth of a given fire in its pre-flashover phase. During this period of development, the rate of fire growth is determined by the heat release rate (HRR) from the burning of individual fuel arrays. This is controlled by the chemical and physical properties of the fuel and the surface area of the fuel array. HRR is expressed in terms of Btu/second or kilowatts. After flashover, the heat release rate in the fire is controlled by the preceding factors and the availability of air and the exposed combustible surface.

Pine shavings, for example, burn faster than a block of wood of the same weight. Finely ground wood flour dispersed in air burns very rapidly and can result in an explosion. Plastics can have heat release rates significantly greater than the same item made of cellulose. Compare a cotton mattress to one of the same size but made of polyurethane foam. *(See Table 3-4.)* The difference between these materials relates not only to the chemical composition of the fuel but also to the physical properties, including those that determine the thermal inertia. *(See 3-2.1.)*

Low-density materials burn faster than high-density materials of similar chemistry. Soft pine, for example, would burn faster than oak, and lightweight foam plastics burn faster than more dense, rigid plastics. Peak heat release rate values for typical fuels are presented in Table 3-4. These values should be considered representative values for typical similar fuel items. The actual peak heat release rate for a particular item is best determined by test.

Table 3-4 Representative Peak Heat Release Rates (unconfined burning)

Fuel (lb)	Peak HRR (kW)
Wastebasket—small (1.5–3)	4–18
Trash bags—11 gal with mixed plastic and paper trash ($2^1/_2$ – $7^1/_2$)	140–350
Cotton mattress (26–29)	40–970
TV sets (69–72)	120–290
Plastic trash bags/paper trash (2.6–31)	120–350
PVC waiting room chair—metal frame (34)	270
Cotton easy chair (39–70)	290–370
Gasoline/kerosene in 2-ft^2 (0.61 m^2) pool	400
Christmas trees—dry (14–16)	500–650
Polyurethane mattress (7–31)	810–2630
Polyurethane easy chair (27–61)	1350–1990
Polyurethane sofa (113)	3120

Sources: Values are from the following publications.
Babrauskas and Krasny, *Fire Behavior of Upholstered Furniture.*
NFPA 72, *National Fire Alarm Code®*, 1996 edition, Table C-2-2.2.1(a).
Lee, *Heat Release Rate Characteristics of Some Combustible Fuel Sources in Nuclear Power Plants.*

3-5 Fire Development. The rate and pattern of fire development depend on a complex relationship between the burning fuel and the surrounding environment. In confined burning, the collection of heat at the top of the room can raise the temperature of the ceiling and produce a large body of high-temperature smoke. The radiation from this upper portion of the space can significantly enhance the rate of heat release from a burning item. In such cases, the values given in Table 3-4 would be inappropriately low.

3-5.1 Plumes. Heat from a fire in the open rises as a column of hot gas called a plume. The resulting airflow draws cool air into the base of the fire from all directions. Cool air is also drawn into the plume above ground level by the moving mass of hot air. *[See Figure 3-5.1(a).]* This inflow of cool air into the plume is called entrainment and results in decreased temperatures with increasing height in the plume. *[See Figure 3-5.1(b).]*

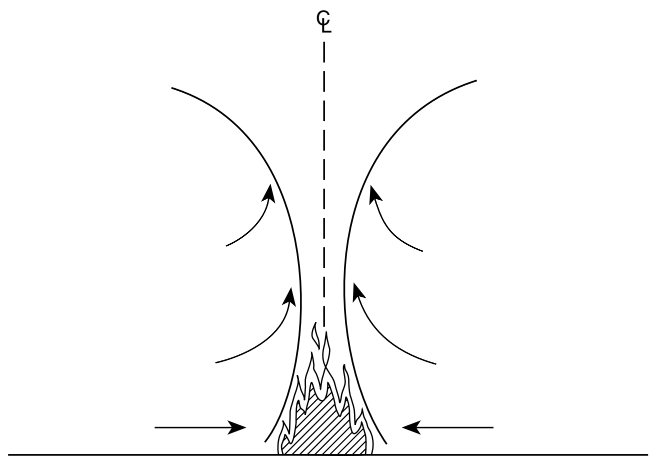


Figure 3-5.1(a) Fire plume in the open.

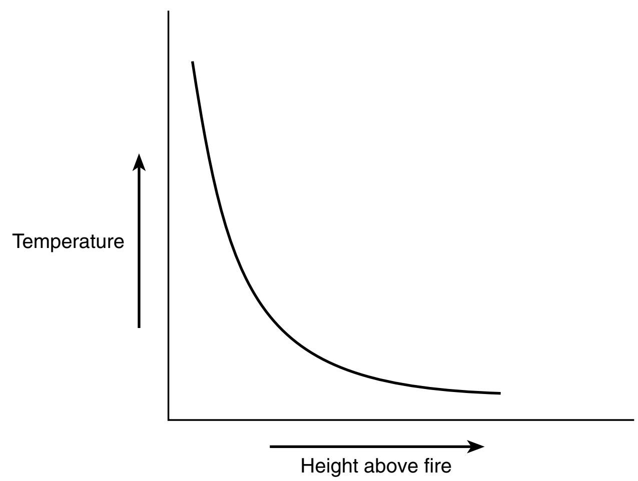


Figure 3-5.1(b) Temperature in a fire plume.

Fire spread will be primarily by radiant ignition of nearby fuels. Spread rate over solids will generally be slow unless aided by air movement (wind) or sloping surfaces.

3-5.2 Unconfined Fires. When no ceiling exists over a fire, and the fire is far from walls, the hot gases and smoke of the plume continue to rise vertically. Such conditions would exist for a fire outdoors. The same conditions can exist with a fire in a building at the very early stages when the plume is small or if the fire is in a very large volume space with a high ceiling such as an atrium. Fire spread from an unconfined fire plume will be primarily by radiant ignition of nearby fuels. The spread rate across solid materials will generally be slow unless aided by air movement (wind in the case of outdoor fires) or sloping surfaces that allow preheating of the fuel.

3-5.3 Confined Fires. When plumes interact with the ceiling or walls of a compartment, the flow of smoke and hot gases and the growth of the fire will be affected. Low heat release rate fires, remote from walls or other bounding surfaces, such as the back of a couch, will behave as if they were in the open.

3-5.3.1 Fires Confined by a Ceiling. When a ceiling exists over a fire, and the fire is far from walls, the hot gases and smoke in the rising plume strike the ceiling surface and spread in all directions until stopped by an intervening wall. As the hot gases flow away from the centerline of the plume under the ceiling, a thin layer is formed. Heat is conducted from this layer into the cooler ceiling above, and cool air is entrained from below. This layer is deepest and hottest near the plume centerline and becomes less deep and cooler as the distance *(r)* from the centerline of the plume increases. *[See Figure 3-5.3.1(a).]*

As in the case of the fire in the open, temperatures will decrease with increasing height above the fire. In addition, due to the cooling by entrainment and heat losses to the ceiling, the layer temperature decreases with increased distance *(r)* from the plume centerline *[see Figure 3-5.3.1(b)]*.

Fire spread with a plume confined by a ceiling will be by ignition of combustible ceiling or wall material, ignition of nearby combustibles such as room contents or warehouse stock, or a combination of these mechanisms. The gases in the upper (smoke) layer may transfer heat to materials in this upper layer by convection and radiation. Transfer of heat below the smoke layer is dominated by radiation. Fire growth, when the plume is confined by a ceiling, will be faster than when the plume is unconfined.

Factors such as ceiling height and distance from the plume can have significant effects on the response time of fire protection devices, such as heat and smoke detectors and automatic sprinklers. For a given device and fire size (HRR), the response time of the device will increase with higher ceilings and with increasing distance from the plume. Stated another way, the higher the ceiling or the farther away the device, the larger the heat output from the fire will be at the time the device responds. These factors should be considered when attempting to understand why a fire appears to be larger than expected at the time of alarm or sprinkler operation.

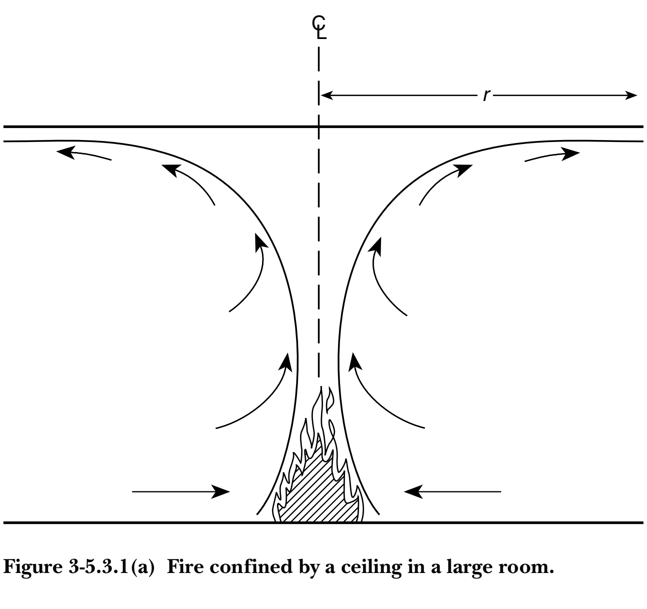


Figure 3-5.3.1(a) Fire confined by a ceiling in a large room.

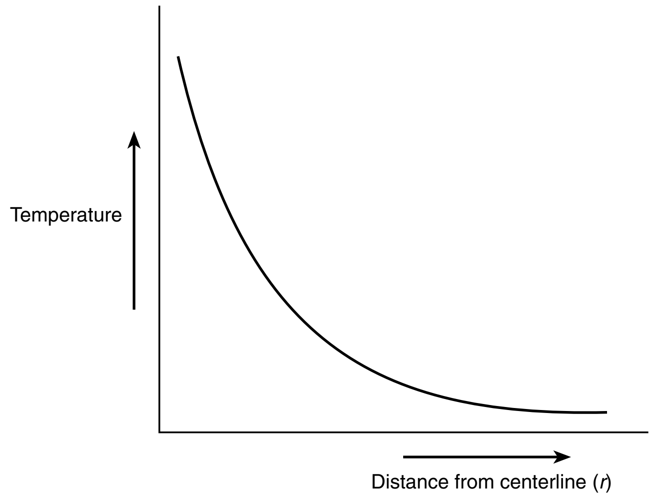


Figure 3-5.3.1(b) Ceiling layer temperature away from the plume.

3-5.3.2 Compartment Fires and Flashover. The heat output from a fire in a compartment is confined by walls as well as the ceiling. The closer proximity of the walls results in a more rapid development of the hot gas layer at the ceiling and the creation of a much deeper layer. Figure 3-5.3.2(a) depicts a room with a door opening. There are two fuel packages in the room; one is the item first ignited, and the other is the "target" fuel or second item ignited. Initially, the ceiling layer will be thin, resembling the no-wall situation. However, as the gases reach the walls and can no longer spread horizontally, the bottom of the layer will descend and become uniform in depth. Smoke detectors in the compartment of origin will generally respond early in this stage of fire development.

When the smoke level reaches the top of the door opening, it will begin to flow out of the compartment. If the rate of smoke production does not exceed the rate of smoke flow out of the compartment, the ceiling layer will not descend further. *[See Figure 3-5.3.2(b).]*

If the fire grows in size, the bottom of the ceiling layer will continue to descend, the temperature of the hot smoke and gases will increase, and radiant heat from the layer will begin to heat the unignited target fuel. A well-defined flow pattern will be established at the opening with the hot combustion products flowing out the top and cool air flowing into the compartment under the smoke layer. *[See Figure 3-5.3.2(c).]*

At the start of this stage of burning, there is sufficient air to burn all of the materials being pyrolyzed. This is referred to as fuel controlled burning. As the burning progresses, the availability of air may continue to be sufficient and the fire may continue to have sufficient oxygen even as it grows. Normally, this would be a location that had a large door or window opening as compared to fuel surface burning. In such cases, the gases collected at the upper portion of the room, while hot, will contain significant oxygen and relatively small amounts of unburned fuel.

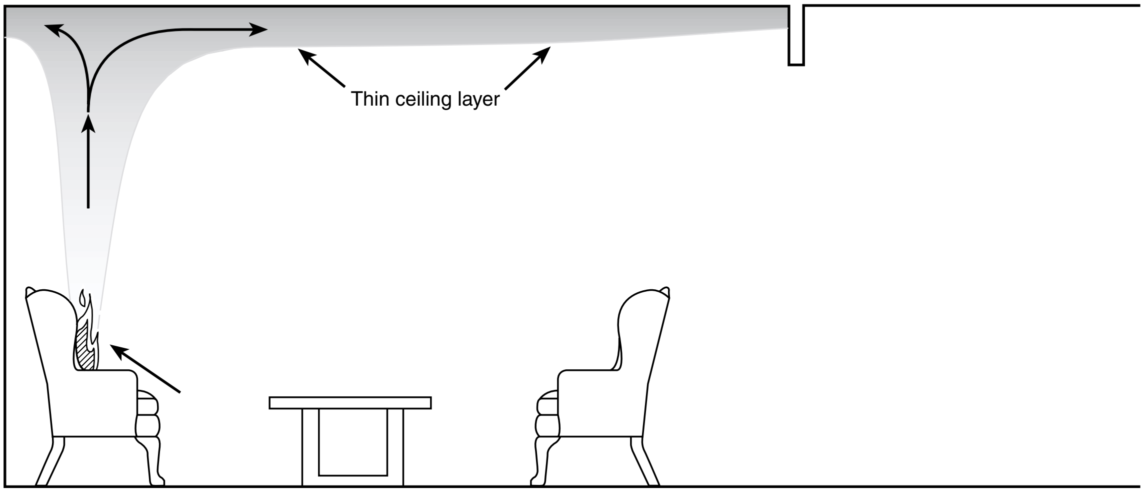


Figure 3-5.3.2(a) Early compartment fire development.

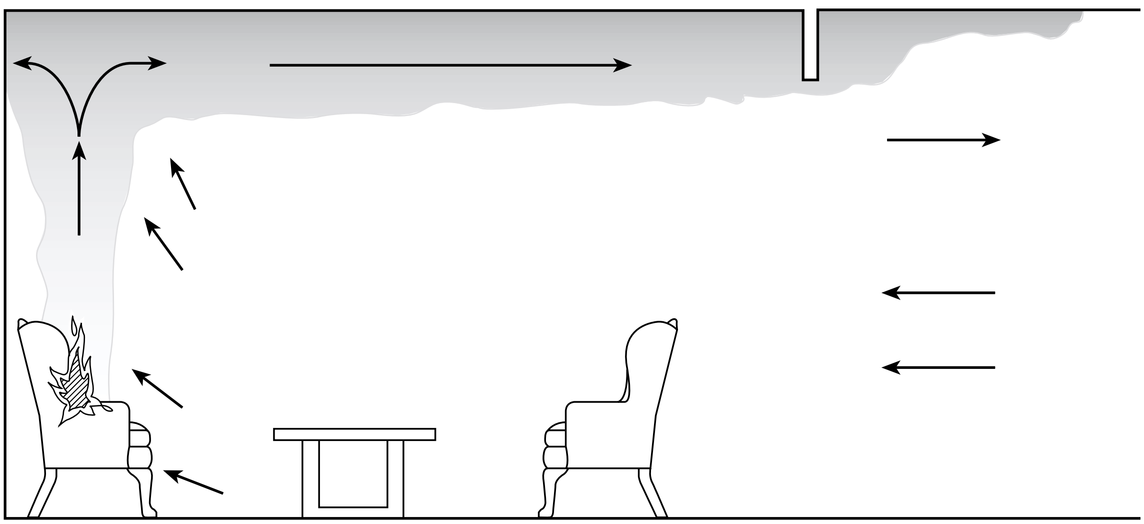


Figure 3-5.3.2(b) Ceiling layer development in compartment fire.

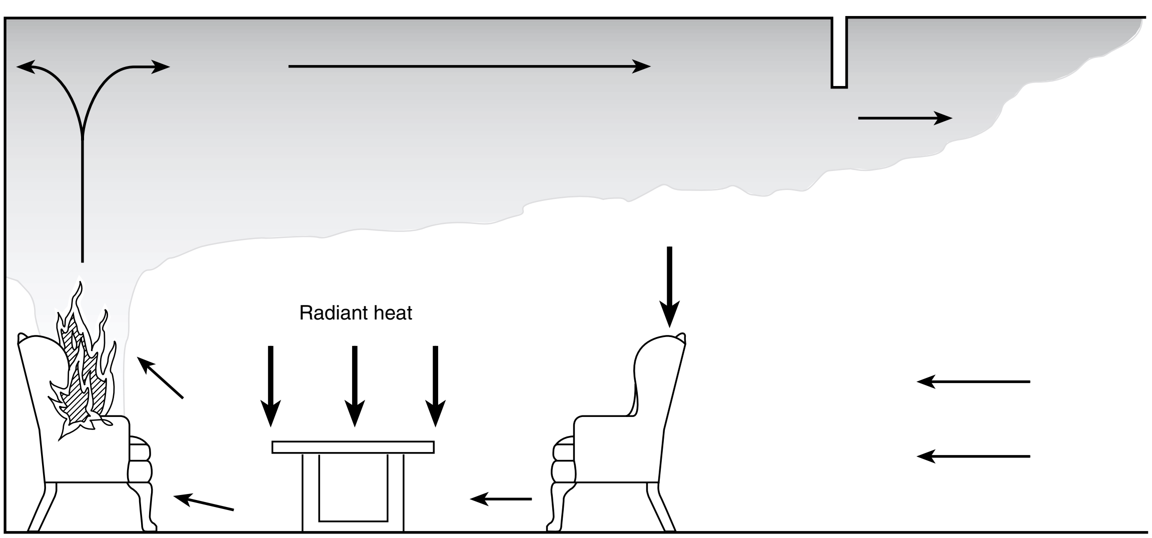


Figure 3-5.3.2(c) Pre-flashover conditions in compartment fire.

If the amount of air resident in the room, plus that transported to the room through the HVAC system or drawn in through openings, is not sufficient to burn all of the combustibles being pyrolyzed by the fire, the fire will shift from fuel control to ventilation control. In that situation, the ceiling layer will contain unburned products of combustion such as hydrocarbon vapors, carbon monoxide, and soot. In general, there will be insufficient oxygen for flaming in the ceiling layer. In both cases, the gases can be well above the temperatures necessary to char or pyrolyze combustible finished materials in the hot layer.

Automatic sprinklers will normally operate early during this phase or even during the prior phase of burning. Quick-response sprinklers will operate much sooner than standard sprinklers. Detectors located outside the compartment may operate depending on their location and the ability of smoke to travel from the fire to the point of the detector.

As the fire continues to grow, the ceiling layer gas temperatures approach 900°F (480°C), increasing the intensity of the radiation on the exposed combustible contents in the room. The surface temperature of these combustible contents rises, and pyrolysis gases are produced and become heated to their ignition temperature. When the upper layer temperature reaches approximately 1100°F (590°C), pyrolysis gases from the combustible contents ignite along with the bottom of the ceiling layer. This is the phenomenon known as flashover. *[See Figure 3-5.3.2(d).]* The terms *flameover* and *rollover* are often used to describe the condition where flames propagate through or across the ceiling layer only and do not involve the surfaces of target fuels. Flameover or rollover generally precede flashover but may not always result in flashover.

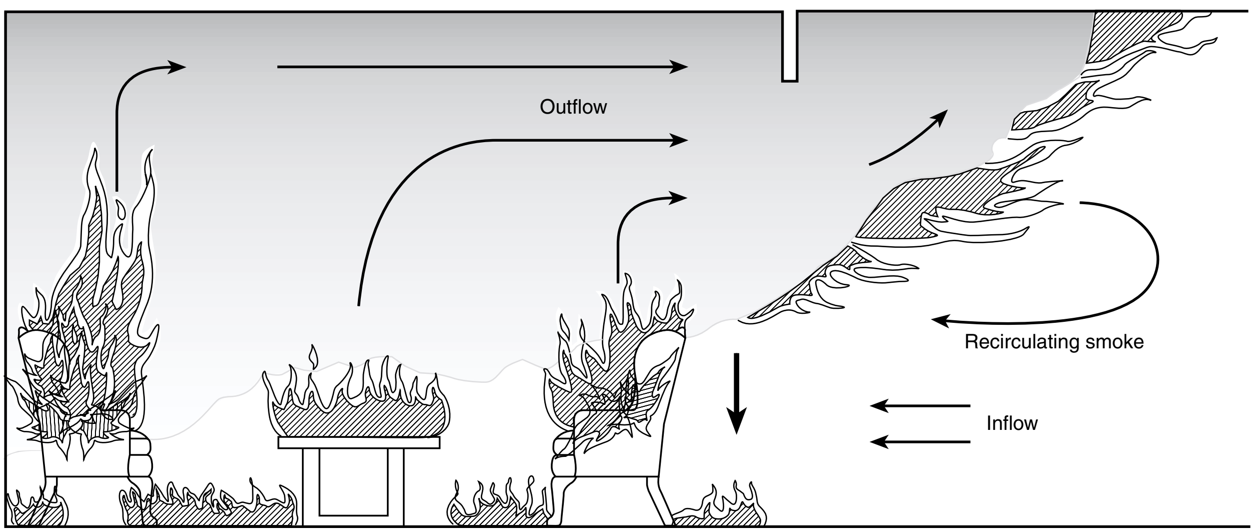


Figure 3-5.3.2(d) Flashover conditions in compartment fire.

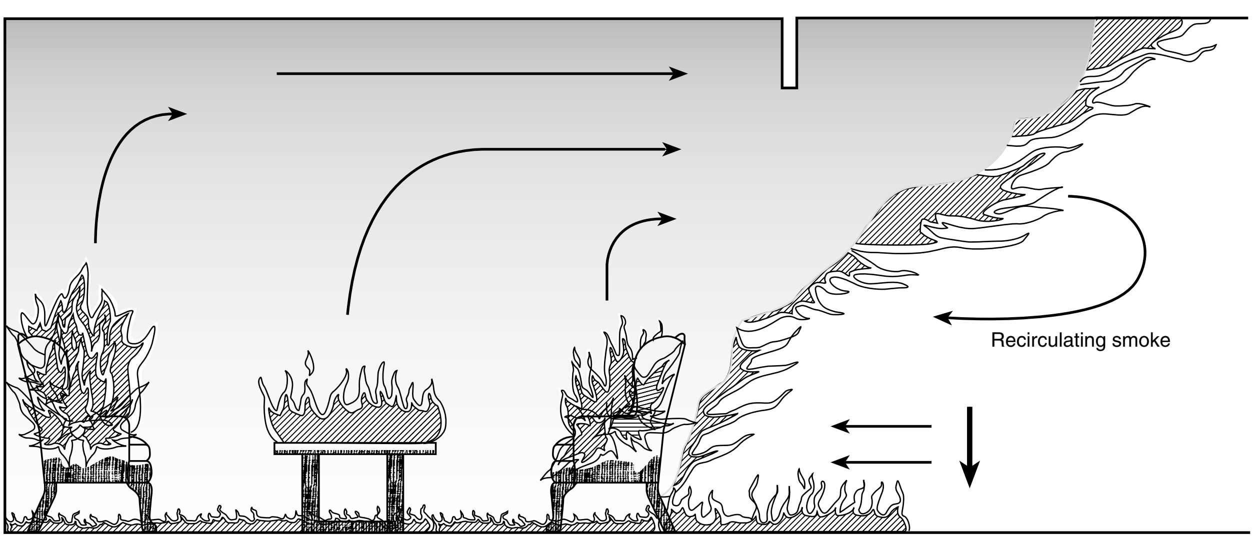


Figure 3-5.3.2(e) Post-flashover or full room involvement in compartment fire.

Post-flashover burning conditions in a compartment are turbulent and dynamic. During post-flashover burning, the position of the ceiling layer bottom and the existence and size of flaming on target fuels within the layer can vary between the conditions shown in Figures 3-5.3.2(d) and 3-5.3.2(e). While the burning of floors or floor coverings is common, such burning may not always extend under target fuels or other shielding surfaces.

Flashover represents a transition from a condition where the fire is dominated by burning of the first item ignited (and nearby items subject to direct ignition) to a condition where the fire is dominated by burning of all items in the compartment. It is important for investigators to be aware of the fact that flashover is a triggering condition, not a closed-ended event. The post-flashover condition is called full room involvement. The onset of flashover occurs when the hot gas layer imposes radiant energy levels (flux) on unignited fuels of approximately 20 kW/m^2. This flux level is usually sufficient to ignite ordinary combustible materials. Flux levels in full room involvement are considerably higher than at the beginning of flashover. Levels at the floor of 170 kW/m^2 have been recorded.

Once flashover conditions have been reached, full room involvement will follow in the majority of fires unless the fuel is exhausted, the fire is oxygen deprived, or the fire is extinguished. In full room involvement, the hot layer can be at floor level but tests and actual fires have shown the hot layer is not always at floor level. *[See Figure 3-5.3.2(e).]*

At the time of flashover, the compartment door becomes a restriction to the amount of air available for combustion inside the compartment, and the majority of the pyrolysis products will burn outside the compartment. Flameover or rollover generally occurs prior to flashover but may not always result in flashover conditions throughout a compartment, particularly where there is a large volume or high ceiling involved or there is limited fuel present.

Research has shown that time to flashover from open flame can be as short as $1^1/_2$ minutes in residential fire tests with contemporary furnishings, or it may never occur. The rate of heat release from a fully developed room flashover can be on the order of 10,000 kW (10 megawatts) or more.

3-5.4 Effects of Enclosures on Fire Growth. For a fire in a given fuel package, the size of the ventilation opening, the volume of the enclosure, the ceiling height, and the location of the fire with respect to the walls and corners will affect the overall fire growth rate in the enclosure.

3-5.4.1* Ventilation Opening. The minimum size fire that can cause a flashover in a given room is a function of the ventilation provided through an opening. This function is known as the ventilation factor and is calculated as the area of the opening (A_o) times the square root of the height of the opening (h_o).

An approximation of the heat release rate for flashover (HRR_{fo}) can be found from the relationship

$$HRR_{fo}(\text{kW}) = (750A_o)(h_o)^{0.5}$$

where A_o is in square meters and h_o is in meters. The same formula using English units is

$$HRR_{fo}(\text{Btu/sec}) = (18.4A_o)(h_o)^{0.5} + 0.69A_w$$

where A_o is in square feet and h_o is in feet. A log versus log graph of the HRR for a range of ventilation factors is shown in Figure 3-5.4.1. If the room dimensions are known, a closer approximation can be found using the following relationship:

$$HRR_{fo}(\text{kW}) = (378A_o)(h_o)^{0.5} + 7.8A_w$$

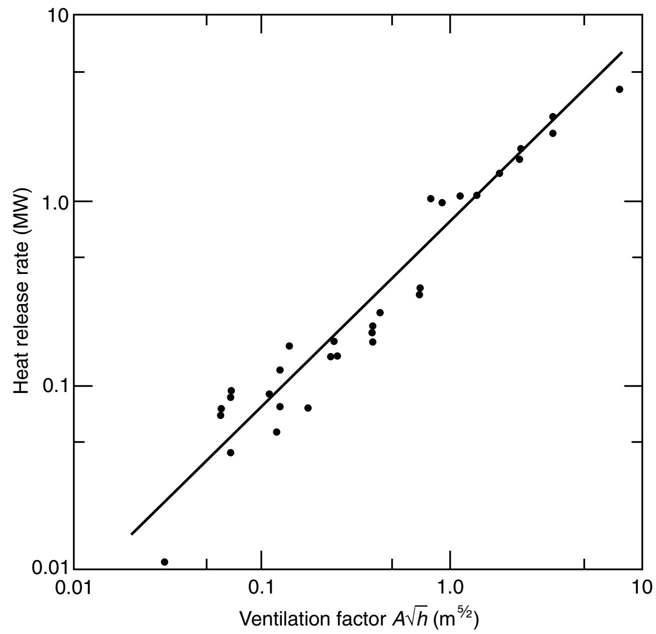


Figure 3-5.4.1 Minimum heat release rate for flashover.

where A_o is the area of the ventilation opening in square meters and A_w is the area of the walls, ceiling, and floor in square meters. This relationship accounts for heat losses to the bounding surfaces of the room (i.e., the walls, ceiling, and floor). If the losses to the floor are small, then the floor area can be deleted from the value of A_w. The same formula using English units is

$$HRR_{fo}(\text{Btu/sec}) = 18.4A_o(h_o)^{0.5} + 0.69$$

where A_o and A_w are in square feet and h_o is in feet.

3-5.4.2 Room Volume and Ceiling Height. Development of a ceiling layer of sufficient temperature to cause radiant ignition of exposed combustible fuels and the layer gases is necessary for flashover. High ceilings or large compartment volumes will delay this buildup of temperature and therefore delay or possibly prevent flashover from occurring. The distance between the bottom of the hot layer and the combustible fuel is also a factor but of less importance.

3-5.4.3 Location of the Fire in the Compartment. When a burning fuel package is away from a wall, air is free to flow into the plume from all directions and mix with the fuel gases. This brings air for combustion into the flame zone and cools the upper part of the plume by entrainment. *(See 3-5.1.)*

If the fuel package or the fire plume is against a wall (not in a corner), air will be able to enter the plume from only about half of the theoretical circle around it. This will result in longer flames and a faster rise in the temperature of the gases in the ceiling layer. This, in turn, leads to flashover sooner than if the same fuel package had been in the center of the compartment.

When the same fuel package is placed in a corner, 75 percent of the airflow into the plume is restricted, resulting in even longer flames, higher plume and ceiling layer temperatures, and shorter times to flashover.

It should be noted that walls or other barriers to airflow will affect flame length and plume temperature outdoors as well.

The possible effect of the location of walls relative to the fire should be considered in interpreting the extent of damage as a clue to fire origin. In making the determination, the possibility that the fuel in the suspected area of origin was not the first material ignited and that the greater degree of damage was the result of wall or corner effects should be considered.

3-5.5* Flame Height. The height of flames above the surface of burning fuels is directly related to the HRR of the fire. For a given fuel, the HRR is related to the amount of surface burning. If the flame height of a fire is known or can be estimated, the approximate HRR can be determined. The height of the flame is related to the heat output of a simple pool or single item fire by the relationship

$$HRR_f = 0.174(k\dot{Q})^{0.4}$$

If the flame height is known, the heat release rate can be estimated by using the following formula:

$$\dot{Q} = \frac{79.18H_f^{5/2}}{k}$$

where:
H_f = flame height in meters

k = wall effect factor

$\dot{Q}$ = fuel heat release rate in kilowatts

The value of k to be used is

k = 1 when there are no nearby walls

k = 2 when the fuel package is at a wall

k = 4 when the fuel package is in a corner

For a typical wastebasket fire of 150 kW where there are no nearby walls (k = 1), this yields an estimated flame plume of 1.3 m (4.3 ft). For an upholstered chair, where the heat $\dot{Q}$ is on the order of 500 kW, the plume would be about 2.1 m (6.9 ft) in height.

3-6 Products of Combustion. The chemical products of combustion can vary widely depending on the fuels involved and the amount of air available. Complete combustion of hydrocarbon fuels containing only hydrogen and carbon will produce carbon dioxide and water. Materials containing nitrogen, such as silk, wool, and polyurethane foam, produce nitrogen oxides and possibly hydrogen cyanide as combustion products. Literally hundreds of compounds have been identified as products of incomplete combustion of wood.

When less air is available for combustion as in ventilation-controlled fires, the production of carbon monoxide increases as does the production of soot and unburned fuels.

Combustion products exist in all three states of matter: solid, liquid, and gas. Solid material makes up the ash and soot products that represent the visible "smoke." Many of the other products of incomplete combustion exist as vapors or as extremely small tarry droplets or aerosols. These vapors and droplets often condense on surfaces that are cooler than the smoke, resulting in smoke patterns that can be used to help determine the origin and spread of the fire. Such surfaces include walls, ceilings, and glass. Since the condensation of residue results from temperature differences between the smoke body and the affected surface, the presence of a deposit is evidence that smoke did engulf the surface, but the lack of deposit or the presence of a sharp line of demarcation is not evidence of the limits of smoke involvement.

Soot and tarry products often accumulate more heavily on ceramic-tiled surfaces than on other surrounding surfaces due to the heat conduction properties of ceramic tile. Those surfaces that remain the coolest the longest tend to collect the most condensate.

Some fuels, such as alcohol or natural gas, burn very cleanly, while others, such as fuel oil or styrene, will produce large amounts of sooty smoke even when the fire is fuel controlled.

Smoke is generally considered to be the collection of the solid, liquid, and gaseous products of incomplete combustion.

Smoke color is not necessarily an indicator of what is burning. While wood smoke from a well-ventilated or fuel-controlled wood fire is light-colored or gray, the same fuel under the low-oxygen conditions, or ventilation-controlled conditions in a post-flashover fire, can be quite dark or black. Black smoke can also be produced by the burning of other materials including most plastics and ignitible liquids.

The action of fire fighting can also have an effect on the color of the smoke being produced. The application of water can produce large volumes of condensing vapor that will appear white or gray when mixed with black smoke from the fire. This is often noted by witnesses at the fire scene and has been misinterpreted to indicate a change of fuel being burned.

Smoke production rates are generally less in the early phase of a fire but increase greatly with the onset of flashover, if flashover occurs.

Chapter 4 Fire Patterns

4-1 Introduction. One of the major objectives of a fire scene examination is the recognition, identification, and analysis of fire patterns. The analysis of fire patterns is performed in an attempt to trace fire spread, identify areas and points of origin, and identify the fuels involved.

The circumstances of every fire are different from every other fire because of the differences in the structures, fuel loads, ignition factors, airflow, ventilation, and many other variable factors. This discussion, therefore, cannot cover every possible variation in fire patterns and how they come about. The basic principles are covered here, and the investigator should apply them to the particular fire incident under investigation.

4-2 Dynamics of Pattern Production. The recognition, identification, and proper analysis of fire patterns by an investigator depends on an understanding of the dynamics of fire development and heat and flame spread. This includes an understanding of the way that the three modes of heat transfer (conduction, convection, and radiation) produce the fire patterns and the nature of flame, heat, and smoke movement within a structure. *(See Chapter 3.)*

The damage created by flame, radiation, hot gases, and smoke creates patterns that investigators use to locate the area or point of fire origin.

The patterns seen by an investigator can represent much of the history of the fire. Each time another fuel package is ignited or the ventilation to the fire changes, the rate of energy production and heat distribution will change. Any burning item can produce a plume and thus a fire pattern.

Determining which pattern was produced at the point of origin by the first material ignited usually becomes more difficult as the size and duration of the fire increase.

The means by which patterns can arise are discussed here. Guidance on the use and interpretation of patterns is found in Chapters 4 and 11.

4-2.1 Plume Generated Patterns. The shape of the plume of rising hot gases above a burning item can be described as a cone with its apex directed down toward the source of heat. When undisturbed, the angle between the plume boundaries and vertical is approximately 15 degrees. Near the source of heat, the sides diverge to form a cone describing the boundary of the flame zone.

As gases rise in the plume, they are cooled by air entrainment, and as the plume temperatures approach that of the surrounding air, the upper boundaries spread outward. The presence of a physical barrier, such as a ceiling, will contribute to the lateral extension of the plume boundary.

When a plume is truncated by a vertical surface, such as a wall surface, V- or U- shaped damage patterns can be created on the surface. In the hot gas portion of the plume, the V will be upright. In the flame zone, the damage pattern will resemble an inverted V. Taken together, the overall pattern is often described as an hourglass. *[See Figure 4-2.1(a).]*

The plume width varies with the size of the base of the fire and will increase over time as the fire spreads. A narrow pattern will develop from a small surface area fire, and a wide pattern will develop from a fire with a large surface area. However, the angles of the legs of the V will remain at approximately 10–15 degrees, regardless of the heat release rate (HRR) of the fuel. *[See Figure 4-2.1(b).]*

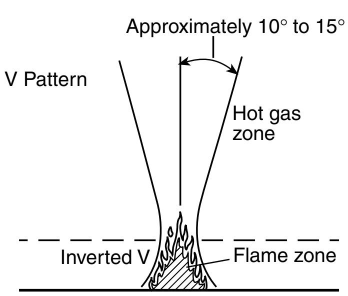


Figure 4-2.1(a) Hourglass pattern.

Although an undisturbed plume above a flaming fire will have boundaries sloping outward at approximately 15 degrees, airflow in the vicinity can cause the plume to become unstable, resulting in larger angles. Fire plumes adjacent to combustible surfaces may also produce larger angles.

Where the surface is combustible, the fire will often spread laterally, expanding the width of the burn pattern beyond that which would have been present on a noncombustible surface. The extent of spread will depend on the flame spread properties of the surface, its orientation to other burning materials, and the temperature of any hot gases impinging on it. In such instances, the pattern can leave marks vastly different from the expected 12–15 degree slope of a single plume.

4-2.2 Ventilation Generated Patterns. Blowing air over glowing embers will raise their temperatures and can generate enough heat to melt metals. More heat is transferred by convection as the velocity of the hot gas increases. These phenomena can explain the presence of numerous burn patterns.

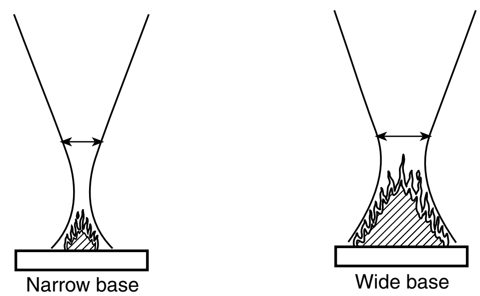


Figure 4-2.1(b) Effects of fire base on V width.

Airflow over coals or embers can raise temperatures high enough to burn holes through floors. If a building burns extensively and collapses, embers buried in debris can produce holes in floors. Once a hole is made, air can flow up through the hole, and the burning rate can increase. Careful interpretation of these patterns should be exercised since they may be mistaken for patterns originating from ignitible liquids. Holes in floors may be caused by glowing combustion, radiation, or an ignitible liquid. Because the surface below a liquid remains cool (or at least below the boiling point of the liquid) until the liquid is consumed, holes in the floor from burning ignitible liquids may result when the ignitible liquid has soaked into the floor or accumulated below the floor level. Evidence other than the hole or its shape is necessary to confirm the cause of a given pattern. *(See 4-3.3, 4-16.1.4, and 4-17.7.2)*

When a door is closed on a fire, hot gases (being lighter) can escape through the space at the top of a closed door, resulting in charring. Cool air may enter the compartment at the bottom of the door. *[See Figure 4-2.2(a).]* In a fully developed room fire where the hot gases extend to the floor, the hot gases may escape under the door and cause charring under the door and possibly through the threshold. *[See Figure 4-2.2(b).]* This can also occur if glowing debris falls against the door either on the inside or the outside. *[See Figure 4-2.2(c).]*

Ventilation of fires and hot gases through windows, doors, or other openings in a structure greatly increases the velocity of the flow over combustible materials. In addition, well-vented fires burn with higher heat release rates. These factors combined with higher radiation temperatures can act to burn wood at a higher rate and can spall concrete or deform metal components. Areas of great damage are indicators of a high heat release rate, ventilation effects, or long exposure. Such areas, however, are not always the point of fire origin. For example, fire could spread from slow burning fuels to rapid burning fuels with the latter producing most of the fire damage.

4-2.3 Hot Gas Layer Generated Patterns. The radiant flux from the overhead hot gas layer can produce damage to the upper surfaces of contents and floor covering materials. This commonly begins as the environment within the room approaches flashover conditions. Similar damage to floor surfaces from radiant heat frequently occurs in adjacent spaces outside rooms that are fully involved in fire. Damage to hallway floors and porches are examples. If the fire does not progress to full room involvement *(see 3-5.3.2)*, the damage may include blistering, charring, or melting. Protected surfaces may exhibit no damage. At this time in the fire development, a line of demarcation representing the lower extent of the hot gas layer may form on vertical surfaces. The degree of damage generally will be uniform except where there is drop down, burning of isolated items that are easily ignited, or protected areas. Damage to the undersides of furnishings below the bottom of the hot layer is unlikely.

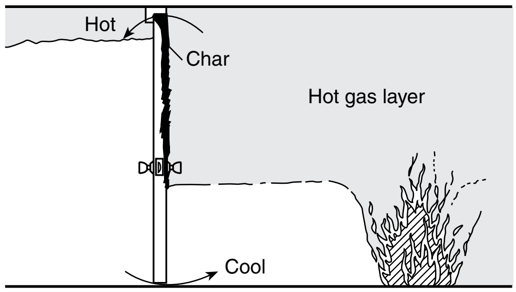


Figure 4-2.2(a) Airflow around door.

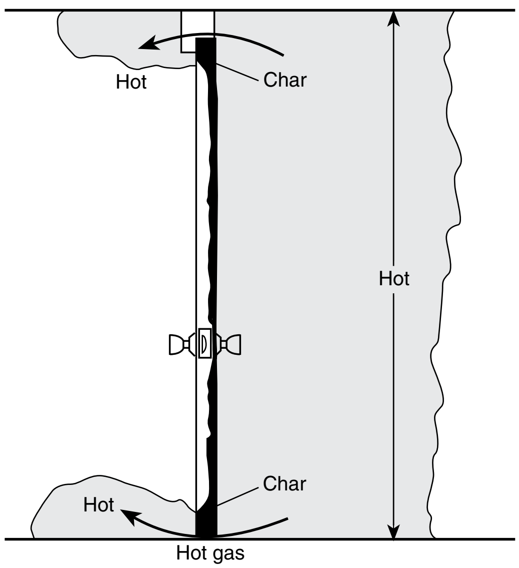


Figure 4-2.2(b) Hot gases under door.

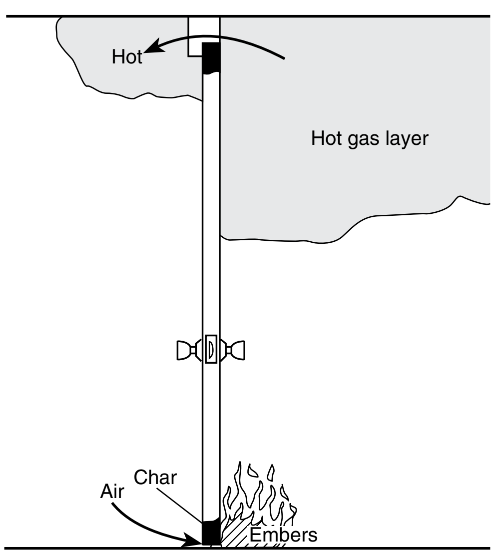


Figure 4-2.2(c) Glowing embers at base of door.

4-2.4 Patterns Generated by Full Room Involvement. If a fire progresses to full room involvement *(see 3-5.3.2)*, damage found at low levels in the room down to and including the floor can be more extensive due to the effects of high radiative flux and the convected heat from the descending hot gas layer. Damage can include charring of the undersides of furniture, burning of carpet under furniture, uniform burning around table legs, burning of baseboards and the undersides of doors, and burning on floor covering in corners. Holes can be burned through carpet and floors. The effects of protected areas and floor clutter on low burn patterns should be considered *(see 4-17.7.2 and 4-18.2)*. Although the degree of damage will increase with time, the extreme conditions of the full room involvement can produce major damage in a few minutes depending on ventilation and fuels present.

4-3 Fire Patterns Defined. Fire patterns are the visible or measurable physical effects that remain after a fire. These include thermal effects on materials, such as charring, oxidation, consumption of combustibles, smoke and soot deposits, distortion, melting, color changes, changes in the character of materials, structural collapse, and other effects.

4-3.1 Lines or Areas of Demarcation. Lines or areas of demarcation are the borders defining the differences in certain heat and smoke effects of the fire on various materials. They appear between the affected area and adjacent unaffected or less affected areas.

The production of lines and areas of demarcation, and the subsequent fire patterns that they define, depend on a combination of variables: the material itself, the rate of heat release of the fire, fire suppression activities, temperature of the heat source, ventilation, and the amount of time that the material is exposed to the heat.

For example, a particular material may display the same heat exposure patterns from exposure to a low-temperature heat source for a long period of time as to a high-temperature heat source for a shorter period of time. The investigator should keep this concept in mind while analyzing the nature of fire patterns.

4-3.2 Surface Effect. The nature and material of the surface that contains the fire pattern will have a bearing on the shape and nature of the pattern itself.

The shape and texture of the surface can affect the actual shape of the lines of demarcation displayed or increase or decrease the amount of pyrolysis and combustion by differing surface areas. If both a smooth and rough surface of the same material are exposed to the same source of heat, the rougher surface will sustain more damage. This is a result of the turbulence of the hot gases interacting with the surface as well as an increase in the surface to mass ratio. Differing surface coverings, such as paint, tiles, brick, wallpaper, plaster, and so forth, may increase or decrease the rate of heat treatment or burning.

Combustible surfaces will be darkened by the beginnings of pyrolysis, be burned, or be in various stages of charring, including the total loss of material. Noncombustible surfaces, such as mineral materials or metals, may exhibit color changes, oxidation, physical distortions, or melting.

4-3.3 Penetrations of Horizontal Surfaces. Penetration of horizontal surfaces, from above or below, can be caused by radiant heat, direct flame impingement, or localized smoldering with or without the effects of ventilation.

Penetrations in a downward direction are often considered unusual because the more natural direction of heat movement is upward through the action of buoyancy. In fully flashed over compartments, however, hot gases may be forced through small, pre-existing openings in a floor, resulting in a penetration. Penetrations may also arise as the result of intense burning under furniture items such as polyurethane mattresses, couches, or chairs. Flaming or smoldering under collapsed floors or roofs can also lead to floor penetrations. Downward penetration, such as a hole burned into a floor or tabletop, may need to be noted and analyzed by the investigator.

Whether a hole burned into a horizontal surface was created from above or below may be identified by an examination of the sloping sides of the hole. Sides that slope downward from above toward the hole are indicators that the fire was from above. Sides that are wider at the bottom and slope upward toward the center of the hole indicate that the fire was from below. *(See Figure 4-3.3.)*

Another reliable means of determining whether a fire moved up through, or down through, a surface is to compare the extent of destruction on the two levels separated by the surface. If fire moved up through the surface, the damage to the bottom side of the penetrated surface will be more extensive when compared to the top side. The converse is true when the fire moved downward.

It is, of course, possible for both upward and downward movement to occur through a hole during the course of a fire. The investigator should keep in mind that only the last movement through the hole may be evident.

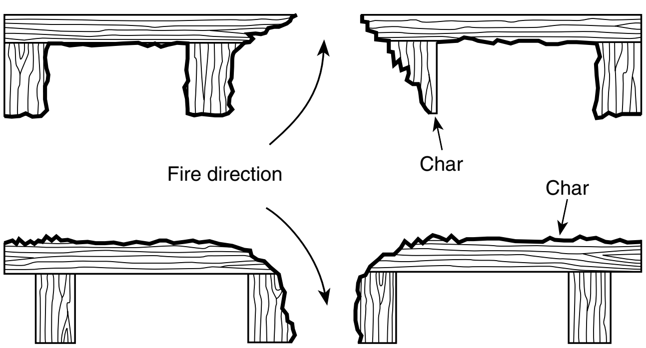


Figure 4-3.3 Burn pattern with fire from above and below.

4-3.4 Loss of Material. Typically when wood or other combustible surfaces burn they lose material and mass. The shapes and quantities of remaining combustibles can themselves produce lines of demarcation and, ultimately, fire patterns to be analyzed by the investigator.

For example, the fact that the tops of wooden wall studs are burned away at progressively lower heights can be used in the "pointer and arrow" fire pattern analysis of fire spread.

4-3.5 Victim Injuries. The investigator should carefully note and document the position and condition of any fire victims and their relationship to other objects or victims. Autopsy reports and medical records may provide useful information regarding burn damage. For example, burn damage patterns and protected areas can be used in a similar way as damage to furniture and other items discussed in previous sections.

4-4 Types of Fire Patterns. There are two basic types of fire patterns: movement patterns and intensity patterns. These types of patterns are defined largely by the fire dynamics discussed in Chapter 3. Often a systematic use of more than one type of fire pattern at a fire scene can be used in combination to lead back to the heat source that produced them.

4-4.1 Movement Patterns. Flame and heat movement patterns are produced by the growth and movement of fire and the products of combustion away from an initial heat source. If accurately identified and analyzed, these patterns can be traced back to the origin of the heat source that produced them.

4-4.2 Intensity (Heat) Patterns. Flame and heat intensity patterns are produced by the response of materials to the effects of various intensities of heat exposure. The various heat effects on a certain material can produce lines of demarcation. These lines of demarcation may be helpful to the investigator in determining the characteristics and quantities of fuel materials, as well as the direction of fire spread.

4-5 Surface Effect of Char. Many surfaces are decomposed in the heat of a fire. The binder in paint will char and darken the color of the painted surface. Wallpaper and the paper surface of gypsum wallboard will char when heated. Vinyl and other plastic surfaces on walls, floors, tables, or counters also will discolor and char. Wood surfaces also will char, but, because of the greater significance of wood char, it is being treated in greater detail in 4-5.1 through 4-5.5.

The degree of discoloration and charring can be compared to adjacent areas to find the areas of greatest burning.

4-5.1 Wood Char. Charred wood is likely to be found in nearly all structural fires. When exposed to elevated temperatures, wood undergoes chemical decomposition that drives off gases, water vapor, and various pyrolysis products as smoke. The solid residue that remains is mainly carbon. Char shrinks as it forms, and develops cracks and blisters.

4-5.2* Rate of Charring. The depth of char measurements should not be relied on to determine the duration of the burning. The rule of 1 in. (2.54 cm) in 45 minutes for the rate of charring of pine is based on one set of laboratory conditions in a test furnace. Fires may burn with more or less intensity during the course of an uncontrolled fire than under a controlled laboratory fire. Actual laboratory char rates from exposure to heat from one side vary from 0.4 in. (1 cm) per hour at 750°F (390°C) to 10 in. (25.4 cm) per hour at temperatures approaching 2000°F (1090°C) in intense fires. Even these figures will vary with the species of the wood, orientation of the grain, moisture content, and other variables. Charring rate is also a function of the velocity of hot gases and the ventilation conditions. Fast moving gases or ventilation can lead to rapid charring.

The rate of charring and burning of wood in general has no relation to its age once the wood has been dried. Wood tends to gain or lose moisture according to the ambient temperature and humidity. Thus, old dry wood is no more combustible than new kiln-dried wood if they have both been exposed to the same atmospheric conditions.

Overall, the use of the nature of char to make determinations about fuels involved in a fire should be done with careful consideration of all the possible variables that can affect the speed and severity of burning.

4-5.3 Depth of Char. Analysis of the depth of charring is most reliable for evaluating fire spread, rather than for the establishment of specific burn times or intensity of heat from adjacent burning materials. By measuring the relative depth and extent of charring, the investigator may be able to determine what portions of a material or construction were exposed the longest to a heat source. The relative depth of char from point to point is the key to appropriate use of charring — locating the places where the damage was most severe due to exposure, ventilation, or fuel placement. The investigator may then deduce the direction of fire spread, with decreasing char depths being farther away from the heat source.

4-5.3.1 Depth of Char Diagram. Lines of demarcation that may not be obviously visible can often be identified for analysis by a process of measuring and charting depths of char on a grid diagram. By drawing lines connecting points of equal char depth (isochars) on the grid diagram, lines of demarcation may be identified.

4-5.3.2 Depth of Char Analysis. Certain key variables affect the validity of depth of char pattern analysis. These factors include the following:

(a) Single versus multiple heat or fuel sources creating the char patterns being measured. Depth of char measurements may be useful in determining more than one fire or heat source.

(b) Comparison of char measurements, which should be done only for identical materials. It would not be valid to compare the depth of char from a 2 in. by 4 in. stud to the depth of char of an adjacent wooden wall panel.

(c) Ventilation factors influencing the rate of burning. Wood can exhibit deeper charring when adjacent to a ventilation source or an opening where hot fire gases can escape.

(d) Consistency of measuring technique and method. Each comparable depth of char measurement should be made with the same tool and same technique. *(See Chapter 8.)*

4-5.3.3 Measuring Depth of Char. Consistency in the method of measuring the depth of char is the key to accurate figures. Sharp pointed instruments, such as pocket knives, are not suitable for accurate measurements. The sharp end of the knife will have a tendency to cut into the noncharred wood beneath.

Thin, blunt-ended probes, such as certain types of calipers, tire tread depth gauges, or specifically modified metal rulers, are best.

The same measuring tool should be used for any set of comparable measurements. Nearly equal pressure for each measurement while inserting the measuring device is also necessary for accurate results.

Char depth measurements should be made at the center of char blisters, rather than in or near the crevasses between blisters. *(See Figure 4-5.3.3.)*

When determining the depth of charring, the investigator should take into consideration any burned wood that may have been completely destroyed by the fire and add that missing depth of wood to the overall depth measurement.

4-5.4 Depth of Char Patterns with Fuel Gases. When fugitive fuel gases are the initial fuel sources for fires, they produce relatively even depths of char over the often wide areas that they cover.

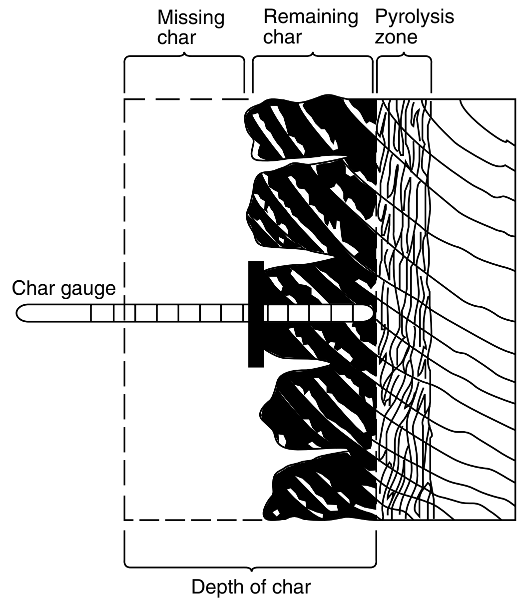


Figure 4-5.3.3 Measuring depth of char.

Progressive changes in depth of char that are used by investigators to trace fire spread may exist only in those areas to which the fire spreads from the initial locations of the pocketed fuel gases.

Deeper charring may exist in close proximity to the point of gas leakage, as burning may continue there after the original quantity of gas is consumed. This charring may be highly localized because of the pressurized gas jets that can exist at the immediate point of leakage and may assist the investigator in locating the leak.

4-5.5 Interpretation of Char. The appearance of the char and cracks has been given meaning by the fire investigation community beyond what has been substantiated by controlled experimentation. It has been widely stated that the presence of large shiny blisters (alligator char) is proof that a liquid accelerant was present during the fire. This is a misconception. These types of blisters can be found in many different types of fires. There is no justification that the appearance of large, curved blisters is an exclusive indicator of an accelerated fire.

It is sometimes claimed that the surface appearance of the char, such as dullness, shininess, or colors, has some relation to the use of a hydrocarbon accelerant or the rate of fire growth. There is no scientific evidence of such a correlation, and the investigator is advised not to claim indications of accelerant or fire growth rate on the basis of the appearance of the char alone.

Depth of char is often used to estimate the duration of a fire. The rate of charring of wood varies widely depending upon such variables as the following:

(a) Rate and duration of heating
(b) Ventilation effects
(c) Surface area to mass ratio
(d) Direction, orientation, and size of wood grain
(e) Species of wood (pine, oak, fir, etc.)
(f) Moisture content
(g) Nature of surface coating

The investigator is cautioned that no specific time of burning can be determined based solely on depth of char.

4-6 Spalling. Spalling is the breakdown in surface tensile strength of concrete, masonry, or brick caused by exposure to high temperatures and rates of heating resulting in mechanical forces within the material. These forces are believed to result from one or more of the following:

(a) Moisture present in uncured or "green" concrete

(b) Differential expansion between reinforcing rods or steel mesh and the surrounding concrete

(c) Differential expansion between the concrete mix and the aggregate (This is most common with silicon aggregates.)

(d) Differential expansion between the fine grained surface finished layers and the courser grained interior layers

(e) Differential expansion between the fire exposed surface and the interior of the slab

Spalling of concrete or masonry surfaces may be caused by heat, freezing chemicals, or abrasion. It may be more readily induced in poorly formulated or finished surfaces. Spalling is characterized by distinct lines of striation and the loss of surface material resulting in cracking, breaking, and chipping or in the formation of craters on the surface.

Spalling of concrete, masonry, or brick has often been linked to unusually high temperatures caused by burning accelerant. While spalling can involve high rates of heat release or a rapid change in temperature, an accelerant need not be involved. The primary mechanism of spalling is the expansion or contraction of the surface while the rest of the mass expands or contracts at a different rate.

Spalled areas may appear lighter in color than adjacent areas. This lightening can be caused by exposure of clean subsurface material. Adjacent areas may also tend to be sooted.

Another factor in the spalling of concrete is the loading and stress in the material at the time of the fire. Since these high-stress or high-load areas may not be related to the fire location, spalling of concrete on the underside of ceilings or beams may not be directly over the origin of the fire. *(See Figure 4-6.)*

Figure 4-6 Spalling on ceiling.

4-6.1* Interpretations of Spalling. Spalling of concrete at a fire scene has been, in the past, thought to be a positive indicator of a liquid accelerant–involved fire.

The rapid cooling of a heated mass of concrete, brick, or masonry can also cause spalling. A common source of rapid cooling in a fire situation is extinguishment by water.

The presence or absence of spalling at a fire scene should not, in and of itself, be construed as an indicator of the presence or absence of liquid fuel accelerant. The presence of ignitible liquids will not normally cause spalling beneath the surface of the liquid. The ability of the surface to absorb or hold the liquid may be a factor in the production of spalling, especially on horizontal surfaces such as concrete floors. For example, a painted or sealed concrete floor is unlikely to spall. Rapid and intense heat development from an ignitible liquid fire may cause spalling on adjacent surfaces, or a resultant fire may cause spalling on the surface after the ignitible liquid burns away.

Since spalling can occur from sources other than fires, it is desirable to determine whether spalling was present prior to the fire.

Overall, it should be noted that the importance of spalling to the fire investigator lies in the documentation and analysis of a heat source.

4-7 Oxidation. Oxidation is the basic chemical process associated with combustion. Oxidation of some materials that do not burn can produce lines of demarcation and fire patterns of use to fire investigators. Oxidation for these purposes may be defined as a combination of oxygen with substances such as metals, rock, or soil that is brought about by high temperatures.

The effects of oxidation include change of color and change of texture. The higher the temperature and the longer the time of exposure, the more pronounced the effects of oxidation will be. Bare galvanized steel with mild heating will get a dull whitish surface from oxidation of the zinc coating. This oxidation also eliminates the protection that the zinc gave the steel. If the unprotected steel is wet for some time, it will then rust. Thus there can be a pattern of rusted compared to nonrusted galvanized steel.

When uncoated iron or steel is oxidized in a fire, the surface first gets a blue-gray dullness. Oxidation can proceed to thick layers of oxide that can flake off. After the fire, if the metal has been wet, the usual rust-colored oxide may appear.

On stainless steel surfaces, mild oxidation can give color fringes, and severe oxidation will give a dull gray color.

Copper forms a dark red or black oxide when exposed to heat. The color is not significant. What is significant is that the oxidation can form a line of demarcation. The thickness of the oxide can show greater fire conditions. The more it is heated, the greater the oxidation. These color changes can form lines of demarcation. Burn patterns created on metal appliance cabinets may be helpful in determining fire origin and direction of travel.

Rocks and soil when heated to very high temperatures will often change colors that may range from yellowish to red.

Soot and char are also subject to oxidation. The dark char of the paper surface of gypsum wallboard, soot deposits, and paint can be oxidized by continued exposure to fire heat. The carbon will be oxidized to gases and disappear from whatever surface it was on. This will result in what is known as clean burn. *(See Section 4-11.)*

4-8 Melting of Materials. The melting of a material is a physical change from a reaction caused by heat. The border between the melted and solid portions of a fusible material can produce lines of heat and temperature demarcation that the investigator can use to define fire patterns.

Many solid materials soften or melt at elevated temperatures ranging from a little over room temperature to thousands of degrees. A specific melting temperature or range is characteristic for each material. *(See Table 4-8.)*

Melting temperatures of common metals range from as low as 338°F to 370°F (170°C to 188°C) for solder to as high as 2660°F (1460°C) for steel. When the metals or their residues are found in fire debris, some inferences concerning the temperatures in the fire can be drawn.

Thermoplastics melt at rather low temperatures ranging from around 200°F (93°C) to near 750°F (400°C). They can also be consumed in a fire. Thus, the melting of plastics can give information on temperatures but mainly where there have been hot gases but little or no flame in that immediate area.

Glass melts or softens over a range of temperatures. Nevertheless, glass can give useful information on temperatures during a fire.

4-8.1 Temperature Determination. If the investigator knows the approximate melting temperature of a material, an estimate can be made of the temperature to which the melted material was subjected. This knowledge may assist in evaluating the intensity and duration of the heating, the extent of heat movement, or the relative rates of heat release from fuels.

When using such variable materials as glass, plastics, and white pot metals for making temperature determinations, the investigator is cautioned that there are a wide variety of melting temperatures for these generic materials. The best method when utilizing such materials as temperature indicators is to take a sample of the material and have its melting temperature ascertained by a competent laboratory, materials scientist, or metallurgist.

Wood and gasoline burn at essentially the same flame temperature. The flame temperatures achieved by all hydrocarbon fuels (plastics and ignitible liquids) and cellulosic fuels are approximately the same, although the fuels release heat at different rates.

The temperature achieved by an item at a given location within a structure or fire area depends on how much it is heated. The amount of heating depends on the temperature and velocity of the airflow, the geometry and physical properties of the heated item, its proximity to the source of heat, and the amount of heat energy present. Burning metals and highly exothermic chemical reactions can produce temperatures significantly higher than those created by hydrocarbon- or cellulosic-fueled fires.

Identifiable temperatures achieved in structural fires rarely remain above 1900°F (1040°C) for long periods of time. These identifiable temperatures are sometimes called "effective fire temperatures," for they reflect physical effects that can be defined by specific temperature ranges. The investigator can use the analysis of the melting and fusion of materials to assist in establishing whether higher than expected heat energy was present.

4-8.2 Alloying of Metals. The melting of certain metals may not always be caused by fire temperatures higher than the metals' stated melting point. It may be caused by alloying.

Table 4-8 Melting Temperatures (Approximate) of Common Materials

Material	°F	°C
Aluminum (alloys)[b]	1050–1200	566–650
Aluminum[a]	1220	660
Brass (yellow)[b]	1710	932
Brass (red)[b]	1825	996
Bronze (aluminum)[b]	1800	982
Cast iron (gray)[a]	2460–2550	1350–1400
Cast iron (white)[a]	1920–2010	1050–1100
Chromium[a]	3350	1845
Copper[a]	1981	1082
Fire brick (insulating)[a]	2980–3000	1638–1650
Glass[a]	1100–2600	593–1427
Gold[a]	1945	1063
Iron[a]	2802	1540
Lead[a]	621	327
Magnesium (AZ31B alloy)[b]	1160	627
Nickel[a]	2651	1455
Paraffin[a]	129	54
Plastics (thermo)		
ABS[d]	190–257	88–125
Acrylic[d]	194–221	90–105
Nylon[d]	349–509	176–265
Polyethylene[d]	251–275	122–135
Polystyrene[d]	248–320	120–160
Polyvinylchloride[d]	167–221	75–105
Platinum[a]	3224	1773
Porcelain[a]	2820	1550
Pot metal[e]	562–752	300–400
Quartz (SiO_2)[a]	3060–3090	1682–1700
Silver[a]	1760	960
Solder (tin)[a]	275–350	135–177
Steel (stainless)[b]	2600	1427
Steel (carbon)[b]	2760	1516
Tin[a]	449	232
Wax (paraffin)[c]	120–167	49–75
White pot metal[e]	562–752	300–400
Zinc[a]	707	375

[a]From Baumeister, Avallone, and Baumeister III, *Marks' Standard Handbook for Mechanical Engineers.*
[b]From Lide, ed., *Handbook of Chemistry and Physics.*
[c]From NFPA 325, *Guide to Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids*, 1994 edition.
[d]From *Plastics Handbook.*
[e]From *Engineering Formulas.*

During a fire, a metal with a relatively low melting point may drip onto other metals that do not often melt in fires. This phenomenon can also occur when component parts of a heated object are in contact with each other. If the lower-melting-temperature metal can mix with the higher-melting-temperature metal, that mixture (alloy) will melt at a temperature less than the melting temperature of the higher-melting-temperature metal and in some cases less than that of either metal. Examples of relatively low-melting-temperature metals are aluminum, zinc, and lead. *(See Table 4-8.)* Metals that can be affected by alloying include copper and iron (steel). Copper alloying is often found, but iron (steel) alloying might be found in only a few cases of sustained fire.

Copper wiring and tubing or piping are often affected by alloying. Drips of low-melting-temperature metal may simply stick to the surface if the heating has been brief. With further heating the low-melting-temperature metal will wet the surface and begin to mix. Aluminum can mix through the wire or wall of the tubing to give a yellow alloy at about 10 percent aluminum, but that is not often found. More commonly the aluminum will mix in higher proportions and give a brittle silvery alloy. The surface of the spot of aluminum on the surface of the copper may appear gray, and the surface may be fairly dark near the copper-aluminum interface. Copper that has been alloyed with aluminum will be very brittle. For example, bending copper wire at the point of alloying will likely cause it to break there.

When zinc alloys with copper, a yellowish brass will result. Because zinc is less common in buildings than aluminum, zinc alloying is not often encountered.

Alloys do not form readily with steel in fires. However, if aluminum or zinc is heated for a long time with a steel object, that object may develop pits or holes from alloying.

If fire evidence containing aluminum-alloyed copper is exposed to weather, the alloy may corrode away, leaving neat holes in tubing or blunt ends on wires. Those edges will not have the appearance of melting.

Alloying may be confirmed by metallurgical analysis, and the alloy may be identified. When metals with high melting temperatures are found to have melted due to alloying, it is not an indication that accelerants or unusually high temperatures were present in the fire.

4-9 Thermal Expansion and Deformation of Materials. Many materials change shape temporarily or permanently during fires. Nearly all common materials expand when heated. That can affect the integrity of solid structures when they are made from different materials. If one material expands more than another material in a structure, the difference in expansion can cause the structure to fail.

The bending of steel beams and columns in a fire above about 1000°F (538°C) is caused by the progressive loss of strength of the steel. The more the load on any unrestrained steel object, the more will be the deformation for a given time and temperature. Bending is not a matter of melting. Thermal expansion can also be a factor in the bending of the beam, if the ends of the beam are restrained.

Plastered surfaces are also subject to thermal expansion. Locally heated portions of plaster walls and ceilings may expand and separate from their support lath. This breaking away of the plaster can produce lines or areas of heat demarcation displaying V patterns, U patterns, and truncated cone patterns.

4-10 Smoke and Soot. Fuels that contain carbon can form soot in their flames. Petroleum products and most plastics form soot most readily. When flames touch walls and ceilings, soot will commonly deposit. A specific deposit shows where there has been a particular fuel load. Soot also deposits on surfaces by settling. Such general soot deposits show merely that soot formed nearby but do not indicate the specific source.

Smoke and soot can collect on cooler surfaces of a building or its contents, often on upper parts of walls in rooms adjacent to the fire. Smoke, especially from smoldering fires, tends to condense on walls, windows, and other cooler surfaces. Because deposits of pyrolysis products tend to be widely distributed, they do not help locate the exact point of origin.

Smoke condensates are shades of brown whereas soot is black. Smoke condensates can be wet and sticky, thin or thick, or dried and resinous. These deposits, after drying, are not easily wiped off. Where there has been open flame, the deposits will likely be a mixture of soot and smoke. When smoke deposits are subsequently heated in a fire, the brown deposit may be changed in color, texture, and composition and may become darker or charred.

Some fires might produce only dry soot deposits that wipe easily from windows or other surfaces. Floors and top surfaces of contents often get a coating of soot that settles on them during and after sooty fires.

Both the carbonized smoke deposit and soot deposits can be burned off of windows or other surfaces by prolonged exposure to fire.

4-11 Clean Burn. Clean burn is a phenomenon that appears on noncombustible surfaces when the soot and smoke condensate that would normally be found adhering to the surface is burned off. This produces a clean area adjacent to areas darkened by products of combustion. *(See Figure 4-11.)* Clean burn is produced most commonly by direct flame contact or intense radiated heat.

Although they can be indicative of intense heating in an area, clean burn areas by themselves do not necessarily indicate areas of origin. The lines of demarcation between the clean burn and sooted areas may be used by the investigator to determine direction of fire spread or differences in intensity or time of burning.

The investigator should be careful not to confuse the clean burn area with spalling. Clean burn does not show the loss of surface material that is a characteristic of spalling.

Figure 4-11 Clean burn on wall surface.

4-12 Calcination. The term *calcination* is used by fire investigators to cover the numerous changes that occur in plaster or gypsum wall surfaces during a fire. Calcination of a true plaster wall involves driving the chemically bound water out of the gypsum.

The gypsum wallboard most often used has a more complex response to heat than plaster. First the paper surface will char and might also burn off. The gypsum on the side exposed to fire becomes gray from charring of the organic binder and destiffener in it. With further heating, the gray color will go all the way through, and the paper surface on the backside will char. The face exposed to fire will become whiter as the carbon is burned away. When the entire thickness of wallboard has turned whitish, there will be no paper left on either face, and the gypsum will be dehydrated and converted to a crumbly solid. Such a wallboard might stay on a vertical wall but will drop off of an overhead surface. Fire-rated gypsum wallboard has mineral fibers or vermiculite particles embedded in the gypsum to preserve the strength of the wallboard during fire exposure. The fibers add strength to the wallboard even after it has been thoroughly calcined.

Color changes other than shades of gray may occur after gypsum wall surfaces are exposed to heat. The color itself has no significance to the fire investigator. However, the difference between colors may show lines of demarcation.

The relationship between the calcined and not calcined areas on plaster or gypsum wallboard can also display lines of demarcation.

4-13 Window Glass. Many texts have related fire growth history or fuels present to the type of cracking and deposits that resulted on window glass. There are several variables that affect the condition of glass after fire. These include the type and thickness of glass, rate of heating, degree of insulation to the edges of the glass provided by the glazing method, degree of restraint provided by the window frame, history of the flame contact, and cooling history.

4-13.1* Breaking of Glass. If a pane of glass is mounted in a frame that protects the edges of the glass from radiated heat of fire, a temperature difference occurs between the unprotected portion of the glass and the protected edge. Experimental research estimates that a temperature difference of about 70°C (158°F) between the center of the pane of glass and the protected edge can cause cracks that start at the edge of the glass. The cracks appear as smooth, undulating lines that can spread and join together. Depending on the degree of cracking, the glass may or may not collapse from its frame.

If a pane of glass has no edge protection from radiated heat of fire, the glass will break at a higher temperature difference. Also, experimental research suggests that fewer cracks are formed and the pane is more likely to stay whole.

Glass that has received an impact will have a characteristic "cobweb" pattern. The cracks will be in straight lines and numerous. The glass may have been broken before, after, or during the fire.

If flame suddenly contacts one side of a glass pane while the unexposed side is relatively cool, a stress can develop between the two faces and the glass can fracture between the faces.

Crazing is a term used in the fire investigation community to describe a complicated pattern of short cracks in glass. These cracks may be straight or crescent-shaped and may or may not extend though the thickness of the glass. Crazing has been theorized as being the result of very rapid heating of one side of the glass while the other side remains cool. There is no published research to confirm this theory. However, there is published research establishing that crazing can be created by the rapid cooling of glass by the application of water spray in a hot environment.

Occasionally with small size panes, differential expansion between the exposed and unexposed faces may result in the pane popping out its frame.

The pressures alone developed by fires in buildings generally are not sufficient to either break glass windows or force them from their frames. Pressures required to break ordinary window glass are in the order of 0.3 psi to 1.0 psi (2.07 kPa to 6.90 kPa) while pressures from fire are in the order of 0.002 psi to 0.004 psi (0.014 kPa to 0.028 kPa). If an overpressure has occurred — such as a deflagration, backdraft, or detonation — glass fragments from a window broken by the pressure will be found some distance from the window. For example, an overpressure of 1.5 psi (10.3 kPa) can cause fragments to travel as far as 100 ft (30.3 m).

The investigator is urged to be careful not to make conclusions from glass breaking morphology alone. Both crazing and long, smooth, undulating cracks have been found in adjacent panes. The small craters or pits found in the surface of glass are believed to be the result of rapid cooling by water spray during fire suppression activities.

4-13.2* Tempered glass, whether broken when heated by fire impact or when exploded, will break into many small cube-shaped pieces. Such glass fragments should not be confused with crazed glass. Tempered glass fragments are more regularly shaped than the complicated pattern of short cracks of crazing.

Tempered glass is commonly found in applications where safety from breakage is a factor — such as in shower stalls, patio doors, TV screens, motor vehicles, and in commercial and other public buildings.

4-13.3 Staining of Glass. Glass fragments that are free of soot or condensates have likely been subjected to rapid heating, failure early in the fire, or flame contact. The proximity of the glass to the area of origin or heat source and ventilation are factors that can affect the degree of staining.

The presence of a thick, oily soot on glass, including hydrocarbon residues, has been interpreted as positive proof of the presence or use of liquid accelerant. Such staining can also result from the incomplete combustion of other fuels such as wood and plastics and cannot be exclusively interpreted as having come from an accelerant.

4-14* Collapsed Furniture Springs. The collapse of furniture springs may provide the investigator with various clues concerning the direction, duration, or intensity of the fire. However, the collapse of the springs cannot be used to indicate exposure to a specific type of heat source or ignition such as smoldering ignition or the presence of an ignitible liquid. The results of laboratory testing indicate that the annealed springs, and the associated loss of tension (tensile strength), is a function of the application of heat. These tests revealed that short-term heating at high temperatures and long-term heating at moderate temperatures over 750°F (400°C) can result in the loss of tensile strength and in the collapse of the springs. Tests also revealed that the presence of a load, or weight, on the springs while they are being heated increases the loss of tension.

The value of analyzing the furniture springs is in comparing (comparative analysis) the differences in the springs to other areas of the mattress, cushion, frame, and so forth. Comparative analysis of the springs can assist the investigator in developing hypotheses concerning the relative exposure to a particular heat source. For example, if at one end of the cushion or mattress the springs have lost their tension and the other end has not, then hypotheses may be developed, while taking into consideration other circumstances, effects (such as ventilation), and evidences at the scene concerning duration or intensity of the fire, the area of origin or the direction of heat travel, or relative proximity of the heat source. In any event, the portion with the loss of spring strength may indicate greater relative exposure to heat than those areas without the loss of strength.

Other circumstances and effects that may be considered along with analyzing the springs include the loss of mass and material or depth of char to the frame if constructed of wood. Similar analysis may also include color changes, possibly indicating intensity, in metal frames.

Still other effects for comparative analysis include considerations of the covering material of the springs. The absence of material may indicate that the portion closer to the source of heat, while the presence of materials may indicate an area more remote from the heat source.

The investigator should also consider the condition of the springs prior to the fire.

4-15 Location of Objects. Certain types of patterns can be used to locate the positions of objects as they were during a fire.

4-15.1 Heat Shadowing. Heat shadowing results from an object blocking the travel of radiated heat, convected heat, or direct flame contact from its source to the material on which the pattern is produced. Conducted heat, however, does not produce heat shadowing.

The object blocking the travel of the heat energy may be a solid or liquid, combustible or noncombustible. Any object that absorbs or reflects the heat energy may cause the production of a pattern on the material it protects.

Heat shadowing can change, mask, or prohibit the production of identifiable lines of demarcation that may have appeared on that material. Patterns produced by the heat shadowing, may, however, assist the fire investigator in the process of reconstruction during origin determination.

4-15.2 Protected Areas. Closely related in appearance to the resulting pattern of heat shadowing is a protected area. A protected area results from an object preventing the products of combustion from depositing on the material that the object protects, or prevents the protected material from burning.

The object preventing the depositing of products of combustion may be a solid or liquid, combustible or noncombustible. Any object that prevents the settling of the products of combustion, or prevents the burning of the material, may prevent the development of a pattern on the material it protects. *(See Figure 4-15.2.)*

Patterns produced by protected areas may, however, assist the fire investigator in the process of fire scene reconstruction during the origin determination by indicating the location of objects in their pre-fire locations. *(See Section 11-7.)*

4-16 Locations of Patterns. Fire patterns may be found on any surface that has been exposed to the effects of the fire or its by-products. These surfaces would include interior surfaces, external surfaces and structural members, and outside exposures surrounding the fire scene.

Interior surfaces would commonly include walls, floors, ceilings, doors, windows, furnishings, appliances, machinery, equipment, other contents, personal property, confined spaces, attics, closets, and the insides of walls.

Exterior surfaces would commonly include walls, eaves, roofs, doors, windows, gutters and downspouts, utilities (meters, service drops, etc.), porches, and decks.

Outside exposures would commonly include outbuildings, adjacent structures, trees and vegetation, utilities (poles, lines, meters, fuel storage tanks, transformers, etc.), vehicles, and other objects.

Figure 4-15.2 Photograph on top shows protected area, while photograph at bottom shows how the chair was positioned during the fire.

4-16.1 Walls, Ceilings, and Floors. Fire patterns are often found on walls, ceilings, and floors. As the hot gas zone and the flame zone of the fire plume encounter these obstructions, patterns are produced that investigators may use to trace a fire's origin. *(See Chapter 3.)*

4-16.1.1 Walls. Patterns that are displayed on walls are the most noticeable. The patterns may appear as heat treatment lines of demarcation on the surfaces of the walls or may be manifested as deeper burning. Once the actual surface coverings of the walls are destroyed by burning, the underlying support studs can also display various patterns. These patterns are most commonly V patterns, U patterns, clean burn, and spalling.

4-16.1.2 Ceilings. The investigator should not ignore patterns that occur on ceilings or the bottom surfaces of such horizontal constructions as tabletops or shelves. The buoyant nature of fire gases concentrate the heat energy at horizontal surfaces above the heat source. Therefore, the patterns that are created on the underside of such horizontal surfaces can be indicators of locations of heat sources. Although areas immediately over the source of heat and flame will generally experience heating before the other areas to which the fire spreads, circumstances can occur where fuel at the origin burns out quickly but the resulting fire spreads to an area where a larger supply of fuel can ignite and burn for a longer period of time. This can cause more damage to the ceiling than in the area immediately over the origin.

These horizontal patterns are roughly circular. Portions of circular patterns are often found where walls meet ceilings or shelves and at the edges of tabletops and shelves.

The investigator should determine the approximate center of the circular pattern and investigate below this center point for a heat source.

4-16.1.3 Damaged Inside Walls and Ceilings. Fire damage to combustible construction elements behind walls and ceilings has sometimes been interpreted to mean that the fire started within the wall or ceiling. This may not always be correct.

It is possible for the heat of a fire to be conducted through a wall or ceiling surface and ignite wooden structural members within the wall or ceiling. The ability of the surface to withstand the passage of heat over time is called its finish rating.

While the finish rating of a surface material only represents the performance of the material in a specific laboratory test (e.g., UL 263, *Standard for Safety Fire Tests of Building Construction and Materials*) and not necessarily the actual performance of the material in a real fire event, knowledge of the finish ratings concept can be of value to an investigator's overall fire spread analysis.

This heat transfer process can be observed by the charring of the wooden structural element covered by the protective membrane. *(See Figure 4-16.1.3.)*

4-16.1.4* Floors. Floors should not be ignored by the investigator. Patterns on floors and floor coverings can be produced by the effects of intense radiation from flaming furniture, burning plastics, or liquids, or from the hot gas layer produced by flaming combustion. Should flashover occur, it results from a radiant heat flux that exceeds 20 kW/m^2, a typical value for the radiant ignition of common combustible construction materials. Post-flashover or full room involvement conditions can typically produce fluxes in excess of 170 kW/m^2 and may modify or obliterate pre-existing patterns. Flashover produces a radiant heat flux that exceeds 2 $watts/cm^2$, a typical value for the radiant ignition of common combustible construction materials.

Since 1970, carpeting and rugs manufactured or imported to be sold in the United States have been resistant to ignition or fire spread. Typically, cigarettes or matches dropped on carpets will not set them on fire. ASTM D 2859, *Standard Test Method for Flammability of Finished Textile Floor Covering Materials* (Methanamine Pill Test) describes the test used to measure the ignition characteristics of carpeting from a small ignition source. Carpeting and rugs passing the pill test will have very limited ability to spread flame or char in a horizontal direction when exposed to small ignition sources such as a cigarette or match.

Fire will not spread across a room on the surface of these carpets or rugs without external help, such as from a fire external to the carpet in which case the fire spread on the carpet will terminate at a point where the radiant energy from the exposing fire is less than the minimum needed to support flame spread on the carpet (critical radiant flux). Carpet is expected to burn when exposed to flashover conditions since the radiant heat flux that produces flashover exceeds the carpet's critical radiant flux.

Burning between seams or cracks of floorboards or around door thresholds, sills, and baseboards may or may not indicate the presence of an ignitible liquid. If the presence of an ignitible liquid is suspected, samples should be collected and laboratory tests used to verify their presence. *(See Section 9-5.)*

Burning from full room involvement can also produce burning of floors or around door thresholds, sills, and baseboards due to radiation, the presence of hot combustible fire gases, or air sources (ventilation) provided by the gaps in construction. These gaps can provide sufficient air for combustion of, on, or near floors *(see 4-2.2)*. If the investigator develops a hypothesis that charring in these areas resulted from these effects, samples can also be taken to indicate an ignitible liquid was not present. Like other areas of low burning, holes burned in floors can be produced by the presence of ignitible liquids, glowing embers, or the effects of flashover or full room involvement. The collection of samples and laboratory verification of the presence or absence of ignitible liquid residues may assist the investigator in developing hypotheses and drawing conclusions concerning the development of the holes.

Fire-damaged vinyl floor tiles often exhibit curled tile edges exposing the floor beneath. The curling of tile edges can frequently be seen in nonfire situations and is due to natural shrinkage and curling of the tiles from loss of plasticizer. In a fire situation, the presence of radiation from a hot gas layer will produce the same patterns. This pattern can also be caused by ignitible liquids. Analysis for their presence may be difficult due to the presence of hydrocarbons in tile adhesives.

Unburned areas present after a fire can reveal the location of content items that protected the floor or floor covering from radiation damage or smoke staining.

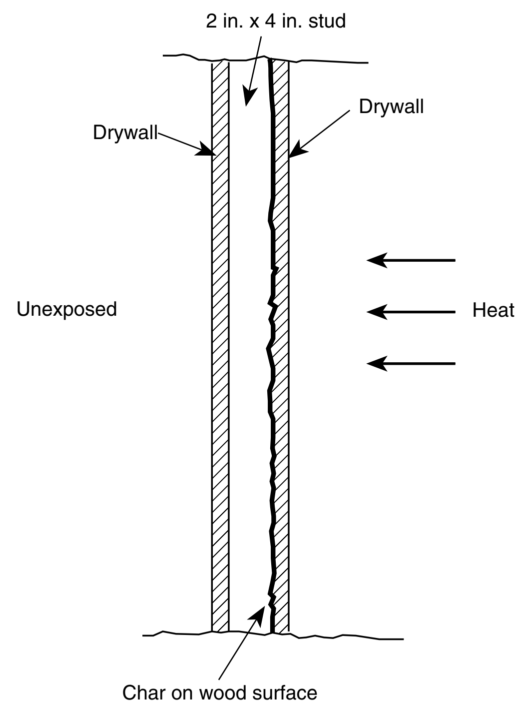


Figure 4-16.1.3 Charring of wooden structural elements by heat conduction through wall surface material.

4-16.2 Outside Surfaces. External surfaces of structures can also display fire patterns. In addition to the regular patterns, both vertical and horizontal external surfaces can display burn-through. All other variables being equal, these burn-through areas can identify areas of intense or long-duration burning.

4-16.3 Building Contents. The sides and tops of building contents can form the bounding surfaces for fire patterns as well. Any patterns that can be produced on walls, ceilings, and floors can also be produced on the sides, tops, and underside of chairs, tables, shelves, furniture, appliances, equipment, machinery, or any other contents. The patterns will be similar in shape but may only display portions of patterns because of their size.

4-16.4 Elevation. Patterns can also be used to determine the height at which burning may have begun within the structure.

4-16.4.1 Low Burn Patterns. It is common for the lowest portions of fire patterns to be closer to their heat sources. In general, fires tend to burn upward and outward from their origins. Fire plumes made up of the hot gases and airborne products of combustion are expanding and less dense than the surrounding air and are therefore buoyant. The growth in volume and buoyancy causes these heated products to rise and spread. The investigator should identify these areas of low burning and be cognizant of their possible proximity to a point of origin.

4-16.4.2 Fall Down (Drop Down). The investigator should keep in mind that during the progress of a fire, burning debris often falls to lower levels and then burns upward from there. This occurrence is known as "fall down" or "drop down." Fall down can ignite other combustible materials producing low burn patterns that may be confused with the area of fire origin.

4-17 Pattern Geometry. Various patterns having distinctive geometry or shape are created by the effects of fire and smoke exposure on building materials and contents. In order to identify them for discussion and analysis they have been described in the field by terms that are indicative of their shapes. While these terms generally do not relate to the manner in which the pattern was formed, the descriptive nature of the terminology makes the patterns easy to recognize. The discussion that follows will refer to patterns by their common names and provide some information about how they were formed and their interpretation. Additional information can be found in Section 4-2.

Since the interpretation of all possible fire patterns cannot be traced directly to scientific research, the user of this guide is cautioned that alternative interpretations of a given pattern are possible. In addition, patterns other than those described may be formed. Definitive scientific research in this area has begun. In any situation where the presence of ignitible liquids is suggested, the effects of flashover, airflow, hot gases, melted plastics, and building collapse should be eliminated.

4-17.1 V Patterns on Vertical Surfaces. The appearance of the V-shaped pattern is created by flames, convective or radiated heat from hot fire gases, and smoke within the fire plume. *(See 4-2.1.)* The V pattern often appears as lines of demarcation *(see 4-3.1)* defining the borders of the fire plume and less heated areas outside the plume. *(See Figure 4-17.1.)*

The angle of the V-shaped pattern is dependent on several variables *(see 4-2.1)*, including the following:

(a) The heat release rate (HRR) and geometry of the fuel

(b) The effects of ventilation

(c) The ignitibility of the vertical surface on which it appears and combustibility of the vertical surface on which they appear

(d) The presence of interceding horizontal surfaces such as ceilings, shelves, table tops, or the overhanging construction on the exterior of a building *(See 4-2.1.)*

The angle of the borders of the V pattern does not indicate the speed of fire growth, such as a wide V indicating a slowly growing fire or a narrow V indicating a rapidly growing fire.

4-17.2 Inverted Cone Patterns. Inverted cones are commonly caused by the vertical flame plumes of the burning volatile fuels not reaching the ceiling.

4-17.2.1 Interpretation of Inverted Cone Patterns. Inverted cone patterns are manifestations of relatively short-lived fires that do not fully evolve into floor-to-ceiling flame plumes or flame plumes that are not vertically restricted by ceilings. Because they often appear on noncombustible surfaces, they do not always readily spread to nearby combustibles. For this reason, many investigators have taken to inferring from these patterns that the fires that caused them were fast burning.

The correct analysis of such patterns is that the burning was of relatively short duration rather than any relationship to the rate of heat release. That short duration occurred because additional fuel sources did not become involved after the initial fuel was consumed.

Inverted cone patterns have been interpreted as proof of flammable liquid fires, but any fuel source (leaking fuel gas, Class A fuels, etc.) that produces flame zones that do not become vertically restricted by a horizontal surface, such as a ceiling or furniture, can produce inverted cone patterns.

Figure 4-17.1 Typical V pattern showing wall and wood stud damage.

4-17.2.2 Inverted Cone Patterns with Natural Gas. Leaking natural gas is prone to the production of inverted cone patterns. This is especially true in the case of natural gas if the leakage occurs from below floor level and escapes above at the intersection of the floor and a wall. *(See Figure 4-17.2.2.)* The subsequent burning often does not reach the ceiling and is manifested in the production of the characteristic triangular inverted cone pattern shape.

4-17.3 Hourglass Patterns. The plume of hot gases above a fire is composed of a hot gas zone shaped like a V and a flame zone at its base. The flame zone is shaped like an inverted V. When the hot gas zone is truncated by a vertical plane surface, the typical V pattern is formed. If the fire itself is very close to or in contact with the vertical surface, the resulting pattern will show the effects of both the hot gas zone and the flame zone together as a large V above an inverted V. The inverted V is generally smaller and may exhibit more intense burning or clean burn. The overall pattern that results is called an "hourglass." *(See 4-2.1.)*

4-17.4 U-Shaped Patterns. U patterns are similar to the more sharply angled V patterns but display gently curved lines of demarcation and curved rather than angled lower vertices. *(See Figure 4-17.4.)* U-shaped patterns are created by the effects of radiant heat energy on the vertical surfaces more distant from the same heat source than surfaces displaying sharp V patterns. The lowest lines of demarcation of the U patterns are generally higher than the lowest lines of demarcation of corresponding V patterns that are closer to the fire source.

U patterns are analyzed similarly to V patterns, with the additional aspect of noting the relationship between the height of the vertex of the U pattern as compared to the height of the vertex of the corresponding V patterns.

If there are two patterns from the same heat source, the one with the lower vertex will be closer to that heat source.

4-17.5 Truncated Cone Patterns. Truncated cone patterns, also called truncated plumes, are three-dimensional fire patterns displayed on both horizontal and vertical surfaces. *(See Figure 4-17.5.)* It is the interception or truncating of the natural cone-shaped or hourglass-shaped effects of the fire plume by these vertical and horizontal surfaces that causes the patterns to be displayed. Many fire movement patterns, such as V patterns, U patterns, circular patterns, and "pointer or arrow" patterns, are related directly to the three-dimensional "cone" effect of the heat energy created by a fire.

The cone-shaped dispersion of heat is caused by the natural expansion of the fire plume as it rises and the horizontal spread of heat energy when the fire plume encounters an obstruction to its vertical movement, such as the ceiling of a room. Thermal damage to a ceiling will generally extend beyond the circular area attributed to a "truncated cone." The truncated cone pattern combines two-dimensional patterns such as V-shaped patterns, pointers and arrows, and U-shaped patterns on vertical surfaces with the circular patterns displayed on ceilings and other horizontal surfaces.

The combination of more than one two-dimensional pattern on perpendicular vertical and horizontal surfaces gives the truncated cone pattern its three-dimensional character.

A theoretical demonstration of the truncated cone pattern is when the four vertical walls of a room each display varied V or U patterns, as well as circular or portions of circular patterns appearing on the ceiling. Corresponding patterns may also be discernible on the furnishings in the room.

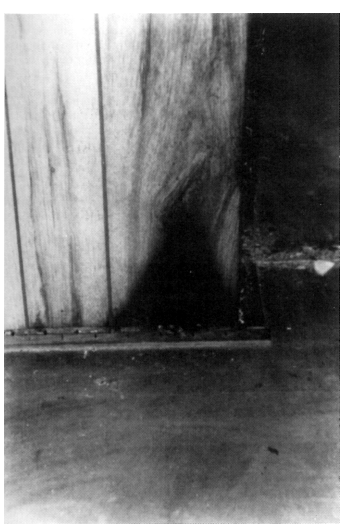


Figure 4-17.2.2 Inverted cone pattern fueled by a natural gas leak below the floor level.

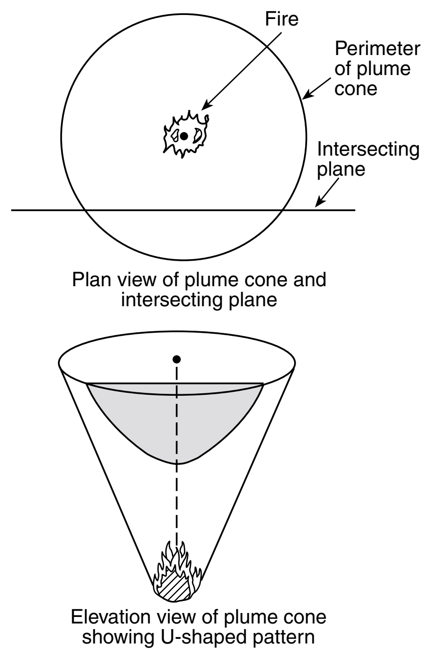


Figure 4-17.4 Development of U-shaped pattern.

4-17.6 Pointer and Arrow Patterns. These fire patterns are commonly displayed on a series of combustible elements such as wooden studs or furring strips of walls whose surface sheathing has been destroyed by fire or was nonexistent. The progress and direction of fire spread along a wall can often be identified and traced back toward its source by an examination of the relative heights and burned-away shapes of the wall studs left standing after a fire. In general, shorter and more severely charred studs will be closer to a source of fire than taller studs. The heights of the remaining studs increase as distance from a source of fire increases. The difference in height and severity of charring will be noted on the studs. *[See Figure 4-17.6(a).]*

The shape of the studs' cross section will tend to produce "arrows" pointing back toward the general area of the source of heat. This is caused by the burning off of the sharp angles of the edges of the studs on the sides toward the heat source that produces them. *[See Figure 4-17.6(b).]*

More severe charring can be expected on the side of the stud closest to the heat source.

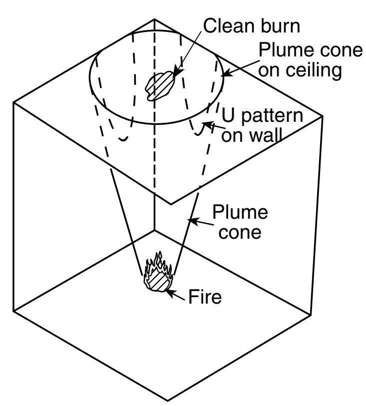


Figure 4-17.5 Truncated cone pattern.

4-17.7 Circular-Shaped Patterns. Patterns that are generally circular in shape are common at fire scenes. These patterns are never truly circular unless they represent areas that have been protected from burning by circular items, such as wastebaskets or the bottoms of furniture items.

4-17.7.1 Bottoms of Horizontal Surfaces. Patterns on the underside of horizontal surfaces — such as ceilings, tabletops, and shelves — can appear in roughly circular shapes. The more centralized the heat source, the more circular or nearly circular the patterns may appear.

Portions of circular patterns can appear on the underside of surfaces that partially block the heated gases or fire plumes. This can occur when the edge of the surface receiving the pattern does not extend far enough to show the entire circular pattern or when the edge of the surface is adjacent to a wall.

Within the circular pattern, the center may show more heat treatment, such as deeper charring. By locating the center of the circular pattern, the investigator may find a valuable clue to the source of greatest heating, immediately below.

4-17.7.2 Irregular Patterns. Irregular, curved, or "pool-shaped" patterns on floors and floor coverings cannot always be reliably identified as resulting from ignitible liquids on the basis of observation alone.

The lines of demarcation between the damaged and undamaged areas of irregular patterns range from sharp edges to smooth graduations depending on the properties of the material and the intensity of heat exposure. Denser materials like oak flooring will generally show sharper lines of demarcation than thermoplastic (e.g., nylon) carpet. The absence of a carpet pad often leads to sharper lines.

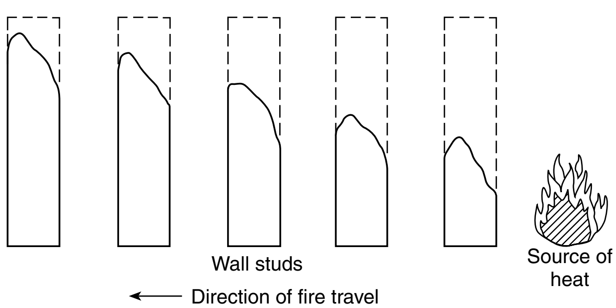


Figure 4-17.6(a) Wood wall studs showing decreasing damage as distance from fire increases.

These patterns are common in situations of post-flashover conditions, long extinguishing times, or building collapse. These patterns may result from the effects of hot gases, flaming and smoldering debris, melted plastics, or ignitible liquids. If the presence of ignitible liquids is suspected, supporting evidence such as the use of a combustible gas indicator, chemical analysis of debris for residues, or the presence of liquid containers should be sought. It should be noted that many plastic materials release hydrocarbon fumes when they pyrolize or burn. These fumes may have an odor similar to that of petroleum products and can be detected by combustible gas indicators when no ignitible liquid accelerant has been used. A "positive" reading should prompt further investigation and the collection of samples for more detailed chemical analysis. It should be noted that pyrolysis products, including hydrocarbons, can be detected in gas chromatographic analysis of fire debris in the absence of the use of accelerants. It can be helpful when analyzing carpet debris for the laboratory to burn a portion of the comparison sample and run a gas chromatographic analysis on both. By comparing the results of the burned and unburned comparison samples with those from the fire debris sample, it may be possible to determine whether or not hydrocarbon residues in the debris sample were products of pyrolysis or residue of an accelerant.

However, when overall fire damage is limited and small or isolated, irregular patterns are found, the presence of ignitible liquids may be more likely, although the use of supporting evidence is still recommended. *(See Figure 4-17.7.2.)*

Pooled ignitible liquids that soak into flooring or floor covering materials as well as melted plastic can produce irregular patterns. These patterns can also be produced by localized heating or fallen fire debris.

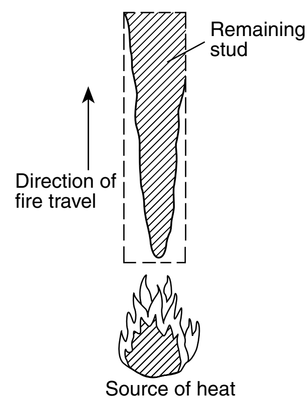


Figure 4-17.6(b) Cross section of wood wall stud pointing toward fire.

4-17.7.3 Doughnut-Shaped Patterns. A distinct doughnut-shaped pattern where a roughly ring-shaped burn area surrounds a less burned area may result from an ignitible liquid. When a liquid causes this pattern, it is due to the effects of the liquid cooling the center of the pool as it burns while flames at the perimeter of the doughnut produce charring of the floor or floor covering. When this condition is found, further examination should be conducted as supporting evidence to the presence of ignitible liquids.

4-17.8 Liquids Versus Melted Solids. Many modern plastic materials will burn. They react to heating by first liquefying, and, then, when they burn as liquids, they produce irregularly shaped or circular patterns. When found in unexpected places, such patterns can be erroneously identified as flammable or combustible liquid patterns and associated with an incendiary fire cause.

Often the association of an ignitible liquid with a particular irregular pattern has been ruled out on the presumption that ignitible liquid vapors will always cause explosions. This is not the case. The expansion of the products of combustion from flammable liquids will cause explosions only if they are sufficiently confined to damage the structure or confining vessel and have the proper fuel/air mixture. *(See 3-1.1.2 and 13-8.2.1.)* Whether an explosion occurs is a function of the quantity of vaporized fuel present at the time of ignition, the presence of venting openings in the structure, and the strength and construction of the confining structure.

The investigator should be careful to properly identify the initial fuel source for any irregularly shaped or circular patterns.

4-17.9 Commercial Fuel Gas Patterns. The burning of the common commercial fuel gases, natural gas and liquefied petroleum (LP) gases, can provide distinctive fire patterns. Distinctive localized burning between ceiling joists, between interior vertical wall studs, and in the corners of ceilings of rooms is quite common and a good indicator of the presence of natural gas. Natural gas has a vapor density of 0.65; therefore, it is lighter than air and will rise when released. This property of natural gas will create gas pockets in the upper areas of rooms and structures.

The liquefied petroleum (LP) gases, being heavier than air (with vapor densities of about 1.5 for propane and 2.0 for butane), also tend to pocket within a structure, though at low levels. However, the buoyant nature of their products of combustion when ignited prevents them from producing similar pocketing burn patterns as natural gas.

Figure 4-17.7.2 Irregularly shaped pattern on floor carpeting resulting from poured ignitible liquid. Burned match can be seen at lower left.

4-17.10 Saddle Burns. "Saddle burns" are distinctive U- or saddle-shaped patterns that are sometimes found on the top edges of floor joists. They are caused by fire burning downward through the floor above the effected joist. Saddle burns display deep charring, and the fire patterns are highly localized and gently curved. *(See Figure 4-17.10.)*

Figure 4-17.10 Saddle burn in a floor joist.

4-18 Linear Patterns. Patterns that have overall linear or elongated shapes can be called linear patterns. They usually appear on horizontal surfaces.

4-18.1 Trailers. In many incendiary fires, when fuels are intentionally distributed or "trailed" from one area to another, the elongated patterns may be visible. Such fire patterns, known as "trailers," can be found along floors to connect separate fire sets, or up stairways to move fires from one floor or level within a structure to another. Fuels used for trailers may be ignitible liquids, solids, or combinations of these. *(See Figure 4-18.1.)*

4-18.2 Protected Floor Areas. Often when the floor area is cleared of debris to examine damage, long, wide, straight patterns will be found showing areas of extensive heat damage bounded on each side by undamaged or less damaged areas. These patterns often have been interpreted to be "trailers." While this is possible, the presence of furniture, stock, counters, or storage may result in these linear patterns. These patterns may also result from wear on floors and the floor covering due to high traffic. Irregularly shaped objects on the floor, such as clothing or bedding, may also provide protection and produce patterns that may be inaccurately interpreted.

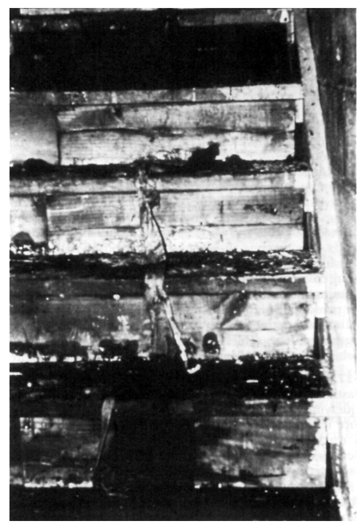


Figure 4-18.1 Trailer running up a stairway.

4-18.3 Fuel Gas Jets. Jets of ignited fuel gases, such as LP or natural gas, can produce linear patterns or lines of demarcation, particularly on noncombustible surfaces.

4-19 Area Patterns. Some patterns may appear to cover entire rooms or large areas without any readily identifiable sources or beginnings. These patterns are most often formed when the fuels that create them are widely dispersed before ignition, or when the movement of the fire through the areas is very rapid as in a flash fire.

4-19.1 Flashover and Full Room Involvement. In the course of a flashover transition, fire spreads rapidly to all exposed combustible materials as the fire progresses to full room involvement. *(See 3-5.3.2.)* This process can produce relatively even burning on vertical surfaces. If the fire is terminated before full room involvement, relatively uniform burning can be evident above the bottom of the hot layer. When the fire has progressed to full room involvement, the area pattern may be uneven and extend to the base of the wall.

4-19.2 Flash Fires. The ignition of gases or the vapors of liquids does not necessarily always cause explosions. Whether or not an explosion occurs depends on the location and concentration of diffuse fuels and on the geometry, venting, and strength of the confining structure. *(See Section 13-1.)*

If the diffuse fuels are near the lower flammable or explosive limit (LEL) and there is no explosion, the fuels may burn as a flash fire, and there may be little or no subsequent burning. In the instance where the first fuel to be ignited is a diffuse fuel/air mixture, the area of greatest destruction may not, and generally does not, coincide with the area where the heat source ignites the mixture. The greatest destruction will occur where the flash fire from the burning mixture encounters a secondary fuel load that is capable of being ignited by the momentary intense temperature in the flame front. Likewise, once secondary ignition occurs, the dynamics of the fire spread will be dictated by the compartment and fuel geometry and the relative heat release rates of these secondary fuels. The relatively short duration of the burning mixture may have little impact on the flashover in the compartment as compared to the burning of the secondary fuels. Therefore, origin determination of such a flash fire is dependent on accurate witness observations and the analysis of the potential ignition sources in the areas where the vapor or gas could have existed.

Figure 4-19.2 Blistering of varnish on door and slight scorching of draperies, the only indications of the natural gas flash fire.

Without accurate witness statements and careful analysis of potential ignition sources, the investigator is left with the analysis of fire patterns as the only means of determining the origin. The difficulty of this task is that the resultant ignition of the secondary fuels and compartment flashover can camouflage the subtle patterns created by the flash fire.

This is caused by the total consumption of the available fuel without significantly raising the temperatures of other combustibles. In this case, the fire patterns may be superficial and difficult to trace to any specific point of ignition. In addition, separate areas of burning from pocket fuel gas may exist and further confuse the tracing of fire spread. *(See Figure 4-19.2.)*

4-20 Material Distortion. Patterns can be seen in the physical change of shape and distortion of some objects that are subjected to the heat of the fire.

4-20.1 Distorted Light Bulbs. Incandescent light bulbs can sometimes show the direction of heat impingement. As the side of the bulb facing the source of heating is heated and softened the gases inside a bulb of greater than 25 watts can begin to expand and bubble out the softened glass. This has been traditionally called a "pulled" light bulb, though the action is really a response to internal pressure rather than a pulling. The bulged or pulled portion of the bulb will be in the direction of the source of the heating.

Because they contain a vacuum, bulbs of 25 watts or less can be pulled inward on the side in the direction of the source of heating.

Often these light bulbs will survive fire extinguishment efforts and can be used by the investigator to show the direction of fire travel. In evaluating a distorted light bulb, the investigator should be careful to ascertain that the bulb has not been turned in its socket by prior investigators or fire service personnel. *(See Figure 4-20.1.)*

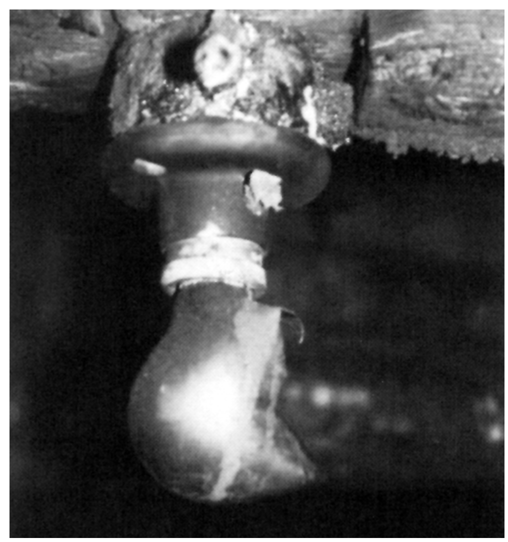


Figure 4-20.1 A typical "pulled" bulb showing that the heating was from the right side.

4-20.2 Metal Construction Elements. Studs, beams, columns, and the construction components that are made of high-melting-point metals, such as steel, can be distorted by heating. The higher the coefficient of thermal expansion of the metal, the more prone it is to heat distortion. The amount and location of distortion in a particular metal construction can indicate which areas were heated to higher temperatures or for longer times. *(See Section 4-9.)* In some cases, elongation of beams can result in damage to walls. *(See Figure 4-20.2.)*

Figure 4-20.2 Damage to an outside brick wall caused by thermal expansion of an I-beam in the basement.

Chapter 5 Legal Considerations

5-1* Introduction. Legal considerations impact on every phase of a fire investigation. Whatever the capacity in which a fire investigator functions (public or private), it is important that the investigator be informed regarding all relevant legal restrictions, requirements, obligations, standards, and duties. Failure to do so could jeopardize the reliability of any investigation and could subject the investigator to civil liability or criminal prosecution.

It is the purpose of this chapter to alert the investigator to those areas that usually require legal advice, knowledge, or information. The legal considerations contained in this chapter and elsewhere in this guide pertain to the law in the United States. This chapter does not attempt to state the law as it is applied in each country or other jurisdiction. Such a task exceeds the scope of this guide. To the extent that statutes or case law are referred to, they are referred to by way of example only, and the user of this guide is reminded that "the law" is in a constant state of flux. Analogized to a living thing, both case law and statutory law are constantly subject to creation (by new enactment or decision), change (by modification or amendment), and death (by being repealed, overruled, or vacated). It is recommended that the investigator seek legal counsel to assist in understanding and complying with the legal requirements of any particular jurisdiction. Recognition of applicable legal requirements and considerations will help to ensure the reliability and admissibility of the investigator's records, data, and opinions.

5-2 Preliminary Legal Considerations.

5-2.1 Authority to Conduct the Investigation. The investigator should ascertain the basis and extent of his or her authority to conduct the investigation. Normally, the authority is public or governmental (i.e., police department, fire department, office of the fire marshal); contractual (e.g., insurance); or otherwise private (e.g., in the event of investigation conducted in anticipation of litigation). Proper identification of the basis of authority will assist the investigator in complying with applicable legal requirements and limitations.

The scope of authority granted to investigators from the public or governmental sector is usually specified within the codified laws of each jurisdiction, as supplemented by applicable local, agency, and department rules and regulations. Many states and local jurisdictions (i.e., cities, towns, or counties) have licensing or certification requirements for investigators. If such requirements are not followed, the results of the investigation may not be admissible and the investigator may face sanctions.

5-2.2 Right of Entry. The fact that an investigator has authority to conduct an investigation does not necessarily mean that he or she has the legal right to enter the property that was involved in the fire. Rights of entry are frequently enumerated by statutes, rules, and regulations. Illegal entry on the property could result in charges against the investigator (i.e., trespassing; breaking and entering; or obstructing, impeding, or hampering a criminal investigation).

Once a legal right of entry onto the property has been established, the investigator should notify the officer or authority in charge of the scene of his or her entry. An otherwise legal right of entry does not authorize entry onto a crime scene investigation. Further authorization by the specific agency or officer in charge is required. Once on the property, extreme caution should be exercised to preserve the scene and protect the evidence.

Frequently, code provisions designed to protect public safety mandate that a building involved in a fire be promptly demolished to avoid danger to the public. This act can deny an investigator the only opportunity to examine the scene of a fire. When it is important to do so, court ordered relief prohibiting the demolition until some later and specified date may be obtained, most typically by way of injunction, to allow for the investigator's presence at the scene. This may prove costly, however, as the party seeking the delay may be required to post a bond, procure guards, and secure the property during the intervening time period. Legal counsel should be able to anticipate needs in this regard and promptly respond to such needs.

The investigator should remain aware that he or she may be required to produce evidence by order of court or pursuant to a subpoena. The investigator should exercise caution and not destroy, dispose of, or remove any evidence unless clearly and legally entitled to do so. Regarding investigations of major or catastrophic fires, courts are becoming increasingly more willing to enter orders designed to preserve the fire scene, thereby preserving the rights of all interested parties and entities to be aware of and examine all available evidence.

In the event that destruction, disposal, or removal is authorized or necessary, the investigator should engage in such acts only after the scene has been properly recorded and the record has been verified as to accuracy and completeness.

5-2.3 Method of Entry. Whereas "right of entry" refers to the legal authority to be on a given premise or fire scene, this section concerns itself with how that authority is obtained. There are four general methods by which entry may be obtained: consent, exigent circumstance, administrative search warrant, and criminal search warrant.

5-2.3.1 Consent. The person in lawful control of the property can grant the investigator permission or consent to enter and remain on the property. This is a voluntary act on the part of the responsible person and can be withdrawn at any time by that person. When consent is granted, the investigator should document it. One effective method is to have the person in lawful control sign a written waiver.

5-2.3.2 Exigent Circumstance. It is generally recognized that the fire department has the legal authority to enter a property to control and extinguish a hostile fire. It has also been held that the fire department has an obligation to determine the origin and cause of the fire in the interest of the public good and general welfare.

The time period in which the investigation may continue or should conclude has been the subject of a Supreme Court decision (*Michigan v. Tyler,* 436 U.S. 499), when the Court held that the investigation may continue for a "reasonable period of time," which may depend on many variables. When the investigator is in doubt as to what is a "reasonable time," one of the other methods to secure or maintain entry should be considered.

5-2.3.3 Administrative Search Warrant. The purpose of an administrative search warrant is generally to allow those charged with the responsibility, by ordinance or statute, to investigate the origin and cause of a fire and fulfill their obligation according to the law.

An administrative search warrant may be obtained from a court of competent jurisdiction upon a showing that consent has not been granted or has been denied. It is not issued on the traditional showing of "probable cause," as is the criminal search warrant, although it is still necessary to demonstrate that the search is reasonable. The search should be justified by a showing of reasonable governmental interest. If a valid public interest justifies the intrusion, then valid and reasonable probable cause has been demonstrated.

The scope of an administrative search warrant is limited to the investigation of the origin and cause of the fire. If during the search permitted by an administrative search warrant, evidence of a crime is discovered, the search should be stopped and a criminal search warrant should be obtained (*Michigan v. Clifford,* 464 U.S. 287).

5-2.3.4 Criminal Search Warrant. The purpose of a criminal search warrant is to allow the entry of government officials or agents to search for and collect any evidence of a crime. A criminal search warrant is obtained on the traditional showing of probable cause, in that the investigator is required to show that probable cause exists that a crime has been committed.

The investigator's application for obtaining a criminal search warrant typically includes the following:

(a) Purpose and scope of the search
(b) Location
(c) Party against whom the search is directed
(d) Time in which the search is to be initiated and concluded
(e) Evidence that can be expected to be recovered

5-3 Evidence. Rules of evidence regulate the admissibility of proof at a trial. The purpose of rules of evidence is to ensure that the proof offered is reliable. A goal of every fire investigation is to produce *reliable* documents, samples, statements, information, data, and conclusions.

It is not necessary that every fire investigator become an expert on rules of evidence. If the practices and procedures recommended within this guide are complied with, the results of the investigation should be admissible.

5-3.1 Federal Rules of Evidence. Evidentiary requirements, standards, and rules vary greatly from jurisdiction to jurisdiction. For this reason, those rules of evidence that are in effect in individual states, territories, provinces, and international jurisdictions should be consulted. The United States Federal Rules of Evidence have been relied on throughout this guide for guidance in promoting their general criteria of relevance and identification.

The Federal Rules of Evidence became effective on July 1, 1975. The federal rules are applicable in all civil and criminal cases in all United States courts of appeal, district courts, courts of claims, and before United States magistrates. The federal rules are recognized as having essentially codified the well-established rules of evidence, and many states have adopted, in whole or in part, the federal rules.

5-3.2 Types of Evidence. There are basically three types of evidence, all of which in some manner relate to fire investigations. They are demonstrative evidence, documentary evidence, and testimonial evidence. They are described in detail below.

5-3.2.1 Demonstrative Evidence. This is a type of evidence that consists of tangible items as distinguished from testimony of witnesses about the items. It is evidence from which one can derive a relevant firsthand impression by seeing, touching, smelling, or hearing the evidence.

Demonstrative evidence should be authenticated. Evidence is authenticated in one of two ways: through witness identification (i.e., recognition testimony) or by establishing a chain of custody (an unbroken chain of possession from the taking of the item from the fire scene to the exhibiting of the item).

5-3.2.1.1 Photographs/Illustrative Forms of Evidence. Among the most frequently utilized types of illustrative demonstrative evidence are maps, sketches, diagrams, and models. They are generally admissible on the basis of testimony that they are substantially accurate representations of what the witness is endeavoring to describe.

Photographs and movies are viewed as a graphic portrayal of oral testimony and become admissible when a witness has testified that they are correct and accurate representations of relevant facts personally observed by the witness. The witness often need not be the photographer but should know about the facts represented or the scene or objects photographed. Once this knowledge is shown, the witness can state whether a photograph correctly and accurately portrays those facts.

5-3.2.1.2 Samples. Chain of custody is especially important regarding samples. To ensure admissibility of a sample an unbroken chain of possession should be established.

5-3.2.2 Documentary Evidence. Documentary evidence is any evidence in written form. It may include business records such as sales receipts, inventory lists, invoices, bank records, including checks and deposit slips; insurance policies; personal items such as diaries, calendars, telephone records; fire department records such as the fire investigator's report, the investigator's notes, the fire incident report, witness statement reduced to writing; or any law enforcement agency reports, including investigation reports, police officer operational reports, fire or police department dispatcher logs; division of motor vehicle records; written transcripts of audio- or videotape recordings. Any information in a written form related to the fire or explosion incident is considered documentary evidence. Documentary evidence is generally admissible if the documents are maintained in the normal course of business.

All witness statements should be properly signed by the witness, dated, and witnessed by a third party when possible. It is important to obtain the full name, address, and telephone number of the witness. Any additional identifying information (e.g., date of birth, social security number, and automobile license number) may prove helpful in the event that difficulties are later encountered in locating the witness. Statements actually written by the witness may be required in certain jurisdictions.

5-3.2.3 Testimonial Evidence. Testimonial evidence is that given by a competent live witness speaking under oath or affirmation. Investigators are frequently called on to give testimonial evidence regarding the nature, scope, conduct, and results of their investigation. It is incumbent on all witnesses to respond completely and honestly to all questions.

5-3.3 Post-fire Interviews and Witness Statements. Post-fire interviews of witnesses and the taking of witness statements are an important aspect of the fire investigation process. For specific procedures and techniques to be utilized when conducting interviews, see Section 7-3.

5-3.4 Constitutional Considerations. Within the United States and its territories, investigators should be aware of the constitutional safeguards that are generally applicable to any witness when the interview is conducted by a representative, employee, or agent of any governmental entity. This includes members of public fire services and generally extends to most investigators functioning in a public capacity.

Within the United States and its territories, witnesses being interviewed have constitutional guarantees under the Fifth and Sixth Amendments. These guarantees include the right to have an attorney present during questioning. Questions regarding personal identification are not subject to constitutional protection.

In light of the numerous criminal charges that can be made as a result of a fire, each investigator should ascertain whether he or she is required to give warning under the Miranda Rule and, if so, when to give it and how to give it.

The Miranda Rule requires that, prior to any custodial interrogation, the person/witness should be warned of the following:

(a) That they have a right to remain silent
(b) That any statement they do make may be used as evidence against them
(c) That they have the right to the presence of an attorney
(d) That, if they cannot afford an attorney, one will be appointed for them prior to any questioning if they so desire

Unless and until these warnings or a waiver of these rights are demonstrated at trial, no evidence obtained in the interrogation may be used against the accused (formerly the witness). (*Miranda v. Arizona*, 384 U.S. 436)

Witnesses interviewed in "custodial settings" should be advised of their constitutional rights. Though interviews conducted on a fire scene are not generally considered to be custodial, depending on the circumstances, they may be custodial. The custodial setting depends on many variables, including the location of the interview; the length of the interview; who is present and who participates; and the witness's perception of whether he or she will be restrained if he or she attempts to leave. If there is any doubt in the mind of the investigator as to whether the witness is being questioned in a custodial setting, the witness should be advised of his or her constitutional rights. It is recommended that, when a witness is advised of his or her constitutional rights, as required by the Miranda Rule, they be on a written form that can be signed by the witness.

5-4 Criminal Prosecution. Though there are certain fire-related crimes that appear to exist in all jurisdictions (e.g., arson), the full scope of possible criminal charges is as varied as the jurisdictions themselves, their resources, histories, interests, and concerns.

5-4.1 Arson. Arson is the most commonly recognized fire-related crime. *Black's Law Dictionary*, 5th edition, 1979, defines arson as follows:

> **Arson.** At common law, the malicious burning of the house of another. This definition, however, has been broadened by state statutes and criminal codes. For example, the Model Penal Code, Section 220.1(1), provides that a person is guilty of arson, a felony of the second degree, if he starts a fire or causes an explosion with the purpose of: (a) destroying a building or occupied structure of another; or (b) destroying or damaging any property, whether his own or another's, to collect insurance for such a loss.
>
> In several states, this crime is divided into arson in the first, second, and third degrees: the first degree including the burning of an inhabited dwelling-house in the nighttime; the second degree, the burning (at night) of a building other than a dwelling-house, but so situated with reference to a dwelling-house as to endanger it; the third degree, the burning of any building or structure not the subject of arson in the first or second degree, or the burning of property, his own or another's with intent to defraud or prejudice the insurer thereof.

5-4.1.1 Arson Statutes. The laws of each jurisdiction should be carefully researched regarding the requirements, burden of proof, and penalties for the crime of arson. Arson generally, or in the first and second degrees (if so classified), is deemed a felony offense. Such felony offenses require proof that the person intentionally damaged property by starting or maintaining a fire or causing an explosion. Arson in the third degree (if so classified) generally requires only reckless conduct that results in the damage of property and is often a misdemeanor offense.

5-4.1.2 Factors to Be Considered. The following factors are of relevance to most investigations when there is a possibility that the criminal act of arson was committed:

(a) Was the building, starting, or maintaining of a fire or the causing of an explosion intentional?
(b) Was another person present in or on the property?
(c) Who owned the property?
(d) If the property involved was a building, what type of building and what type of occupancy was involved in the fire?
(e) Did the perpetrator act recklessly, though aware of the risk present?
(f) Was there actual presence of flame?
(g) Was actual damage to the property or bodily injury to a person caused by the fire or explosion?

5-4.2 Other Fire-Related Criminal Acts. The bases of fire-related criminal prosecution vary greatly from jurisdiction to jurisdiction. It is impossible to list all possible offenses. The following nonexclusive list of sample acts that can result in criminal prosecution will alert the investigator to the possibilities in any given jurisdiction: insurance fraud; leaving fires unattended; allowing fires to burn uncontrolled; allowing fires to escape; burning without proper permits; reckless burning; negligent burning; reckless endangerment; criminal mischief; threatening a fire or bombing; failure to report a fire; failure to report smoldering conditions; tampering with machinery, equipment, or warning signs used for fire detection, prevention, or suppression; failure to assist in suppression or control of a fire; sale or installation of illegal or inoperative fire suppression or detection devices; and use of certain equipment or machinery without proper safety devices, without the presence of fire extinguishers, or without other precautions to prevent fires.

Criminal sanctions are almost universally imposed for failures to obey orders of fire marshals, fire wardens, and other officials and agents of public sector entities created to promote, accomplish, or otherwise ensure fire prevention, protection, suppression, or safety.

Key industries or resources within a given jurisdiction often result in the enactment of special and detailed criminal provisions. By way of example, criminal statutes exist with specific reference to fires in coal mines, woods, prairie lands, forests, and parks and during drought or emergency conditions. Special provisions also exist regarding the type of occupancy or use of a given structure (i.e., penal/correctional institutions, hospitals, nursing homes, day-care or child-care centers, and schools). The use or transporting of hazardous or explosive materials is regulated in nearly all jurisdictions.

5-5 Arson Reporting Statutes. Many jurisdictions have enacted statutes requiring that information be released to public officials regarding fires that may have been the result of a criminal act.

Commonly referred to as the "arson immunity acts," the arson reporting statutes generally provide that an insurance company should, on written request from a designated public entity or official, release enumerated items of information and documentation regarding any loss or potential loss due to a fire of "suspicious" or incendiary origin. The information is held in confidence until its use is required in a civil or criminal proceeding. The insurance company is held immune from civil liability and criminal prosecution, premised upon its release of the information, pursuant to the statute.

The number of jurisdictions with an arson reporting act is growing, and it is anticipated that they will continue to grow. As enacted in each jurisdiction, the acts vary greatly as to both requirements and criminal sanctions. Each act does impose criminal sanctions for failure to comply.

In order to avoid criminal prosecution, the insurance companies and investigators operating on its behalf should be aware of any applicable arson reporting act. One should be alert to the following variations that currently exist:

(a) In addition to the insurance company, some jurisdictions require compliance by its employees, agents, investigators, insureds, and attorneys.

(b) In addition to response to specific written requests for information or documentation, some jurisdictions state that an insurance company *may* inform the proper authorities whenever it suspects a fire was of "suspicious origin." Other jurisdictions state that an insurance company must inform the proper authorities whenever it suspects a fire was of "suspicious origin."

NOTE: The term *suspicious origin,* as used within this section, refers to the actual language of some arson reporting statutes. This guide does not recognize mere suspicion as an accurate or acceptable level of proof for making determinations of origin or cause, nor does it recognize "suspicious origin" as an accurate or acceptable description of cause or origin. This guide discourages the use of such terms.

(c) In addition to requiring production of specifically enumerated items of information and documentation, some jurisdictions require production of all information and documentation.

(d) Though most jurisdictions ensure absolute confidentiality of the information and documentation released, pending its use at a criminal or civil proceeding, other jurisdictions allow its release to other interested public entities and officials.

(e) In many jurisdictions, the immunity from civil liability and criminal prosecution is lost in the event that information was released maliciously or in bad faith.

5-6 Civil Litigation. Many fires result in civil litigation. These lawsuits typically involve claims of damages for death, injury, property damage, and financial loss caused by a fire or explosion. The majority of civil lawsuits are premised on allegations of negligence. A significant number of civil lawsuits are premised on the legal principle of product liability or alleged violations of applicable codes and standards.

5-6.1 Negligence. Negligence generally applies to situations in which a person has not behaved in the manner of a reasonably prudent person in the same or similar circumstances. Liability for negligence requires more than conduct. The elements that traditionally should be established to impose legal liability for negligence may be stated briefly as follows:

(a) *Duty.* A duty requiring a person to conform to a certain standard of conduct, for the protection of others against unreasonable risks

(b) *Failure.* A failure by the person to conform to the standard required

(c) *Cause.* A reasonably close causal connection between the conduct of the person and resulting injury to another (generally referred to as "legal cause" or "proximate cause")

(d) *Loss.* Actual loss or damage resulting to the interests of another

A hypothetical example of the application of the elements of negligence follows:

The operator of a nursing home has a *duty* to install operable smoke detectors within the nursing home for the protection of the inhabitants of the nursing home. A reasonably prudent nursing home operator would have installed the smoke detectors. The operator of the nursing home *failed* to install operable smoke detectors. A fire began in a storage room. Because there were no smoke detectors, the staff and occupants of the nursing home were not alerted to the presence of the fire in time to allow the occupants to reach safety, and an occupant who could have otherwise been saved died as a result of the fire. The death of the occupant was proximately *caused* by the failure to install operable smoke detectors. The death constitutes actual *loss* or *damage* to the deceased occupant and his or her family. Once all four elements are established, liability for negligence may be imposed.

5-6.2 Codes, Regulations, and Standards. Various codes, regulations, and standards have evolved through the years to protect lives and property from fire. Violations of codes, regulations, rules, orders, or standards can establish a basis of civil liability in fire or explosion cases. Further, many jurisdictions have legislatively determined that such violations either establish negligence or raise a presumption of negligence. By statute, violation of criminal or penal code provisions may also entitle the injured party to double or triple damages.

5-6.3 Product Liability. Product liability refers to the legal liability of manufacturers and sellers to compensate buyers, users, and even bystanders for damages or injuries suffered because of defects in goods purchased. This tort makes manufacturers liable if their product has a defective condition that makes it unreasonably dangerous (unsafe) to the user or consumer.

Although the ultimate responsibility for injury or damage most frequently rests with the manufacturer, liability may also be imposed upon a retailer, occasionally on a wholesaler or middleman, on a bailor or lessor, and infrequently on a party wholly outside the manufacturing and distributing process, such as a certifier. This ultimate responsibility may be imposed by an action by the plaintiff against the manufacturer directly, or by way of claims for indemnification or contribution against others who might be held liable for the injury caused by the defective product. *[See Black's Law Dictionary, 6th edition, p. 1209 (1990).]*

5-6.4 Strict Liability. Courts apply the concept of strict liability in product liability cases in which a seller is liable for any and all defective or hazardous products that unduly threaten a consumer's personal safety. This concept applies to all members involved in the manufacturing and selling of any facet of the product.

The concept of strict liability in tort is founded on the premise that when a manufacturer presents a product or good to the public for sale, the manufacturer represents that the product or good is suitable for its intended use.

In order to recover in strict liability, it is essential to prove that the product was defective when placed in the stream of commerce and was, therefore, unreasonably dangerous.

The following types of defects have been recognized: design defects; manufacturing defects; failure to warn or inadequacy of warning; and failure to comply with applicable standards, codes, rules, or regulations. The three most commonly applied defects are described as follows:

(a) *Design Defect.* The basic design of the product contains a fault or flaw that has made the product unreasonably dangerous.

(b) *Manufacturing Defect.* The design of the product may have been adequate, but a fault or mistake in the manufacturing or assembly of the product has made it unsafe.

(c) *Inadequate Warnings.* The consumer was not properly instructed in the proper or safe use of the product; nor was the consumer warned of any inherent danger in the possession of, or any reasonably foreseeable use or misuse of, the product.

Strict liability applies, although the seller has exercised all possible care in the preparation and sale of a product. It is not required that negligence be established. *(See Restatement of the Law, Second, Torts, §402A.)*

5-7 Expert Testimony.

5-7.1 General Witness. An investigator will often be called to give testimony before courts, administrative bodies, regulatory agencies, and related entities. In addition to giving factual testimony, an investigator may be called to give conclusions or opinions regarding a fire.

5-7.2 Litigation or Expert Witness. For purposes of litigation, only expert witnesses are allowed to offer opinion testimony at the discretion of the court. An expert witness is generally defined as someone with sufficient skill, knowledge, or experience in a given field so as to be capable of drawing inferences or reaching conclusions or opinions that an average person would not be competent to reach. The expert's opinion testimony should aid the judge or jury in their understanding of the fact at issue and thereby aid in the search for truth.

The opinion or conclusion of the investigator testifying as an expert witness is of no greater value in ascertaining the truth of a matter than that warranted by the soundness of the investigator's underlying reasons and facts. The evidence that forms the basis of any opinion or conclusion should be relevant and reliable and, therefore, admissible. The proper conduct of an investigation will ensure that these indices of reliability and credibility are met.

Chapter 6 Planning the Investigation

6-1 Introduction. The intent of this chapter is to identify basic considerations of concern to the investigator prior to beginning the incident scene investigation.

Regardless of the number of people involved, the need to preplan investigations remains constant. Considerations for determining the number of investigators assigned include budgetary constraints, available staffing, complexity, loss of life, and size of the scene to be investigated.

The person responsible for the investigation of the incident should identify the resources at their disposal and those available from outside sources before those resources are needed. It is their responsibility to acquire additional resources as needed. Assistance can be gained from local or state building officials, universities and state colleges, and numerous other public and private agencies.

The "team concept" of investigating an incident is recommended. It is understood that the investigator, at many incident scenes, may have to photograph, sketch the scene, collect evidence, interview, and be responsible for the entire scene investigation without other assistance. These functions and others described in this document should be performed regardless of the number of people involved with the investigation.

6-2 Basic Incident Information. Prior to beginning the incident scene investigation, numerous events, facts, and circumstances should be identified. Accuracy is important since a mistake at this point could jeopardize the subsequent investigation results.

6-2.1 Location. The investigator, once notified of an incident, should obtain as much background information as possible relative to the incident from the notifier. If the travel distance is great, arrangements may be required to transport the investigation team to the incident scene.

The location of the incident may also dictate the need for specialized equipment and facilities. *(See 6-4.1.)*

6-2.2 Date and Time of Incident. The investigator should accurately determine the day, date, and time of the incident. The age of the scene may have an effect on the planning of the investigation. The greater the delay between the incident and the investigation, the more important it becomes to review pre-existing documentation and information such as incident reports, photographs, building plans, and diagrams.

6-2.3 Weather Conditions. Weather at the time of the investigation may necessitate the need for special clothing and equipment. Weather may also determine the amount of time the team members can work an incident scene. Extreme weather may also require that greater safety precautions be taken on behalf of the team members, for example, when the weight of snow on a structure weakens it.

Weather conditions such as wind direction and velocity, temperature, and rain during a fire should be noted because all can have an effect on the ignition and fire spread.

6-2.4 Size and Complexity of Incident. The size and complexity of the incident scene may suggest the need for assistance for the investigator. A large incident scene area may create communication problems for investigators, and arrangements for efficient communications should be made.

The size and complexity of the scene will also affect the length of the investigation, and preparations may be needed for housing and feeding the team members. Generally, the larger the incident scene, the greater the length of time required to conduct the investigation.

6-2.5 Type and Use of Structure. The investigator should identify the type and use of the incident structure. The use or occupancy of the structure (e.g., industrial plant, chemical processing plant, storage warehouse, nuclear facility, or radiological waste storage) may necessitate special containment of debris, contamination, or radiation, including water run-off at the scene. Additionally, appropriate hazardous materials or contamination clothing, breathing apparatus, and other protective devices and equipment may be necessary to ensure safety at the incident scene. Conditions at certain scenes may be so hazardous that the investigators should work within monitored stay times.

Knowledge of the type of construction and construction materials will provide the investigator with valuable background information and allow anticipation of circumstances and problems to be encountered by the investigation team.

6-2.6 Nature and Extent of Damage. Information on the condition of the scene may alert the investigator to special requirements for the investigation, such as utility testing equipment, specialized expertise, additional staffing, and special safety equipment. The investigator may be operating under time constraints and should plan accordingly.

6-2.7 Security of Scene. The investigator should promptly determine the identity of the individual, authority, or entity that has possession or control of the scene. Right of access and means of access should be established.

Scene security is a consideration. If possible, arrangements should be made to preserve the scene until the arrival of the investigator(s). If this is not possible, arrangements should be made to photograph and document existing conditions prior to disturbance or demolition.

6-2.8 Purpose of Investigation. While planning the investigation, the investigator should remain aware of his or her role, scope, and areas of responsibility. Numerous investigators may be involved from both the private and public sectors. Mutual respect and cooperation in the investigation is required.

6-3 Organizing the Investigation Functions. There are basic functions that are commonly performed in each investigation. These are the leadership/coordinating function; photography, note taking, mapping, and diagramming *(see Chapter 8);* interviewing witnesses *(see Chapter 7);* searching the scene *(see Chapter 11);* evidence collection and preservation *(see Chapter 9);* and safety assessment *(see Chapter 10).*

In addition, specialized expertise in such fields as electrical, heating and air conditioning, or other engineering fields is often needed. The investigator should, if possible, fulfill these functions with the personnel available. In assigning functions, those special talents or training that individual members possess should be utilized.

6-4 Preinvestigation Team Meeting. If the investigator has established a team, a meeting should take place prior to the on-scene investigation. The team leader or investigator should address questions of jurisdictional boundaries and assign specific responsibilities to the team members. Personnel should be advised of the condition of the scene and the safety precautions required.

6-4.1 Equipment and Facilities. Each person on the fire scene should be equipped with appropriate safety equipment, as required. A complement of basic tools should also be available. The tools and equipment listed below may not be needed on every scene, but in planning the investigation, the investigator should know where to obtain these tools and equipment if the investigator does not carry them.

Personal Safety Equipment

Eye protection
Flashlight
Gloves
Helmet or hard hat
Respiratory protection (type depending on exposure)
Safety boots or shoes
Turnout gear or coveralls

Tools and Equipment

Absorption material
Axe
Broom
Camera and film *(See 8-2.2.1 and 8-2.2.2 for recommendations.)*
Claw hammer
Directional compass
Evidence collecting container *(See Section 9-5 for recommendtions.)*
Evidence labels (sticky)
Hand towels
Hatchet
Hydrocarbon detector
Ladder
LightingTape recorder
Magnet
Marking pens
Paint brushes
Paper towels/wiping cloths
Pen knife
Pliers/wire cutters
Pry bar
Rake
Rope
Rulers
Saw
Screwdrivers (multiple types)
Shovel
Sieve
Soap and hand cleaner
Styrofoam cups
Tape measure
Tongs
Tweezers
Twine
Voltmeter/ohmmeter
Water
Writing/drawing equipment

6-5 Specialized Personnel and Technical Consultants. In planning a fire investigation, specialized personnel may be needed to provide technical assistance. There are many different facets to fire investigation. If unfamiliar with a particular aspect, the investigator should never hesitate to call in another fire investigative expert who has more knowledge or experience in a particular aspect of the investigation. For example, there are some experts who specialize in explosions.

Sources for these specialized personnel/experts include colleges or universities, government agencies (federal, state, and local), societies or trade groups, consulting firms, and others. When bringing in specialized personnel, it is important to remember that conflict of interest should be avoided. Identification of special personnel in advance is recommended. The following paragraphs list examples of professional or specific engineering and scientific disciplines along with areas where these personnel may help the fire investigator. This section is not intended to list all sources for these specialized personnel and technical consultants.

It should be kept in mind that fire investigation is a specialized field. Those individuals not specifically trained and experienced in the discipline of fire investigation and analysis, even though they may be expert in related fields, may not be well qualified to render opinions regarding fire origin and cause. In order to offer origin and cause opinions, additional training or experience is generally necessary.

The following descriptions are general and do not imply that the presence or absence of a referenced area of training affects the qualifications of a particular specialist.

6-5.1 Materials Engineer or Scientist. A person in this field can provide specialized knowledge about how materials react to different conditions, including heat and fire. In the case of metals, someone with a metallurgical background may be able to answer questions about corrosion, stress, failure or fatigue, heating, or melting. A polymer scientist or chemist may offer assistance regarding how plastics react to heat and other conditions present during a fire and regarding the combustion and flammability properties of plastics.

6-5.2 Mechanical Engineer. A mechanical engineer may be needed to analyze complex mechanical systems or equipment, including heating, ventilation, and air conditioning (HVAC) systems, especially how these systems may have affected the movement of smoke within a building. The mechanical engineer may also be able to perform strength-of-material tests.

6-5.3 Electrical Engineer. An electrical engineer may provide information regarding building fire alarm systems, energy systems, power supplies, or other electrical systems or components. An electrical engineer may assist by quantifying the normal operating parameters of a particular system and determining failure modes.

6-5.4 Chemical Engineer/Chemist. A chemical engineer has education in chemical processes, fluid dynamics, and heat transfer. When a fire involves chemicals, a chemical process, or a chemical plant, the chemical engineer may help the investigator identify and analyze possible failure modes.

A chemist has extensive education in the identification and analysis of chemicals and may be used by the investigator in identifying a particular substance found at a fire scene. The chemist may be able to test a substance to determine its chemical and physical reaction to heat. When there are concerns about toxicity or the human reaction to chemicals or chemical decomposition products, a chemist, biochemist, or microbiologist should be consulted by the investigator.

6-5.5 Fire Science and Engineering. Within the field of fire science and engineering, there are a number of areas of special expertise that can provide advice and assistance to the investigator.

6-5.5.1 Fire Protection Engineer. Fire protection engineering encompasses all the traditional engineering disciplines in the science and technology of fire and explosions. The fire protection engineer deals with the relationship of ignition sources to materials in determination of what may have started the fire. He or she is also concerned with the dynamics of fire, and how it affects various types of materials and structures. The fire protection engineer should also have knowledge of how fire detection and suppression systems (e.g., smoke detectors, automatic sprinklers, or halon systems) function and be able to assist in the analysis of how a system may have failed to detect or extinguish a fire. The complexity of fire often requires the fire protection engineer to use many of the other engineering and scientific disciplines to study how a fire starts, grows, and goes out. Additionally, a fire protection engineer should be able to provide knowledge of building and fire codes, fire test methods, fire performance of materials, computer modeling of fires, and failure analysis.

6-5.5.2 Fire Engineering Technologist. Individuals with bachelor of science degrees in fire engineering technology, fire and safety engineering technology, or a similar discipline, or recognized equivalent, typically have studied fire dynamics and fire science; fire and arson investigation, fire suppression technology, fire extinguishment tactics, and fire department management; fire protection; fire protection structures and systems design; fire prevention; hazardous materials; applied upper-level mathematics and computer science; fire-related human behavior; safety and loss management; fire and safety codes and standards; and fire science research.

6-5.5.3 Fire Engineering Technician. Individuals with associate of science level degrees in fire and safety engineering technology or similar disciplines, or recognized equivalent, typically may have studied fire dynamics and fire science; fire and arson investigation; fire suppression technology, tactics, and management; fire protection; fire protection structures and systems design; fire prevention; hazardous materials; mathematics and computer science topics; fire-related human behavior; safety and loss management; fire and safety codes and standards; or fire science research.

6-5.6 Industry Expert. When the investigation involves a specialized industry, piece of equipment, or processing system, an expert in that field may be needed to fully understand the processes involved. Experience with the specific fire hazards involved and the standards or regulations associated with the industry and its equipment and processes can provide valuable information to the investigator. Industry experts can be found within companies, trade groups, or associations.

6-5.7 Attorney. An attorney can provide needed legal assistance with regard to rules of evidence, search and seizure laws, gaining access to a fire scene, and obtaining court orders.

6-5.8 Insurance Agent/Adjuster. An insurance agent or adjuster may be able to provide the investigator with information concerning the building and its contents prior to the fire, fire protection systems in the building, and the condition of those systems. Additional information regarding insurance coverage and prior losses may be available.

6-5.9 Canine Teams. Trained canine/handler teams may assist investigators in locating areas for collection of samples for laboratory analysis to identify the presence of ignitible liquids.

6-6* Case Management. A method should be employed to organize the information generated throughout the investigation and to coordinate the efforts of the various people involved. This topic of case management is addressed in the context of major loss investigations in Chapter 16 of this guide. It is also the focus of some of the reference material listed at the back of this guide.

Chapter 7 Sources of Information

7-1* General.

7-1.1 Purpose of Obtaining Information. The thorough fire investigation always involves the examination of the fire scene, either by visiting the actual scene or by evaluating the prior documentation of that scene.

By necessity, the thorough fire investigation also encompasses interviewing and the research and analysis of other sources of information. These activities are not a substitute for the fire scene examination. They are a complement to it.

In harmony, then, examining the fire scene, interviewing, and conducting research and analysis of other sources of information provide the fire investigator with an opportunity to establish the origin, cause, and responsibility for a particular fire.

7-1.2 Reliability of Information Obtained. Generally, any information solicited or received by the fire investigator during a fire investigation is only as reliable as the source of that information. As such, it is essential that the fire investigator evaluate the accuracy of the information's source. Certainly, no information should be considered to be accurate or reliable without such an evaluation of its source.

This evaluation may be based on many varying factors depending on the type and form of information. These factors may include the fire investigator's common sense, the fire investigator's personal knowledge and experience, the information source's reputation, or the source's particular interest in the results of the fire investigation.

7-2 Legal Considerations.

7-2.1 Freedom of Information Act. The Freedom of Information Act provides for making information held by federal agencies available to the public unless it is specifically exempted from such disclosure by law. Most agencies of the federal government have implemented procedures designed to comply with the provisions of the act. These procedures inform the public where specific sources of information are available and what appeal rights are available to the public if requested information is not disclosed.

Like the federal government, most states have also enacted similar laws that provide the public with the opportunity to access sources of information concerning government operations and their work products. The fire investigator is cautioned, however, that the provisions of such state laws may vary greatly from state to state.

7-2.2 Privileged Communications. Privileged communications are those statements made by certain persons within a protected relationship such as husband-wife, attorney-client, priest-penitent, and the like. Such communications are protected by law from forced disclosure on the witness stand at the option of the witness spouse, client, or penitent.

Privileged communications are generally defined by state law. As such, the fire investigator is cautioned that the provisions of such laws may vary greatly from state to state.

7-2.3 Confidential Communications. Closely related to privileged communications, confidential communications are those statements made under circumstances showing the speaker intended the statements only for the ears of the person addressed.

7-3 Forms of Information. Sources of information will present themselves in different forms. Generally, information is available to the fire investigator in four forms: verbal, written, visual, and electronic.

7-3.1 Verbal. Verbal sources of information, by definition, are limited to the spoken word. Such sources, which may be encountered by the fire investigator, may include, but are not limited to, verbal statements during interviews, telephone conversations, tape recordings, radio transmissions, commercial radio broadcasts, and the like.

7-3.2 Written. Written sources of information are likely to be encountered by the fire investigator during all stages of an investigation. Such sources may include, but are not limited to, written reports, written documents, reference materials, newspapers, and the like.

7-3.3 Visual. Visual sources of information, by definition, are limited to those that are gathered utilizing the sense of sight. Beginning first with the advent of still photography, such sources may include, but are not limited to, photographs, videotapes, motion pictures, and computer generated animations.

7-3.4 Electronic. Computers have become an integral part of modern informational and data systems. As such, the computer system maintained by any particular source of information may provide a wealth of information relevant to the fire investigation.

7-4 Interviews.

7-4.1 Purpose of Interviews. The purpose of any interview is to gather both useful and accurate information. Witnesses can provide such information about the fire and explosion incident even if they were not eyewitnesses to the incident.

7-4.2 Types of Interviews. Interviews can generally be categorized into three different types. These include interviews with those you can approach with an attitude of trust, interviews with those you should approach with caution, and interviews with those you should approach with an attitude of distrust.

7-4.3 Preparation for the Interview. The fire investigator should be thoroughly prepared prior to conducting any type of interview, especially if the investigator intends to solicit relevant and useful information. The most important aspect of this preparation is a thorough understanding of all facets of the investigation.

The fire investigator should also carefully plan the setting of the interview, namely, when and where the interview will be held. Although the time that the interview is conducted may be determined by a variety of factors, the interview should generally be conducted as soon as possible after the fire or explosion incident. A timely interview will ensure an accurate recollection of the incident by the witness.

Whenever possible, the interview should be conducted after the examination of the fire scene, although there are instances when this may be impractical. The scene examination may serve as the basis for specific questions relating to the incident. The environmental setting is an important consideration for the effectiveness of the interview. The interview should be conducted in a setting that is free of distractions.

The interviewer and the person being interviewed should be properly identified. The interview should, therefore, begin with the proper identification of the person conducting the interview. The date, time, and location of the interview, as well as any witnesses to it, should be documented.

The person being interviewed should also be completely and positively identified. Positive identification may include the person's full name, date of birth, Social Security number, driver's license number, physical description, home address, home telephone number, place of employment, business address, business telephone number, or other information that may be deemed pertinent to establish positive identification.

Lastly, the fire investigator should also establish a flexible plan or outline for the interview.

7-4.4 Interviews with Those You Can Approach with an Attitude of Trust. This type of interview involves those persons whose information can be substantially considered as reliable. Such persons may include, but are not limited to, government officials, representatives of financial institutions, citizen witnesses, and others who have no specific interest in the results of the investigation.

Generally, when preparing to conduct this type of interview, the fire investigator may want to make an appointment to establish a comfortable and cooperative mood. The setting of the interview is not of great importance and, in fact, the interview may be best conducted at the home or office of the person being interviewed to maintain that comfortable and cooperative mood. During the interview itself, the fire investigator should use a flexible checklist to ensure that all necessary information is solicited from the person being interviewed.

7-4.5 Interviews with Those You Should Approach with Caution. This type of interview involves those persons whose information may or may not be considered reliable. Such persons include those who may potentially have a specific interest in the results of the investigation. As such, the fire investigator should be certain to verify the validity of any information solicited during this type of interview. Generally, when preparing to conduct this type of interview, the fire investigator should not make an appointment. This prevents the person being interviewed from preparing responses to inquiries that may be made during the interview. The setting of the interview becomes more important and, in fact, the fire investigator may wish to conduct the interview in a location where the person being interviewed may not feel so comfortable. Like the previous type of interview, the fire investigator should use a flexible checklist to ensure that all necessary information is solicited from the person being interviewed.

7-4.6 Interviews with Those You Should Approach with an Attitude of Distrust. This type of interview involves those persons whose information should be considered as unreliable unless substantially verified. Such persons include those who have an obvious or documented specific interest in the results of the investigation such as the suspect(s) in an incendiary fire investigation.

Generally, when preparing to conduct this type of investigation, the fire investigator should not make an appointment. This prevents the person being interviewed from preparing responses to inquiries that may be made during the interview. The setting of the interview becomes extremely important and, in fact, the fire investigator should conduct the interview in a location where the investigator feels comfortable. And, like the previous types of interviews, the fire investigator should use a flexible checklist to ensure that all necessary information is solicited from the person being interviewed.

7-4.7 Documenting the Interview. All interviews, regardless of their type, should be documented. Tape recording the interview or taking written notes during the interview are two of the most common methods of documenting the interview. Both of these methods, however, often tend to distract or annoy the person being interviewed, resulting in some information not being solicited from them. An alternative method used to document interviews can be accomplished through the use of visual taping. All taping must be done in accordance with applicable laws and regulations. The investigator should obtain signed written statements from as many witnesses as possible to enhance their admissibility in court.

7-5 Governmental Sources of Information.

7-5.1 Municipal Government.

7-5.1.1 Municipal Clerk. The municipal clerk maintains public records regarding municipal licensing and general municipal business.

7-5.1.2 Municipal Assessor. The municipal assessor maintains public records regarding plats or maps of real property including dimensions, addresses, owners, and taxable value of the real property and any improvements.

7-5.1.3 Municipal Treasurer. The municipal treasurer maintains public records regarding names and addresses of property owners, names and addresses of taxpayers, legal descriptions of property, amount of taxes paid or owed on real and personal property, and former owners of the property.

7-5.1.4 Municipal Street Department. The municipal street department maintains public records regarding maps of the streets; maps showing the locations of conduits, drains, sewers, utility conduits; correct street numbers; old names of streets; abandoned streets and rights-of-way; and alleys, easements, and rights-of-way.

7-5.1.5 Municipal Building Department. The municipal building department maintains public records regarding building permits, electrical permits, plumbing permits, blueprints, and diagrams showing construction details and records of various municipal inspectors.

7-5.1.6 Municipal Health Department. The municipal health department maintains public records regarding birth certificates, death certificates, records of investigations related to pollution, and other health hazards and records of health inspectors.

7-5.1.7 Municipal Board of Education. The municipal board of education maintains public records regarding all aspects of the public school system.

7-5.1.8 Municipal Police Department. The municipal police department maintains public records regarding local criminal investigations and other aspects of the activities of that department.

7-5.1.9 Municipal Fire Department. The municipal fire department maintains public records regarding fire incident reports, emergency medical incident reports, records of fire inspections, and other aspects of the activities of that department.

7-5.1.10 Other Municipal Agencies. Many other offices, departments, and agencies typically exist at the municipal level of government. The fire investigator may encounter different governmental structuring in each municipality. As such, the fire investigator may need to solicit information from these additional sources.

7-5.2 County Government.

7-5.2.1 County Recorder. The county recorder's office maintains public records regarding documents relating to real estate transactions, mortgages, certificates of marriage and marriage contracts, divorces, wills admitted to probate, official bonds, notices of mechanics' liens, birth certificates, death certificates, papers in connection with bankruptcy, and other such writings as are required or permitted by law.

7-5.2.2 County Clerk. The county clerk maintains public records regarding naturalization records, civil litigation records, probate records, criminal litigation records, and records of general county business.

7-5.2.3 County Assessor. The county assessor maintains public records such as plats or maps of real property in the county, which include dimensions, addresses, owners, and taxable value.

7-5.2.4 County Treasurer. The county treasurer maintains public records regarding names and addresses of property owners, names and addresses of taxpayers, legal descriptions of property, amounts of taxes paid or owed on real and personal property, and all county fiscal transactions.

7-5.2.5 County Coroner/Medical Examiner. The county coroner/medical examiner maintains public records regarding the names or descriptions of the deceased, dates of inquests, property found on the deceased, causes and manners of death, and documents regarding the disposition of the deceased.

7-5.2.6 County Sheriff's Department. The county sheriff's department maintains public records regarding county criminal investigations and other aspects of the activities of that department.

7-5.2.7 Other County Agencies. Many other offices, departments, and agencies typically exist at the county level of government. The fire investigator may encounter different governmental structuring in each county. As such, the fire investigator may need to solicit information from these additional sources.

7-5.3 State Government.

7-5.3.1 Secretary of State. The secretary of state maintains public records regarding charters and annual reports of corporations, annexations, and charter ordinances of towns, villages, and cities; trade names and trademarks registration; notary public records; and UCC statements.

7-5.3.2 State Treasurer. The state treasurer maintains public records regarding all state fiscal transactions.

7-5.3.3 State Department of Vital Statistics. The state department of vital statistics maintains public records regarding births, deaths, and marriages.

7-5.3.4 State Department of Revenue. The state department of revenue maintains public records regarding individual state tax returns; corporate state tax returns; and past, present, and pending investigations.

7-5.3.5 State Department of Regulation. The state department of regulation maintains public records regarding names of professional occupation license holders and their backgrounds; results of licensing examinations; consumer complaints; past, present, or pending investigations; and the annual reports of charitable organizations.

7-5.3.6 State Department of Transportation. The state department of transportation maintains public records regarding highway construction and improvement projects, motor vehicle accident information, motor vehicle registrations, and driver's license testing and registration.

7-5.3.7 State Department of Natural Resources. The state department of natural resources maintains public records regarding fish and game regulations, fishing and hunting license data, recreational vehicles license data, waste disposal regulation, and environmental protection regulation.

7-5.3.8 State Insurance Commissioner's Office. The state insurance commissioner's office maintains public records regarding insurance companies licensed to transact business in the state; licensed insurance agents; consumer complaints; and records of past, present, or pending investigations.

7-5.3.9 State Police. The state police maintain public records regarding state criminal investigations and other aspects of the activities of that agency.

7-5.3.10 State Fire Marshal's Office. The state fire marshal's office maintains public records regarding fire inspection and prevention activities, fire incident databases, and fire investigation activities.

7-5.3.11 Other State Agencies. Many other offices, departments, and agencies typically exist at the state level of government. The fire investigator may encounter different government structuring in each state. As such, the fire investigator may need to solicit information from these additional sources.

7-5.4 Federal Government.

7-5.4.1 Department of Agriculture. Under this department, the Food Stamps and Nutrition Services Agency maintains public records regarding food stamps and their issuance.

The Consumer and Marketing Service maintains public records regarding meat inspection, meat packers and stockyards, poultry inspection, and dairy product inspection.

The U.S. Forest Service maintains public records regarding forestry and mining activities.

The investigative activities of the Department of Agriculture are contained in the Office of the Inspector General. The investigative area of the Secretary of Agriculture is the Office of Investigations.

7-5.4.2 Department of Commerce. Under this department, the Bureau of Public Roads maintains public records regarding all highway programs in which federal assistance was given.

The National Marine Fisheries Service maintains public records regarding the names, addresses, and registration of all ships fishing in local waters.

The Commercial Intelligence Division Office maintains public records regarding trade lists, trade contract surveys, and world trade directory reports.

The U.S. Patent Office maintains public records regarding all patents issued in the United States, as well as a roster of attorneys and agents registered to practice before that office.

The Trade Mission Division maintains public records regarding information on members of trade missions.

The investigative activities of the Department of Commerce are contained in the Office of Investigations and Security.

7-5.4.3 Department of Defense. The Department of Defense oversees all of the military branches of the armed services including the army, the navy, the marine corps, the air force, and the coast guard. Each of these branches of the military maintains public records regarding its activities and personnel. Each of these branches has offices that conduct criminal investigations within its specific branch of armed service.

7-5.4.4 Department of Health and Human Services. Under this department, the Food and Drug Administration maintains public records regarding its enforcement of federal laws under its jurisdiction.

The Social Security Administration maintains public records with regard to its activities.

The investigative activities of the Department of Health and Human Services are contained in the Office of Security and Investigations.

7-5.4.5 Department of Housing and Urban Development. The Department of Housing and Urban Development maintains public records regarding all public housing programs in which federal assistance has been given. The investigative activities of the Department of Housing and Urban Development are contained in the compliance division.

7-5.4.6 Department of the Interior. Under this department, the Fish and Wildlife Service maintains public records regarding violations of federal laws related to fish and game.

The Bureau of Indian Affairs maintains public records regarding censuses of Indian reservations, names, degree of Indian blood, tribe, family background, and current addresses of all Indians, especially those residing on federal Indian reservations.

The National Park Service maintains public records regarding all federally owned or federally maintained parks and lands.

Each division of the Department of Interior has its own investigative office.

7-5.4.7 Department of Labor. Under this department, the Labor Management Services Administration maintains public records regarding information on labor and management organizations and their officials.

The Employment Standards Administration maintains public records regarding federal laws related to minimum wage, overtime standards, equal pay, and age discrimination in employment.

The investigative activities of the Department of Labor are contained in the Labor Pension Reports Office Division.

7-5.4.8 Department of State. The Department of State maintains public records regarding passports, visas, and import/export licenses.

The investigative activities of the Department of State are contained in the Visa Office.

7-5.4.9 Department of Transportation. Under this department, the Environmental Safety and Consumer Affairs Office maintains public records regarding its programs to protect the environment, to enhance the safety and security of passengers and cargo in domestic and international transport, and to monitor the transportation of hazardous and dangerous materials.

The United States Coast Guard maintains public records regarding persons serving on U.S. registered ships, vessels equipped with permanently installed motors, vessels over 16 ft (4.877 m) long equipped with detachable motors, information on where and when ships departed or returned from U.S. ports, and violations of environmental laws.

7-5.4.10 Department of the Treasury. Under this department, the Bureau of Alcohol, Tobacco, and Firearms maintains public records regarding distillers, brewers, and persons or firms that manufacture or handle alcohol; retail liquor dealers; manufacturers and distributors of tobacco products; firearms registration; federal firearms license holders, including manufacturers, importers, and dealers; federal explosive license holders, including manufacturers, importers, and dealers; and the origin of all firearms manufactured and imported after 1968.

The U.S. Customs Service maintains public records regarding importers; exporters; customhouse brokers; customhouse truckers; and the registry, enrollment, and licensing of vessels not licensed by the Coast Guard or the United States that transport goods to and from the United States.

The Internal Revenue Service maintains public records regarding compliance with all federal tax laws.

The U.S. Secret Service maintains public records regarding counterfeiting and forgery of U.S. coins and currencies and records of all threats on the life of the president and his immediate family, the vice president, former presidents and their wives, wives of deceased presidents, children of deceased presidents until age sixteen, president- and vice president-elect, major candidates for the office of president and vice president, and heads of states representing foreign countries visiting in the United States.

7-5.4.11 Department of Justice. Under this department, the Antitrust Division maintains public records regarding federal sources of information relating to antitrust matters.

The Civil Rights Division maintains public records regarding its enforcement of all federal civil rights laws that prohibit discrimination on the basis of race, color, religion, or national origin in the areas of education, employment, and housing, and the use of public facilities and public accommodations.

The Criminal Division maintains public records regarding its enforcement of all federal criminal laws except those specifically assigned to the Antitrust, Civil Rights, or Tax Divisions.

The Drug Enforcement Administration maintains public records regarding all licensed handlers of narcotics, the legal trade of narcotics and dangerous drugs, and its enforcement of federal laws relating to narcotics and other drugs.

The Federal Bureau of Investigation maintains public records regarding criminal records, fingerprints, and its enforcement of federal criminal laws.

The Immigration and Naturalization Service maintains public records regarding immigrants, aliens, passengers and crews on vessels from foreign ports, naturalization records, deportation proceedings, and the financial statements of aliens and persons sponsoring their entry into the United States.

7-5.4.12 U.S. Postal Service. The U.S. Postal Service maintains public records regarding all of its activities. The investigative activities of the U.S. Postal Service are contained in the Office of the Postal Inspector.

7-5.4.13 Department of Energy. The Department of Energy is an executive department of the U.S. government that works to meet the nation's energy needs. The department develops and coordinates national energy policies and programs. It promotes conservation of fuel and electricity. It also conducts research to develop new energy sources and more efficient ways to use present supplies. The secretary of energy, a member of the president's cabinet, heads the department.

7-5.4.14 United States Fire Administration. The United States Fire Administration maintains an extensive database of information related to fire incidents through its administration of the National Fire Incident Reporting System (NFIRS).

In addition, the administration maintains records of ongoing research in fire investigation, information regarding arson awareness programs, and technical and reference materials focusing on fire investigation, and coordinates the distribution of the Arson Information Management System (AIMS) software.

7-5.4.15 National Oceanographic and Atmospheric Administration. Weather data past or present for all reporting stations in the United States are available from the National Climatic Data Center in Asheville, N.C. Local NOAA weather stations can provide data for their areas.

7-5.4.16 Other Federal Agencies. There are a variety of other federal agencies and commissions that are part of the federal level of government. These federal agencies and commissions all maintain a variety of public records. As such, the fire investigator may need to solicit information from these additional sources. The U.S. Senate Committee on Government Operations publishes a handy reference entitled *Chart of the Organization of Federal Executive Departments and Agencies.* This chart provides the exact name of an office, division, or bureau and the place it occupies in the organizational structure in a department or agency. With this reference, it should not be difficult for the fire investigator to determine the jurisdiction of a federal government agency or commission.

7-6 Private Sources of Information.

7-6.1 National Fire Protection Association (NFPA). The National Fire Protection Association was organized in 1896 to promote the science of and improve the methods of fire protection and prevention, to obtain and circulate information on these subjects, and to secure the cooperation of its members in establishing proper safeguards against loss of life and property. The Association is an international, charitable, technical, and educational organization.

The Association is responsible for the development and distribution of the *National Fire Codes®*. In addition to these, the Association has developed and distributed a wealth of technical information, much of which is of significant interest to the fire investigator.

7-6.2 Society of Fire Protection Engineers (SFPE). Organized in 1950, the Society of Fire Protection Engineers is a professional organization for engineers involved in the multifaceted field of fire protection. The society works to advance fire protection engineering and its allied fields, to maintain a high ethical standard among its members, and to foster fire protection engineering education.

7-6.3 American Society for Testing and Materials (ASTM). The American Society for Testing and Materials, founded in 1898, is a scientific and technical organization formed for "the development of standards on characteristics and performance of materials, products, systems, and services, and the promotion of related knowledge." It is the world's largest source of voluntary consensus standards.

Many of these standards focus on acceptable test methods when conducting a variety of fire-related tests often requested by fire investigators. Those predominant standards, which outline fire tests, are discussed in Chapter 9 of this document.

7-6.4 National Association of Fire Investigators (NAFI). The National Association of Fire Investigators was organized in 1961. Its primary purposes are to increase the knowledge of and improve the skills of persons engaged in the investigation and analysis of fires, explosions, or in the litigation that ensues from such investigations.

The Association also originated and implemented the National Certification Board. Each year, the Board certifies fire and explosion investigators and fire investigation instructors. Through this program, those certified are recognized for their knowledge, training, and experience and accepted for their expertise.

7-6.5 International Association of Arson Investigators (IAAI). The International Association of Arson Investigators was founded in 1949 by a group of public and private officials to address fire and arson issues. The purpose of the Association is to strive to control arson and other related crimes, through education and training, in addition to providing basic and advanced fire investigator training. The IAAI has chapters located throughout the world.

In addition to an annual seminar, there are also regional seminars focusing on fire investigator training and education. The Association publishes the *Fire and Arson Investigator*, a quarterly magazine. The IAAI offers a written examination for investigators meeting IAAI minimum qualifications to become an IAAI-certified fire investigator (CFI).

7-6.6 Regional Fire Investigations Organizations. In addition to the National Association of Fire Investigators, the International Association of Arson Investigators, and its state chapters, many regional fire investigation organizations exist. These organizations generally exist as state or local fire/arson task forces, professional societies or groups of fire investigators, or mutual aid fire investigation teams.

7-6.7 Real Estate Industry. The real estate industry maintains certain records that may prove beneficial to the fire investigator during the investigation. Besides records of persons and businesses that are selling or purchasing property, real estate offices often maintain extensive libraries of photographs of homes and businesses located in their sales territory. These photographs may be of interest to the fire investigator.

7-6.8 Abstract and Title Companies. Abstract and title companies are another valuable source of information. Records maintained by such companies include maps and tract books; escrow indexes of purchasers and sellers of real estate; escrow files containing escrow instructions, agreements, and settlements; and abstract and title policies.

7-6.9 Financial Institutions. Financial institutions, including banks, saving and loan associations, brokers, transfer agents, dividend disbursing agents, and commercial lending services, all maintain records that serve as sources of valuable information. Besides the financial information about a particular person or business, the records of financial institutions contain other information about all facets of a person's life or a business's history.

7-6.10 Insurance Industry. The insurance industry certainly has an interest in the results of most fire and explosion incidents. The industry's primary interest in such investigations is the detection of the crime of arson and other fraud offenses. The insurance industry can, however, also provide the fire investigator with a diverse amount of information concerning the involved structure or vehicle and the person(s) who have insured it. *(See Section 5-5.)*

The insurance industry also funds the Property Insurance Loss Register (PILR), which receives reports of property losses through fire, burglaries, and thefts. It is a computerized index of the insurance companies that paid the claims, the person to whom the claim was paid, the type of claim, and the like. It can serve as a valuable source of information to the fire investigator.

7-6.11 Educational Institutions. Educational institutions are not often considered as a source of information by fire investigators. The records maintained by such institutions can, however, provide an insight into a person's background and interests.

7-6.12 Utility Companies. During the normal course of business, utility companies maintain extensive databases, particularly concerning their customers. The fire investigator should not overlook that these companies, whether publicly owned or private, also maintain records concerning the quality of and problems associated with the distribution of their products or services.

7-6.13 Trade Organizations. Trade organizations are often one of the most valuable sources of information available to the fire investigator. These organizations promote the interest of many of the prominent trades. Their value to the fire investigator is that each organization focuses on a specific trade or discipline. As such, they often function as clearinghouses for knowledge in their area of expertise. Besides this expertise, most trade organizations develop and distribute publications that serve as important reference materials to the fire investigator.

7-6.14 Local Television Stations. Local TV stations often send camera crews to newsworthy fires. Copies of their videotape coverage may be obtained, if still available. TV stations also have records of the weather in the area, and often have limited data from local amateur weather watchers from areas away from the airports.

7-6.15 Other Private Sources. There are a variety of other private sources of information. These private sources all maintain a variety of records. As such, the fire investigator may need to solicit information from these additional sources.

7-7 Conclusion. The number and diversity of governmental and private sources of information for the fire investigator is unlimited. While not a comprehensive listing, by any means, those sources of information enumerated in this chapter should provide the fire investigator with a realization that his or her ability to solicit information pertinent to a particular fire investigator is also unlimited.

Chapter 8 Recording the Scene

8-1* Introduction. In recording any fire or explosion scene, the investigator's goal is to record the scene through a medium that will allow the investigator to recall his or her observations at a later date and to document the conditions at the scene. Common methods of accomplishing this goal include the use of photographs, videotapes, diagrams, maps, overlays, tape recordings, and notes.

Thorough and accurate recording of the scene is critical because it is from this compilation of factual data that investigative opinions and conclusions will be supported and verified. There are a number of resources to assist the investigator in recording the scene.

8-2 Photography. A visual documentation of the fire scene can be made using either film or video photography. Images can portray the scene better than words. They are the most efficient reminders of what the investigator saw while at the scene. Patterns and items may become evident that were overlooked at the time the photographs or videos were made. They can also substantiate reports and statements of the investigator.

Taking a basic photography or video course through a vocational school, camera club, or camera store would be most helpful in getting the photographer familiar with the equipment.

As many photographs should be taken as are necessary to adequately document and record the fire scene. It is recognized that time and expense considerations may impact the number of photographs taken, and the photographer should exercise discretion. It is far preferable to err on the side of taking too many photographs rather than too few.

The exclusive use of videotapes, motion pictures, or slides is not recommended. They are more effective when used in conjunction with still photographs. Also, additional equipment is obviously required to review and utilize videos, films, and slides.

8-2.1 Timing. Taking photographs during or as soon as possible after a fire is important when recording the fire scene, as the scene may become altered, disturbed, or even destroyed. Some reasons why time is important include the following:

(a) The building is in danger of imminent collapse or the structure must be demolished for safety reasons.

(b) The condition of the building contents creates an environmental hazard that needs immediate attention.

(c) Evidence should be documented when discovered as layers of debris are removed, similar to an archaeological dig. Documenting the layers can also assist in understanding the course of the fire.

8-2.2 Basics. The most fundamental aspect of photography that an investigator should grasp and comprehend is how a camera works. The easiest way to learn how a camera works is to compare the camera to the human eye.

One of the most important aspects to remember about fire investigation photography is light. The average fire scene consists of blackened subjects and blackened background creating much less than ideal conditions for taking a photograph. As one can imagine walking into a dark room causes the human eye to expand its pupil in order to gather more light, likewise the camera requires similar operation. The person in a dark room normally turns on the light to enhance the vision just as a photographer uses flash or floodlight to enhance the imitated vision of the camera.

Both the human eye and the camera project an inverted image on the light sensitive surface: the film in the camera and the retina in the eye. The amount of light admitted is regulated by the iris (eye) or diaphragm (camera). In both, the chamber through which the light passes is coated with a black lining to absorb the stray light and avoid reflection.

8-2.2.1 Types of Cameras. There is a multitude of camera types available to the investigator from small, inexpensive models to elaborate versions with a wide range of attachments.

Some cameras are fully automatic, giving some investigators a sense of comfort knowing that all they need to do is point and shoot. These cameras will set the film speed from a code on the film canister, adjust the lens opening (f-stop), and focus the lens by means of a beam of infrared light.

Manual operation is sometimes desired by the investigator so that specialty photographs can be obtained that the automatic camera with its built-in options cannot perform. For example, with a manual camera, bracketing (taking a series of photographs with sequentially adjusted exposures) can be performed to ensure at least one properly exposed photograph when the correct exposure is difficult to measure. There are some cameras that can be operated in a manual as well as an automatic mode, providing a choice from the same camera. Most investigators prefer an automatic camera.

A 35-mm single lens reflex camera is preferred over other formats, but the investigator who has a non-35-mm camera should continue to take photographs as recommended. A back-up camera that instantly develops prints can be advantageous, especially for an important photograph of a valuable piece of evidence.

8-2.2.2 Film. There are many types of film and film speeds available in both slide and print film. There are numerous speeds of film (ASA ratings) especially in the 35-mm range. Since 35 mm (which designates the size of the film) is most recognized and utilized by fire investigators, film speeds will be discussed using this size only. The common speeds range from 25 to 1600 in color and to 6400 in black and white. The numbers are merely a rating system. As the numbers get larger, the film requires less light. While the higher ASA-rated (faster) film is better in low light conditions with no flash, a drawback is that it will produce poorer-quality enlargements, which will have a grainy appearance. The film with the lowest rating that the investigator is comfortable with should be used because of the potential need for enlargements. Most investigators use a film with an ASA rating between 100 and 400. Fire investigators should practice and become familiar with the type and speed of film they intend to use on a regular basis.

8-2.2.3 Prints Versus Slides. There are advantages and disadvantages to both prints and slides. A benefit of slides over prints is that large size images may be displayed at no additional cost. When showing slides in court, every juror's attention can be kept on what the investigator is testifying about. If prints are utilized, the investigator's testimony may only be vaguely recalled if the jury member is busy looking at photographs being passed among the jurors as testimony continues. The use of poster-sized enlargements can help.

Conversely, during testimony of a long duration or detailed explanations of the scene, slides are a burden to refer to without the use of a projector. In this case photographs are easier to handle and analyze. When slides are used, problems can occur, such as the slides jamming or a lamp burning out in the projector. In this case there may be no alternate way to display the scene to the jurors without delay. Prints require no mechanical devices to display them, and notations for purposes of identification, documentation, or description are easily affixed on or adjacent to a still photograph.

Regardless of camera type, film speed, or whether slides or prints are being taken, it is recommended that the investigator use color film. The advantage of color film is that the final product can more realistically depict the fire scene by showing color variations between objects and smoke stains.

8-2.2.4 Lenses. The camera lens is used to gather light and to focus the image on the surface of the film. Most of today's lenses are compound, meaning that multiple lenses are located in the same housing. The fire investigator needs a basic understanding of the lens function to obtain quality photographs. The convex surface of the lens collects the light and sends it to the back of the camera where the film lies. The aperture is an adjustable opening in the lens that controls the amount of light admitted. The adjustments of this opening are sectioned into measurements called f-stops. As the f-stop numbers get larger, the opening gets smaller, admitting less light. These f-stop numbers are listed on the movable ring of the adjustable lenses. Normally the higher the f-stop that can be used, the better the quality of the photograph.

Focal lengths in lenses range from a normal lens (50 mm, which is most similar to the human eye) to the wide angle (28 mm or less) lenses, to telephoto and zoom lenses (typically 100 mm or greater). The investigator needs to determine what focal lengths will be used regularly and become familiar with the abilities of each.

The area of clear definition or depth of field is the distance between the farthest and nearest objects that will be in focus at any given time. The depth of field depends on the distance to the object being photographed, the lens opening, and the focal length of the lens being used. The depth of field will also determine the quality of detail in the investigator's photographs. For a given f-stop, the shorter the focal length of the lens, the greater the depth of field. For a given focal length lens, a larger f-stop (smaller opening) will provide a greater depth of field. The more depth of field, the more minute details that will be seen. This is an important technique to master. These are the most common lens factors with which the fire investigator needs to be familiar. If a fixed lens camera is used, the investigator need not be concerned with adjustments because the manufacturer has preset the lens. A recommended lens is a medium range zoom, such as the 35–70 mm, providing a wide angle with a good depth of field and the ability to take high-magnification close-ups (macros).

8-2.2.5 Filters. The investigator should know that problems can occur with the use of colored filters. Unless proper knowledge of their end results is known, it is recommended that they not be used. If colored filters are used, the investigator should take a photograph with a clear filter also. The clear filter can be continually used and is a good means of protecting the lens.

8-2.2.6 Lighting. The most usable light source known is the sun. No artificial light source can compare realistically in terms of color, definition, and clarity. At the beginning and end of the day, inside a structure or an enclosure, or on an overcast day, a substitute light source will most likely be needed. This can be obtained from a floodlight or from a strobe or flash unit integrated with the camera.

Because a burned area has poor reflective properties, artificial lighting using floodlights is useful. These, however, will need a power source either from a portable generator or from a source within reach by extension cord.

Flash units are necessary for the fire investigator's work. The flash unit should be removable from the camera body so that it can be operated at an angle oblique to that of the lens view. This practice is valuable in reducing the amount of reflection, exposing more depth perception, and amplifying the texture of the heat and flame damaged surfaces. Another advantage to a detachable flash unit is that, if the desired composition is over a larger area, the angle and distance between the flash and the subject can be more balanced.

A technique that will cover a large scene is called photo painting. This can be accomplished by placing the camera in a fixed position with the shutter locked open. A flash unit can be fired from multiple angles, to illuminate multiple subjects or large areas from all angles. The same general effect can be obtained by the use of multiple flash units and remote operating devices called slaves.

For close-up work, a ring flash will reduce glare and give adequate lighting for the subject matter. Multiple flash units can also be used to give a similar effect to the ring flash by placing them to flash at oblique angles.

A photograph of an 18 percent gray card standard may be beneficial for calibration in the printing stages of the photographs and can be photographed at the first frame of a roll of film. This will set the standard of light or flash utilized at each scene.

The investigator should be sure that glare from a flash or floodlight does not distort the actual appearance of an object. For example, smoke stains could appear lighter or nonexistent. In addition, shadows created could be interpreted as burn patterns. Movie lights used with videotapes can cause the same problems as still camera flash units. Using bounce flash, light defusers, or other techniques could alleviate this problem.

The investigator concerned with the potential outcome of a photograph can bracket the exposure. Bracketing is the process of taking the same subject matter at slightly different exposure settings to ensure at least one correct exposure.

8-2.2.7 Special Types of Photography. Today's technology has produced some specialty types of photography. Infrared, laser, and microscopic photography can be used under controlled circumstances. An example would be the ability of laser photography to document a latent fingerprint found on a body.

8-2.3 Composition and Techniques. Photographs may be the most persuasive factor in the acceptance of the fire investigator's theory of the fire's evolution.

In fire investigation, a series of photographs should be taken to portray the structure and contents that remain at the fire scene. The investigator generally takes a series of photographs working from the outside toward the inside of a structure as well as from the unburned toward the heaviest burned areas. The concluding photographs are usually of the area and point of origin as well as any elements of the cause of the fire.

It can be useful for the photographer to record, and thereby document, the entire fire scene and not just the suspected point of origin as it may be necessary to show the degree of smoke spread or evidence of undamaged areas.

8-2.3.1 Sequential Photos. Sequential photographs are helpful in understanding the relationship of a small subject to its relative position in a known area. The small subject is first photographed from a distant position where it is shown in context with its surroundings. Additional photographs are then taken increasingly closer until the subject is the focus of the entire frame. *(See Figure 8-2.3.1.)*

8-2.3.2 Mosaics. A mosaic or collage of photographs can be useful at times when a sufficiently wide angle lens is not available and a panoramic view is desired. This is created by assembling a number of photographs in overlay form to give a more than peripheral view of an area. *(See Figure 8-2.3.2.)* An investigator needs to identify items (e.g., benchmarks) in the edge of the view finder that will appear in the print and take the next photograph with that same reference point on the opposite side of the view finder. The two prints can then be combined to obtain a wider view than the camera is capable of taking in a single shot.

8-2.3.3 Photo Diagram. A photo diagram can be useful to the investigator. When the finished product of a floor plan is complete, it can be copied and directional arrows can be drawn to indicate the direction from which each of the photographs was taken. Corresponding numbers are then placed on the photographs. This diagram will assist in orienting a viewer who is unfamiliar with the fire scene. A diagram prepared to log a set of photographs might appear as shown in Figure 8-2.3.3.

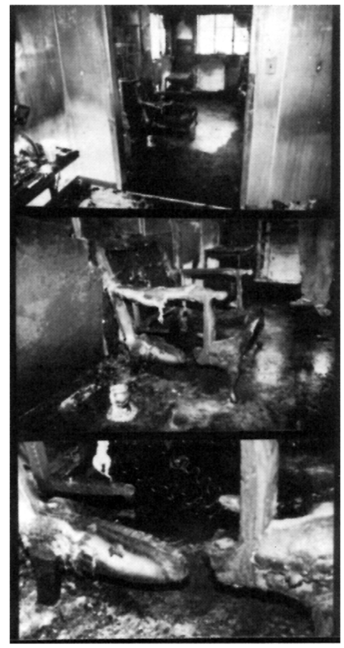


Figure 8-2.3.1 Sequential photographs of a chair.

Recommended documentation includes identification of the photographer, identification of the fire scene (i.e., address or incident number), and the date that the photographs were taken.

The exact time a photograph is taken does not always need to be recorded. There are instances, however, when the time period during which a photograph was taken will be important to an understanding of what the photograph depicts. In photographing an identical subject, natural lighting conditions that exist at noon may result in a significantly different photographic image than natural lighting conditions that exist at dusk. When lighting is a factor, the approximate time or period of day should be noted. Also, the specific time should be noted for any photograph taken prior to extinguishment of the fire as these often help establish time lines in the fire's progress.

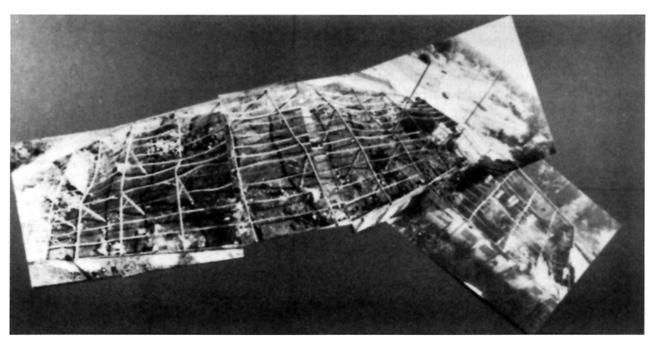


Figure 8-2.3.2 Mosaic of warehouse burn scene from aerial truck.

8-2.3.4 Assisting Photographer. If a person other than the fire investigator is taking the photographs, the angles and composition should be supervised by the fire investigator to ensure the shots needed to document the fire are obtained. Investigators should communicate their needs to the photographer, as they may not have a chance to return to the fire scene. The investigators should not assume the photographer understands what essential photographs are needed without discussing the content of each photo.

8-2.3.5 Photography and the Courts. For the fire investigator to weave photographs and testimony together in the court room, one requirement in all jurisdictions is that the photograph should be relevant to the testimony. There are other requirements that may exist in other jurisdictions, including noninflammatory content, clarity of the photograph, or lack of distortion. In most courts, if the relevancy exists, the photograph will usually withstand objections. Since the first color photographs were introduced into evidence in a fire trial, most jurisdictions have not distinguished between color or black and white photographs, if the photograph met all other jurisdictional criteria.

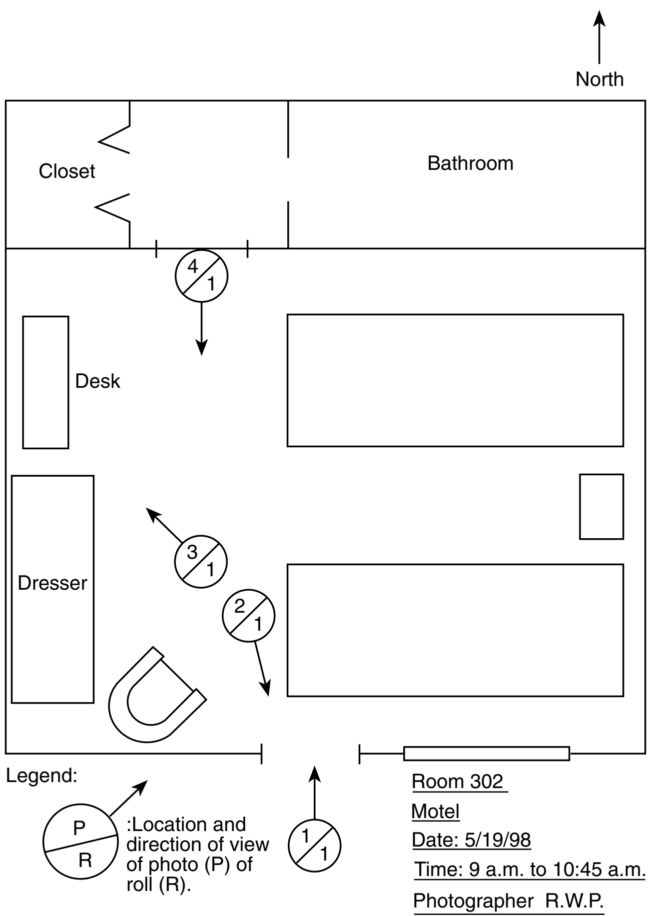


Figure 8-2.3.3 Diagram showing photo locations.

8-2.4 Video. In recent years, advancements have made motion pictures more available to the nonprofessional through the use of video cameras. There are different formats available for video cameras including VHS, BETA, and 8 mm. Video is a very useful tool to the fire investigator. A great advantage to video is the ability to orient the fire scene by progressive movement of the viewing angle. In some ways it combines the use of the photo diagram, photo indexing, floor plan diagram, and still photos into a single operation.

When taking videos or movies, "zooming-in" or otherwise exaggerating an object should be avoided, as it can be considered as presenting a dramatic effect rather than an objective effect that is sometimes required for evidence in litigation work.

Another use of video is for interviews of witnesses, owners, occupants, or suspects when the documentation of their testimony is of prime importance. If demeanor is important to an investigator or to a jury, the video can be helpful in revealing that.

The exclusive use of videotape or movies is not recommended, because such types of photography are often considered less objective and less reliable than still photographs. Video should be used in conjunction with still photographs.

Videotape recording of the fire scene can be a method of recording and documenting the fire scene. The investigator can narrate observations, similar to an audio (only) tape recorder, while videorecording the fire scene. The added benefit is that the investigator can better recall the fire scene, specifically fire patterns or artifact evidence, their location, and other important elements of the fire scene. Utilized in this method, the recording is not necessarily for the purpose of later presentation but is simply another method by which the investigator can record and document the fire scene.

Video recording can also be effective to document the examination of evidence, especially destructive examination. By videotaping the examination, the condition and position of particular elements of evidence can be documented.

8-2.5 Suggested Activities to Be Documented. An investigation may be enhanced if as many aspects of the fire ground activities can be documented as possible or practical. Such documentation may include the suppression activities, overhaul, and the cause and origin investigation.

8-2.5.1 During the Fire. Photographs of the fire in progress should be taken if the opportunity exists. These help show the fire's progression as well as fire department operations. As the overhaul phase often involves moving the contents and sometimes structural elements, photographing the overhaul phase will assist in understanding the scene before the fire.

8-2.5.2 Crowd or People Photographs. Photographs of people in a crowd are often valuable for identifying individuals who may have additional knowledge that can be valuable to the overall investigation.

8-2.5.3 Fire Suppression Photographs. Fire suppression activities pertinent to the investigation include the operation of automatic systems as well as the activities of the responding fire services, whenever possible. All aspects pertinent to these, such as hydrant locations, engine company positions, hose lays, attack line locations, and so forth, play a roll in the eventual outcome of the fire. Therefore, all components of those systems should be photographed.

8-2.5.4 Exterior Photographs. A series of exterior shots should be taken to establish the location of a fire scene. These could include street signs or access streets, numerical addresses, or landmarks that can be readily identified and are likely to remain for some time. Surrounding areas that would represent remote evidence, such as fire protection and exposure damage, should also be photographed. Exterior photographs should also be taken of all sides and corners of a structure to reveal all structural members and their relationships with each other. *(See Figure 8-2.5.4.)*

8-2.5.5 Structural Photographs. Structural photographs document the damage to the structure after heat and flame exposure. Structural photos can expose burn patterns to track the evolution of the fire and can assist in understanding the fire's origin.

A recommended procedure is to include as much as possible all exterior angles and views of the structure. Oblique corner shots can give reference points for orientation. Photographs should show all angles necessary for a full explanation of a condition.

Photographs of structural failures such as windows, roofs, or walls should be taken because such failures can change the route of fire travel and play a significant roll in the eventual outcome of the fire. Code violations or structural deficiencies should also be photographed because fire travel patterns may have resulted from those deficiencies.

8-2.5.6 Interior Photographs. Interior photographs are equally important. Lighting conditions will likely change from the exterior, calling for the need to adjust technique, but the concerns (tracking and documenting fire travel backward toward the fire origin) are the same. All significant ventilation points accessed or created by the fire should be photographed, as well as all significant smoke, heat, and burn patterns.

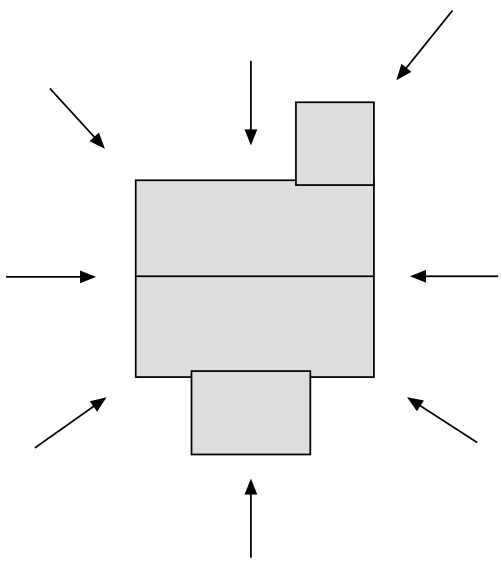


Figure 8-2.5.4 Photographing the scene from all angles and corners.

Rooms within the immediate area of the fire origin should be photographed even if there is no damage. If warranted, closets and cabinet interiors should also be documented. In small buildings this could involve all rooms, but in large buildings it may not be necessary to photograph all rooms unless there is a need to document the presence, absence, or condition of contents. *[See Figure 8-2.5.6(a).]*

All heat-producing appliances or equipment, such as furnaces, in the immediate area of the origin or connected to the area of origin should be photographed to document their role, if any, in the fire cause.

All furniture or other contents within the area of origin should be photographed as found and again after reconstruction. Protected areas left by any furnishings or other contents should also be photographed. *[See Figure 8-2.5.6(b).]*

The position of doors and windows during a fire is important, so photographs should be taken that would document those indications and resulting patterns.

Interior fire protection devices such as detectors, sprinklers, extinguishers used, door closers, or dampers should be photographed.

Clocks may indicate the time power was discontinued to them or the time in which fire or heat physically stopped their movement.

8-2.5.7 Utility and Appliance Photographs. The utility (gas, electric) entrances and controls both inside and outside a structure should be photographed. This includes gas and electric meters, gas regulators, and their location relative to the structure. The electric utility pole(s) near the structure that is equipped with the transformer serving the structure and the electrical services coming into the structure as well as the fuse or circuit breaker panels should also be photographed. If there are gas appliances in the fire area of origin, the position of all controls on the gas appliances should be photographed. When photographing electrical circuit breaker panels, the position of all circuit breaker handles and the panel's schedule indicating what electrical equipment is supplied by each breaker, when available, should be photographed. Likewise, all electrical cords and convenience outlets pertinent to the fire's location should be photographed.

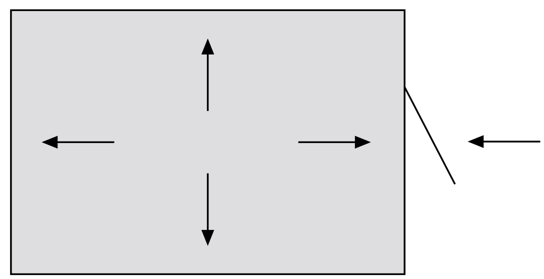


Figure 8-2.5.6(a) Photographing all four walls and both sides of each door.

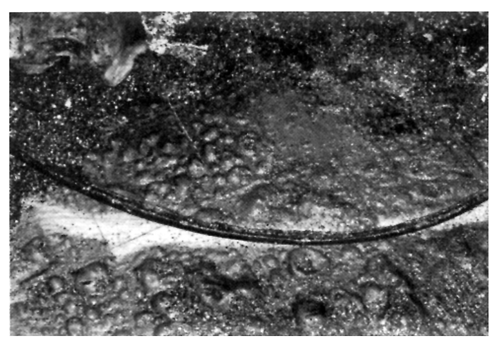


Figure 8-2.5.6(b) Floor tile protected from radiant heat by wire.

8-2.5.8 Evidence Photographs. Items of evidentiary value should be photographed at the scene and can be rephotographed at the investigator's office or laboratory if a more detailed view is needed. During the excavation of the debris strata, articles in the debris may or may not be recognized as evidence. If photographs are taken in a archaeological manner, the location and position of evidence that can be of vital importance will be documented permanently. Photographs orient the articles of evidence in their original location as well as show their condition when found. Evidence is essential in any court case, and the photographs of evidence stand strong with proper identification. In an evidentiary photograph, a ruler can be used to identify relative size of the evidence. Other items can also be used to identify the size of evidence as long as the item is readily identifiable and of constant size (e.g., a penny). A photograph should be taken of the evidence without the ruler or marker prior to taking a photograph with the marker.

8-2.5.9 Victim Photographs. The locations of occupants should be documented, and any evidence of actions taken or performed by those occupants photographed. This would include marks on walls, beds they were in, or protected areas where a body was located. *(See Figure 8-2.5.9.)* If there is a death involved, the body should be photographed. Surviving victims' injuries and their clothing worn should also be photographed.

8-2.5.10 Witness Viewpoint Photographs. If during an investigation witnesses surface and give testimony as to what they observed from a certain vantage point, a photograph should be taken from the most identical view available. This photograph will orient all persons involved with the investigation as well as a jury to the direction of the witnesses' observations and could support or refute the possibility of their seeing what they said they saw.

Figure 8-2.5.9 Protected area where body was located.

8-2.5.11 Aerial Photographs. The views from a high vantage point, which can be an aerial fire apparatus, adjacent building or hill, or from an airplane or helicopter, can often reveal fire spread patterns. Aerial photography can be expensive, and a number of special problems exist that can affect the quality of the results. It is suggested that the investigator seek the advice or assistance of an experienced aerial photographer when such photographs are desired.

8-2.6 Photography Tips. Investigators may help themselves by applying some or all of the following photography tips:

(a) Upon arrival at a fire scene and after shooting an 18 percent gray card, photograph a written "title sheet" that shows identifying information (i.e., location, date, or situational information).

(b) Label the film canister after each use to prevent confusion or loss.

(c) If the investigator's budget will allow, bulk film can be purchased and loaded into individual canisters that can allow for specific needs in multiple roll sizes and can be less expensive in certain situations.

(d) Carry a tripod that will allow for a more consistent mosaic pattern, alleviate movement and blurred photographs, and assist in keeping the camera free of fire debris. A quick release shoe on the tripod will save time.

(e) Do not combine multiple fire incidents on one roll of film. Complete each fire scene and remove the last roll from the camera before leaving the scene. This will eliminate potential confusion and problems later on.

(f) Carry extra batteries, especially in cold weather when they can be drained quickly. Larger and longer-life battery packs and battery styles are available.

(g) Remember not to leave the batteries in the photography equipment for an extended period of time. Leaking batteries can cause a multitude of problems to electrical and mechanical parts.

(h) Avoid obstruction of the flash or lens by hands, camera strap, or parts of the fire scene. Additionally, when the camera is focused and ready to shoot, both eyes should be opened to determine whether the flash went off.

8-3 Note Taking. Note taking is a complement to drawings and photographs and should primarily be used to supplement items and document items that cannot be photographed or drawn. These may include the following:

(a) Names and addresses

(b) Model/serial numbers

(c) Statements

(d) Photo log

(e) Identification of items

(f) Types of materials (e.g., wood paneling, foam plastic, carpet)

8-3.1 Tape Recorders. Many investigators like to dictate their notes into portable tape recorders. Since people may have difficulty phrasing sentences, it is perfectly acceptable to edit the transcribed version of a tape recording before filing the notes.

The investigator should be careful not to rely solely on tape recorders or any single piece of equipment when documenting critical pieces of information or evidence.

8-4 Drawings. Various types of drawings — including sketches, diagrams, and plans — can be made or obtained to assist the investigator in documenting and analyzing the fire scene.

Depending on the size or complexity of the fire, various techniques can be used to prepare the drawings. The exact detail required in the drawings depends on the decision of the specific investigator. As with photographs, drawings are used to support memory, as the investigator typically gets only one chance to inspect the fire scene.

8-4.1 Fire Investigation Drawings. After selecting the level of detail to which a drawing will be made, the fire investigator needs to decide how to record the damage patterns observed during the investigation. Once again, the detail needed is the decision of the investigator and should be made with the realization that there may be only one chance to document the scene. The detail may be a general approximation or a precise measurement. Supplemented by photographs, drawings of damage patterns provide good documentation of a fire scene and can assist an investigator in reanalyzing a fire scene if previously unknown information becomes available.

8-4.2 Types of Drawings. The investigator may wish to make several types of drawings to assist in analyzing or explaining a fire scene. Figures 8-4.2(a) through 8-4.2(f) are illustrative of drawing documentation.

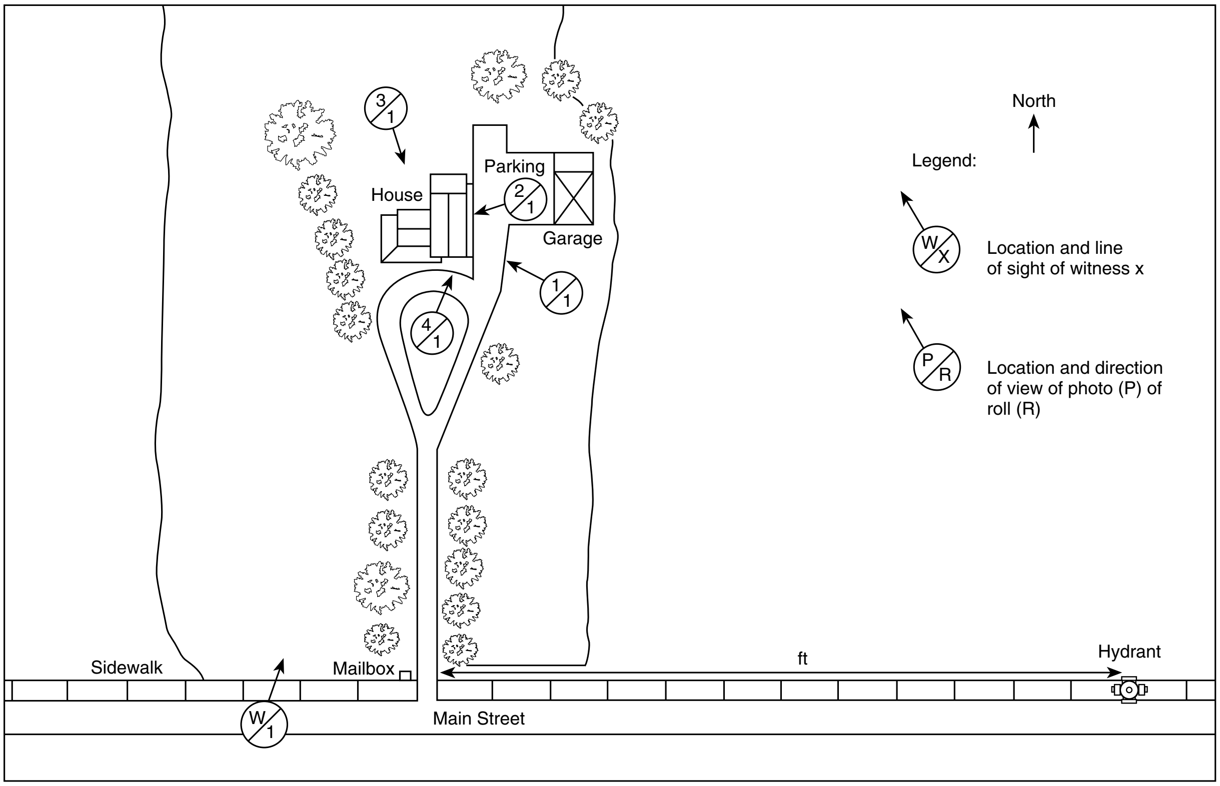


Figure 8-4.2(a) Site plan showing photo and witness locations.

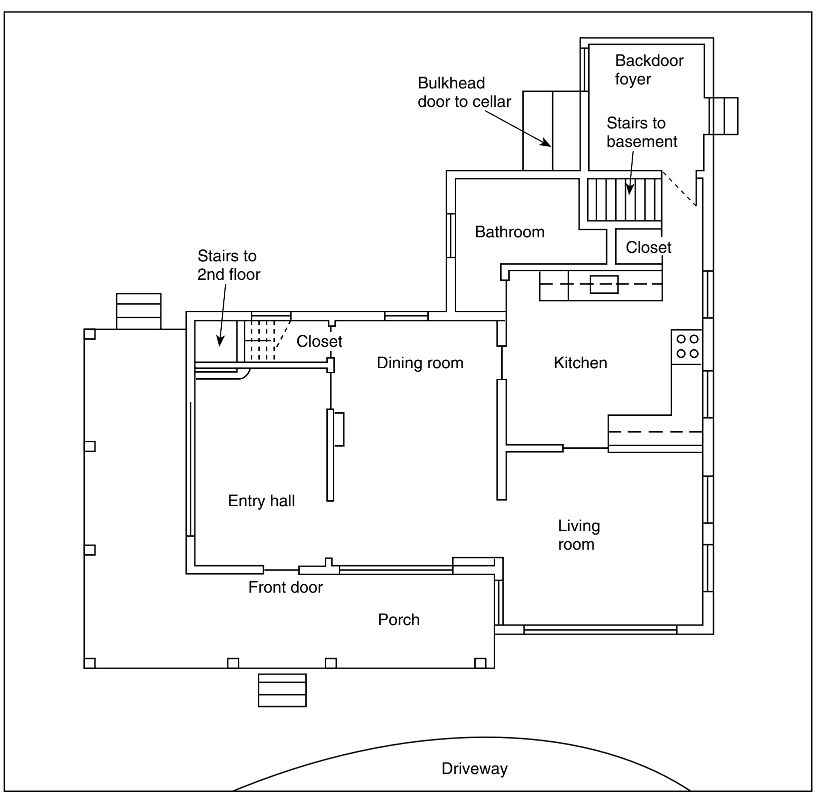


Figure 8-4.2(b) Detailed floor plan.

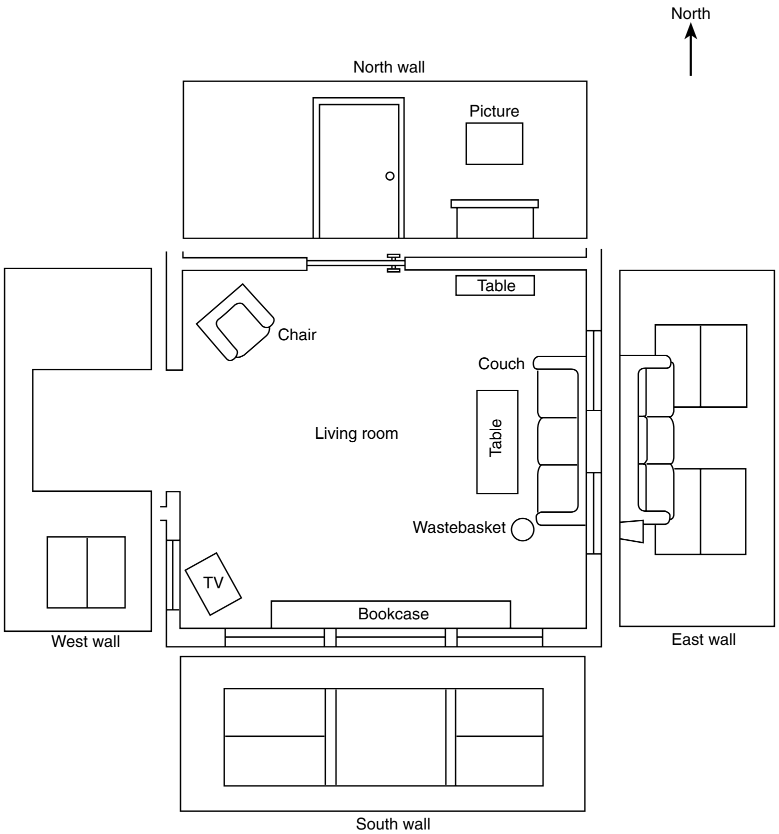


Figure 8-4.2(c) Pre-fire contents diagram.

8-4.3 Selection of Drawings. In selecting the type of drawing to obtain or create, the investigator should ask what construction features, equipment, or other factors were important to the cause, origin, and spread of the fire. For example, if the interior finish of a facility contributed to the fire, then a drawing showing the location of the material is important; or if the building caught fire due to an adjoining building burning, then a plan showing the location of the two buildings would be important. If a flammable liquid was used in a fire, it would be important to show where it was used and how it was connected.

8-4.4* Symbols. The selection of drawing symbols is the investigator's decision. Most importantly, the investigator should be consistent with the symbols used on a fire scene drawing. If an *E* is used to represent an exit sign, it should not also represent an entrance.

8-4.5 Minimum Drawings. In all fire cases the minimum drawing should consist of a simple sketch. A typical building sketch would show the relative locations of rooms, stairs, windows, doors, and associated damage. These drawings can be done freehand with dimensions that are paced off or approximated. This type of drawing should suffice on fire cases where the fire analysis and conclusions are simple. *(See Figure 8-4.5.)*

More complex scenes or litigation cases may require developing or acquiring actual building plans and detailed documentation of construction, equipment, furnishings, witnesses, and damage.

8-4.6 Architectural and Engineering Drawings. Many types of drawings are available and, to a student of drawing presentation, there are many references available for additional reading. For the fire investigator trying to document a scene, it is more important to be aware of the general names of drawings and the level of detail on each type of drawing. The architectural and engineering community generally use the following types of drawings in the design and construction process, starting with the least detail:

(a) *Sketches.* Freehand drawings of concepts

(b) *Schematic Design Drawings.* Drafted drawings showing the preliminary design layout with little detail

(c) *Design Development Drawings.* Drafted drawings defining and detailing the schematic drawings

(d) *Construction Drawings.* Drafted drawings with extensive detail showing what was used by contractors to build the structure

(e) *As-Built Drawings.* Drafted drawings showing any field modifications to the construction drawings and reflecting the finished structure

8-4.6.1 Drawing Variations. Within the design and construction process, there are several types of drawings with which the investigator should be familiar. The most common drawings, along with the discipline that generally prepares them, are shown in Table 8-4.6.1.

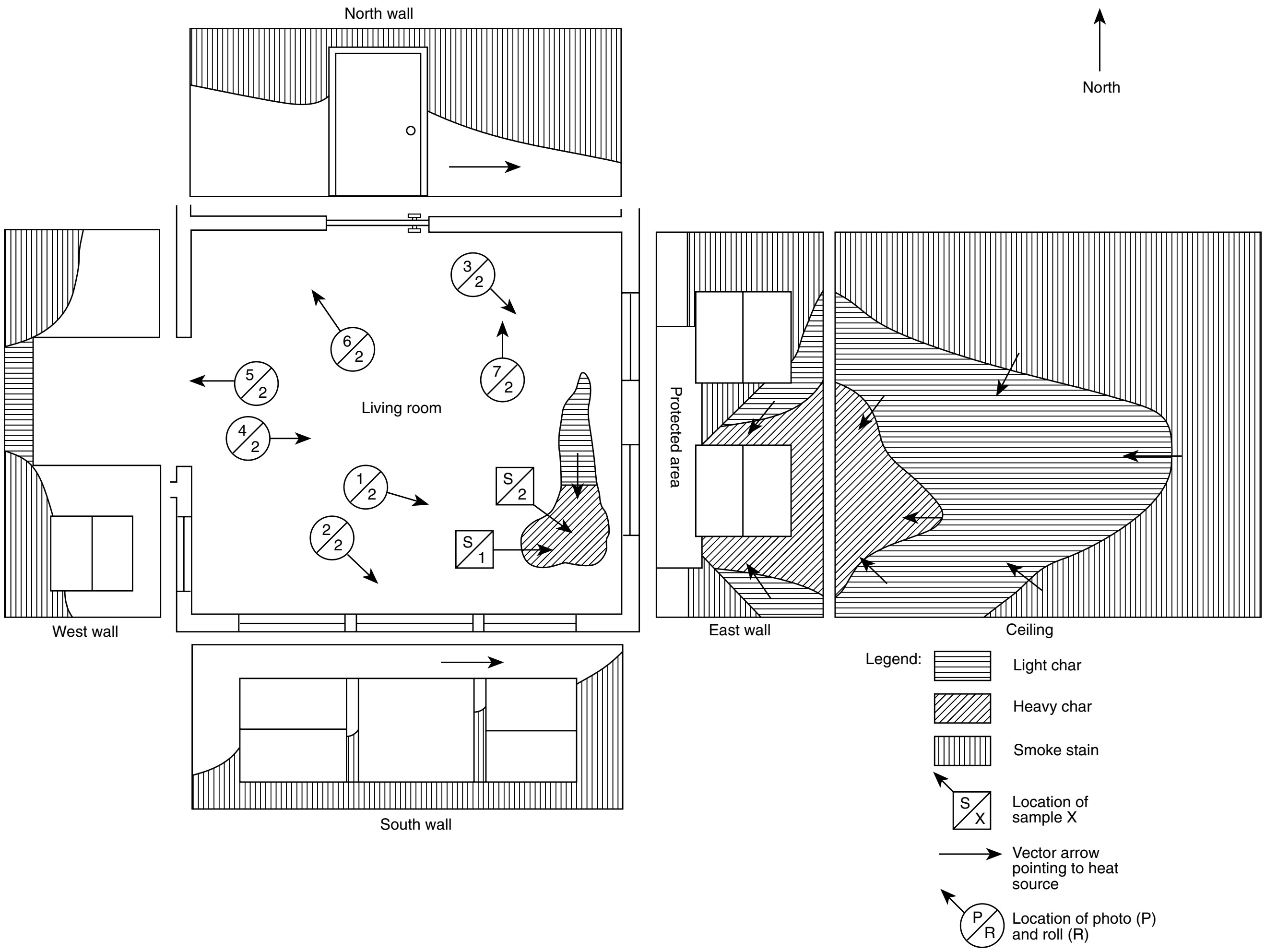


Figure 8-4.2(d) Exploded room diagram showing damage patterns, sample locations, and photo locations.

8-5 Architectural and Engineering Schedules. On larger projects, it may be necessary to detail the types of equipment in lists that are called *schedules.* Where many components are needed with great detail, a schedule will usually exist. Typical schedules are as follows:

(a) Fan schedule

(b) Door schedule

(c) Interior finish schedule

(d) Lighting schedule

8-6* Specifications. Architects and engineers prepare specifications to accompany their drawings. While the drawings show the geometry of the project, the specifications detail the quality of the materials, responsibilities of various contractors, and the general administration of the project. Specifications are usually divided into sections for the various components of the building. For the fire investigator, the properties of materials could be identified through a specification review and may assist in the analysis.

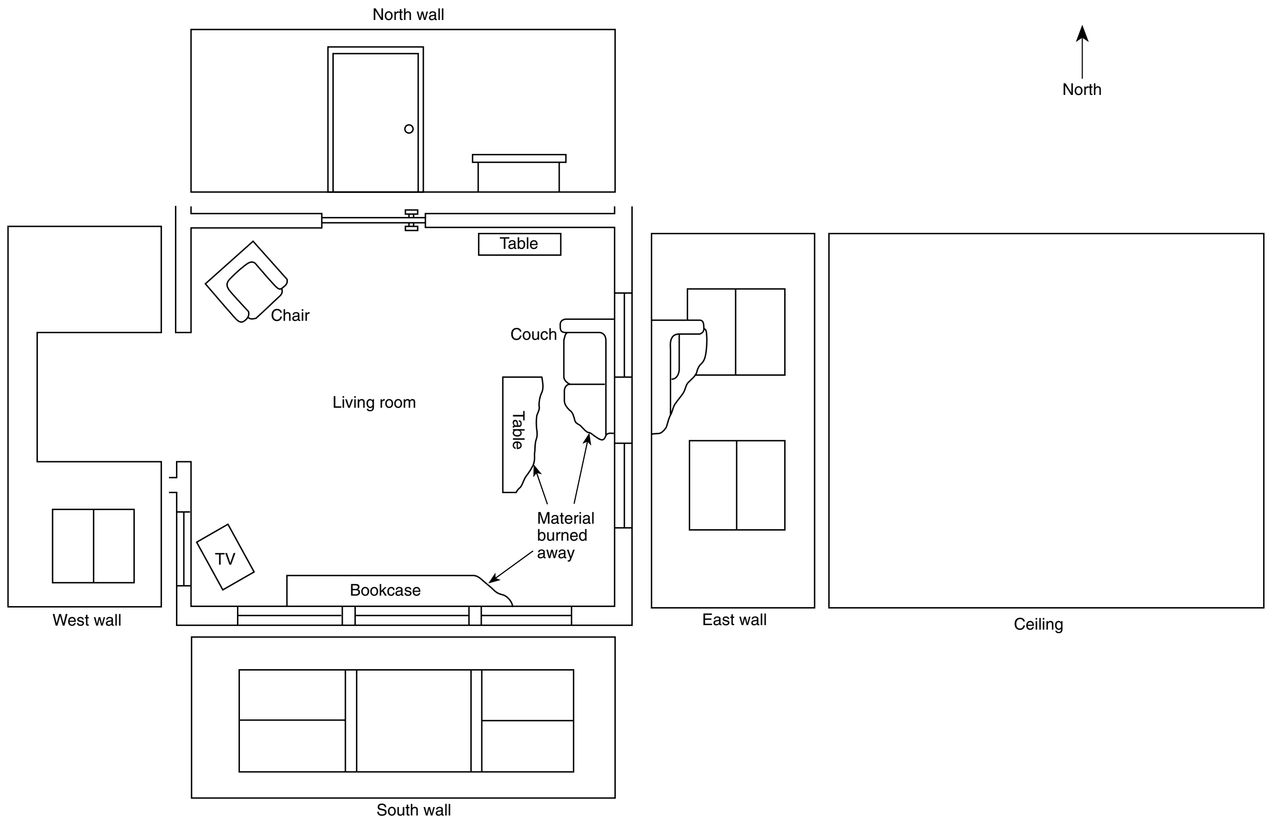
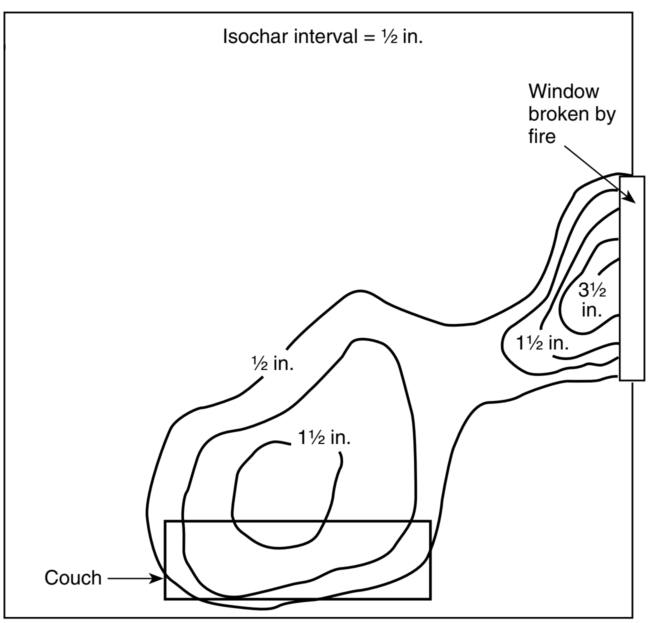


Figure 8-4.2(e) Contents reconstruction diagram showing damaged furniture in original positions.



For SI units: 1 in. = 25.4 mm.

Figure 8-4.2(f) An Isochar diagram showing lines of equal char depth on exposed floor joists.

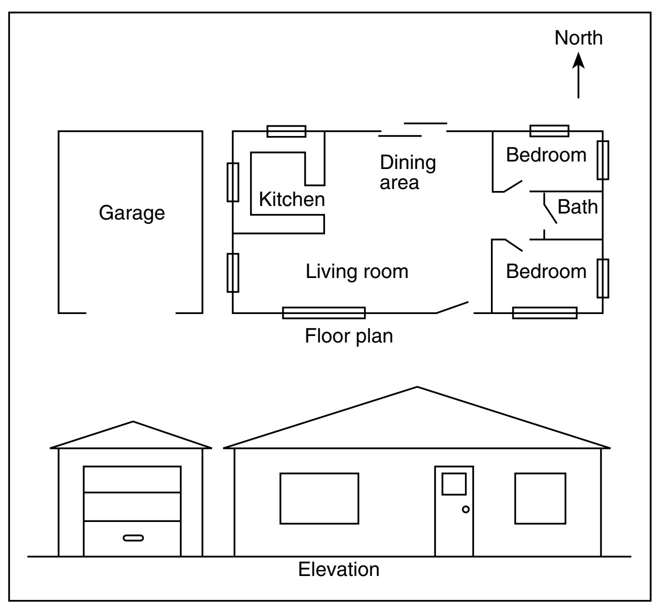


Figure 8-4.5 Minimum drawing for simple fire analysis.

Table 8-4.6.1 Design and Construction Drawing that May Be Available

Type	Information	Discipline
Topographical	Shows the varying grade of the land	Surveyor
Site plan	Shows the structure on the property with sewer, water, electrical distributions to the structure	Civil engineer
Floor plan	Shows the walls and rooms of structure as if you were looking down on it	Architect
Plumbing	Layout and size of piping for fresh and waste water	Mechanical engineer
Electrical	Size and arrangement of service entrance, switches and outlets, fixed electrical appliances	Electrical engineer
Mechanical	HVAC system	Mechanical engineer
Sprinkler/fire alarm	Self-explanatory	Fire protection engineer
Structural	Frame of building	Structural engineer
Elevations	Shows interior/exterior walls	Architect
Cross section	Shows what the inside of components look like if cut through	Architect
Details	Show close-ups of complex areas	All disciplines

Chapter 9 Physical Evidence

9-1* General. During the course of any fire investigation, the fire investigator is likely to be responsible for locating, collecting, identifying, storing, examining, and arranging for testing of physical evidence. The fire investigator should be thoroughly familiar with the recommended and accepted methods of processing such physical evidence.

9-2 Physical Evidence. Physical evidence, defined generally, is any physical or tangible item that tends to prove or disprove a particular fact or issue. Physical evidence at the fire scene may be relevant to the issues of the origin, cause, spread, or the responsibility for the fire.

9-2.1 Authority and Decision to Collect Physical Evidence. The decision on what physical evidence to collect at the incident scene for submission to a laboratory or other testing facility for examination and testing, or for support of a fact or opinion, rests with the fire investigator. This decision may be based on a variety of considerations, such as the scope of the investigation, legal requirements, or prohibition. *(See Section 5-2.)* Additional evidence may also be collected by others, including other investigators, insurance company representatives, manufacturer's representatives, owners, and occupants.

9-2.2* Comparison Samples. When collecting physical evidence for examination and testing, it is often necessary to also collect comparison samples. *(See Figure 9-2.2.)*

The collection of comparison samples is especially important when collecting materials that are believed to contain liquid or solid accelerant. For example, the comparison sample for physical evidence consisting of a piece of carpeting believed to contain a liquid accelerant would be a piece of the same carpeting that does not contain any of the liquid accelerant. Comparison samples allow the laboratory to evaluate the possible contributions of volatile pyrolysis products to the analysis and also to estimate the flammability properties of the normal fuel present.

It is recognized that comparison samples may be unavailable due to the condition of the fire scene. It is also recognized that comparison samples are frequently unnecessary for the valid identification of ignitible liquid residue. The determination of whether comparison samples are necessary is made by the laboratory analyst, but because it is usually impossible for an investigator to return to a scene to collect comparison samples, they should be collected at the time of the initial investigation.

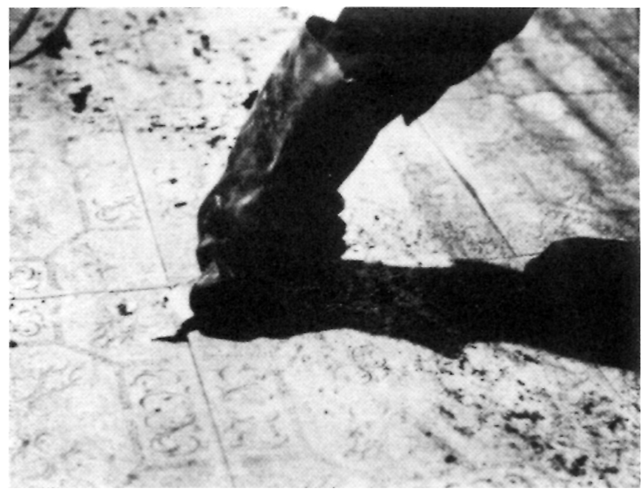


Figure 9-2.2 Collection of a comparison sample.

If mechanical or electrical equipment is suspected in the fire ignition, exemplar equipment may be identified and collected or purchased as a comparison sample.

9-3* Preservation of the Fire Scene and Physical Evidence. Every attempt should be made to protect and preserve the fire scene, as intact and undisturbed as possible with the structure, contents, fixtures, and furnishings remaining in their pre-fire locations. *(See Figure 9-3.)*

Generally, the cause of a fire or explosion is not known until near the end of the investigation. Therefore, the evidentiary or interpretative value of various pieces of physical evidence observed at the scene may not be known until, at, or near the end of the fire scene examination or until the end of the investigation overall. As a result, the entire fire scene should be considered physical evidence and should be protected and preserved.

The responsibility for the preservation of the fire scene and physical evidence does not lie solely with the fire investigator but should begin with arriving fire-fighting units or police authorities. Lack of preservation may result in the destruction, contamination, loss, or unnecessary movement of physical evidence. Initially, the incident commander and, later, the fire investigator should secure or ensure the security of the fire scene from unnecessary and unauthorized intrusions and should limit fire suppression activities to those that are necessary.

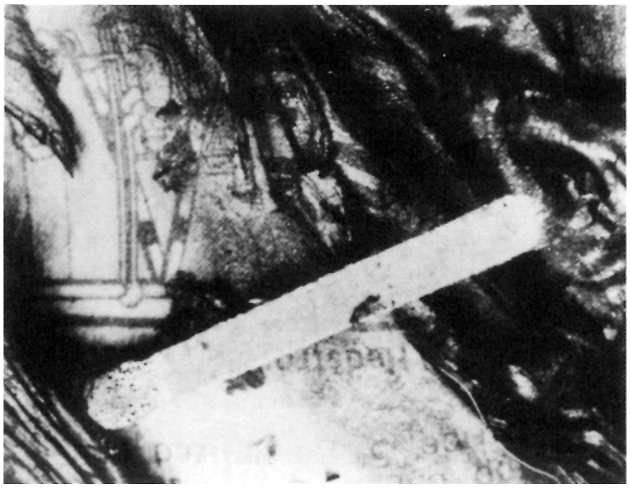


Figure 9-3 Physical evidence at a fire scene. Evidence such as this small paper match could easily be destroyed or lost in an improperly preserved fire scene.

Evidence at the fire scene should not be considered only in a criminal context such as in traditional forensic evidence (e.g., weapons, bodily fluids, footprints) or limited to arson-related evidence, items, or artifacts such as incendiary devices or containers. Potential evidence at the fire scene and surrounding areas can include the physical structure, the contents, artifacts, and any materials ignited or any material on which fire patterns appear.

9-3.1 Fire Patterns as Physical Evidence. The evidentiary and interpretative value of fire patterns may be as valuable as the identification of a potential ignition source, such as an incendiary device in an arson fire or an appliance in an accidental fire. Fire patterns are the visible or measurable physical effects that remain after a fire. These include thermal effects on materials, such as charring, oxidation, consumption of combustibles, smoke and soot deposits, distortion, melting, color changes, changes in the character of materials, structural collapse, and other effects. *(See Section 4-3.)*

9-3.2 Artifact Evidence. Artifacts can be the remains of the material first ignited, the ignition source, or other items or components in some way related to the fire ignition, development, or spread. An artifact may also be an item on which fire patterns are present, in which case the preservation of the artifact is not for the item itself but for the fire pattern that is contained thereon.

9-3.3 Protecting Evidence. There are a number of methods that can be utilized to protect evidence from destruction. Some methods include posting a fire fighter or police officer as a sentry to prevent or limit access to a building, a room, or an area; use of traffic cones or numerical markers to identify evidence or areas that warrant further examination; covering the area or evidence with tarpaulins prior to overhaul; or isolating the room or area with rope, caution tape, or police line tape. The investigator may benefit from supervising overhaul and salvage operations.

Items found at the fire scene, such as empty boxes or buckets, may be placed over an artifact. However, these items may not clearly identify the artifact as evidence that should be preserved by fire fighters or others at the fire scene. If evidence is not clearly identified, it may be susceptible to movement or destruction at the scene.

9-3.4 Role and Responsibilities of Fire Suppression Personnel in Preserving the Fire Scene. Generally, fire officers and fire fighters have been instructed during basic fire training that they have a responsibility on the fire scene regarding fire investigation. In most cases this responsibility is identified as recognizing the indicators of incendiarism such as multiple fires, the presence of incendiary devices or trailers, and the presence of ignitible liquids at the area of origin *(see Chapter 17).* While this is an important aspect of their responsibilities in the investigation of the fire cause, it is only a small part.

Prompt control and extinguishment of the fire protects evidence. The ability to preserve the fire scene is often an important element in the investigation. Even when fire officers and fire fighters are not responsible for actually determining the origin or cause of the fire, they play an integral part in the investigation by preserving the fire scene and physical evidence.

9-3.4.1 Preservation. Once an artifact or other evidence has been discovered, preliminary steps should be taken to preserve and protect the item from loss, destruction, or movement. The person making the discovery should notify the incident commander as soon as practical. The incident commander should notify the fire investigator or other appropriate individual or agency with the authority and responsibility for the documentation and collection of the evidence.

9-3.4.2 Caution in Fire Suppression Operations. Fire crews should avoid causing unnecessary damage to evidence when using straight stream hose lines, pulling ceilings, breaking windows, collapsing walls, and performing overhaul and salvage.

9-3.4.2.1 Use of Water Lines and Hose Streams. When possible, fire fighters should use caution with straight stream applications, particularly at the base of the fire, because the base of the fire may be the area of origin. Evidence of the ignition source can sometimes be found at the area of origin. The use of hose lines, and straight stream applications in particular, can move, damage, or destroy physical evidence that may be present.

The use of water hose lines for overhaul operations, like washing down, or for opening up walls or ceilings, should also be restricted to areas away from possible areas of origin.

The use of water should be controlled in areas where the investigator may wish to look at the floor for possible fire patterns. When draining the floor of standing water, the drain hole should be located so as to have the least impact on the fire scene and fire patterns.

9-3.4.2.2 Overhaul. It is during overhaul that any remaining evidence not damaged by the fire is susceptible to being destroyed or displaced. Excessive overhaul of the fire scene prior to the documentation and analysis of fire patterns can affect the investigation, including failure to determine the area of origin.

While the fire fighters have a responsibility to control and extinguish the fire and then check for fire extension, they are also responsible for the preservation of evidence. These two responsibilities may appear to be in conflict and, as a result, it is usually the evidence that is affected during the search for hidden fire. However, if overhaul operations are performed in a systematic manner, both responsibilities can be successfully met.

9-3.4.2.3 Salvage. The movement or removal of artifacts from a fire scene can make the reconstruction difficult for the investigator. If the investigator cannot determine the pre-fire location of the evidence, the analytical or interpretative value of the evidence may be lost. Moving, and particularly removing, contents and furnishings or other evidences at the fire scene should be avoided until the documentation, reconstruction, and analysis is completed.

9-3.4.2.4 Movement of Knobs and Switches. Fire fighters should refrain from turning knobs and operating switches on any equipment, appliances, or utility services at the fire scene. The position of components, such as the knobs and switches, may be a necessary element in the investigation, particularly in developing fire ignition scenarios or hypotheses. These components, which are often constructed of plastics, can become very brittle when subjected to heating. Their movement may alter the original post-fire state and may cause the switch to break or otherwise not be able to be relocated in its original post-fire position. *(See 18-5.3.)*

9-3.4.2.5 Use of Power Tools. The use of gasoline- or diesel-powered tools and equipment should be carefully controlled in certain locations. The refueling of any fuel-powered equipment or tools should be done outside the perimeter of the fire scene. Whenever fuel-powered equipment is used on the fire scene, its use and location should be documented and the investigator advised.

9-3.4.2.6 Limiting Access of Fire Fighters and Other Emergency Personnel. Access to the fire scene should be limited to those persons who need to be there. This includes limiting fire fighters and other emergency or rescue personnel to those necessary for the task at hand. When possible, the activity or operation should be postponed until the evidence has been documented, protected, evaluated, and collected.

9-3.5 Role and Responsibilities of the Fire Investigator. If the fire fighters have not taken the preliminary steps to preserve or protect the fire scene, then the fire investigator should assume the responsibility for doing so. Then, depending on the individual's authority and responsibility, the investigator should document, analyze, and collect the evidence.

9-3.6 Practical Considerations. The precautions in this section should not be interpreted as requiring the unsafe or infinite preservation of the fire scene. It may be necessary to repair or demolish the scene for safety or other practical reasons. Once the scene has been documented by interested parties and the relevant evidence removed, there is no reason to continue to preserve the scene. The decision as to when sufficient steps have been taken to allow the resumption of normal activities should be made by all interested parties known at that time.

9-4 Contamination of Physical Evidence. Contamination of physical evidence can occur from improper methods of collection, storage, or shipment. Like improper preservation of the fire scene, any contamination of physical evidence may reduce the evidentiary value of the physical evidence.

9-4.1 Contamination of Evidence Containers. Unless care is taken, physical evidence may become contaminated through the use of contaminated evidence containers. As such, the fire investigator should take every reasonable precaution to ensure that new and uncontaminated evidence containers are stored separately from used containers or contaminated areas.

One practice that may help to limit a possible source of cross contamination of evidence collection containers, including steel paint cans or glass jars, is to seal them immediately after receipt from the supplier. The containers should remain sealed during storage and transportation to the evidence collection site. An evidence collection container should be opened only to receive evidence at the collection point at which time it would be resealed pending laboratory examination.

9-4.2* Contamination During Collection. Most contamination of physical evidence occurs during its collection. This is especially true during the collection of liquid and solid accelerant evidence. The liquid and solid accelerant may be absorbed by the fire investigator's gloves or may be transferred onto the collection tools and instruments.

Avoiding cross contamination of any subsequent physical evidence, therefore, becomes critical to the fire investigator. To prevent such cross contamination, the fire investigator can wear disposable plastic gloves or place his or her hands into plastic bags during the collection of the liquid or solid accelerant evidence. New gloves or bags should always be used during the collection of each subsequent item of liquid or solid accelerant evidence.

An alternative method to limit contamination during collection is to utilize the evidence container itself as the collection tool. For example, the lid of a metal can may be used to scoop the physical evidence into the can, thereby eliminating any cross contamination from the fire investigator's hands, gloves, or tools.

Similarly, any collection tools or overhaul equipment such as brooms, shovels, or squeegees utilized by the fire investigator need to be thoroughly cleaned between the collection of each item of liquid or solid accelerant evidence to prevent similar cross contamination. The fire investigator should be careful, however, not to use waterless or other types of cleaners that may contain volatile solvents.

9-4.3 Contamination by Fire Fighters. Contamination is possible when fire fighters are using or refilling fuel-powered tools and equipment in an area where an investigator later tests for the presence or omission of an ignitible liquid. Fire fighters should take the necessary precautions to ensure the possibility of contamination is kept to a minimum, and the investigator should be informed when the possibility of contamination exists.

9-5 Methods of Collection. The collection of physical evidence is an integral part of a properly conducted fire investigation. The method of collection of the physical evidence is determined by many factors including the following:

(a) *Physical state.* Whether the physical evidence is a solid, liquid, or gas

(b) *Physical characteristics.* The size, shape, and weight of the physical evidence

(c) *Fragility.* How easily the physical evidence may be broken, damaged, or altered

(d) *Volatility.* How easily the physical evidence may evaporate

Regardless of which method of collection is employed, the fire investigator should be guided by the policies and procedures of the laboratory that will examine or test the physical evidence.

9-5.1* Documenting the Collection of Physical Evidence. Physical evidence should be thoroughly documented before it is moved. This documentation can be best accomplished through field notes, written reports, sketches, and diagrams with accurate measurements and photography. *(See Figure 9-5.1.)* The diagramming and photography should always be accomplished before the physical evidence is moved or disturbed. The investigator should strive to maintain a list of all evidence removed and of who removed it.

The purpose of such documentation is twofold. First, the documentation should assist the fire investigator in establishing the origin of the physical evidence, including not only its location at the time of discovery, but also its condition and relationship to the fire investigation. Second, the documentation should also assist the fire investigator in establishing that the physical evidence has not been contaminated or altered.

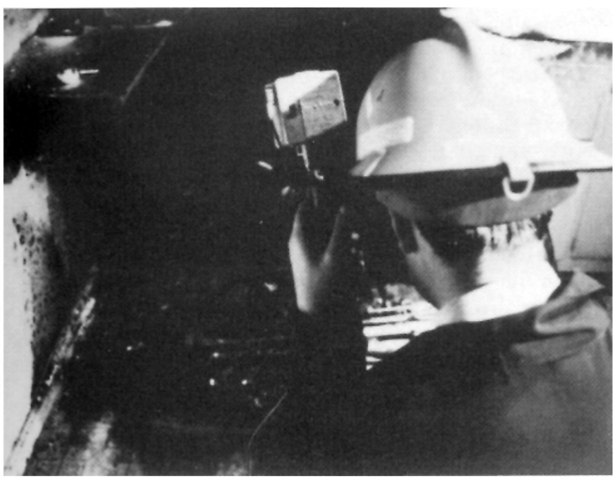


Figure 9-5.1 Using photography to document the collection of evidence.

9-5.2 Collection of Traditional Forensic Physical Evidence. Traditional forensic physical evidence includes, but is not limited to, finger and palm prints, bodily fluids such as blood and saliva, hair and fibers, footwear impressions, tool marks, soils and sand, woods and sawdust, glass, paint, metals, handwriting, questioned documents, and general types of trace evidence. Although usually associated with other types of investigations, these types of physical evidence may also become part of a fire investigation. The recommended methods of collection of such traditional forensic physical evidence vary greatly. As such, the fire investigator should consult with the forensic laboratory that will examine or test the physical evidence.

9-5.3 Collection of Evidence for Accelerant Testing. An accelerant is any agent, often an ignitible liquid, used to initiate or speed the spread of fire. Accelerant may be found in any state: gas, liquid, or solid. Evidence for accelerant testing should be collected and tested in accordance with ASTM E 1387, *Standard Test Method for Ignitable Liquid Residues in Extracts from Fire Debris Samples by Gas Chromatography,* or with ASTM E 1618, *Standard Guide for Identification of Ignitible Liquid Residues in Extracts from Samples of Fire Debris by Gas Chromatography–Mass Spectrometry.*

Liquid accelerants have unique characteristics that are directly related to their collection as physical evidence. These characteristics include the following:

(a) Liquid accelerants are readily absorbed by most structural components, interior furnishings, and other fire debris.

(b) Generally, liquid accelerants float when in contact with water (alcohol is a noted exception).

(c) Liquid accelerants have remarkable persistence (survivability) when trapped within porous material.

When a canine/handler team is used to detect possible evidence of accelerant use, the handler should be allowed to decide what areas (if any) of a building or site to examine. Prior to any search, the handler should carefully evaluate the site for safety and health risks such as collapse, falling, toxic materials, residual heat, and vapors and should be the final arbiter of whether the canine is allowed to search. It should also be the handler's decision whether to search all of a building or site, even areas not involved in the fire.

The canine/handler team can assist with the examination of debris (loose or packaged) removed from the immediate scene as a screening step to confirm whether the appropriate debris has been recovered for laboratory analysis.

9-5.3.1 Collection of Liquid Samples for Accelerant Testing. When a possible liquid accelerant is found in a liquid state, it can easily be collected using any one of a variety of methods. Whichever method is employed, however, the fire investigator should be certain that the evidence does not become contaminated.

If readily accessible, the liquid accelerant may be collected with a new syringe, eye dropper, pipette, siphoning device, or the evidence container itself. Sterile cotton balls or gauze pads may also be used to absorb the liquid. This method of collection results in the liquid accelerant's becoming absorbed by the cotton balls or gauze pads. The cotton balls or gauze pads and their absorbed contents then become the physical evidence that should be sealed in an airtight container and submitted to the laboratory for examination and testing.

9-5.3.2 Collection of Liquid Evidence Absorbed by Solid Materials. Often, liquid accelerant evidence may be found only if the liquid accelerant has been absorbed by solid materials, including soils and sands. This method of collection merely involves the collection of these solid materials with their absorbed contents. The collection of these solid materials may be accomplished by scooping them with the evidence container itself or by cutting, sawing, or scraping. Raw, unsealed, or sawed edges, ends, nail holes, cracks, knot holes, and other similar areas of wood, plaster, sheet rock, mortar, or even concrete are particularly good areas to sample. If deep penetration is suspected, the entire cross section of material should be removed and preserved for laboratory evaluation. In some solid material, such as soil or sand, the liquid accelerant may absorb deeply into the material. The investigator should therefore remove samples from a greater depth.

In those situations where liquid accelerants are believed to have become trapped in porous material, such as a concrete floor, the fire investigator may use absorbent materials such as lime, diatomaceous earth, or non-self-rising flour. This method of collection involves spreading the absorbent onto the concrete surface, allowing it to stand for 20 to 30 minutes, and securing it in a clean, airtight container. The absorbent is then extracted in the laboratory. The investigator should be careful to use clean tools and containers for the recovery step since the absorbent is easily contaminated. A sample of the unused absorbent should be preserved separately for analysis as a comparison sample.

9-5.3.3 Collection of Solid Samples for Accelerant Testing. Solid accelerant may be common household materials and compounds or dangerous chemicals. Since some incendiary materials remain corrosive or reactive, care should be taken in packaging to ensure the corrosive nature of these residues does not attack the packaging container. In addition such materials should be handled carefully by personnel for their own safety.

9-5.3.4* Canine Teams. Properly trained and validated ignitible liquid detection canine/handler teams have proven their ability to improve fire investigations by assisting in the location and collection of samples for laboratory analysis for the presence of ignitible liquids. The proper use of detection canines is to assist with the location and selection of samples.

In order for the presence or absence of an ignitible liquid to be scientifically confirmed in a sample, that sample should be analyzed by a laboratory in accordance with 9-5.3. Any canine alert not confirmed by laboratory analysis should not be considered validated.

Research has shown that canines have responded or have been alerted to pyrolysis products that are not produced by an ignitible liquid and have not always responded when an ignitible liquid accelerant was known to be present. If an investigator feels that there are indicators of an accelerant, samples should be taken even in the absence of a canine alert.

The canine olfactory system is believed capable of detecting gasoline at concentrations below those normally cited for laboratory methods. The detection limit, however, is not the sole criterion or even the most important criterion for any forensic technique. Specificity, the ability to distinguish between ignitible liquids and background materials, is even more important than sensitivity for detection of any ignitible liquid residues. Unlike explosive- or drug-detecting dogs, these canines are trained to detect substances that are common to our everyday environment. The techniques exist today for forensic laboratories to detect submicroliter quantities of ignitible liquids, but because these substances are intrinsic to our mechanized world, merely detecting such quantities is of limited evidential value.

Current research does not indicate which individual chemical compounds or classes of chemical compounds are the key "triggers" for canine alerts. Research reveals that most classes of compounds contained in ignitible liquids may be produced from the burning of common synthetic materials. Laboratories that use ASTM guidelines *(see Section 9-10)* have minimum standards that define those chemical compounds that must be present in order to make a positive determination. The sheer variety of pyrolysis products present in fire scenes suggests possible reasons for some unconfirmed alerts by canines. The discriminatory ability of the canine to distinguish between pyrolysis products and ignitible liquids is remarkable but not infallible.

The proper objective of the use of canine/handler teams is to assist with the selection of samples that have a higher probability of laboratory confirmation than samples selected without the canine's assistance.

Canine ignitible liquid detection should be used in conjunction with, and not in place of, the other fire investigation and analysis methods described in this guide.

9-5.4 Collection of Gaseous Samples. During certain types of fire and explosion investigations, especially those involving fuel gases, it may become necessary for the fire investigator to collect a gaseous sample. The collection of gaseous samples may be accomplished by several methods.

The first method involves the use of commercially available mechanical sampling devices. These devices merely draw a sample of the gaseous atmosphere and contain it in a sample chamber or draw it through a trap of charcoal- or polymer-adsorbing material for later analysis.

Another method is the utilization of evacuated air-sampling cans. These cans are specifically designed for taking gaseous samples.

Still another method employs the use of a clean glass bottle filled with distilled water. Distilled water is utilized, as it has had most of the impurities removed from it. This method simply requires that the fire investigator pour the distilled water out of its bottle in the atmosphere to be sampled. *(See Figure 9-5.4.)* As the distilled water leaves the bottle, it is replaced by the gaseous sample. The bottle is then capped, and the sample has been obtained.

Figure 9-5.4 Gathering a gaseous sample.

9-5.5 Collection of Electrical Equipment and Components. Before attempting to collect electrical equipment or components, the fire investigator should verify that all sources of electricity are off or disconnected. All safety procedures described in Chapter 10 should be followed. Electrical equipment and components may be collected as physical evidence to assist the fire investigator in determining whether the component was related to the cause of the fire.

Electrical components, after being involved in a fire, may become brittle and subject to damage if mishandled. Therefore, methods and procedures used in collection should preserve, as far as practical, the condition in which the physical evidence was found. Before any electrical component is collected as physical evidence, it should be thoroughly documented, including being photographed and diagrammed. Electrical wiring can usually be cut easily and removed. This type of evidence may consist of a short piece, a severed or melted end, or it might be a much longer piece, including an unburned section where the wiring's insulation is still intact. The fire investigator should collect the longest section of wiring practicable so that any remaining insulation can also be examined. Before wires are cut, a photograph should be taken of the wire(s), and then both ends of the wire should be tagged and cut so that they can be identified as one of the following:

(a) The device or appliance to which it was attached or from which it was severed

(b) The circuit breaker or fuse number or location to which the wire was attached or from which it was severed

(c) The wire's path or the route it took between the device and the circuit protector

Electrical switches, receptacles, thermostats, relays, junction boxes, electrical distribution panels, and similar equipment and components are often collected as physical evidence. It is recommended that these types of electrical evidence be removed intact, in the condition in which they were found.

When practical, it is recommended that any fixtures housing such equipment and components be removed without disturbing the components within them. Electrical distribution panels, for example, should be removed intact. An alternative method, however, would be the removal of individual fuse holders or circuit breakers from the panel. If the removal of individual components becomes necessary, the fire investigator should be careful not to operate or manipulate them while being careful to document their position and their function in the overall electrical distribution system.

If the investigator is unfamiliar with the equipment,he or she should obtain assistance from someone knowledgeable regarding the equipment prior to disassembly or on-scene testing to prevent damage to the equipment or components.

9-5.6 Collection of Appliances or Small Electrical Equipment. Whenever an appliance or other type of equipment is believed to be part of the ignition scenario, it is recommended that the fire investigator have it examined or tested. Appliances may be collected as physical evidence to support the fire investigator's determination that the appliance was or was not the cause of the fire. This type of physical evidence may include many diverse items from the large (e.g., furnaces, water heaters, stoves, washers, dryers) to the small (e.g., toasters, coffee pots, radios, irons, lamps).

Where practical, the entire appliance or item of equipment should be collected as physical evidence. This includes any electrical power cords or fuel lines supplying or controlling it.

Where the size or damaged condition of an appliance or item of equipment makes it impractical to be removed in its entirety, it is recommended that it be secured in place for examination and testing. Often, however, only a single component or group of components in an appliance or item of equipment may be collected as physical evidence. In that case, the fire investigator should strive to ensure that the removal, transportation, and storage of such evidence maintains the physical evidence in its originally discovered condition.

9-6 Evidence Containers. Once collected, physical evidence should be placed and stored in an appropriate evidence container. Like the collection of the physical evidence itself, the selection of an appropriate evidence container also depends on the physical state, physical characteristics, fragility, and volatility of the physical evidence. The evidence container should preserve the integrity of the evidence and prevent any change to or contamination of the evidence.

Evidence containers may be common items, such as envelopes, paper bags, plastic bags, glass containers, or metal cans, or they may be containers specifically designed for certain types of physical evidence. The investigator's selection of an appropriate evidence container should be guided by the policies and procedures of the laboratory that will examine or test the physical evidence or the use to which the evidence will be subjected.

9-6.1 Liquid and Solid Accelerant Evidence Containers. It is recommended that containers used for the collection of liquid and solid accelerant evidence be limited to four types. These include metal cans, glass jars, special evidence bags, and common plastic evidence bags.

The fire investigator should be concerned with preventing the evaporation of the accelerant and preventing its contamination. It is important, therefore, that the container used be completely sealed to prohibit such evaporation or contamination.

9-6.1.1 Metal Cans. The recommended container for the collection of liquid and solid accelerant evidence is an unused, clean metal can. *(See Figure 9-6.1.1.)* In order to allow space for vapors to collect, the can should be not more than two-thirds full.

The advantages of using metal cans include their availability, economic price, durability, and ability to prevent the evaporation of volatile liquids.

The disadvantages, however, include the inability to view the evidence without opening the container, the space requirements for storage, and the tendency of the container to rust when stored for long periods of time. If metal cans are used to store bulk quantities of volatile liquids, such as gasoline, high storage temperatures [above 100°F (38°C)] can produce sufficient vapor pressure to force the lid open and cause loss of sample. For such samples, glass jars may be more appropriate.

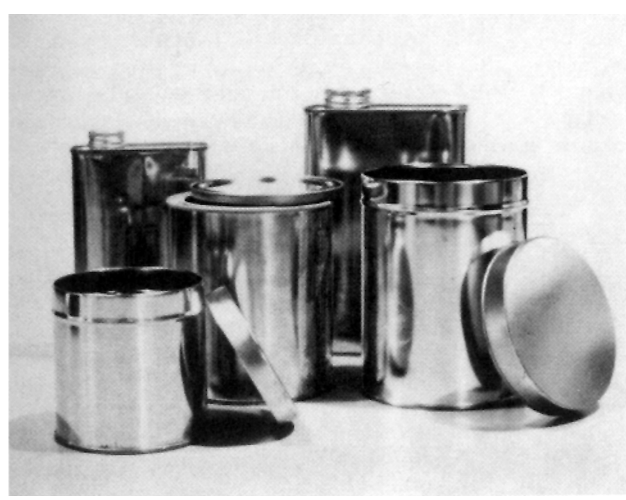


Figure 9-6.1.1 Various types of metal cans.

9-6.1.2 Glass Jars. Glass jars can also be used for the collection of liquid and solid accelerant evidence. It is important that the jars not have glued cap liners or rubber seals, especially when bulk liquids are collected. The glue often contains traces of solvent that can contaminate the sample, and rubber seals can soften or even dissolve in the presence of liquid accelerants or their vapors, allowing leakage or loss of the sample. In order to allow space for vapor samples to be taken during examination and testing, the glass jar should not be more than two-thirds full.

The advantages of using glass jars include their availability, their low price, the ability to view the evidence without opening the jar, the ability to prevent the evaporation of volatile liquids, and their lack of deterioration when stored for long periods of time.

The disadvantages, however, include their tendency to break easily and their physical size, which often prohibits the storage of large quantities of physical evidence.

9-6.1.3 Special Evidence Bags. Special bags designed specifically for liquid and solid accelerant evidence can also be used for collection. Unlike common plastic evidence bags, these special evidence bags do not have a chemical composition that can cause erroneous test results during laboratory examination and during testing of the physical evidence contained in such bags.

The advantages of using special evidence bags include their availability in a variety of shapes and sizes, their economic price, the ability to view the evidence without opening the bag, their ease of storage, and the ability to prevent the evaporation of volatile liquids.

The disadvantages, however, are that they are susceptible to being damaged easily, resulting in the contamination of the physical evidence contained in them, and they may be difficult to seal adequately.

9-6.1.4 Common Plastic Bags. While they are not generally usable for volatile evidence, common (polyethylene) plastic bags can be used for some evidence packaging. They can be used for packaging incendiary devices or solid accelerant residues, but they could be permeable, allowing for loss and contamination.

The advantages of using common plastic bags include their availability in a variety of shapes and sizes, their economic price, the ability to view the evidence without opening the bag, and their ease of storage.

The disadvantages, however, are their susceptibility to easy damage (tearing and penetration), resulting in the contamination of the physical evidence contained in them, and their marked inability to retain light hydrocarbons and alcohols, resulting in loss of the sample, misidentification, or cross contamination between containers in the same box.

9-7 Identification of Physical Evidence. All evidence should be marked or labeled for identification at the time of collection.

Recommended identification includes the name of the fire investigator collecting the physical evidence, the date and time of collection, an identification name or number, the case number and item designation, a description of the physical evidence, and where the physical evidence was located. This can be accomplished directly on the container *(see Figure 9-7)* or on a preprinted tag or label that is then securely fastened to the container.

The fire investigator should be careful that the identification of the physical evidence cannot be easily damaged, lost, removed, or altered. The fire investigator also should be careful that the placement of the identification, especially adhesive labels, does not interfere with subsequent examination or testing of the physical evidence at the laboratory.

9-8 Transportation and Storage of Physical Evidence. Transportation of physical evidence to the laboratory or testing facility can be done either by hand delivery or by shipment.

9-8.1 Hand Delivery. Whenever possible, it is recommended that physical evidence be hand delivered for examination and testing. Hand delivery minimizes the potential of the physical evidence becoming damaged, misplaced, or stolen.

During such hand delivery, the fire investigator should take every precaution to preserve the integrity of the physical evidence. It is recommended that the physical evidence remain in the immediate possession and control of the fire investigator until arrival and transfer of custody at the laboratory or testing facility.

The fire investigator should define the scope of the examination or testing desired in writing. This request should include the name, address, and telephone number of the fire investigator; a detailed listing of the physical evidence being submitted for examination and testing; and any other information required, dependent on the nature and scope of the examination and testing requested. This request may also include the facts and circumstances of the incident yielding the physical evidence.

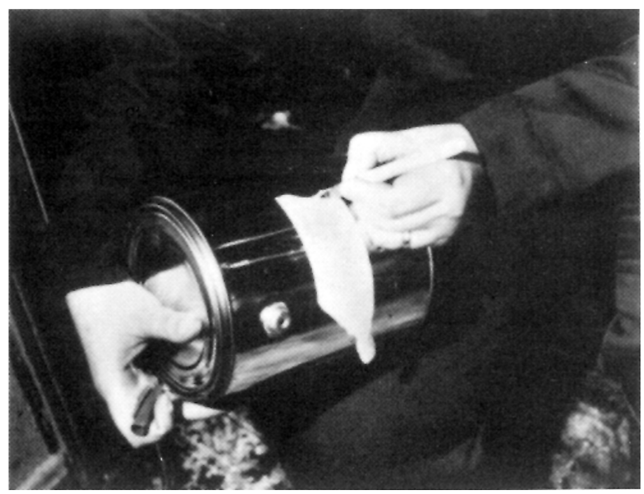


Figure 9-7 Marking of the evidence container.

9-8.2 Shipment. It may sometimes become necessary to ship physical evidence to a laboratory or testing facility for examination and testing. When this becomes necessary, the fire investigator should take every precaution to preserve the integrity of that physical evidence.

The fire investigator should choose a container of sufficient size to adequately hold all of the individual evidence containers from a single investigation. Physical evidence from more than one investigation should never be placed in the same shipment.

The individual evidence container should be packaged securely within the shipping container. A letter of transmittal should be included. The letter of transmittal is a written request for laboratory examination and testing. It should include the name, address, and telephone number of the fire investigator; a detailed listing of the physical evidence being submitted for examination and testing; the nature and scope of the examination and testing desired; and any other information required, depending on the nature and scope of the examination and testing requested. This letter of transmittal may also include the facts and circumstances of the incident yielding the physical evidence.

The sealed package should be shipped by registered United States mail or any commercial courier service. The fire investigator should, however, always request return receipts and signature surveillance.

9-8.2.1 Shipping Electrical Evidence. In addition to the procedures described in 9-8.2, the investigator should be aware that some electrical equipment components with sensitive electromechanical components may not be suitable for shipment. Examples include certain circuit breakers, relays, or thermostats. The fire investigator should consult personnel at laboratory or testing facilities for advice on how to transport the evidence.

9-8.2.2 Volatile or Hazardous Materials. The fire investigator is cautioned about shipping volatile or hazardous materials. The investigator should ensure that such shipments are made in accordance with applicable federal, state, and local law. When dealing with volatile evidence, it is important that the evidence be protected from extremes of temperature. Freezing or heating of the volatile materials may affect lab test results. Generally, the lower the temperature at which the evidence is stored, the better the volatile sample will be preserved, but it should not be allowed to freeze.

9-8.3 Storage of Evidence. Physical evidence should be maintained in the best possible condition until it is no longer needed. It should always be protected from loss, contamination, and degradation. Heat, sunlight, and moisture are the chief sources of degradation of most kinds of evidence. Dry and dark conditions are preferred, and the cooler the better. Refrigeration of volatile evidence is strongly recommended. If a sample is being collected for fire-debris analysis, it may be frozen since freezing will prevent microbial and other biological degradation. However, freezing may interfere with flash point or other physical tests and may burst water-filled containers.

9-9 Chain of Custody of Physical Evidence. The value of physical evidence entirely depends on the fire investigator's efforts to maintain the security and integrity of that physical evidence from the time of its initial discovery and collection to its subsequent examination and testing. At all times after its discovery and collection, physical evidence should be stored in a secured location that is designed and designated for this purpose. Access to this storage location should be limited in order to limit the chain of custody to as few persons as possible. Wherever possible, the desired storage location is one that is under the sole control of the fire investigator.

When it is necessary to pass chain of custody from one person to another, this should be done using a form on which the receiving person signs for the physical evidence. Figure 9-9 shows an example of such a form.

9-10 Examination and Testing of Physical Evidence. Once collected, physical evidence is usually examined and tested in a laboratory or other testing facility. Physical evidence may be examined and tested to identify its chemical composition; to establish its physical properties; to determine its conformity or lack of conformity to certain legal standards; to establish its operation, inoperation, or malfunction; to determine its design sufficiency or deficiency, or other issues that will provide the fire investigator with an opportunity to understand and determine the origin of a fire, the specific cause of a fire, the contributing factors to a fire's spread, or the responsibility for a fire. The investigator should consult with the laboratory or other testing facility to determine what specific services are provided and what limitations are in effect.

9-10.1 Laboratory Examination and Testing. A wide variety of standardized tests are available depending on the physical evidence and the issue or hypothesis being examined or tested. Such tests should be performed and carried out by procedures that have been standardized by some recognized group. Such conformance better ensures that the results are valid and that they will be comparable to results from other laboratories or testing facilities.

It should be noted that the results of many laboratory examinations and tests may be affected by a variety of factors. These factors include the abilities of the person conducting or interpreting the test, the capabilities of the particular test apparatus, the maintenance or condition of the particular test apparatus, sufficiency of the test protocol, and the quality of the sample or specimen being tested. Fire investigators should be aware of these factors when using the interpretations of test results.

If it is determined that testing might alter the evidence, interested parties should be notified prior to testing to allow them an opportunity to object or be present at the testing. Guidance regarding notification can be found in ASTM E 860, *Standard Practice for Examining and Testing Items That Are or May Become Involved in Product Liability Litigation.*

Crime Scene Search Evidence Report

Name of subject ....

Offense ....

Date of incident .... Time .... a.m. p.m.

Search officer ....

Evidence description ....

....

Location ....

....

Chain of Possession

Received from ....

By..........

Date .... Time .... a.m. p.m.

Received from ....

By..........

Date .... Time .... a.m. p.m.

Received from ....

By..........

Date .... Time .... a.m. p.m.

Received from ....

By..........

Date .... Time .... a.m. p.m.

Figure 9-9 Chain of custody form.

9-10.2 Test Methods. The following is a listing of selected analytical methods and tests that are applicable to certain fire investigations. When utilizing laboratories to perform any of these tests, investigators should be aware of the quality of the laboratory results that can be expected.

9-10.2.1 Gas Chromatography (GC). The test method separates the mixtures into their individual components and then provides a graphical representation of each component and its relative amount. The method is useful for mixtures of gases or liquids that can be vaporized without decomposition. Gas chromatography is sometimes a preliminary test that may indicate the need for additional testing to specifically identify the components. For most petroleum distillate accelerants, gas chromatography provides adequate characterization if conducted according to accepted methods. These methods are described in ASTM E 1387, *Standard Test Method for Ignitable Liquid Residue in Extracts from Fire Debris Samples by Gas Chromatography.*

9-10.2.2 Mass Spectrometry (MS). This test method is usually employed in conjunction with gas chromatography. The method further analyzes the individual components that have been separated during gas chromatography. Methods of GC/MS analysis are described in ASTM E 1618, *Standard Guide for Ignitable Liquid Residues in Extracts from Fire Debris Samples by Gas Chromatography–Mass Spectrometry.*

9-10.2.3 Infrared Spectrophotometer (IR). This test method can identify some chemical species by their ability to absorb infrared light in specific wavelength regions.

9-10.2.4 Atomic Absorption (AA). This test method identifies the individual elements in nonvolatile substances such as metals, ceramics, or soils.

9-10.2.5 X-Ray Fluorescence. This test analyzes for metallic elements by evaluating an element's response to X-ray photons.

9-10.2.6 Flash Point by Tag Closed Tester (ASTM D 56). This test method covers the determination of the flash point, by tag closed tester, of liquids having low viscosity and a flash point below 200°F (93°C). Asphalt and those liquids that tend to form a surface film under test conditions and materials that contain suspended solids are tested using the Pensky-Martens *(see 9-10.2.8)* closed tester.

9-10.2.7 Flash and Fire Points by Cleveland Open Cup (ASTM D 92). This test method covers determination of the flash and fire points of all petroleum products (except oils) and those products having an open cup flash point below 175°F (79°C).

9-10.2.8 Flash Point by Pensky-Martens Closed Tester (ASTM D 93). This test method covers the determination of the flash point by Pensky-Martens closed-cup tester of fuel oils, lubricating oils, suspensions of solids, liquids that tend to form a surface film under test conditions, and other liquids.

9-10.2.9 Flash Point and Fire Point of Liquids by Tag Open-Cup Apparatus (ASTM D 1310). This test method covers the determination by tag open-cup apparatus of the flash point and fire point of liquids having flash points between 0°F and 325°F (–18°C and 163°C) and fire points up to 325°F (163°C).

9-10.2.10 Flash Point by Setaflash Closed Tester (ASTM D 3828). This test method covers procedures for the determination of flash point by a Setaflash closed tester. Setaflash methods require smaller specimens than the other flash point tests.

9-10.2.11 Autoignition Temperature of Liquid Chemicals (ASTM E 659). This test method covers the determination of hot- and cool-flame autoignition temperatures of a liquid chemical in air at atmospheric pressure in a uniformly heated vessel.

9-10.2.12 Heat of Combustion of Hydrocarbon Fuels by Bomb Calorimeter (High-Precision Method) (ASTM D 2382). This test method covers the determination of the heat of combustion of hydrocarbon fuels. It is designed specifically for use with aviation fuels when the permissible difference between duplicate determinations is of the order of 0.1 percent. It can be used for a wide range of volatile and nonvolatile materials where slightly greater differences in precision can be tolerated.

9-10.2.13 Flammability of Apparel Textiles (ASTM D 1230). This test method covers the evaluation of the flammability of textile fabrics as they reach the consumer for or from apparel other than children's sleepwear or protective clothing.

9-10.2.14 Cigarette Ignition Resistance of Mock-Up Upholstered Furniture Assemblies (ASTM E 1352). This test method is intended to cover the assessment of the resistance of upholstered furniture mock-up assemblies to combustion after exposure to smoldering cigarettes under specified conditions.

9-10.2.15 Cigarette Ignition Resistance of Components of Upholstered Furniture (ASTM E 1353). This test method is intended to evaluate the ignition resistance of upholstered furniture component assemblies when exposed to smoldering cigarettes under specified conditions.

9-10.2.16 Flammability of Finished Textile Floor Covering Materials (ASTM D 2859). This test method covers the determination of the flammability of finished textile floor covering materials when exposed to an ignition source under controlled laboratory conditions. It is applicable to all types of textile floor coverings regardless of the method of fabrication or whether they are made from natural or manmade fibers. Although this test method may be applied to unfinished material, such a test is not considered satisfactory for the evaluation of a textile floor covering material for ultimate consumer use.

9-10.2.17 Flammability of Aerosol Products (ASTM D 3065). This method covers the determination of flammability hazards for aerosol products.

9-10.2.18 Surface Burning Characteristics of Building Materials (ASTM E 84). This test method for the comparative surface burning behavior of building materials is applicable to exposed surfaces, such as ceilings or walls, provided that the material or assembly of materials, by its own structural quality or the manner in which it is tested and intended for use, is capable of supporting itself in position or being supported during the test period. This test is conducted with the material in the ceiling position. This test is not recommended for use with cellular plastic.

9-10.2.19 Fire Tests of Roof Coverings (ASTM E 108). This test method covers the measurement of relative fire characteristics of roof coverings under simulated fire originating outside the building. It is applicable to roof coverings intended for installation on either combustible or noncombustible decks, when applied as intended for use.

9-10.2.20 Critical Radiant Flux of Floor-Covering Systems Using a Radiant Heat Energy Source (ASTM E 648). This test method describes a procedure for measuring the critical radiant flux of horizontally mounted floor covering systems exposed to a flaming ignition source in graded radiant heat energy environment in a test chamber. The specimen can be mounted over underlayment or to a simulated concrete structural floor, bonded to a simulated structural floor, or otherwise mounted in a typical and representative way.

9-10.2.21 Room Fire Experiments (ASTM E 603). This guide covers full-scale compartment fire experiments that are designed to evaluate the fire characteristics of materials, products, or systems under actual fire conditions. It is intended to serve as a guide for the design of the experiment and for the interpretation of its results. The guide may be used as a guide for establishing laboratory conditions that simulate a given set of fire conditions to the greatest extent possible.

9-10.2.22 Concentration Limits of Flammability of Chemicals (ASTM E 681). This test method covers the determination of the lower and upper concentration limits of flammability of chemicals having sufficient vapor pressure to form flammable mixtures in air at 1 atmosphere pressure at the test temperature. This method may be used to determine these limits in the presence of inert dilution gases. No oxidant stronger than air should be used.

9-10.2.23 Measurement of Gases Present or Generated During Fires (ASTM E 800). Analytical methods for the measurement of carbon monoxide, carbon dioxide, oxygen, nitrogen oxides, sulfur oxides, carbonyl sulfide, hydrogen halide, hydrogen cyanide, aldehydes, and hydrocarbons are described, along with sampling considerations. Many of these gases may be present in any fire environment. Several analytical techniques are described for each gaseous species, together with advantages and disadvantages of each. The test environment, sampling constraints, analytical range, and accuracy often dictate use of one analytical method over another.

9-10.2.24 Heat and Visible Smoke Release Rates for Materials and Products (ASTM E 906). This test method can be used to determine the release rates of heat and visible smoke from materials and products when exposed to different levels of radiant heat using the test apparatus, specimen configurations, and procedures described in this test method.

9-10.2.25 Pressure and Rate of Pressure Rise for Combustible Dusts (ASTM E 1226). This test method can be used to measure composition limits of explosibility, ease of ignition, and explosion pressures of dusts and gases.

9-10.2.26 Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter (ASTM E 1354). This test method is a bench-scale laboratory instrument for measuring heat release rate, radiant ignitibility, smoke production, mass loss rate, and certain toxic gases of materials.

9-10.2.27 Ignition Properties of Plastics (ASTM D 1929). This test method covers a laboratory determination of the self-ignition and flash-ignition temperatures of plastics using a hot-air ignition furnace.

9-10.2.28 Flammability of Apparel Fabrics by Semi-Restraint Method (ASTM D 3659). This test method covers the evaluation of the flammable properties of fabrics in a vertical configuration.

9-10.2.29 Dielectric Withstand Voltage (Mil-Std-202F Method 301). This test method — also called high-potential/, overpotential/, voltage-breakdown/, or dielectric-strength/test — consists of the application of a voltage higher than rated voltage for a specific time between mutually insulated portions of a component part or between insulated portions and ground.

9-10.2.30 Insulation Resistance (Mil-Std-202F Method 302). This test measures the resistance offered by the insulating members of a component part to an impressed direct voltage tending to produce a leakage current through or on the surface of these members.

9-10.3 Sufficiency of Samples. Fire investigators often misunderstand the abilities of laboratory personnel and the capabilities of their scientific laboratory equipment. These misconceptions usually result in the fire investigator's collecting a quantity of physical evidence that is too small to examine or test.

Certainly, the fire investigator will not always have the opportunity to determine the quantity of physical evidence he or she can collect. Often, the fire investigator can collect only that quantity that is discovered during his or her investigation.

Each laboratory examination or test requires a certain minimum quantity of physical evidence to facilitate proper and accurate results. The fire investigator should be familiar with these minimum requirements. The laboratory that examines or tests the physical evidence should be consulted concerning these minimum quantities.

9-10.4 Comparative Examination and Testing. During the course of certain fire investigations, the fire investigator may wish to have appliances, electrical equipment, or other products examined to determine their compliance with recognized standards. Such standards are published by the American Society for Testing and Materials, Underwriters Laboratories Inc., and other agencies.

Another method of comparative examination and testing involves the use of an exemplar appliance or product. Utilizing an exemplar allows the testing of an undamaged example of a particular appliance or product to determine whether or not it was capable of causing the fire. The sample should be the same make and model as the product involved in the fire.

9-11 Evidence Disposition. The fire investigator is often faced with disposing of evidence after an investigation has been completed. The investigator should not destroy or discard evidence unless proper authorization is received. Circumstances may require that evidence be retained for many years and ultimately may be returned to the owner.

Criminal cases such as arson require that the evidence be kept until the case is adjudicated. During the trial, evidence submitted — such as reports, photographs, diagrams, and items of physical evidence — will become part of the court record and will be kept by the courts. Volatile or large physical items may be returned to the investigator by the court. There may be other evidence still in the investigator's possession that was not used in the trial. Once all appeals have been exhausted, the investigator may petition the court to either destroy or distribute all of the evidence accordingly. A written record of authorization to dispose of the evidence should be kept. The criminal investigator should be mindful of potential civil cases resulting from this incident. This may require retention of the evidence beyond the criminal proceedings.

Chapter 10 Safety

10-1* General. Fire scenes by their nature are dangerous places. Fire investigators have a duty to themselves and to others who may be endangered at fire scenes to exercise due caution during their investigations.

10-1.1 Investigating the Scene Alone. Fire scene examinations should not be undertaken alone. A minimum of two individuals should be present to ensure that assistance is at hand if an investigator should become trapped or injured.

If it is impossible for the investigator to be accompanied, he or she should, at the least, notify a responsible person of where the investigator will be and of when he or she can reasonably be expected to return.

10-1.2 Safety Clothing and Equipment. Proper safety equipment — including safety shoes or boots, gloves, safety helmet, and protective clothing, such as coveralls or turnout gear — should be worn at all times while investigating the scene.

Certain other equipment might also be necessary to maintain safety. This equipment includes flashlights or portable lighting, safety glasses or goggles, appropriate filter masks or self-contained breathing apparatus (SCBA), lifelines or nets, ladders, and hazardous environment suits. Some of this equipment requires special training in its use. The investigator should not attempt to use personal protective equipment or other safety equipment without the appropriate training.

10-1.3 Fire Scene Hazards. The investigator should remain aware of the general and particular dangers of the scene under investigation. The investigator should keep in mind the potential for serious injury at any time and not become complacent or take unnecessary risks. The need for this awareness is especially important when the structural stability of the scene is unknown or when the investigation requires that the investigator be working above or below ground level.

10-1.4 Personal Health and Safety. The investigator should be cognizant of factors associated with chemical, biological, radiological, or other potential hazards that may threaten personal health and safety while conducting fire scene examinations. Where these conditions exist, special precautions should be taken as necessary. Special equipment such as rubber gloves, specialized filter masks or self-contained breathing apparatus (SCBA), or hazardous material suits may be required.

10-1.5 Investigator Fatigue. It is common for investigators to put in long periods of strenuous personal labor during an incident scene investigation. This may result in fatigue, which can adversely influence an investigator's physical coordination, strength, or judgment to recognize or respond to hazardous conditions or situations.

Periodic rest, fluid replacement, and nourishment should be provided. This is particularly necessary on large or major incident scenes.

10-2 Factors Influencing Scene Safety. Many varying factors can influence the danger potential of a fire or explosion scene. The investigator should be constantly on the alert for these conditions and should ensure that appropriate safety precautions are taken by all persons working at the scene.

10-2.1 Status of Suppression. If the investigator is going to enter parts of the structure before the fire is completely extinguished, he or she should receive permission from the fire ground commander. The investigator should coordinate his or her activities with the fire suppression personnel and keep the fire ground commander advised of the areas into which he or she will be entering and working. The investigator should not move into other areas of the structure without informing the fire ground commander. The investigator should never enter a burning structure unless accompanied by fire suppression personnel.

When conducting an investigation in a structure soon after the fire is believed to be extinguished, the investigator should be mindful of the possibility of a rekindle. The investigator should be alert for continued burning or a rekindle and should remain aware at all times of the fastest or safest means of egress.

10-2.2 Structural Stability. By their nature, most structures that have been involved in fires or explosions are structurally weakened. Roofs, ceilings, partitions, load-bearing walls, and floors may have been compromised by the fire or explosion.

The investigator's task requires that he or she enter these structures and often requires that he or she perform tasks of debris removal that may dislodge or further weaken these already unsound structures. Before entering such structures or beginning debris removal, the investigator should make a careful assessment of the stability and safety of the structure. If necessary, the investigator should seek the help of qualified structural experts to assess the need for the removal of dangerously weakened construction or should make provisions for shoring up load-bearing walls, floors, ceilings, or roofs.

The investigator should also be especially mindful of hidden holes in floors or of other dangers that may be hidden by standing water or loosely stacked debris. The investigator should also keep in mind that the presence of pooled extinguishment water or of weather-related factors — such as the weight of rain water, high winds, snow, and ice — can affect the ability of structures to remain sound. For example, a badly damaged structure may only continue to stand until the ice melts.

10-2.3 Utilities. The investigator should learn the status of all utilities (i.e., electric, gas, and water) within the structure under investigation. He or she should know before entering if electric lines are energized, if fuel gas lines are charged, or if water mains and lines are operative. This knowledge is necessary to prevent the possibility of electrical shock or inadvertent release of fuel gases or water during the course of the investigation.

10-2.4 Electrical Hazards. Although the fire investigators may arrive on the scene hours or even days later, they should recognize potential hazards in order to avoid injury or even death. Serious injury or death can result from electric shocks or burns. Investigators as well as fire officers should learn to protect themselves from the dangers of electricity while conducting fire scene examinations. The risk is particularly high during an examination of the scene immediately following the fire. When conditions warrant, the investigator should ensure that the power to the building or to the area affected has been disconnected. The fire investigator should not disconnect the building's electric power but should ensure that the authorized utility does so.

When electrical service has been interrupted and the power supply has been disconnected, a tag or lock should be attached to the meter indicating that power has been shut off. In considering potential electrical hazards, always assume that danger is present. The investigator should personally verify that the power has been disconnected. If any doubt exists as to whether the equipment is energized, call the local electric utility for verification.

The investigator may be working at fire scenes that have been equipped with temporary wiring. The investigator should be aware that temporary wiring for lighting or power arrangements is often not properly installed, grounded, or insulated and, therefore, may be unsafe.

The investigator should consider the following electrical hazards when examining the fire scene:

(a) Consider all wires energized or "hot," even when the meter has been removed or disconnected.

(b) When approaching a fire scene, be alert to fallen electrical wires on the street; on the ground; or in contact with a metal fence, guard rail, or other conductive material, including water.

(c) Look out for antennas that have fallen on existing power lines, for metal siding that has become energized, and for underground wiring.

(d) Use caution when using or operating ladders or when elevating equipment in the vicinity of overhead electric lines.

(e) Note that building services are capable of delivering high amperage and that short circuiting can result in an intense electrical flash with the possibility of serious physical injury and burns.

(f) Rubber footwear should not be depended on as an insulator.

(g) A flooded basement should not be entered if the electrical system is energized. Energized electrical equipment should not be turned off manually while standing in water.

(h) Avoid operating any electrical switch or non-explosion-proof equipment in the area that might cause an explosion if flammable gas or vapors are suspected of being present. *(See 10-2.7.)* When electric power must be shut off, it should be done at a point remote from the explosive atmosphere.

(i) Establish lines of communication and close cooperation with the utility company. Power company personnel possess the expertise and equipment necessary to deal with electrical emergencies.

(j) Locate and avoid underground electric supply cables before digging or excavating on the fire scene.

(k) Be aware of multiple electrical services that may not be disconnected, extension cords from neighboring buildings, and similar installations.

(l) Always use a meter to determine whether the electricity is off.

10-2.5 Standing Water. Standing water can pose a variety of dangers to the investigator. Puddles of water in the presence of energized electrical systems can be lethal if the investigator should touch an energized wire while standing in a puddle.

Pools of water that may appear to be only inches deep may in fact be well over the investigator's head. Pools of water may also conceal hidden danger such as holes or dangerous objects that may trip or otherwise injure the investigator.

Investigators should be cognizant of these hidden dangers and take proper precautions to avoid injury.

10-2.6 Safety of Bystanders. Fire and explosion scenes always generate the interest of bystanders. Their safety, as well as the security of the scene and its evidence, should be addressed by the investigator.

The investigation scene should be secured from entry by curious bystanders. This may be accomplished by merely roping off the area and posting "Keep Out" signs, or it may require the assistance of police officers, fire service personnel, or other persons serving as guards. Any unauthorized individuals found within the fire investigation scene area should be identified, their identity noted, and then they should be required to leave.

10-2.7 Safety of the Fire Scene Atmosphere. Fires and explosions often generate toxic or noxious gases. The presence of hazardous materials in the structure is certain. Homes contain chemicals in the kitchen, bath, and garage that can create great risk to the investigator if he or she is exposed to them. Commercial and business structures are generally more organized in the storage of hazardous materials, but the investigator cannot assume that the risk is less in such structures. Many buildings older than 20 years will contain asbestos. The investigator should be aware of the possibility that he or she could become exposed to dangerous atmospheres during the course of an investigation.

In addition, it is not uncommon for atmospheres with insufficient oxygen to be present within a structure that has been exposed to fire or explosion. Fire scene atmospheres may contain ignitible gas, vapors, and liquids. The atmosphere should be tested using appropriate equipment to determine whether such hazards or conditions exist before working in or introducing ignition sources into the area. Such ignition sources may include electrical arcs from flashlights, radios, cameras and their flashes, and smoking materials.

Chapter 11 Origin Determination

11-1 Introduction. This chapter will recommend a procedure to follow in determining the origin of a fire. Chapter 12 will further develop the investigative effort based on the results from the origin determination. Generally, if the origin of a fire cannot be determined, the cause cannot be determined.

Determination of the origin of the fire frequently involves the coordination of information derived from the following:

(a) The physical marks (fire patterns) left by the fire

(b) The observations reported by persons who witnessed the fire or were aware of conditions present at the time of the fire

(c) The analysis of the physics and chemistry of fire initiation, development, and growth as an instrument to related known or hypothesized fire conditions capable of producing those conditions

In some instances, a single item, such as an irrefutable article of physical evidence or dependable eyewitness to the initiation, can be the basis for a conclusive determination of origin. In most cases, however, no single item is sufficient in itself. The investigator then should use all of the available resources in developing potential scenarios and determining which scenarios plausibly fit all of the evidence available. When an apparently plausible scenario fails to fit some item of evidence, it is critical that the investigator determine whether the scenario or the evidence is erroneous. In some cases, it will be impossible to unquestionably fix the origin of a fire. It is important that the determination of a single point of origin not be made unless the evidence is conclusive. Where a single point cannot be identified, it can still be valuable for many purposes to identify possible sources of origin. In such instances, the investigator should provide a complete list of plausible explanations for the origin with the supporting evidence for each option.

The various activities of origin determination often occur simultaneously with those of cause investigation and failure analysis. Likewise, recording the scene, note taking, photography, and evidence identification and collection are performed simultaneously with these efforts. Generally, the various activities of origin determination will follow a routine sequence, while the specific actions within each activity are taking place at the same time.

The area of origin is almost always determined by examining the fire scene, starting with the areas of least damage and moving toward the areas of greatest damage. Once the area of origin has been established, the investigator should be able to understand and document the fire spread. The purpose of determining the origin of the fire is to identify the geographical location where the fire began. Once the area of origin has been determined, based on the patterns produced by the movement of heat, flame, and smoke, then the specific location of the origin can be identified. The specific origin will be where the heat ignited the first fuel and is commonly referred to as the point of origin.

Investigators should establish a systematic procedure to follow for each type of incident. By following a familiar procedure, the investigator can concentrate on the incident at hand and not have to dwell on the details of what the next step in the procedure will be. More importantly, the investigator may avoid inadvertently overlooking a significant facet of the investigation.

This chapter will discuss a recommended procedure for the examination of the fire scene. Basically, this procedure consists of a preliminary scene examination, development of a preliminary fire-spread scenario, an in-depth examination of the fire scene, a fire scene reconstruction, development of a final fire-spread scenario, and identification of the fire's origin.

Throughout this chapter, the discussion will address the recommended techniques to follow when examining a fire scene. This technique serves to inform the investigator but is not meant to limit the origin determination to only this procedure. All aspects of the fire event should be considered by the investigator during the investigation. Such aspects as witness statements, the investigator's past experiences, and fire-fighting procedures play important roles in the determination of the fire origin. However, these aspects are addressed in other areas of this guide and in other texts on these subjects.

11-2 Fire Damage Assessment. Investigators will be making assessments of fire spread throughout the examination of the scene. These assessments include recognizing and documenting heat movement and intensity patterns and analyzing the importance and direction of each pattern found. *(See Chapters 4 and 8.)*

11-2.1 Notes. During this process, the investigator should be making detailed, written or tape-recorded notes. These notes should list all the pertinent observations, including the type, location, description, and measurements of the patterns; the material on which the patterns are displayed; and the investigator's analysis of the direction and intensity of the patterns.

11-2.2 Photography. The patterns should be photographed several different ways to effectively show their shape, size, relationship to other patterns, and the location within the fire scene. These variations should include changes in the viewing angle of the camera when documenting the pattern and different lighting techniques to highlight the texture of the pattern.

11-2.3 Vector Diagrams. The use of heat and flame vector diagrams can be a very useful tool for analysis by the investigator. Vectoring is applied by constructing a diagram of the scene. The diagram should include walls, doorways and doors, windows, and any pertinent furnishings or contents. Then, through the use of arrows, the investigator notes his or her interpretations of the direction of heat or flame spread. The arrows can point in the direction of fire travel from the heat source, or point back toward the heat source, as long as the direction of the vectors is consistent throughout the diagram. The arrows can be labeled to show any one of several variable factors, such as temperature, duration of heating, heat flux, or intensity.

Complimentary vectors can be added together to show actual heat movement directions. In that case, the investigator should clearly identify which vectors represent actual fire patterns and which vectors represent heat flow derived from the investigator's interpretations of these patterns. A vector diagram can give the investigator an overall viewpoint to analyze. The diagram can also be used to identify any conflicting patterns that need to be explained.

An important point to be made regarding this discussion is the terminology *heat source* and *source of heat.* These terms are not synonymous with the *origin* of the fire. Instead, these terms relate to any heat source. The heat source may or may not be generated by the initial fuel. An example of this would be a fire that spreads into a garage and ignites the flammable liquids stored there. These flammable liquids then produce a new heat source that produces fire patterns on the garage's surfaces.

11-2.4 Depth-of-Char Survey Grid Diagrams. The investigator should record in his or her notes the results of any depth-of-char surveys that are conducted. This notation should be documented in the notes as well as on a drawn diagram. For analysis purposes, the investigator can construct a depth-of-char grid diagram. On this diagram the char measurements are recorded on graph paper to a convenient scale. Once the depth-of-char measurements have been recorded on the diagram, lines are drawn connecting points of equal, or nearly equal, char depths. The resulting "isochars" may display identifiable lines of demarcation and intensity patterns.

11-3 Preliminary Scene Assessment. An initial assessment should be made of the fire scene. This assessment should begin from the areas of least damage to the areas of greatest damage and should include an overall look at the structure, both exterior and interior, and at all pertinent areas surrounding the building. The purpose of this initial examination is to determine the scope of the investigation, such as equipment and manpower needed, to determine the safety of the fire scene, and to determine the areas that warrant further study.

Descriptions of all locations should be as precise as possible. Directions should be oriented to a compass or to a reference, such as the front of the structure. In every instance, the location, and any related discussion, should be stated in such a fashion that others using the description can clearly locate the area in question.

11-3.1 Surrounding Areas. Investigators should include in their examination the areas around the structure. These areas may exhibit significant evidence or fire patterns away from the involved structure that enable the investigator to better define the site and the investigation. Anything of interest should be documented as to its location in reference to the structure.

Surrounding areas should be examined for evidence that may relate to the incident, such as contents from the burned structure and fire patterns. This phase of the examination can be used to canvas the neighborhood for witnesses to the fire and for persons who could provide information about the building that burned.

11-3.2 Weather. Analyze weather factors that may have influenced the fire. The surrounding area may provide evidence of the weather conditions. Wind direction may be indicated by smoke movement or by fire damage on the surrounding structures or vegetation.

11-3.3 Structural Exterior. A walk around the entire structure may reveal the extent and location of damage and may help determine the size of the scene that should be examined as well as the possibility of extension from an outside fire source. The construction and use of the structure should be noted. The construction refers to how the building was built, types of materials used, exterior surfaces, previous remodeling, and any unusual features that may have affected how the fire began and spread. A significant consideration is the degree of destruction that can occur in a structure consisting of mixed types and methods of construction. For instance, if a structure consists of two parts, one built in the early 1900s and the second built in the 1960s, the degree of destruction can vary considerably within these two areas with all other influencing factors being equal.

The nature of occupancy refers to the current use of the building. Use is defined as the activities conducted; the manner in which such activities are undertaken; and the type, number, and condition of those individuals occupying the space. If the use of the building has changed from what it was originally built for, this change should be considered.

The fire damage on the exterior should be noted to assist in determining those areas that warrant further study. An in-depth examination of the damage is not necessary at this point in the investigation.

11-3.4 Structure Interior. On the initial assessment, investigators should examine all rooms and areas of the structure. The investigator should be observant of conditions of occupancy, including methods of storage, nature of contents, and shape of living conditions. The type of construction and surface covering should be noted. Moving from the least burned to the most burned areas, indicators of smoke and heat movement, areas of fire damage, and extent of damage in each area — severe, moderate, minor, or none — should be noted. This damage should be compared with the damage seen on the exterior. The investigator should use this opportunity to assess the soundness of the structure so that the safety of the structure can be determined. See Chapter 10 for further information regarding safety.

The primary purpose of the preliminary interior assessment is to identify the areas that require closer examination. Therefore, the investigator should be observant for possible fire origins, fire patterns, fuel loading, burning, and potential ignition sources.

During this assessment, the investigator should note any indication of post-fire site alterations. Site alterations can include debris removal or movement, content removal or movement, electrical service panel alterations to facilitate temporary lighting, and gas meter removal. Such alterations can greatly affect the investigator's interpretation of the physical evidence. If site alterations are indicated, the persons who altered the site should be questioned as to the extent of their alterations and the documentation they may have of the unaltered site.

At the conclusion of the preliminary scene assessment, the investigator should have determined the safety of the fire scene, the probable staffing and equipment requirements, and the areas around and in the structure that will require a detailed inspection. The preliminary scene assessment is an important aspect of the investigation. The investigator should take as much time in this assessment as is needed to make these determinations. Time spent in this endeavor will save much time and effort in later steps of the investigation.

11-4 Preliminary Scenario Development. The identification of areas of interest comes by formulating a preliminary scenario as to how the fire spread through the structure. This preliminary scenario is developed by noting the areas of greater destruction and lesser destruction and by attempting to track the fire back to its source. Such a scenario allows the investigator to organize and plan for the work to be done. The development of the preliminary scenario is a critical point in the investigation. It is important at this stage that the investigator attempt to identify any other feasible scenarios and, through the remaining course of the investigation, keep these alternative scenarios under consideration until or at such time as conclusive evidence or rationale is developed for setting them aside.

One very important consideration should be kept in mind, however. The investigation should not be planned solely to prove the preliminary scenario to the detriment of maintaining an unbiased mind. The investigation is intended to identify all facts that exist and to use those facts to develop opinions based on sound fire-science principles and experience. The investigative effort may cause the scenario to change many times before the final opinion is formed. These changes are why the scenario should be considered preliminary until the investigation is completed. A narrow-minded approach to this effort prevents the normal development of the scenario from preliminary to final. *(See Chapter 2.)*

The investigator should continue to reevaluate the areas of interest by considering the additional data accumulated as the investigation progresses. The examination and documentation of heating, ventilation, and air conditioning (HVAC) systems; fire protection systems; cooking and other appliances; electrical distribution systems; and utilities should be included. The areas to be examined should not be limited to those that suffered fire damage. Examination of the systems that have little or no fire damage may provide assistance later in identifying the cause for the fire.

11-5 Detailed Exterior Surface Examination. Once the preliminary scene assessment is completed, the structure needs to be analyzed in detail. The purpose of this effort is to identify where the fire began. This analysis begins with the exterior surface examination.

Even if the fire clearly originated from within the structure, the exterior analysis should be performed. Observations, photographs, and sketches can help orient the investigator to the structure, help to determine the manner in which the structure burned, and document details that may resolve issues that have not yet been raised.

11-5.1 Pre-Fire Conditions. The pre-fire conditions of the structure should be determined. Such details as state of repair, condition of foundations and chimneys, insect damage, state of repair of fire suppression systems, and so forth may prove to be significant data. Documentation of these conditions at this time may be the only opportunity to record them.

11-5.2 Utilities. The investigator should locate and document the utilities associated with the structure, including the type and rated size of the electrical service and the fuel gas type. The meter readings for the utilities that provide them should be recorded. The locations of fuel tanks and their manner of connection to the structure should be noted.

11-5.3 Doors and Windows. The condition of each door, especially those that allow access to the structure, should be documented. The investigator should note whether the door is intact or broken and whether it has been forced open. The means of securing the door — such as dead bolt, padlock, and so forth — should be documented. If the door is broken, the investigator should determine whether the door was broken before or after the fire began. In some cases this can be accomplished by inspecting the splintered wood and noting whether it is burned or unburned and whether it is clean of smoke or smoke stained. Sometimes, observing whether the hidden surfaces on the door jamb or the hinges are clear of smoke can help determine the position of the door (i.e., open or closed) during the fire.

Clean surfaces indicate that the door was closed during the time smoke was present. However, stained surfaces do not always indicate the door was open. If smoke accumulates in sufficient quantity and if there is a pressure difference between the areas separated by the door, smoke can flow through cracks around a closed door to stain those hidden surfaces. The pressure differences involved can be due to the fire-produced smoke temperatures; mechanically produced air movement from ventilation, exhaust, or similar fan-driven systems; wind effects; or buoyant (stack) effects caused by the temperature differentials between the building and the exterior environment.

The condition of the windows and the glass should be documented. Regarding what position the windows were in during the fire, the same characteristics that were discussed with the doors apply. With broken glass, the location of the pieces may provide insight as to what broke the pane. Once the fire breaches either the doors or windows, the improved ventilation affects the rate of combustion of the fire and the manner in which it spreads in the structure. The investigator should strive to learn whether the opening occurred prior to, during, or after extinguishment of the fire.

11-5.4 Explosion Evidence. Any displacement of the exterior surfaces should be documented. The distance the pieces traveled and the extent of movement of walls and roofs should be noted on a diagram of the structure. Charring or smoke staining on hidden surfaces, which became exposed by the displacement of the structural component, should be noted on the diagram also. A detailed discussion of explosions can be found in Chapter 13.

11-5.5 Fire Damage. The fire damage on the exterior surfaces should be documented. The investigator should pay particular attention to the damage that is associated with natural and unnatural openings. Window, door, and vent openings provide natural passages for smoke and heat and can be indicators of the flow of fire and fire products. Unnatural openings include holes created by the fire and holes created during the suppression effort. Holes created by the fire indicate an area of intense burning inside the structure. Separate and distant holes created by fire can be indicative of multiple origins, concentrated fuel loads, or simply a spreading fire that developed more than one intense impact on a vulnerable point in the structure envelope.

Holes created by fire suppression activities are generally associated with forced entry attempts, ventilation of the combustion gases, or spot-fire extinguishment. Ventilation attempts can greatly affect fire movement inside the building, thereby creating fire patterns that appear abnormal. Investigators should use care in evaluating such fire damage by conferring with the fire combat personnel to learn what happened inside the structure when the ventilation took place. Such evidence can be helpful in appraising, through methods such as vectoring, the flow of fire and fire effects.

11-6 Detailed Interior Surface Examination. An interior surface examination generally is performed before any attempt is made to formulate an opinion as to fire origin. In the majority of structure fires, the origin is within the structure, and no finite origin determination is possible by just an exterior examination. In the event the fire clearly did not begin inside, the interior should still be evaluated and documented. Many issues can arise from a fire's occurrence that do not relate to origin determination. Photographs and diagrams of the interior can provide answers to questions that arise from these issues.

The interior surface examination will follow a procedure similar to the exterior surface examination. The analysis of the fire damage should utilize the same techniques discussed in Section 11-5.

11-6.1 Pre-Fire Conditions. The pre-fire conditions in the interior of the structure should be documented, especially in the areas where there was fire development and spread. The housekeeping, or lack of it, should be noted. The presence of any evidence of concentrations of easily ignitible materials, such as trash, should be noted. The investigator should note whether the electrical devices are properly utilized. Any indications that might relate to electrical overloading, power cord abuse, appliance abuse, and so forth should be noted. These do not solely determine a fire cause, but they can be supportive, or contradictory, to subsequent cause determinations.

Any interior fire suppression or fire protection devices such as smoke alarms, fire extinguishing systems, fire doors, and so forth should be located. The investigator should determine whether they are in working order and whether they functioned properly during the fire. The investigator should note whether they have been disabled or inadequately maintained.

The investigator should look at the fuel loads present in the structure and should note whether they are consistent with what is expected in this structure and whether they added to the fire's development. The fuel load considerations should include the interior surface covering and furnishings.

The ultimate determination is whether the pre-fire conditions created the fire or greatly contributed to the fire's origin, cause, or spread.

11-6.2 Utilities. The condition of the utility services in the structure should be located and documented. Documentation may involve simply photographing the electrical distribution panel for a home, or it may involve studying a complex electrical distribution system for a large industrial building. In either event, the type and method used to distribute electricity should be determined, and damage to the systems should be documented.

The fuel gas utility should be identified and documented. The purpose of this examination is to assist in determining whether the fuel gas contributed to the fire's spread. If the examination reveals that fuel gases may have had a role in the fire's spread, then the distribution system should be examined in detail, including pressure testing for leaks. Remember, fires can, and usually do, cause a perfectly good gas distribution system to leak.

11-6.3 Explosion. The procedure used in the exterior surface examination should also be used inside the building. Any displacement of interior structures should be noted, including the distance of the displacement and the direction. The center of explosion damage should be located if possible.

Once the investigation has determined that an explosion has occurred, the investigator should try to determine whether the explosion preceded a fire or followed a fire's inception. This can sometimes be determined by noting the condition of normally hidden or protected surfaces, such as inside the walls. Unburned components from the structure found outside the perimeter of the structure can also be an indication of a pre-fire explosion. Post-fire explosions can produce flaming brands that have been propelled outside the structure. See Chapter 13 for a detailed discussion on the investigation of explosions.

11-7 Fire Scene Reconstruction. The purpose of fire scene reconstruction is to recreate as near as possible the state that existed prior to the fire. Such fire scene reconstruction allows the investigator to see the fire patterns on the exposed surfaces and enables the investigator to make a more accurate origin analysis. A further benefit is the probability that complete exposure of the fire scene will enable other persons to better visualize the fire patterns. Interviews, diagrams, photographs, and other means can be helpful in establishing pre-fire conditions.

Since the preliminary scene assessment has identified the areas warranting further study, the task of fire scene reconstruction may not require the removal of debris and the replacement of the contents throughout the entire structure. As mentioned previously, the preliminary scene assessment should not be done hastily. Careful analysis of the fire scene may help to reduce to a practical level the strenuous task of debris removal. If the area to be reconstructed cannot be reduced, then the investigator should accept the necessity of removing the debris from the entire area of destruction.

11-7.1 Safety. Another important consideration is safety during the reconstruction effort. Debris removal can weaken a structure and cause it to collapse. Debris removal can uncover holes in the floor and can expose energized electrical wiring. A recent development is the recognition of the risk to the investigator from hazardous substances. Risks encountered during an investigation should be minimized before the investigation continues. See Chapter 10 for a detailed discussion on safety.

11-7.2 Debris Removal. Adequate debris removal is essential. Inadequate removal of debris and the resultant exposure of only portions of the fire patterns can lead to gross misinterpretation of the fire patterns. A fire scene investigation involves dirty, strenuous work. Acceptance of this fact is the first step in conducting a proper fire investigation.

The removal of debris during overhaul is an area of concern to the fire investigator. Fire crews that remove all debris and contents from the fire scene may remove evidence, thus making origin determination more difficult. During the suppression stage of the fire ground activities, no more site alteration should be made than necessary to ensure extinguishment of the fire. When circumstances call for substantial site alterations, an attempt should be made to document the fire scene prior to the alterations if possible.

Use some thought as to where debris will be placed during reconstruction. Moving debris twice is counterproductive. Debris removal should be performed in a deliberate and systematic fashion. This means the debris should be removed in layers with adequate documentation as the process continues. If more than one investigator is doing the removal, they should discuss the purpose for the debris removal and what they expect to find. A discussion may prevent one investigator from throwing away something the other investigator feels is important.

11-7.3 Contents. Any contents or their remains that are uncovered during debris removal should be noted as to their location, condition, and orientation. This is important to the replacement of these contents in their pre-fire positions. Once the debris has been removed, the contents should be placed in their pre-fire positions for analysis of the fire patterns on them.

When the contents have been displaced during fire suppression activities, post-fire replacement becomes much more difficult. Usually the position where the item sat will bear a mark from the item, such as table legs leaving small clear spots on the floor. The problem is knowing which leg goes to which spot. If a definite determination is not possible, then the item should not be included in the fire scene reconstruction. A guess as to how contents were oriented can be wrong, thereby contributing false data to the analysis process. An alternative is to document the contents in all probable positions in the hope that later information will pinpoint the true location.

11-7.4 Models in Reconstruction. In recent years, the development of fire science and technology has produced a number of analytical tools derived from the physics and chemistry of fire and the measurement of the property of materials. Many of these are in the form of collected interrelated calculations frequently called *fire models.* The analytical reconstruction techniques provide an additional tool in the analysis of the fire and origin determinations. Until very recently, the computational methods required large computers and a high level of science expertise to use and understand the meaning and validity of the outputs.

Currently a series of more user-friendly, simpler-to-operate analytical tools have emerged. Some can be executed with simple handheld calculators. Most, however, require the modern personal computer as the minimum tool. As emerging tools, these fire models require varying degrees of expertise by the user. In general, the user of a fire model is responsible for ascertaining that the method used is appropriate, that the data input is proper, and that the output is properly interpreted. Those who are not sufficiently informed to have an adequate level of confidence so they can support the use of the fire models and their validity, if challenged, should not unilaterally use such methods. Users who do not have that competence should not use these analytical tools without the guidance and assistance of a person who can take that responsibility. Because of the value of these tools, however, practitioners are urged to become aware of them and to study, understand, and use those most appropriate to their needs and capabilities.

11-8 Fire-Spread Scenario. Once the factual information is compiled from the exterior and interior surface examinations, the investigator should finalize the fire-spread scenario on how the fire spread in and on the structure. The purpose of the fire-spread scenario is to determine an area of fire origin. Contradictions to the scenario should be recognized and resolved. If resolution is not possible, then the scenario should be reevaluated to minimize the contradictions. To resolve contradictions, the data should be reexamined to see whether another reason can be found for why the damage exists as it does. Other investigators can be enlisted to assist in the evaluation of the fire damage and its explanation. Ultimately, a weighing of the scenario against the remaining contradictions should be made to decide whether the determination of an area of origin is valid.

If an area of origin is identified, then all potential ignition sources should be located and identified for a further reduction of the area of origin to a point of origin.

If no determination is made as to the fire's origin, then the determination of the fire's cause becomes very difficult. In some instances, where no origin determination is possible, a witness may be found who saw the fire in its incipient stage and can provide the investigator with an area of fire origin. Such circumstances create a burden on the fire investigator to conduct as thorough an investigation as possible to find facts that can support or refute the witness's statements.

11-9 Total Burns. A fire that is allowed to burn unimpeded until it self-extinguishes due to a lack of fuel can present unique problems to the investigator. This does not mean, however, that such fire scenes are not worthy of investigation. While such circumstances generally produce fire scenes incapable of origin and cause determinations, some will render valuable information when subjected to a systematic and thorough analysis.

The information to be obtained includes the physical description of the structure and the type of construction. This information may be obtained from the insurance carrier, local zoning authorities, and local building officials. The local utilities should be consulted for information on the building's past and recent utility requirements.

In the case of the occupancy of the building, the insurance carrier, real estate officials, and neighbors should be consulted.

Even though the initial view of the site may show nothing other than a hole in the ground containing fire debris, the site should be approached systematically. A slow methodical search from the perimeter should be made by walking around the entire remains. All recognizable items should be noted and inspected. A site plan should be made with these items located on it.

Inspection within the perimeter may verify the floor plan of the structure. The noncombustible contents of the structure generally will be found almost directly beneath their pre-fire location. This generally will allow the investigator to identify the bathrooms, kitchens, and utility rooms.

Sometimes the vertical locations of contents will assist the investigator in determining what level they had occupied within the structure. For instance, bed frames from second story bedrooms will generally end up on top of the first story contents with debris sandwiched between them.

Once the initial site assessment is complete, the debris should be carefully removed and the contents located, identified, and studied. One of the benefits of this type of structural destruction is that the site is rarely altered by earlier investigations or overhaul operations.

A purpose of the examination of the contents is to determine whether the noncombustible contents found correspond to the type and amount of contents expected in a structure of the same occupancy. Residential structures contain essential contents such as refrigerators and heating systems, and most contain other contents such as televisions and cooking appliances. These items will survive to some degree even in the most severe fires.

Another purpose for studying the contents is to note the differing degrees of heating effects on them. If contents in one area of the structure exhibit melted metal remains while others do not, then the investigator can make the assumption that temperatures in one area exceeded temperatures in another. If the metal remains of the contents are badly oxidized, such examinations may not be possible.

Total burn fire scenes present their own unique problems, but then so do many other fire scenes. Although the primary objective of the fire investigator is to determine the origin and cause of a fire, there are areas of interest to other involved parties that deserve to be considered. Careful examination of totally burned sites can answer questions that may arise from these other parties long after the fire scene has been cleaned up.

Chapter 12 Cause Determination

12-1 General. While the focus of this chapter is on determining the cause of a fire or explosion incident, it is recognized that the purpose of fire investigations is often much broader. The ideal goal of any particular fire investigation is to come to a correct conclusion about the significant features of a particular fire or explosion incident. The significant features can be grouped under four headings.

(a) *The cause of the fire or explosion.* This feature involves a consideration of the circumstances, conditions, or agencies that bring together a fuel, ignition source, and oxidizer (such as air or oxygen) resulting in a fire or a combustion explosion.

(b) *The cause of damage to property resulting from the incident.* This feature involves a consideration of those factors that were responsible for the spread of the fire and for the extent of the loss, including the adequacy of fire protection, the sufficiency of building construction, and the contribution of any products to flame spread and to smoke propagation.

(c) *The cause of bodily injury or loss of life.* This feature addresses life safety features such as the adequacy of alarm systems, sufficiency of means of egress or in-place protective confinement, the role of products that emit toxic by-products that endanger human life, and the reason for fire fighter injuries or fatalities.

(d) *The degree to which human fault contributed to any one or more of the causal issues described above.* This feature deals with the human factor in the cause or spread of fire or in bodily injury and loss of life. It encompasses acts and omissions that contribute to a loss, such as incendiarism and negligence.

The cause of a fire or the causes of damage or casualties may be grouped in broad categories for general discussion, for assignment of legal responsibility or culpability, or for reporting purposes. Local, state, or federal reporting systems or legal systems may have alternative definitions that should be applied as required.

The determination of the cause of a fire requires the identification of those circumstances and factors that were necessary for the fire to have occurred. Those circumstances and factors include, but are not limited to, the device or equipment involved in the ignition, the presence of a competent ignition source, the type and form of the material first ignited, and the circumstances or human actions that allowed the factors to come together to allow the fire to occur. An individual investigator may not have responsibility for, or be required to address, all of the issues described in this section. A particular investigation may or may not require that all of these issues be addressed.

The cause of any particular fire may involve several circumstances and factors. For example, consider a fire that starts when a blanket is ignited by an incandescent lamp in a closet. The various factors include having a lamp hanging down too close to the shelf, putting combustibles too close to the lamp, and leaving the lamp on while not using the closet. The absence of any one of those factors would have prevented the fire. The function of the investigator is to identify those factors and circumstances that contributed to the cause.

12-2 Classification of the Cause. The cause of a fire may be classified as accidental, natural, incendiary (arson), or undetermined. Use of the term *suspicious* is not an accurate description of a fire cause. Mere suspicion is not an acceptable level of proof for making a determination of cause within the scope of this guide and should be avoided. Such fires should be classified as undetermined.

12-2.1 Accidental Fire Cause. Accidental fires involve all those for which the proven cause does not involve a deliberate human act to ignite or spread fire into an area where the fire should not be. In most cases this classification will be clear, but some deliberately ignited fires can still be accidental. For example, in a legal setting, a trash fire might be spread by a sudden gust of wind. The spread of fire was accidental even though the initial fire was deliberate.

12-2.2 Natural Fire Cause. Natural fire causes involve fires caused without direct human intervention, such as lightning, earthquake, wind, and the like.

12-2.3 Incendiary Fire Cause. The incendiary fire is one deliberately ignited under circumstances in which the person knows that the fire should not be ignited.

12-2.4 Undetermined Fire Cause. Whenever the cause cannot be proven, the proper classification is undetermined. The fire might still be under investigation, and the cause may be determined later. In the instance in which the investigator fails to identify all of the components of the cause of the fire, it need not always be classified as undetermined. If the physical evidence establishes one factor, such as the presence of an accelerant, that may be sufficient to establish the cause even where other factors such as ignition source cannot be determined. Those situations are also encountered to a lesser degree in accidentally caused fires. Determinations under such situations are more subjective. Therefore, investigators should strive to keep an open unbiased thought process during an investigation.

12-3 Source and Form of Heat of Ignition. The source of ignition energy will be at or near the point of origin, although in some circumstances the two may appear not to coincide. Some sources of ignition will remain at the point of origin in recognizable form, whereas others may be greatly altered or even completely destroyed. Nevertheless, the source should be identified in order for the cause to be proven. Sometimes the source can only be inferred, and the cause as found will be the most probable one.

A competent ignition source will have sufficient temperature and energy and be in contact with the fuel long enough to raise it to its ignition temperature.

The ignition process involves generation, transmission, and heating.

(a) The competent ignition source will generate a level of energy sufficient to raise the fuel to its ignition temperature and will be capable of transmitting that level of energy to the fuel.

(b) Transmission of sufficient energy raises the fuel to its ignition temperature. Where the energy source is in direct contact with the fuel, such as the contact of an overheated wire with its insulation, the transfer is a direct conduction from the source to the fuel. Where there is a separation, however, there should be a form of energy transport. This can be by contact with the flaming gases from a burning item, by radiation from the flame or surfaces or gases heated by that flame, or a combination of heating by the flow of hot gases and radiation.

(c) Heating of the potential fuel will occur by the energy that reaches it. Each fuel reacts differently to the energy that impacts on it. Some may be reflected, and some may be transmitted through the material. Some is dispersed through the material, and some heats the material, causing its temperature to rise. The term *thermal inertia* is used to describe the response of a material to the energy impacting on it. Thermal inertia is defined as the product of thermal conductivity, density, and specific heat. These three properties determine the manner in which a material will transmit heat from the exposed surface to its core or an unexposed surface and distribute and absorb heat within the element itself. The surface temperature of a material with a low thermal inertia (such as foam plastic) will rise much more quickly when exposed to energy from a high-temperature source than a material with higher thermal inertia (such as wood paneling). Thin materials will also heat more quickly from a given source of energy.

Once the area and possibly the point of origin is identified, the investigator should identify the heat-producing device, substance, or circumstance that could have caused the ignition. Heat-producing devices can include fixed and portable heaters, gas-fired or electric appliances, furnaces, water heaters, wood stoves, lamps, internal combustion engines, clothes dryers, and incendiary devices.

The investigator should also look for devices that may have malfunctioned. Such devices include many of the foregoing plus electrical service equipment, receptacles, kitchen and laundry appliances, motors, transformers, and heavy machinery.

Sources of ignition for gases or vapors include arcs from motors with brushes, arcs from switches that are not explosion-proof, gas or electric pilots, or flames in gas appliances.

Flammable gases or liquid vapors, such as those from gasoline, may travel a considerable distance before reaching an ignition source. Only under specific conditions will ignition take place, the most important condition being concentration within the flammable limits and an ignition source of sufficient energy located in the flammable mixture. This separation of the fuel source and the origin of the fire can cause confusion.

Information should be obtained from owners or occupants when possible about what potential ignition sources were in the area of origin, how and when they were used, and recent activities in the area. That type of gathering of information is especially important when the source of ignition does not survive the fire. The information would also be helpful in alerting an investigator to small or easily overlooked items when examining the area of origin. When electrical energy sources are considered as potential producers of the heat of ignition, the investigator should refer to Chapter 14 of this guide.

12-4 First Material Ignited. The first material ignited (initial fuel) is that which first sustains combustion beyond the igniting source. For example, the wood of the match would not be the initial fuel, but paper, flammable liquid, or draperies would be if the match was used to ignite them.

The physical configuration of the fuel plays a significant role in its ability to be ignited. A nongaseous fuel with a high surface-to-mass ratio is much more readily ignitible than a fuel with a low surface-to-mass ratio. Examples of high surface-to-mass fuels include dusts, fibers, and paper. If the initial fuel has a high surface-to-mass ratio, then the intensity and duration characteristics for a heat source become less stringent. The higher the surface-to-mass ratio of the fuel, the less energy the heat source should produce to ignite the fuel, although the ignition temperature is the same. Gases and vapors are fully dispersed (in effect an extremely high surface-to-mass ratio) and can be ignited by a low heat energy source instantly.

The initial fuel could be part of a device that malfunctions. Examples include insulation on a wire that is heated red hot by excessive current or the plastic case on an overheating coffee maker.

The initial fuel might be something too close to a heat-producing device. Examples are clothing against an incandescent lamp or a radiant heater, wood framing too close to a wood stove or fireplace, or combustibles too close to an engine exhaust manifold or catalytic converter.

The initial fuel is important for understanding the events that caused the fire. For example, if the remains of a match were found on the burned surface of a wood end table in the area of origin, one should not jump to the conclusion that the match ignited the wood tabletop. The match almost certainly would go out without igniting the solid wood surface. Maybe the match had been blown out and dropped there by an occupant. Was there any paper or other light fuel that could have carried flame to a chair or other fuels? Remember that the initial fuel must be capable of being ignited within the limitations of the ignition source. The components in most buildings are not susceptible to ready ignition. For example, flooring, drywall, structural lumber, wood cabinets, and carpeting do not ignite unless they are exposed to a substantial heat source.

Unusual residues might remain from the initial fuel. Those residues could arise from thermite, magnesium, or other pyrotechnic materials.

Gases and vapors can be the initial fuel and can cause confusion because the point of ignition can be some distance away from where sustained fire starts in the structure or furnishings. When ignition causes a low order explosion, it is obvious that a gas, vapor, or dust is involved. Layered vapors of gasoline might not ignite violently so that, unless evidence of the accelerant is found, the source of ignition many feet from where the puddle burned might be difficult to associate with the fire.

12-5 Ignition Factor (Cause). A fuel by itself or an ignition source by itself does not create a fire. Fire results from the combination of fuel and an ignition source. Therefore, the investigator should be cautious about deciding on a cause of a fire just because a readily ignitible fuel and a potential ignition source are present. The sequence of events that allow the source of ignition and the fuel to get together establishes the cause.

To define the ignition sequence requires determining events and conditions that might have occurred or have been created in the past. Furthermore, the order in which those past events occurred might have to be determined. Consider a fire in a restaurant kitchen that started when a deep-fat fryer ignited and spread through the kitchen. The cause is more than simply "the deep-fat fryer overheated." Was the control turned up too high? Did the control contacts stick? Why did the high temperature cut-off not prevent overheating? Those factors could make a difference between a minor incident and a large hostile fire. In each fire investigation the various contributing factors should be investigated and included in the ultimate explanation of the ignition sequence.

The investigator is cautioned not to rule out a cause merely because there is no obvious evidence for it. Do not rule out the electric heater because there is no arcing in the wires or the contacts are not stuck. Obviously, arson is not eliminated because the lab did not find accelerant in the evidence. The same standard applies to accidental fire causes. Potential causes should be ruled out only if there is definite evidence that they could not have caused the fire. The electric heater could be ruled out if it was not plugged in. A smoldering cigarette can be ruled out if the room was well involved 10 minutes after a reliable witness passed through and saw no smoke.

12-6 Opinions. When forming opinions from hypotheses about fires or explosions, the investigator should set standards for the degree of confidence in those opinions. Use of the scientific method dictates that any hypothesis formed from an analysis of the data collected in an investigation must stand the challenge of reasonable examination. *(See Chapter 2.)* [*See Daubert v. Merrel Dow Pharmaceuticals, Inc.,* 509 U.S. 579, 113 S.Ct. 2786 (1993).]

Ultimately, the decision as to the level of confidence in data collected in the investigation or any hypothesis drawn from an analysis of the data rests with the investigator. The final opinion is only as good as the quality of the data used in reaching that opinion. If the confidence level of the opinion is only "possible" or "suspected," the cause should be listed as undetermined.

Chapter 13 Explosions

13-1* General. Historically, the term *explosion* has been difficult to define precisely.

The manifestation that indicates an explosion occurred includes damage or change brought about by the restriction of the expanding blast pressure front as an integral element, producing physical effects on containers or nearby surfaces.

This effect can result from the confinement of the blast pressure front or the impact of an unconfined pressure or shock wave on an object, such as a person or structure.

For fire and explosion investigations, an explosion is the sudden conversion of potential energy (chemical or mechanical) into kinetic energy with the production and release of gas(es) under pressure. These high-pressure gases then do mechanical work, such as moving, changing, or shattering nearby materials.

Although an explosion is almost always accompanied by the production of a loud noise, the noise itself is not an essential element in the definition of an explosion. The generation and violent escape of gases are the primary criteria of an explosion.

Although the ignition of a flammable vapor/air mixture within a can, which bursts the can or even only pops off the lid, is considered an explosion, the ignition of the same mixture in an open field, while it is a deflagration, may not be an explosion as defined in this document even though there may be the release of high-pressure gas, a localized increase in air pressure, and a distinct noise. The failure and bursting of a tank or vessel from hydrostatic pressure of a noncompressible fluid such as water is not an explosion because the pressure is not created by gas. Explosions are gas dynamic.

In applying this chapter, the investigator should keep in mind that there are numerous factors that control the effects of explosions and the nature of the damage produced. These factors include the type, quantity, and configuration of the fuel; the size and shape of the containment vessel or structure; the type and strength of the materials of construction of the containment vessel or structure; and the type and amount of venting present. *(See Section 13-5.)*

Sections of this chapter present explosion analysis techniques and terms that have been developed primarily from the analysis of explosions involving diffuse fuel sources, such as combustible industrial and fuel gases, dusts, and the vapors from ignitible liquids in buildings of lightweight construction. The reader is cautioned that application of these principles to structures of other construction types may require additional research to other references on explosions. The analysis of explosions involving condensed phase (solid or liquid) explosives, particularly detonating (high) explosives, may also require specialized knowledge that goes beyond the scope of this text.

13-2* Types of Explosions. There are two major types of explosions with which investigators are routinely involved: mechanical and chemical, with several subtypes within these. These types are differentiated by the source or mechanism by which the explosive pressures are produced.

13-2.1* Mechanical Explosions. Mechanical explosions are explosions in which a high-pressure gas produces a purely physical reaction. These reactions do not involve changes in the basic chemical nature of the substances in the container. A purely mechanical explosion is the rupture of a gas storage cylinder or tank under high pressure resulting in the release of the stored high-pressure gas, such as compressed air, carbon dioxide, or oxygen.

13-2.1.1 BLEVEs. The boiling liquid expanding vapor explosion (BLEVE) is the type of mechanical explosion that will be encountered most frequently by the fire investigator. These are explosions involving vessels that contain liquids under pressure at temperatures above their atmospheric boiling points. The liquid need not be flammable. BLEVEs are a subtype of mechanical explosions but are so common that they are treated here as a separate explosion type. A BLEVE can occur in vessels as small as disposable lighters or aerosol cans and as large as tank cars or industrial storage tanks.

A BLEVE frequently occurs when the temperature of the liquid and vapor within a confining tank or vessel is raised by an exposure fire to the point where the increasing internal pressure can no longer be contained and the vessel explodes. *[See Figure 13-2.1.1(a).]* This rupture of the confining vessel releases the pressurized liquid and allows it to vaporize almost instantaneously. If the contents are ignitible, there is almost always a fire. If the contents are noncombustible, there can still be a BLEVE, but no ignition of the vapors. Ignition usually occurs either from the original external heat that caused the BLEVE or from some electrical or friction source created by the blast or shrapnel.

A BLEVE may also result from a reduction in the strength of a container as a result of mechanical damage or localized heating above the liquid level. This rupture of the confining vessel releases the pressurized liquid and allows it to vaporize almost instantaneously. A common example of a BLEVE not involving an ignitible liquid is the bursting of a steam boiler. The source of overpressure is the steam created by heating and vaporizing water. When the pressure of the steam can no longer be confined by the boiler, the vessel fails and an explosion results. No chemical, combustion, or nuclear reaction is necessary. The steam under pressure is the energy source. The chemical nature of the steam (H_2O) is not changed.

BLEVEs may also result from mechanical damage, overfilling, runaway reaction, overheating vapor-space explosion, and mechanical failure. *[See Figure 13-2.1.1(b).]*

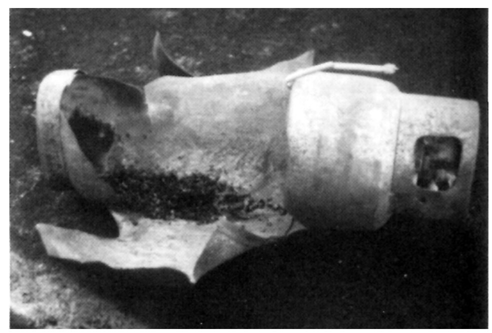


Figure 13-2.1.1(a) An LP-Gas cylinder that suffered a BLEVE as a result of exposure to an external fire.

13-2.2* Chemical Explosions. In chemical explosions, the generation of high-pressure gas is the result of exothermic reactions wherein the fundamental chemical nature of the fuel is changed. Chemical reactions of the type involved in an explosion usually propagate in a reaction front away from the point of initiation.

Chemical explosions can involve solid combustible or explosive mixtures of fuel and oxidizer, but more common to the fire investigator will be the propagating reactions involving gases, vapors, or dusts mixed with air. Such combustion reactions are called propagation reactions because they occur progressively through the reactant (fuel) with a definable flame front separating the reacted and unreacted fuel.

Figure 13-2.1.1(b) A railroad tank car of butadiene that suffered a BLEVE as a result of heating created by an internal chemical reaction.

13-2.2.1 Combustion Explosions. The most common of the chemical explosions are those caused by the burning of combustible hydrocarbon fuels. These are combustion explosions and are characterized by the presence of a fuel with air as an oxidizer. A combustion explosion may also involve dusts. In combustion explosions, the elevated pressures are created by the rapid burning of the fuel and rapid production of large volumes of combustion by-products and heated gases. Because these events are likely to be encountered by the fire investigator, combustion explosions are considered here as a separate explosion type.

Combustion reactions are classified as either deflagrations or detonations, depending on the velocity of the flame front propagation through the fuel. Deflagrations are combustion reactions in which the velocity of the reaction is less than the speed of sound in the unreacted fuel medium. Detonations are combustion reactions in which the velocity of the reaction is faster than the speed of sound in the unreacted fuel medium.

Several subtypes of combustion explosions can be classified according to the types of fuels involved. The most common of these fuels are as follows:

(a) Flammable gases

(b) Vapors of ignitible (flammable and combustible) liquids

(c) Dusts

(d) Low explosives (those that undergo deflagration)

(e) High explosives (those that undergo detonation)

(f) Smoke and flammable products of incomplete combustion (backdraft explosions)

13-2.3 Electrical Explosions. High-energy electrical arcs may generate sufficient heat to cause an explosion. The rapid heating of the surrounding gases results in a mechanical explosion that may or may not cause a fire. The clap of thunder accompanying a lightning bolt is an example of an electrical explosion effect. Electrical explosions require special expertise to investigate and are not covered in this document.

13-2.4 Nuclear Explosions. In nuclear explosions, the high pressure is created by the enormous quantities of heat produced by the fusion or fission of the nuclei of atoms. The investigation of nuclear explosions is not covered by this document.

13-3 Characterization of Explosion Damage. For descriptive and investigative purposes, it can be helpful to characterize incidents, particularly in structures, on the basis of the type of damage noted. The terms *high-order* and *low-order explosion* have been used to characterize explosion damage. The terms *high-* and *low-yield explosion* have also been used. Use of the terms *high-* and *low-order damage* is recommended to reduce confusion with similar terms used to describe the energy release from explosives. *(See Section 13-12.)* The differences in damage are more a function of the rate of pressure rise and the strength of the confining or restricting structure than the maximum pressures being reached.

It should be recognized that the use of the terms *low-order damage* and *high-order damage* may not always be appropriate and a site may contain evidence spanning both categories.

13-3.1 Low-Order Damage. Low-order damage is characterized by walls bulged out or laid down, virtually intact, next to the structure. Roofs may be lifted slightly and returned to their approximate original position. Windows may be dislodged, sometimes without glass being broken. Debris produced is generally large and thrown short distances. Low-order damage is produced by slow rates of pressure rise. *(See Figure 13-3.1.)*

Figure 13-3.1 Low-order damage in a dwelling.

13-3.2* High-Order Damage. High-order damage is characterized by shattering of the structure, producing small, pulverized debris. Walls, roofs, and structural members are splintered or shattered with the building completely demolished. Debris is thrown great distances, possibly hundreds of feet. High-order damage is the result of rapid rates of pressure rise. *(See Figure 13-3.2.)*

13-4 Effects of Explosions. An explosion is a gas dynamic phenomenon that under ideal theoretical circumstances will manifest itself as an expanding spherical heat and pressure wave front. The heat and pressure waves produce the damage characteristic of explosions. The effects of explosions can be observed in four major groups: blast pressure wave effect, shrapnel effect, thermal effect, and seismic effect.

13-4.1 Blast Pressure Front Effect. The explosion of a material produces a large quantity of gases. These gases expand at a high speed and move outward from the point of origin. The gases and the displaced air moved by the gases produce a pressure front that is primarily responsible for the damage and injuries associated with explosions.

The blast pressure front occurs in two distinct phases based on the direction of the forces in relation to the point of origin of the explosion. These are the positive pressure phase and negative pressure phase.

A typical pressure history from an idealized detonation is shown in Figure 13-4.1 and consists of a positive and negative phase. The area under the pressure-time curve is called the "impulse" of the explosion.

Figure 13-3.2 High-order damage shown by shattered and splintered remains of a four-bedroom house.

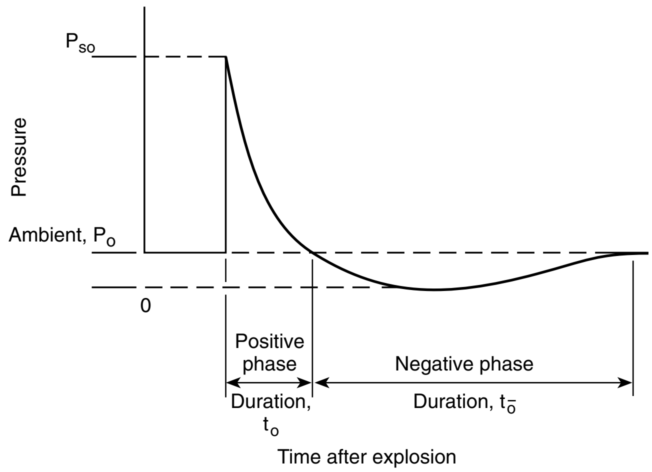


Figure 13-4.1 Typical pressure history from an idealized detonation.

13-4.1.1 Positive Pressure Phase. The positive pressure phase is that portion of the blast pressure front in which the expanding gases are moving away from the point of origin. The positive pressure phase is more powerful than the negative and is responsible for the majority of pressure damage. The negative pressure phase may be undetectable by witnesses or by postblast examination in diffuse-phase (gas/vapor) explosions.

13-4.1.2 Negative Pressure Phase. As the extremely rapid expansion of the positive pressure phase of the explosion moves outward from the origin of the explosion, it displaces, compresses, and heats the ambient surrounding air. A low air pressure condition (relative to ambient) is created at the epicenter or origin. When the positive pressure phase dissipates, air rushes back to the area of origin to equilibrate the low air pressure condition, creating the negative pressure phase.

The negative pressure phase can cause secondary damage and move items of physical evidence toward the point of origin. Movement of debris during the negative pressure phase may conceal the point of origin. The negative pressure phase is usually of considerably less power than the positive pressure phase but may be of sufficient strength to cause collapse of structural features already weakened by the positive pressure phase.

13-4.1.3 Shape of Blast Front. Under ideal theoretical conditions the shape of the blast front from an explosion would be spherical. It expands evenly in all directions from the epicenter. In the real world, the confinement or obstruction of the blast pressure wave changes and modifies the direction, shape, and force of the front itself.

Venting of the confining vessel or structure may cause damage outside of the vessel or structure. The most damage can be expected to be in the path of the venting. For example, the blast pressure front in a room may travel through a doorway and damage items or materials directly in line with the doorway in the adjacent room. The same relative effect may be seen directly in line with the structural seam of a tank or drum that fails before the sidewalls.

The blast pressure front may also be reflected off solid obstacles and redirected, resulting in a substantial increase or possible decrease in pressure depending on the characteristics of the obstacle struck.

After propagating reactions have consumed their available fuel, the force of the expanding blast pressure front decreases with the increase in distance from the epicenter of the explosion.

13-4.1.4 Rate of Pressure Rise vs. Maximum Pressure. The type of damage caused by the blast pressure front of an explosion is dependent not only on the total amount of energy generated but also, and often to a larger degree, on the rate of energy release and the resulting rate of pressure rise.

Relatively slow rates of pressure rise will produce the pushing or bulging type of damage effects seen in low-order damage. The weaker parts of the confining structure, such as windows or structural seams, will rupture first, thereby venting the blast pressure wave and reducing the total damage effects of the explosion.

In explosions where the rate of pressure rise is very rapid, there will be more shattering of the confining vessel or container, and debris will be thrown great distances, as the venting effects are not allowed sufficient time to develop. This is characteristic of high-order damage.

Where the pressure rise is less rapid, the venting effect will have an important impact on the maximum pressure developed. *(See NFPA 68, Guide for Venting of Deflagrations, for equations, data, and guidance on calculating the theoretical effect of venting on pressure during a deflagration.)* Such calculations assume a structure or vessel that can sustain such a high pressure. The maximum theoretical pressure developable by a deflagration can, under some circumstances, be as high as 7–9 atmospheres [in the range of 120 psi (827 kPa)]. In commonly encountered situations, such as fugitive gas explosions in residential or commercial buildings, the maximum pressure will be limited to a level slightly higher than the pressure that major elements of the building enclosure (i.e., walls, roof, large windows, etc.) can sustain without rupture. In a well-built residence, this will seldom exceed 3 psi (21 kPa).

13-4.2 Shrapnel Effect. When the containers, structures, or vessels that contain or restrict the blast pressure fronts are ruptured, they are often broken into pieces that may be thrown over great distances. These pieces of debris are called shrapnel or missiles. They can cause great damage and personal injury often far from the source of the explosion. In addition, shrapnel can often sever electric utility lines, fuel gas or other flammable fuel lines, or storage containers, thereby adding to the size and intensity of postexplosion fires or causing additional explosions.

The distance to which missiles can be propelled outward from an explosion depends greatly on their initial direction. Other factors include their weight and aerodynamic characteristics. An idealized diagram for missile trajectories is shown in Figure 13-4.2 for several different initial directions. The actual distances that missiles can travel depend greatly on aerodynamic conditions and occurrences of ricochet impacts.

13-4.3 Thermal Effect. Combustion explosions release quantities of energy that heat combustion gases and ambient air to high temperatures. This energy can ignite nearby combustibles or cause burn injuries to anyone nearby. These secondary fires increase the damage and injury from the explosion and complicate the investigation process. Often it is difficult to determine which occurred first, the fire or the explosion.

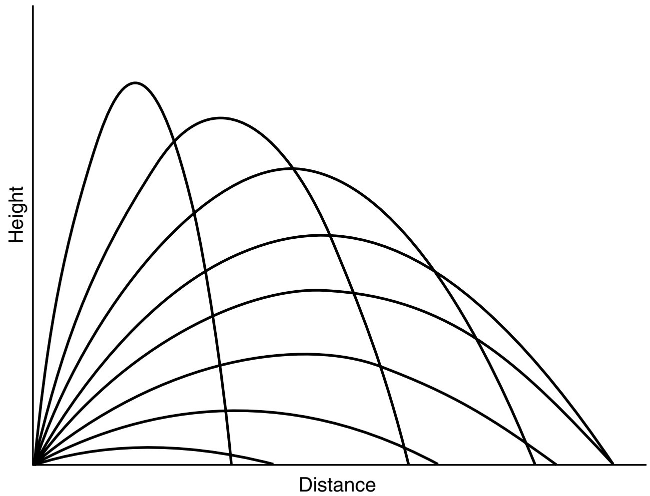


Figure 13-4.2 Idealized missile trajectories for several initial flight directions.

All chemical explosions produce great quantities of heat. The thermal damage *(see effective temperature in 4-8.1)* depends on the nature of the explosive fuel as well as the duration of peak temperature. Detonating explosions produce extremely high temperatures of very limited duration, whereas deflagration explosions produce lower temperatures but for much longer periods. The duration and intensity of the heat greatly affect the damage and injury potential of the explosion.

Fireballs and firebrands are possible thermal effects of explosions, particularly BLEVEs involving flammable vapors. Fireballs are the momentary ball of flame present during or after the explosive event. High-intensity, short-duration thermal radiation may be present with a fireball. Firebrands are hot or burning fragments propelled from the explosion. All these effects may serve to initiate fires away from the center of the explosion.

13-4.4 Seismic Effect. As the blast pressure wave expands, and as the damaged portions of large structures are knocked to the ground, significant localized seismic or earth tremors can be transmitted through the ground. These seismic effects, usually negligible for small explosions, can produce additional damage to structures and underground utility services, pipelines, tanks, or cables.

13-5 Factors Controlling Explosion Effects. Factors that can control the effects of explosions include the type and configuration of the fuel; nature, size, volume, and shape of any containment vessel or object affected; location and magnitude of ignition source; venting of the blast pressure wave; relative maximum pressure; and rate of pressure rise. The nature of these factors and their various combinations in any one explosion incident can produce a wide variety of physical effects with which the investigator will be confronted.

13-5.1 Blast Pressure Front Modifiers. Various phenomena affect the characteristics of a blast pressure front as it travels away from the source. These phenomena are described next.

13-5.1.1 Reflection. As a blast pressure front encounters objects in its path, the blast pressure front may amplify due to its reflection. This reflection in some cases will cause the overpressure to increase and sometimes amplify it as much as eight times at the surface of reflection, depending on the angle of incidence. This effect is negligible with deflagrations, where the pressure in an entire vessel equalizes at approximately the speed of sound in air (i.e., strong shock wave not present).

13-5.1.2 Refraction and Blast Focusing. Atmospheric inhomogeneities can cause nonideal blast pressure front behavior at times. When a blast pressure front encounters a layer of air at a significantly different temperature, it may cause it to bend, or refract. This is because the speed of sound is proportional to the square root of temperature in air. A low-level temperature inversion can cause an initially hemispherical blast front to refract and focus on the ground around the center of the explosion. Severe weather-related wind shear can cause focusing in the downwind direction. This effect is negligible with deflagrations.

13-6 Seated Explosions. The “seat” of an explosion is defined as the crater or area of greatest damage located at the point of initiation (epicenter) of an explosion. Material may be thrown out of the crater. This material is called ejecta and may range from large rocks to fine dust. The presence of a seat indicates the explosion of a concentrated fuel source in contact with or in close proximity to the seat.

These seats can be of any size, depending on the size and strength of the explosive material involved. They typically range in size from a few inches (cm) to 25 ft (7.6 m) in diameter. They display an easily recognizable crater of pulverized soil, floors, or walls located at the center of otherwise less damaged areas. Seated explosions are generally characterized by high pressure and rapid rates of pressure rise.

Only specific types or configurations of explosive fuels can produce seated explosions. These include explosives, steam boilers, tightly confined fuel gases or liquid fuel vapors, and BLEVEs occurring in relatively small containers, such as cans or barrels.

In general, it is accepted that explosive velocities should exceed the speed of sound (detonations) to produce seated explosions, unless the damage is produced by shrapnel from a failing vessel.

13-6.1 Explosives. Explosions fueled by many explosives are most easily identified by their highly centralized epicenters, or “seats.” High explosives especially produce such high-velocity positive-pressure phases at detonation that they often shatter their immediate surroundings and produce craters or highly localized areas of great damage.

13-6.2 Boiler and Pressure Vessels. A boiler explosion often creates a seated explosion because of its high energy, rapid rate of pressure release, and confined area of origin.

Boiler and pressure vessel explosions will exhibit effects similar to explosives, though with lesser localized overpressure near the source.

Each of these involves a rapid release of energy from a containment vessel resulting in a pressure wave that decays with distance.

13-6.3 Confined Fuel Gas and Liquid Vapor. Fuel gases or ignitible liquid vapors — when confined to such small vessels as tanks, barrels, or other containers — can also produce seated explosions.

13-6.4 BLEVE. A boiling liquid expanding vapor explosion will produce a seated explosion if the confining vessel (e.g., a barrel or small tank) is of a small size and if the rate of pressure release when the vessel fails is rapid enough.

13-7 Nonseated Explosions. Nonseated explosions occur most often when the fuels are dispersed or diffused at the time of the explosion because the rates of pressure rise are moderate and the explosive velocities are subsonic. It should be kept in mind that even supersonic detonations may produce nonseated explosions under certain conditions.

13-7.1 Fuel Gases. Fuel gases, such as natural gas and liquefied petroleum (LP) gases, most often produce nonseated explosions. This is because these gases often are confined in large containers, such as individual rooms or structures, and their explosive speeds are subsonic.

13-7.2 Pooled Flammable/Combustible Liquids. Explosions from the vapors of pooled flammable or combustible liquids are nonseated explosions. The large areas that they cover and their subsonic explosive speeds preclude the production of small, high-damage seats.

13-7.3* Dusts. Although dust explosions are often among the most violent and damaging of explosions, they most often occur in confined areas of relatively wide dispersal, such as grain elevators, materials-processing plants, and coal mines. These large areas of origin preclude the production of pronounced seats.

13-7.4 Backdraft or Smoke Explosion. Backdraft or smoke explosions almost always involve a widely diffused volume of combustible gases and particulate matter. Their explosive velocities are subsonic, thereby precluding the production of pronounced seats.

13-8 Gas/Vapor Explosions. The most commonly encountered explosions are those involving gases or vapors, especially fuel gases or the vapors of ignitible liquids. Violent explosions can be encountered with lighter-than-air gases, such as natural gas, but are reported less frequently than with gases or vapors having vapor densities higher than 1.0 (heavier than air). Table 13-8 provides some useful properties of common flammable gases. NFPA 68, *Guide for Venting of Deflagrations*, provides a more complete introduction to the fundamentals of these explosions.

13-8.1* Minimum Ignition Energy for Gases and Vapors. Gaseous fuel/air mixtures are the most easily ignitible fuels capable of causing an explosion. Ignition temperatures in the 700°F to 1100°F (370°C to 590°C) range are common. Minimum ignition energies begin at approximately 0.25 millijoules.

13-8.2 Interpretation of Explosion Damage. The explosion damage to structures (low-order and high-order) is related to a number of factors. These include the fuel/air ratio, vapor density of the fuel, turbulence effects, volume of the confining space, location and magnitude of the ignition source, venting, and the characteristic strength of the structure.

13-8.2.1* Fuel/Air Ratio. Often the nature of damage to the confining structure can be an indicator of the fuel/air mixture at the time of ignition.

Some fire investigation literature has indicated that an entire volume should be occupied by a flammable mixture of gas and air for there to be an explosion. This is not the case because relatively small volumes of explosive mixtures capable of causing damage may result from gases or vapors collecting in a given area. *(See 13-8.2.2.)*

Explosions that occur in mixtures at or near the lower explosive limit (LEL) or upper explosive limit (UEL) of a gas or vapor produce less violent explosions than those near the optimum concentration (i.e., usually just slightly rich of stoichiometric). This is because the less-than-optimum ratio of fuel and air results in lower flame speeds and lower maximum pressures. In general, these explosions tend to push and heave at the confining structure, producing low-order damage.

The flame speed is the local velocity of a freely propagating flame relative to a fixed point. It is the sum of the burning velocity and the translational velocity of the flame front. The maximum laminar flame speeds for methane and propane are 11.5 ft/sec (3.5 m/sec) and 13.1 ft/sec (4 m/sec), respectively.

The burning velocity is the rate of flame propagation relative to the velocity of the unburned gas ahead of it. The fundamental burning velocity is the burning velocity for laminar flame under stated conditions of composition, temperature, and pressure of the unburned gas. Fundamental burning velocity is an inherent characteristic of a combustible and is a fixed value, whereas flame speed can vary widely depending on the existing parameters of temperature, pressure, confining volume and configuration, combustible concentration, and turbulence.

The burning velocity is the velocity at which a flame reaction front moves into the unburned mixture as it chemically transforms the fuel and oxidant into combustion products. It is only a fraction of the flame speed. The transitional velocity is the sum of the velocity of the flame front caused by the volume expansion of the combustion products due to the increase in temperature and any increase in the number of moles and any flow velocity due to motion of the gas mixture prior to ignition. The burning velocity of the flame front can be calculated from the fundamental burning velocity, which is reported in NFPA 68, *Guide for Venting of Deflagrations*, at standardized conditions of temperature, pressure, and composition of unburned gas. As pressure and turbulence increase substantially during an explosion, the fundamental burning velocity will increase, further accelerating the rate of pressure increase. NFPA 68 lists data on the various materials.

Explosions of mixtures near the LEL do not tend to produce large quantities of postexplosion fire, as nearly all of the available fuel is consumed during the explosive propagation.

Explosions of mixtures near the UEL tend to produce postexplosion fires because of the fuel-rich mixtures. The delayed combustion of the remaining fuel produces the postexplosion fire. Often a portion of the mixture over the UEL has fuel that does not burn until it is mixed with air during the explosion's venting phase or negative pressure phase, thereby producing the characteristic following fire.

When optimum (i.e., most violent) explosions occur, it is almost always at mixtures near or just above the stoichiometric mixture (i.e., slightly fuel rich). This is the optimum mixture. These mixtures produce the most efficient combustion and, therefore, the highest flame speeds, rates of pressure rise, maximum pressures, and consequently the most damage. Postexplosion fires can occur if there are pockets of overly rich mixture.

For common lighter-than-air gases in residential buildings, an explosion involving an optimum concentration will sometimes result in some destructive shattering effects of wooden structural materials.

Table 13-8 Combustion Properties of Common Flammable Gases

Gas	Btu per ft^3 (gross)	MJ/m^3 (gross)	Limits of Flammability Percent by Volum in Air: Lower	Upper	Specific Gravity (air = 1.0)	Air Needed to Burn 1 ft^3 of Gas (ft^3)	Air Needed to Burn 1 m^3 of Gas (m^3)	Ignition Temp °F	°C
Natural gas									
High inert type[a]	958–1051	35.7–39.2	4.5	14.0	0.660–0.708	9.2	9.2	—	—
High methane type[b]	1008–1071	37.6–39.9	4.7	15.0	0.590–0.614	10.2	10.2	900–1170	482–632
High Btu type[c]	1071–1124	39.9–41.9	4.7	14.5	0.620–0.719	9.4	9.4	—	—
Blast furnace gas	81–111	3.0–4.1	33.2	71.3	1.04–1.00	0.8	0.8	—	—
Coke oven gas	575	21.4	4.4	34.0	0.38	4.7	4.7	—	—
Propane (commercial)	2516	93.7	2.15	9.6	1.52	24.0	24.0	920–1120	493–604
Butane (commercial)	3300	122.9	1.9	8.5	2.0	31.0	31.0	900–1000	482–538
Sewage gas	670	24.9	6.0	17.0	0.79	6.5	6.5	—	—
Acetylene	1499	208.1	2.5	81.0	0.91	11.9	11.9	581	305
Hydrogen	325	12.1	4.0	75.0	0.07	2.4	2.4	932	500
Anhydrous ammonia	386	14.4	16.0	25.0	0.60	8.3	8.3	1204	651
Carbon monoxide	314	11.7	12.5	74.0	0.97	2.4	2.4	1128	609
Ethylene	1600	59.6	2.7	36.0	0.98	14.3	14.3	914	490
Methyl acetylene, propadiene, stabilized[d]	2450	91.3	3.4	10.8	1.48	—	—	850	454

[a]Typical composition CH_4 71.9–83.2%; N_2 6.3–16.20%
[b]Typical composition CH_4 87.6–95.7%; N_2 0.1–2.39%
[c]Typical composition CH_4 85.0–90.1%; N_2 1.2–7.5%
[d]MAPP® Gas from the NFPA *Fire Protection Handbook*, 17th edition, Table 3-7C

13-8.2.2* Vapor Density. The vapor density of the gas or vapor fuel can have a marked effect on the nature of the explosion damage to the confining structure. This is especially true in dwellings and other buildings.

Heavier-than-air gases and vapors (i.e., vapor density greater than 1.0), such as from ignitible liquids and LP-Gases, tend to settle to lower areas. Lighter-than-air gases, such as natural gas, tend to rise and collect in upper areas. For example, signs of postblast burning in pocketed areas between ceiling joists may be indicative of a lighter-than-air fuel rather than heavier-than-air gases or vapors. *(See 4-17.9.)* Due to their higher mobility and tendency to escape upward, lighter-than-air gases are less likely to produce hazardous situations than heavier-than-air gases, which can pool in basements, crawl spaces, wells, and tanks.

A natural gas leak in the first story of a multistory structure may well be manifested in an explosion with an epicenter in an upper story. The natural gas, being lighter than air, will have a tendency to rise through natural openings and may even migrate inside walls. The gas will continue to disperse in the structure until an ignition source is encountered.

An LP-Gas leak on the first story of a house, if it is not ignited there, can travel away from the source and, due to its density, will tend to migrate downward. The gas may collect in lower areas of the house and concentrate.

Ignition of the gas will only occur if the concentration is within the flammable limits and in contact with a competent ignition source (one with enough energy).

Whether lighter- or heavier-than-air gases are involved, there may be evidence of the passage of flame where the fuel air layer was. Scorching, blistering of paintwork, and showing of "tidemarks" are indicators of this type of phenomena. The operation of heating and air-conditioning systems, temperature gradients, and the effects of wind on a building can cause mixing and movement that can reduce the effects of vapor density. Vapor density effects are greatest in still-air conditions.

Full-scale testing of the distribution of flammable gas concentrations in rooms has shown that near stoichiometric concentrations of gas would develop between the location of the leak and either (1) the ceiling for lighter-than-air gases or (2) the floor for heavier-than-air gases. It was also reported that a heavier-than-air gas that leaked at floor level would create a greater concentration at floor level and that the gas would slowly diffuse upward. A similar but inverse relationship is true for a lighter-than-air gas leaked at ceiling height. Ventilation, both natural and mechanical, can change the movement and mixing of the gas and can result in gas spreading to adjacent rooms.

The vapor density of the fuel is not necessarily indicated by the relative elevation of the structural explosion damage above floor level. It was once widely thought that if the walls of a particular structure were blown out at floor level, the fuel gas was heavier than air, and, conversely, if the walls were blown out at ceiling level, the fuel was lighter than air. Since explosive pressure within a room equilibrates at the speed of sound, a wall will experience a similar pressure-time history across its entire height. The level of the explosion damage within a conventional room is a function of the construction strength of the wall headers and bottom plates, the least resistive giving away first.

13-8.2.3 Turbulence. Turbulence within a fuel/air mixture increases the flame speed and, therefore, greatly increases the rate of combustion and the rate of pressure rise. Turbulence can produce rates of pressure rise with relatively small amounts of fuel that can result in high-order damage even though there may have only been a lean limit [i.e., lower flammable limit (LFL)] mixture present. The shape and size of the confining vessel can have a profound effect on the severity of the explosion by affecting the nature of turbulence. The presence of many obstacles in the path of the combustion wave has been shown to increase turbulence and greatly increase the severity of the explosion, mainly due to increasing the flame speed of the mixture involved. Other mixing and turbulence sources, such as fans and forced air ventilation, may increase the explosion effects.

13-8.2.4* Nature of Confining Space. The nature of containment, its size, shape, construction, volume, materials, and design, will also greatly change the effects of the explosion. For example, a specific percentage by volume of natural gas mixed with air will produce completely different effects if it is contained in a 1000-ft^3 (28.3-m^3) room than if it is contained in a 10,000-ft^3 (283.2-m^3) room at the time of ignition. This is true even though the velocity of the flame front and the maximum overpressure achieved will be essentially the same.

A long, narrow corridor filled with a combustible vapor/air mixture, when ignited at one end, will be very different in its pressure distribution, rate of pressure rise, and its effects on the structure than if the same volume of fuel/air were ignited in a cubical compartment.

In general, the smaller the volume of the vessel, the higher the rate of pressure rise for a given fuel/air mixture, and the more violent the explosion.

During the explosion, turbulence caused by obstructions within the containment vessel can increase the damage effects. This turbulence can be caused by solid obstructions, such as columns or posts, machinery, or wall partitions, which may concentrate or reflect the blast pressure wave.

13-8.2.5* Location and Magnitude of Ignition Source. The highest rate of pressure rise will occur if the ignition source is in the center of the confining structure. The closer the ignition source is to the walls of the confining vessel or structure, the sooner the flame front will reach the wall and be cooled by heat transfer to the walls. The result is a loss of energy and a corresponding lower rate of pressure rise and a less violent explosion. The energy of the ignition source generally has a minimal effect on the course of an explosion, but unusually large ignition sources (e.g., blasting caps, explosive devices, etc.) can significantly increase the speed of pressure development and in some instances cause a deflagration to transition into a detonation.

13-8.2.6 Venting. With gas-, vapor-, or dust-fueled explosions, the venting of the containment vessel will also have a profound effect on the nature of explosion damage. For example, it is possible to cause a length of steel pipe to burst in the center if it is sufficiently long, in spite of the fact that it may be open at both ends. The number, size, and location of doors and windows in a room may determine whether the room experiences complete destruction or merely a slight movement of the walls and ceiling.

Venting of a confining vessel or structure may also cause damage outside of the vessel or structure. The most damage can be expected in the path of venting. For example, the blast pressure front in a room may travel through a doorway and damage items or materials directly in line with the doorway in the adjacent room The same relative effect may be seen directly in line with the structural seam of a tank or drum that fails before the sidewalls.

With detonations, venting effects are minimal as the high speeds of the blast pressure fronts are too fast for any venting to relieve the pressures.

13-8.3 Underground Migration of Fuel Gases. It is quite common for fuel gases that have leaked from underground piping systems to migrate underground, enter structures, and fuel fires or explosions there. Because the soil surrounding underground pipes and utility lines has been more disturbed than adjacent soil, it is generally less dense and more porous. Both lighter-than-air and heavier-than-air fugitive fuel gases will tend to follow the exterior of such underground constructions and can enter structures in this manner. Often these fugitive gases will permeate the soil, migrate upward, and dissipate harmlessly onto the air. However, if the surface of the ground is then obstructed by rain, snow, freezing, or new paving, the gases may then migrate laterally and enter structures.

Fuel gases migrating underground have been known to enter buildings by seeping into sewer lines, underground electrical or telephone conduits, drain tiles, or even directly through basement and foundation walls, none of which is as gastight as water or gas lines.

Cases where gases have migrated underground for hundreds of feet and then fueled explosions or fires in distant structures are well known. *(See 19-9.7.)*

Natural gas and propane have little or no natural odors of their own. In order for them to be readily detected when leaking, foul smelling malodorant compounds are added to the gases. Odorant verification should be a part of any explosion investigation involving or potentially involving fuel gas, especially if it appears that there were no indications of a leaking gas being detected by people present. The odorant's presence, in the proper amount, should be verified. *(See 19-2.4.)*

13-8.4 Multiple Explosions. A migration and pocketing effect is also often manifested by the production of multiple explosions, generally referred to as secondary explosions (and sometimes cascade explosions). Gas and vapors that have migrated to adjacent stories or rooms can collect or pocket on each level. When an ignition and explosion takes place in one story or room, subsequent explosions can occur in adjoining areas or stories.

The migration and pocketing of gases often produces areas or pockets with different air/fuel mixtures. One pocket could be within the explosive range of the fuel, while a pocket in an adjoining room or story could be over the upper explosive limit (UEL). When the first mixture is ignited and explodes, damaging the structure, the dynamic forces of the explosion, including the positive and negative pressure phases, tend to mix air into the fuel-rich mixture and bring it into the explosive range. This mixture in turn will explode if an ignition source of sufficient energy is present. In this way a series of vapor/gas explosions is possible.

Multiple explosions are a very common occurrence. However, often the explosions occur so rapidly that witnesses report hearing only one, but the physical evidence, including multiple epicenters, indicates more than one explosion.

13-9 Dust Explosions. Finely divided solid materials (e.g., dusts and fines), when dispersed in the air, can fuel particularly violent and destructive explosions. Even materials that are not normally considered to be combustible, such as aspirin, aluminum, or milk powders, can produce explosions when burned as dispersed dusts.

Dust explosions occur in a wide variety of materials: agricultural products, such as grain dusts and sawdust; carbonaceous materials, such as coal and charcoal; chemicals; drugs, such as aspirin and ascorbic acid (i.e., vitamin C); dyes and pigments; metals, such as aluminum, magnesium, and titanium; plastics; and resins, such as synthetic rubber.

NFPA 68, *Guide for Venting of Deflagrations,* provides a more complete introduction to fundamentals of dust explosions.

13-9.1* Particle Size. Since the combustion reaction takes place at the surface of the dust particle, the rates of pressure rise generated by combustion are largely dependent on the surface area of the dispersed dust particles. For a given mass of dust material, the total surface area, and consequently the violence of the explosion, increases as the particle size decreases. The finer the dust, the more violent the explosion. In general, an explosion hazard concentration of combustible dusts can exist when the particles are 420 microns or less in diameter.

13-9.2* Concentration. The concentration of the dust in air has a profound effect on its ignitibility and violence of the blast pressure wave. As with ignitible vapors and gases, there are minimum explosive concentrations of specific dusts required for a propagating combustion reaction to occur. Minimum concentrations can vary with the specific dust from as low as 0.015 oz/ft^3 to 2.0 oz/ft^3 (20 g/m^3 to 2000 g/m^3) with the most common concentrations being less than 1.0 oz/ft^3 (1000 g/m^3).

Unlike most gases and vapors, however, there is generally no reliable maximum limit of concentration. The reaction rate is controlled more by the surface-area-to-mass ratio than by a maximum concentration.

Similar to gases and vapors, the rate of pressure rise and the maximum pressure that occur in the dust explosion are higher if the pre-explosion dust concentration is at or close to the optimum mixture. The combustion rate and maximum pressure decrease if the mixture is fuel-rich or fuel-lean. The rate of pressure rise and total explosion pressure are very low at the lower explosive limit and at very high fuel-rich concentrations.

13-9.3 Turbulence in Dust Explosions. Turbulence within the suspended dust/air mixture greatly increases the rate of combustion and thereby the rate of pressure rise. The shape and size of the confining vessel can have a profound effect on the severity of the dust explosion by affecting the nature of turbulence. An example is the pouring of grain from a great height into a largely empty storage bin.

13-9.4* Moisture. Generally, increasing the moisture content of the dust particles increases the minimum energy required for ignition and the ignition temperature of the dust suspension. The initial increase in ignition energy and temperature is generally low, but, as the limiting value of moisture concentration is approached, the rate of increase in ignition energy and temperature becomes high. Above the limiting values of moisture, suspensions of the dust will not ignite. The moisture content of the surrounding air, however, has little effect on the propagation reaction once ignition has occurred.

13-9.5 Minimum Ignition Energy for Dust. Dust explosions have been ignited by open flames, smoking materials, lightbulb filaments, welding and cutting, electric arcs, static electric discharges, friction sparks, heated surfaces, and spontaneous heating.

Ignition temperatures for most material dusts range from 600°F to 1100°F (320°C to 590°C). Layered dusts generally have lower ignition temperatures than the same dusts suspended in air. Minimum ignition energies are higher for dusts than for gas or vapor fuels and generally fall within the range of 10 to 40 millijoules, higher than most flammable gases or vapors.

13-9.6 Multiple Explosions. Dust explosions in industrial scenarios usually occur in a series. The initial ignition and explosion are most often less severe than subsequent secondary explosions. However, the first explosion puts additional dust into suspension, which results in additional explosions. The mechanism for this is that structural vibrations due to one explosion will propagate faster than the combustion wave, lofting dust ahead of it. In facilities such as grain elevators, these secondary explosions often progress from one area to another, or from building to building.

13-10 Backdraft or Smoke Explosions. When fires occur within rooms or structures that are relatively airtight, it is common for fires to become oxygen depleted. In these cases, high concentrations of heated airborne particulates and aerosols, carbon monoxide, and other flammable gases can be generated due to incomplete combustion. These heated fuels will collect in a structure where there is insufficient oxygen to allow combustion to occur and insufficient ventilation to allow them to escape.

When this accumulation of fuels mixes with air, such as by the opening of a window or door, they can ignite and burn sufficiently fast to produce low-order damage, though usually with less than 2 psi (13.8 kPa) overpressure in conventional structures. These are called backdrafts and smoke explosions.

13-11 Outdoor Vapor Cloud Explosions. An outdoor vapor cloud explosion is the result of the release of gas, vapor, or mist into the atmosphere forming a cloud within the fuel's flammable limits and causing subsequent ignition. The principal characteristic of the event is potentially damaging pressures within and beyond the boundary of the cloud due to deflagration or detonation phenomena.

This phenomenon also has been referred to as an *unconfined vapor/air explosion* or *unconfined vapor/cloud explosion.* While completely unconfined, vapor/cloud explosions are possible. Most involve at least some partial restriction of pressure by manmade or natural structures.

Outdoor vapor cloud explosions have generally occurred at process plants and in flammable liquid or flammable gas storage areas or have involved large transport vehicles (e.g., railroad tank cars). Large amounts of fuel (hundreds of pounds or more) are generally involved.

13-12* Explosives. Explosives are any chemical compound, mixture, or device, the primary purpose of which is to function by explosion. Explosives are categorized into two main types, low explosives and high explosives (not to be confused with low-order and high-order damage).

13-12.1 Low Explosives. Low explosives are characterized by deflagration (subsonic blast pressure wave) or a relatively slow rate of reaction and the development of low pressure when initiated. Common low explosives are smokeless gunpowder, flash powders, solid rocket fuels, and black powder. Low explosives are designed to work by the pushing or heaving effects of the rapidly produced hot reaction gases.

It should be noted that some low explosives (i.e., double base smokeless powder) can achieve detonation under circumstances where confinement is adequate to produce adequate reaction speed, where the ignition source is very strong, or where instabilities in combustion occur.

13-12.2 High Explosives. High explosives are characterized by a detonation propagation mechanism. Common high explosives are dynamites, water gel, TNT, ANFO, RDX, and PETN. High explosives are designed to produce shattering effects by nature of their high rate-of-pressure rise and extremely high detonation pressure (on the order of one million psi). These high, localized pressures are responsible for cratering and localized damage near the center of the explosion.

The effects produced by diffuse phase (i.e., fuel/air) explosions and solid explosives are very different. In a diffuse phase explosion (usually deflagration), structural damage will tend to be uniform and omnidirectional, and there will be relatively widespread evidence of burning, scorching, and blistering. In contrast, the rate of combustion of a solid explosive is extremely fast in comparison to the speed of sound. Therefore, pressure does not equalize through the explosion volume and extremely high pressures are generated near the explosive. The pressure and the resultant level of damage rapidly decay with distance away from the center of the explosion. At the location of the explosion, there should be evidence of crushing, splintering, and shattering effects produced by the higher pressures. Away from the source of the explosion there is usually very little evidence of intense burning or scorching, except where hot shrapnel or firebrands have landed on combustible materials.

13-12.3 Investigation of Explosive Incidents. The investigation of incidents involving explosives requires very specialized training. Explosives are strictly regulated by local and federal laws, so most explosives incidents will be investigated by law enforcement or regulatory agencies. It is suggested that only investigators with the appropriate training endeavor to conduct such investigations. Those without this training should contact law enforcement or other agencies for assistance.

13-13 Investigating the Explosion Scene. The objectives of the explosion scene investigation are no different from those for a regular fire investigation: determine the origin, identify the fuel and ignition source, determine the cause, and establish the responsibility for the incident. A systematic approach to the scene examination is equally or even more important with an explosion investigation than in a fire investigation. Explosion scenes are often larger and more disturbed than fire scenes. Without a preplanned, systematic approach, explosion investigations become even more difficult or impossible to conduct effectively.

Typical explosion incidents can range from a small pipe bomb in a dwelling to a large process explosion encompassing an entire facility. While the investigative procedures described below are more comprehensive for the large incidents, the same principles should be applied to small incidents, with appropriate simplification.

When damage is very extensive and includes much structural damage, an explosion dynamics expert and structural expert should be consulted early in the investigation to aid in the complex issues involved.

13-13.1 Securing the Scene. The first duty of the investigator is to secure the scene of the explosion. First responders to the explosion should establish and maintain physical control of the structure and surrounding areas. Unauthorized persons should be prevented from entering the scene or touching blast debris remote from the scene itself because the critical evidence from an explosion (whether accidental or criminal) may be very small and may be easily disturbed or moved by people passing through. Evidence is also easily picked up on shoes and tracked out. Properly securing the scene also tends to prevent additional injuries to unauthorized persons or the curious who may attempt to enter an unsafe area.

13-13.1.1 Establishing the Scene. As a general rule, the outer perimeter of the incident scene should be established at $1\frac{1}{2}$ times the distance of the farthest piece of debris found. Significant pieces of blast debris can be propelled great distances or into nearby buildings or vehicles, and these areas should be included in the scene perimeter. If additional pieces of debris are found, the scene perimeter should be widened.

13-13.1.2 Obtain Background Information. Before beginning any search, all relevant information should be obtained pertaining to the incident. This should include a description of the incident site and systems or operations involved and of conditions and events that led to the incident. The locations of any combustibles and oxidants that were present and what abnormal or hazardous conditions existed that might account for the incident need to be determined. Any pertinent information regarding suspected explosive materials and causes will of course be of interest and will aid in the search as well.

Examination should be made of witness accounts, maintenance records, operational logs, manuals, weather reports, previous incident reports, and other relevant records in developing the evidence. Recent changes in equipment, procedures, and operating conditions can be especially significant.

Obtaining drawings of the building or process will greatly improve documentation of the scene, especially if notes can be made on them.

13-13.1.3 Establish a Scene Search Pattern. The investigator should establish a scene search pattern. With the assistance of investigation team members, the scene should be searched from the outer perimeter inward toward the area of greatest damage. The final determination of the location of the explosion's epicenter should be made only after all of the scene has been examined.

The search pattern itself may be spiral, circular, or grid shaped. Often the particular circumstances of the scene will dictate the nature of the pattern. In any case, the assigned areas of the search pattern should overlap so that no evidence will be lost at the edge of any search area. It is often useful to search areas more than once. When this is done, a different searcher should be used to help ensure that evidence is not overlooked.

The number of actual searchers will depend on the physical size and complexity of the scene. The investigator in charge should keep in mind, however, that too many searchers can often be as counterproductive as too few. Searchers should be briefed as to the proper procedures for identifying, logging, photographing, and marking and mapping the location of evidence. Consistent procedures are imperative whenever there are several searchers involved.

The location of evidence may be marked with chalk marks, spray paint, flags, stakes, or other marking means. After photographing, the evidence may be tagged, moved, and secured. *(See Chapters 8 and 9.)*

13-13.1.4 Safety at the Explosion Scene. All of the fire investigation safety recommendations listed in Chapter 10 also apply for the investigation of explosions. In addition, there are some special safety considerations when dealing with an explosion scene.

Structures that have suffered explosions are often more structurally damaged than merely burned buildings. The possibility of floor, wall, ceiling, roof, or entire building collapse is much greater and should always be considered.

In the case of fuel gas or dust explosions, secondary explosions are the rule rather than the exception. Early responders need to remain alert to that possibility. Leaking gas or pools of flammable liquids need to be made safe before the investigation is begun. Toxic materials in the air or on material surfaces need to be neutralized. The use of appropriate personal safety equipment is recommended.

Explosion scenes that involve bombings or explosives have added dangers. Investigators should be on the lookout for additional devices and undetonated explosives. The modus operandi (M.O.) of some bomber/arsonists includes using secondary explosive devices specifically targeted for the law enforcement or fire service personnel who will be responding to the bombing incident.

A thorough search of the scene should be conducted for any secondary devices prior to the initiation of the postblast investigation. If undetonated explosive devices or explosives are found, it is imperative that they not be moved or touched. The area should be evacuated and isolated, and explosives disposal authorities summoned.

13-13.2 Initial Scene Assessment. Once the explosion scene has been established, the investigator should make an initial assessment of the type of incident with which he or she is dealing. If at any time during the investigation the investigator determines that the explosion was fueled by explosives or involved an improvised explosive device (IED), he or she should discontinue the scene investigation, secure the scene, and contact the appropriate law enforcement agency.

Table 13-13.2 provides the investigator with a basic general guide for comparing the characteristics of explosion damage and fuels. It can aid in including or eliminating some kinds of explosions or fuels from the initial investigative assessment. For example, if the evidence indicates that high-order damage occurred, it can be assumed that the explosion was not the result of a backdraft.

13-13.2.1 Identify Explosion or Fire. The first task in the initial assessment is to determine whether the incident was a fire, explosion, or both, and which came first. Often the evidence of an explosion is not obvious, for example, where a weak explosion of fuel gases is involved.

The investigator should look for signs of an overpressure condition existing within the structure, including displacement or bulging of walls, floors, ceilings, doors and windows, roofs, other structural members, nails, screws, utility service lines, panels, and boxes. Localized fragmentation and pressure damage should be noted as attributable to condensed phase explosive fuel reaction.

The investigator should look for and assess the nature and extent of heat damage to the structure and its components and decide whether it can be attributed to fire alone.

13-13.2.2 High- or Low-Order Damage. The investigator should attempt to determine whether the nature of damage indicates high-order or low-order damage. *(See Section 13-3.)* This will help classify the type, quantity, and mixture of the fuel involved.

13-13.2.3 Seated or Nonseated Explosion. The investigator should determine whether the explosion was seated or nonseated. This will help classify the type of possible fuel involved. *(See Section 13-6.)*

13-13.2.4 Identify Type of Explosion. The investigator should identify the type of explosion involved (e.g., mechanical, combustion, other chemical reaction, or BLEVE).

13-13.2.5 Identify Potential General Fuel Type. The investigator should identify which types of fuel were potentially available at the explosion scene by identifying the condition and location of utility services, especially fuel gases and sources of ignitible dusts or liquids.

The investigator should analyze the nature of damage in comparison to the typical damage patterns available from the following:

(a) Lighter-than-air gases

(b) Heavier-than-air gases

(c) Liquid vapors

(d) Dusts

(e) Explosives

(f) Backdrafts

(g) BLEVEs

13-13.2.6 Establish the Origin. The investigator should attempt early on to establish the origin of the explosion. This will usually be identified as the area of most damage and will sometimes include a crater or other localized area of severe damage in the case of a seated explosion. In the case of a diffuse fuel/air explosion, the origin will be the confining volume or room of origin. *(See 4-19.2.)*

13-13.2.7 Establish the Fuel Source and Explosion Type. The investigator should identify which types of fuel were available at the explosion scene by identifying the condition and location of utility services, especially fuel gases, processing by-product dusts, or ignitible liquids.

The investigator should analyze the nature of damage in comparison to the typical damage patterns attributable to the following:

(a) Lighter-than-air gases

(b) Heavier-than-air gases

(c) Liquid vapors

(d) Dusts

(e) Explosives

(f) Backdrafts

(g) BLEVEs

Thus, the type of explosion is established.

Table 13-13.2 Typical Explosion Characteristics

Typical Characteristics	Lighter-than-Air Gases	Heavier-than-Air Gases	Liquid Vapors	Dusts	Explosives	Backdrafts	BLEVEs
Low-order damage	3	4	4	2	2	5	2
High-order damage	2	1	1	2	3	0	2
Secondary explosion	3	3	2	4	0	1	0
Gas/vapor/dust pocketing	3	2	2	2	0	0	0
Deflagration[a]	4	4	4	4	1	5	4[b]
Detonation	1	1	1	1	4	0	1[b]
Underground migration	2	2	2	0	0	0	0
BLEVEs	2	3	5	0	0	0	5
Postexplosion fires	3	3	4	3	1	5	3
Preexplosion fires	2	2	2	3	2	5	4
Seated explosions	0[c]	0[c]	0[c]	0	4[d]	0	2
Min. ignition energy (mJ)[e]	0.17–0.25	0.17–0.25	0.25	10–40	[e]		[f]

Note: 0 = never, 1 = seldom, 2 = sometimes, 3 = often, 4 = nearly always, 5 = always.
[a]Deflagrations may transition into detonations under certain conditions.
[b]The strength of the confining vessel may allow the pressure wave at failure to be supersonic.
[c]Gases and vapors may produce seats if confined in small vessels, and the materials on which they explode can be sufficiently compressed or shattered.
[d]All high explosives and some low explosives will produce seated explosions if the materials on which they explode can be sufficiently compressed or shattered.
[e]Ignition energies vary widely. Most modern high explosives are designed to be insensitive to ignition. Energies for detonations are nine orders of magnitude larger than the minimum ignition energies.
[f]BLEVEs are not combustion explosions and do not require ignitions.

13-13.2.8 Establish Ignition Source. The investigator should attempt to identify the ignition source involved. This can at times be very difficult. Examination should be made for potential sources — such as hot surfaces, electrical arcing, static electricity, open flames, sparks, chemicals, and so forth — where fuel/air mixtures are involved.

Where explosives are involved, the initiation source may be a blasting cap or other pyrotechnic device. Wires and device components will sometimes survive.

13-13.3 Detailed Scene Assessment. Armed with general information from the initial scene assessment, the investigator may now begin a more detailed study of the blast damage and debris. As in any fire incident investigation, the investigator should record his or her investigation and findings by accurate note taking, photography, diagramming, and mapping. It is important to use proper collection and preservation techniques. *(See Chapters 8 and 9.)*

13-13.3.1 Identify Damage Effects of Explosion. The investigator should make a detailed examination and analysis of the specific explosion or overpressure damage. Damaged articles should be identified as having been affected by one or more of the following typical explosion forces:

(a) Blast pressure wave — positive phase
(b) Blast pressure wave — negative phase
(c) Shrapnel impact
(d) Thermal
(e) Seismic

The investigator should examine and classify the type of damage present — whether it was shattered, bent, broken, or flattened — and also look for changes in the pattern. At distances away from a detonation explosion epicenter, the pressure rise will be fairly moderate and the effects will resemble those of a deflagration explosion, while materials in the immediate vicinity of the detonation epicenter will exhibit splintering and shattering.

The investigator should make a detailed examination and analysis of the specific explosion or overpressure damage. Damaged articles should be identified as having been affected by one or more of the damaging effects of explosions: blast pressure fronts, shrapnel impact, thermal effects, and seismic effects.

The investigator should examine and classify the type of damage to each significant item present — whether it was shattered, bent, broken, or flattened — and also look for changes in the pattern. At distances away from a detonation explosion center, the pressure rise will be fairly moderate and the effects will resemble those of a deflagration explosion. Items in the immediate vicinity of the detonation center will exhibit splintering and shattering (i.e., brittle failure).

The scene should be carefully examined and fragments of any foreign material recovered, as well as debris from the seat itself. The fragments may require forensic laboratory analysis for their identification, but whether they are fragments of the original vessel or container or portions of an improvised explosive device, they may be critical to the investigation.

Tables 13-13.3.1(a) and (b) can be used as a simplified guide to estimate the peak blast overpressure from the observed building damage and casualty data. These data are from peak overpressure applied to the structure's exterior. The effects of overpressure on the inside of the structure are considered to be similar, but the overpressure values may be different in some cases, depending on the construction involved.

It is noted that the estimation of structural damage from an explosion is a very complex topic. A thorough treatment involves maximum pressure and impulse of the explosion, as well as the natural period and strength characteristics of the confining structure. Generally, one can expect a peak overpressure of 1 to 2 psi (6.9 to 13.8 kPa) to cause the failure of most light structural assemblies such as nonreinforced wood siding, corrugated steel panels, or masonry block walls. In comparison, much higher overpressures can be tolerated when the structural design is reinforced, particularly with materials of good ductility (e.g., steel).

13-13.3.2 Identify Preblast and Postblast Fire Damage. Fire or heat damage should be identified as having been caused by a pre-existing fire or by the thermal effect of the explosion. Debris that has been propelled away from the point of origin should be examined to determine whether it has been burned. Debris of this nature that is burned may be an indicator that a fire preceded the explosion.

Probably the most common sign of an overpressure condition is window glass thrown some distance from the windows of the structure. The residue of smoke or soot on fragments of window glass or other structural debris reveals that the explosion followed a fire by some time, whereas perfectly clean pieces of glass or debris thrown large distances from the structure indicate an explosion preceding the fire.

The direction of flow of melted and resolidified debris may tell the investigator the position or attitude of the debris at the time of heat exposure.

13-13.3.3 Locate and Identify Articles of Evidence. Investigators should locate, identify, note, log, photograph, and map any of the many and varied articles of physical evidence. Because of the propelling nature of explosions, the investigator should keep in mind that significant pieces of evidence may be found in a wide variety of locations such as outside the exploded structure, embedded in the walls or other structural members of the exploded structure, on or in nearby vegetation, inside adjacent structures or vehicles, or embedded in these adjacent structures. In the case of bombing incidents or incidents involving the explosion of tanks, appliances, or equipment, significant pieces of evidence debris may have pierced the bodies of victims or be contained in their clothing.

The clothing of anyone injured in an explosion should be obtained for examination and possible analysis. The investigator should ensure that photographs are taken of the injuries and that any material removed from the victims during medical treatment or surgery is preserved. This is true whether the person survives or not.

Investigators should note the condition and position of any damaged and displaced structural components, such as walls, ceilings, floors, roofs, foundations, support columns, doors, windows, sidewalks, driveways, and patios.

Table 13-13.3.1(a) Human Injury Criteria (includes injury from flying glass and direct overpressure effects)

Overpressure (psi)	Injury	Comments	Source
0.6	Threshold for injury from flying glass*	Based on studies using sheep and dogs	a
1.0–2.0	Threshold for skin laceration from flying glass	Based on U.S. Army data	b
1.5	Threshold for multiple skin penetrations from flying glass (bare skin)*	Based on studies using sheep and dogs	a
2.0–3.0	Threshold for serious wounds from flying glass	Based on U.S. Army data	b
2.4	Threshold for eardrum rupture	Conflicting data on eardrum rupture	b
2.8	10% probability of eardrum rupture	Conflicting data on eardrum rupture	b
3.0	Overpressure will hurl a person to the ground	One source suggested an overpressure of 1.0 psi for this effect	c
3.4	1% eardrum rupture	Not a serious lesion	d
4.0–5.0	Serious wounds from flying glass near 50% probability	Based on U.S. Army data	b
5.8	Threshold for body-wall penetration from flying glass (bare skin)*	Based on studies using sheep and dogs	a
6.3	50% probability of eardrum rupture	Conflicting data on eardrum rupture	b
7.0–8.0	Serious wounds from flying glass near 100% probability	Based on U.S. Army data	b
10.0	Threshold lung hemorrhage	Not a serious lesion [applies to a blast of long duration (over 50 m/sec)]; 20–30 psi required for 3 m/sec duration waves	d
14.5	Fatality threshold for direct blast effects	Fatality primarily from lung hemorrhage	b
16.0	50% eardrum rupture	Some of the ear injuries would be severe	d
17.5	10% probability of fatality from direct blast effects	Conflicting data on mortality	b
20.5	50% probability of fatality from direct blast effects	Conflicting data on mortality	b
25.5	90% probability of fatality from direct blast effects	Conflicting data on mortality	b
27.0	1% mortality	A high incidence of severe lung injuries [applies to a blast of long duration (over 50 m/sec)]; 60–70 psi required for 3 m/sec duration waves	d
29.0	99% probability of fatality from direct blast effects	Conflicting data on mortality	b

*Interpretation of tables of data presented in reference.
[a]Fletcher, Richmond, and Yelverron, 1980.
[b]*Loss Prevention in the Process Industries*.
[c]Brasie and Simpson, 1968.
[d]U.S. Department of Transportation, 1988.

Investigators should note the condition and position of any damaged and displaced building contents, such as furnishings, appliances, heating or cooking equipment, manufacturing equipment, victims' clothing, and personal effects.

Investigators should note the condition and position of any damaged and displaced utility equipment, such as fuel gas meters and regulators, fuel gas piping and tanks, electrical boxes/meters, electrical conduits and conductors, heating oil tanks, parts of explosive devices, or fuel vessels.

13-13.3.4 Identify Force Vectors. Investigators should identify, diagram, photograph, and note those pieces of debris that indicate the direction and relative force of the explosion. Keep in mind that the force necessary to shatter a wall is more than that necessary to merely dislodge or displace it. The force necessary to shatter a window is less than that to displace a wall, but more than that necessary to blow out a window intact. The greater the force, the farther that similar pieces of debris will be thrown from the epicenter.

Table 13-13.3.1(b) Property Damage Criteria

Overpressure (psi)	Damage	Source
0.03	Occasional breaking of large glass windows already under strain	a
0.04	Loud noise (143 dB). Sonic boom glass failure	a
0.10	Breakage of small windows, under strain	a
0.15	Typical pressure for glass failure	a
0.30	"Safe distance" (probability 0.95 no serious damage beyond this value) Missile limit. Some damage to house ceilings 10% window glass broken	a
0.4	Minor structural damage	a,c
0.5–1.0	Shattering of glass windows, occasional damage to window frames. One source reported glass failure at 0.147 psi (1 kPa).	a,c,d,e
0.7	Minor damage to house structures	a
1.0	Partial demolition of houses, made uninhabitable	a
1.0–2.0	Shattering of corrugated asbestos siding	a,b,d,e
	Failure of corrugated aluminum/steel paneling	
	Failure of wood siding panels (standard housing construction)	
1.3	Steel frame of clad building slightly distorted	a
2.0	Partial collapse of walls and roofs of houses	a
2.0–3.0	Shattering of nonreinforced concrete or cinder block wall panels [1.5 psi (10.3 kPa) according to another source]	a,b,c,d
2.3	Lower limit of serious structural damage	a
2.5	50% destruction of brickwork of house	a
3.0	Steel frame building distorted and pulled away from foundations	a
3.0–4.10	Collapse of self-framing steel panel buildings	a,b,c
	Rupture of oil storage tanks	
	Snapping failure — wooden utility tanks	
4.0	Cladding of light industrial buildings ruptured	a
4.8	Failure of reinforced concrete structures	e
5.0	Snapping failure — wooden utility poles	a,b
5.0–7.0	Nearly complete destruction of houses	a
7.0	Loaded train wagons overturned	a
7.0–8.0	Shearing/flexure failure of brick wall panels [8 in. to 12 in. (20.3 cm to 30.5 cm) thick, not reinforced]	a,b,c,d
	Sides blown in of steel frame buildings	d
	Overturning of loaded rail cars	b,c
9.0	Loaded train box cars completely demolished	a
10.0	Probable total destruction of buildings	a
30.0	Steel towers blown down	b,c
88.0	Crater damage	e

[a] *Loss Prevention in the Process Industries.*
[b] Brasie and Simpson, 1968.
[c] U.S. Department of Transportation, 1988.
[d] U.S. Air Force, 1983.
[e] McRae, 1984.

The investigator should log, diagram, and photograph varying missile distances and directions of travel for similar debris, such as window glass. Larger, more massive missiles should be measured and weighed for comparison of the forces necessary to propel them.

The distance as well as the direction of significant pieces of evidence from the apparent epicenter of the explosion may be critical. The location of all significant pieces should be completely documented on the explosion scene diagram along with notes as to both distance and direction. This allows the investigator to reconstruct the trajectories of various components.

13-14 Analyze Origin (Epicenter). After identifying the force vectors, the investigator should trace backward from the least to the most damaged areas following the general path of the explosion force vectors. This is known as an explosion dynamics analysis. It can be accomplished most efficiently by plotting on a diagram of the exploded structure the various directions of debris movement and, if possible, an estimate of the relative force necessary for the damage or movement of each significant piece of debris. *(See Figure 13-14.)*

The analysis of the explosion dynamics is based on the debris movement away from the epicenter of the explosion in a roughly spherical pattern and the decreasing force of the explosion as the distance from the epicenter increases.

Often, more than one explosion dynamics diagram is necessary. The first would show a relatively large area that may indicate a specific area or room for further study as the origin. A second, smaller-scale diagram can then be constructed to analyze the explosion dynamics of the area of origin itself. This is especially useful when dealing with a seated explosion.

Often, especially when dealing with nonseated explosions, such as fugitive fuel gas explosions, the epicenter may not be pinpointed any more than to a specific room or area.

The explosion dynamics analysis is often complicated by evidence of a series of explosions, each with its own epicenter. This situation calls for a detailed comparison of the force vectors. Movement of more solid debris, such as walls, floors, and roofs, is generally less in subsequent explosions than in the first. The first forceful explosion tends to vent the structure, allowing more of the positive pressure phase of subsequent explosions to be released.

This is true, however, only when the secondary explosions are of the same or lesser force than the first. Dust explosions are a notable exception to this phenomenon with subsequent explosions almost always being more powerful than the first.

13-15 Analyze Fuel Source. Once the origin or epicenter of the explosion has been identified, the investigator should determine the fuel. This is done by a comparison of the nature and type of damage to the known available fuels at the scene.

All available fuel sources should be considered and eliminated until one fuel can be identified as meeting all of the physical damage criteria. For example, if the epicenter of the explosion is identified as a 6-ft (1.8-m) crater of pulverized concrete in the center of the floor, fugitive natural gas can be eliminated as the fuel, and only fuels that can create seated explosions should be considered.

Chemical analysis of debris, soot, soil, or air samples can be helpful in identifying the fuel. With explosives or liquid fuels, gas chromatography, mass spectrography, or other chemical tests of properly collected samples may be able to identify their presence.

Air samples taken in the vicinity of the area of origin can be used in identifying gases or the vapors of liquid fuels. For example, commercial "natural gas" is a mixture of methane, ethane, propane, nitrogen, and butane. The presence of ethane in an air sample may show that commercial "natural gas" was there rather than naturally occurring "swamp, marsh, or sewer" gas, which is all methane.

Once a fuel is identified, the investigator should determine its source. For example, if the fuel is identified as a lighter-than-air gas and the structure is serviced by natural gas, the investigator should locate the source of gas that will most likely be at or below the epicenter, possibly from a leaking service line or malfunctioning gas appliance.

All gas piping, including from the street mains or LP-Gas storage tanks, up to and through the service regulator and meter, to and including all appliances, should be examined and leak tested if possible. *(See NFPA 54, National Fuel Gas Code, Appendix D, or the National Fuel Gas Code Handbook.)* Leak testing inside a building that has had a fire or gas explosion should be performed using air or an inert gas.

Odorant verification should be part of any explosion investigation involving, or potentially involving, flammable gas, especially if there are indications that there were no indications of a leaking gas detected by people present. Its presence should be verified. Stain tubes can be used in the field, and gas chromatography can be used as a lab test for accurate results.

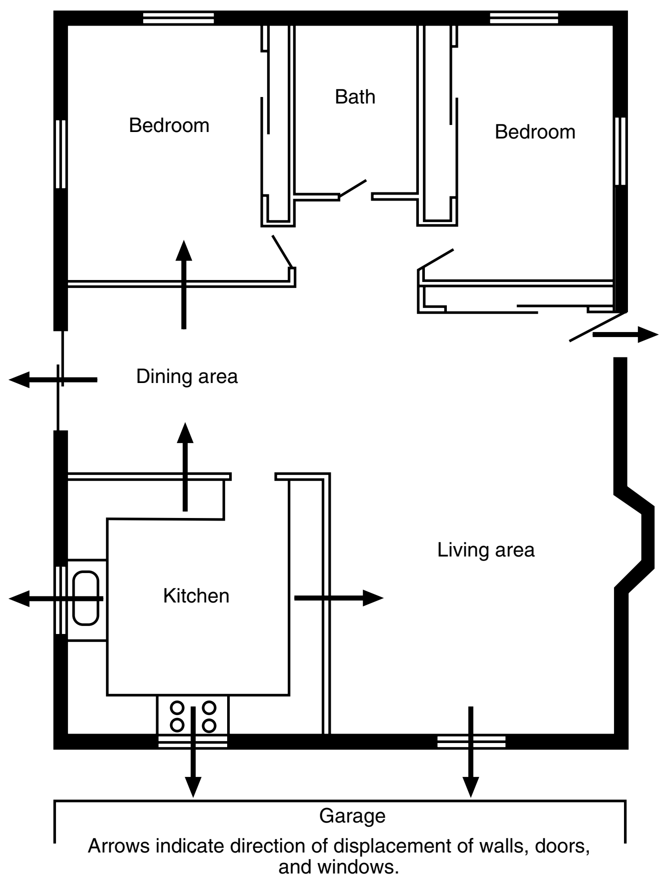


Figure 13-14 Explosion dynamics diagram.

13-16 Analyze Ignition Source. When the origin and fuel are identified, the means of ignition should be analyzed. This is often the most difficult part of the overall explosion investigation because, especially with fugitive fuel gases, multiple ignition sources are present. In the event of multiple possible ignition sources, the investigator should take into consideration all the available information including witness statements. A careful evaluation of every possible ignition source should be made. Factors to consider include the following:

(a) Minimum ignition energy of the fuel

(b) Ignition energy of the potential ignition source

(c) Ignition temperature of the fuel

(d) Temperature of the ignition source

(e) Location of the ignition source in relation to the fuel

(f) Simultaneous presence of the fuel and ignition source at the time of ignition

(g) Witness accounts of conditions and actions immediately prior to and at the time of the explosion

13-17 Analyze to Establish Cause. Having identified the origin, fuel, and ignition source, the investigator should now analyze and determine what brought together the fuel and ignition at the origin. The circumstances that brought these elements together at that time and place are the cause. *(See Chapter 12.)*

Part of this analysis may include considerations of how the explosion could have been prevented, such as failure to conform to existing codes or standards. It should be noted that due to the destructive effects of fire and explosions, the cause cannot always be determined.

Many techniques are suggested below to aid in establishing causation. The choice of the technique(s) used will depend on the unique circumstances of the incident.

13-17.1 Time Line Analysis. Based on the background information gathered (i.e., statements, logs, etc.), a sequence of events should be tabulated for both prior to the explosion and during the explosion. Consistencies and inconsistencies with causation theories can then be surmised and a "best fit" theory established.

13-17.2 Damage Pattern Analysis. Various types of damage patterns can be documented for further analysis, principally debris and structural damage.

13-17.2.1 Debris Analysis. Investigators should identify, diagram, photograph, and note those pieces of debris that indicate the direction and relative force of the explosion. In general, the greater the explosive energy, the farther that similar pieces of debris will be thrown from the center of the explosion. However, different drag/lift (i.e., aerodynamic) characteristics of various fragment shapes will tend to favor some going farther.

The distance as well as the direction of significant pieces of evidence from the apparent center of the explosion may be critical. The location of all significant pieces should be completely documented on the explosion scene diagram along with notes as to both distance and direction. This allows the investigator to reconstruct the trajectories of various components. In some cases it is desirable to weigh and make geometric measurements of significant missiles, especially large ones. This can then be used in a more complete engineering analysis of trajectories.

13-17.2.2 Relative Structural Damage Analysis. Investigators should diagram the relative damage to the areas surrounding the explosion site. Such a diagram can be called an "isodamage contour map." Criteria for contours may be simple overpressure levels in some cases, or the relative damage ratings for structures. Several techniques are employed for this purpose. Such an analysis will give additional clues to explosion propagation and can be used for further input to a more complete engineering analysis.

13-17.3* Correlation of Blast Yield with Damage Incurred. There are several methods that analysts use to correlate the degree of damage and projectile distance with the type and amount of fuel involved. Due to the great differences in chemical dynamics between solid explosives and gas/vapor deflagrations, it is not possible to directly correlate the amount of fuel involved in one to the weight of explosive used in the other. Weight equivalencies for common condensed-phase explosives can be found in the literature. *(See Appendix A.)*

13-17.4 Analysis of Damaged Items and Structures. Frequently the determination of the cause in explosion incidents requires a multidisciplinary approach to relate damage to the fuels involved. The use of special experts may be necessary. *(See Section 6-5.)*

13-17.5 Correlation of Thermal Effects. A collection of articles exhibiting heat damage from an explosive event may be evidence of a fireball or fire during the sequence of events. This may be further proof that the explosion involved a BLEVE, a fuel jet fire, or other phenomena, depending on the character of those articles. Specialized analysis of thermal damage effects can be conducted by a person trained in this area. From this material, an isothermal diagram (i.e., heat damage map) can be developed.

Chapter 14 Electricity and Fire

14-1 Introduction. This chapter discusses the analysis of electrical systems and equipment. The primary emphasis is on buildings with 120/240-volt, single-phase electrical systems. These voltages are typical in residential and commercial buildings. This chapter also discusses the basic principles of physics that relate to electricity and fire.

Prior to beginning an analysis of a specific electrical item, it is assumed that the person responsible for determining the cause of the fire will have already defined the area or point of origin. Electrical equipment should be considered as an ignition source equally with all other possible sources and not as either a first or last choice. The presence of electrical wiring or equipment at or near the origin of a fire does not necessarily mean that the fire was caused by electrical energy. Often the fire may destroy insulation or cause changes in the appearance of conductors or equipment that can lead to false assumptions. Careful evaluation is warranted.

Electrical conductors and equipment that are appropriately used and protected by properly sized and operating fuses or circuit breakers do not normally present a fire hazard. However, the conductors and equipment can provide ignition sources if easily ignitible materials are present when they have been improperly installed or used. A condition in the electrical wiring that does not conform to the *National Electrical Code®* might or might not be related to the cause of a fire.

14-2 Basic Electricity.

14-2.1 The purpose of this section is to present basic electrical terms and concepts briefly and simply in order to develop a working understanding of them.

14-2.2 Water flowing through a pipe is familiar to everyone. This has some similarities to electrical current flowing in an electrical system. Because of these similarities, a limited comparison between a hydraulic system and an electrical system can be used to understand an electrical system.

14-2.3 Table 14-2.3 shows the basic elements of a hydraulic system along with the corresponding elements of an electrical system.

Table 14-2.3 Elements of Hydraulic and Electrical Systems Compared

Elements of a Hydraulic System	Elements of an Electrical System
Pump	Generator
Pressure	Voltage (potential or electromotive force)
Pounds per square inch (psi)	Volts (V)
Pressure gauge	Voltmeter
Water	Electrons
Flow	Current
Gallons per minute (gpm)	Amperes (A)
Flowmeter	Ammeter
Valve	Switch
Friction	Resistance (ohms)
Friction loss	Voltage drop
Pipe size — inside diameter	Conductor size — AWG No.

14-2.4 In a hydraulic system, a pump is used to create the hydraulic pressure necessary to force water through pipes. In an electrical system, a generator is used to create the necessary electrical pressure to force electrons through a conductor. This electrical pressure is voltage. The amount of hydraulic pressure is expressed in pounds per square inch (psi) and can be measured with a pressure gauge. The amount of electrical pressure is expressed in volts and is measured with a voltmeter.

14-2.5 In the hydraulic system, it is water that flows in a useful way. In the electrical system, it is electrons that flow in a useful way. This flow is called electrical current. The amount of water flow is expressed in gallons per minute (gpm) and may be measured with a flowmeter. The amount of electrical current is expressed in amperes (A) and may be measured with an ammeter. Electric current can be either direct current (dc), such as supplied by a battery, or alternating current (ac), such as supplied by the electric utility companies.

14-2.6 Direct current flows in only one direction, as in a circulating water system, while alternating current flows back and forth with a specific frequency. In the United States, the frequency of 60 Hertz, or 60 cycles-per-second, is used. For the majority of applications encountered in this text, it is satisfactory to visualize ac circuits as if they were the more easily understood dc circuits. Notable exceptions include transformers and many electric motors that will not work on direct current. In addition, three-phase circuits and single-phase circuits that are not principally resistive cannot be analyzed in the same way as direct current circuits or common single-phase ac circuits. The specific differences between the behavior of alternating current versus direct current are beyond the scope of this document.

14-2.7 The water pipe provides the pathway for the water to flow. In the electrical system, conductors such as wires provide the pathway for the current.

14-2.8 In a closed circulating hydraulic system (as opposed to a fire hose delivery system where water is discharged out of the end), water flows in a loop, returning to the pump, where it is circulated again through the loop. When the valve is closed, the flow stops everywhere in the system. When the valve is opened, the flow resumes. An electrical system must be a closed system, in that the current must flow in a loop or in a completed circuit. When the switch is turned on, the circuit is completed and the current flows. When the switch is turned off, the circuit is opened and current flow stops everywhere in the circuit. This voltage drop is called potential or electromotive force as shown in Figure 14-2.8.

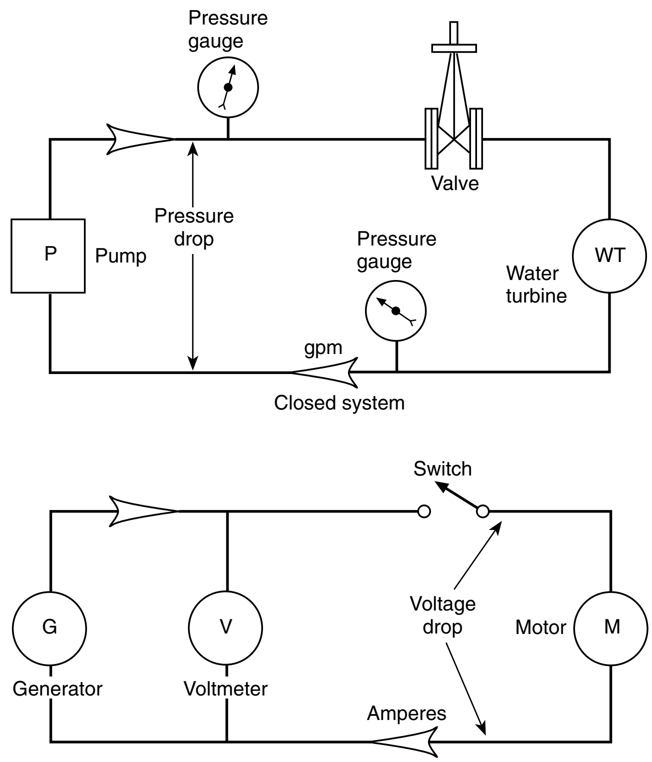


Figure 14-2.8 Typical components of water and electrical systems.

14-2.9 Friction losses in pipes result in pressure drops. Electrical friction (i.e., resistance) in conductors and other parts also results in electrical pressure drops or voltage drops. To express resistance as a voltage drop, Ohm's law must be used. *(See 14-2.13.)*

When electricity flows through a conducting material such as a conductor, a pipe, or any piece of metal, heat is generated. The amount of heat depends on the resistance of the material through which the current is flowing and the amount of current. Some electrical equipment, such as heating units, is designed with appropriate resistance to convert electricity to heat.

14-2.10 The flow of water in a pipe at a given pressure drop is controlled by the pipe size. A larger pipe will allow more gallons per minute of water to flow than will a smaller pipe at a given pressure drop. Similarly, larger conductors allow more current to flow than do smaller conductors. Conductor sizes are given American Wire Gauge (AWG) numbers. The larger the number, the smaller the conductor diameter. Small conductors, such as No. 22 AWG, are used in telephone and other signal circuits where small currents are involved. Larger conductors, such as Nos. 14, 12, and 10 AWG, are used in residential circuits. The larger the diameter (and hence the larger the cross-sectional area) of the conductor, the lower the AWG number and the less the resistance of the conductor. This means that a No. 12 AWG copper conductor will be allowed to conduct a larger current than a smaller No. 14 AWG copper conductor. *(See Figure 14-2.10.)*

Solid Copper Wire

	Diameter	Resistance in ohms per 1000 ft (305 m) at 158°F (70°C)
14 AWG —— ● ——	.064 in. (1.63 mm)	3.1
12 AWG —— ● ——	.081 in. (2.06 mm)	2.0
10 AWG —— ● ——	.102 in. (2.60 mm)	1.2

Figure 14-2.10 Conductors. American Wire Gauge (AWG) sizes, diameters of cross sections, and resistance of conductors commonly found in building wiring.

14-2.11 The ampacity of a conductor is the current in amperes a conductor can carry continuously under the conditions of use without exceeding its temperature rating. This depends on the ambient temperature the conductor is operating in as well as other factors such as whether the conductor is in conduit with other conductors carrying similar current, alone or in free air, and so forth. For example, Table 310-16 from NFPA 70, *National Electrical Code,* lists the ampacity of No. 8 AWG copper conductor with TW insulation (moisture-resistant thermoplastic) as 40 amperes. This is based on an ambient temperature of 86°F (30°C) and on being installed in a conduit or raceway in free air containing no more than three conductors. Any changes — such as more conductors in a raceway, higher ambient temperature, or insulation around the conduit — that reduce the loss of heat to the environment will decrease the ampacity. This same size conductor is rated at 50 amperes with THWN insulation (moisture- and heat-resistant thermoplastic); the THWN insulation has a temperature rating of 167°F (75°C) compared to 140°F (60°C) for the TW insulation. The temperature rating of the insulation is the maximum temperature at any location along its length that the conductor can withstand for a prolonged period of time without serious degradation.

The ampacity values for a conductor depend on the heating of the conductor caused by the electric current, the ambient temperature that the conductor is operating in, the temperature rating of the insulation, and the amount of heat dissipated from the conductor to the surroundings. Current passing through an aluminum conductor generates more heat than the same current passing through a copper conductor of the same diameter; the ampacity of an aluminum conductor is less than that for the same size copper conductor. Also, the ampacity of a conductor is reduced when it is operated at an elevated ;temperature or when it is covered with a material that provides thermal insulation. Conversely, the actual ampacity of a single conductor in open air or in a conduit will be higher than that given in the tables. The actual as-used ampacity may be an important consideration in evaluating the cause of electrical faulting.

A safety factor is included in ampacity values. Simply demonstrating that ampacity has been exceeded does not mean the fire had an electrical ignition source.

14-2.12 Some conductor materials conduct current with less resistance than do other materials. Silver conducts better than copper. Copper conducts better than aluminum. Aluminum conducts better than steel. This means that a No. 12 AWG copper conductor will have less resistance than the same size No. 12 AWG aluminum conductor. There will be less heat generated in a copper conductor than in an aluminum conductor for the same current and AWG size.

14-2.13 Ohm's law states that the voltage *(see Figure 14-2.13)* in a circuit is equal to the current multiplied by the resistance, or

$$\text{voltage} = \text{current} \times \text{resistance} \quad (E = I \times R)$$

Voltage (E) is measured in volts, current (I) is measured in amperes, and resistance (R) is measured in ohms.

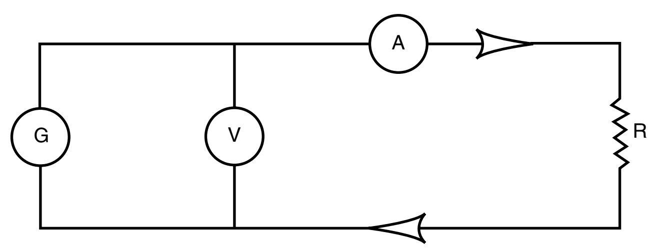
Using this simple law, the voltage drop can be found if the current and resistance are known. Rearranging the terms, we can solve for current if voltage and resistance are known.

$$\text{current} = \frac{\text{voltage}}{\text{resistance}} \quad \text{or} \quad \text{amperes} = \frac{\text{volts}}{\text{ohms}}$$

Also, resistance can be found if the current and voltage are known.

$$\text{resistance} = \frac{\text{voltage}}{\text{current}} \quad \text{or} \quad \text{ohms} = \frac{\text{volts}}{\text{amperes}}$$

A voltmeter and an ammeter can be used to determine the resistance. If the resistance and the voltage can be measured, the amperage can be calculated.



$$\text{R (resistance)} = \frac{V}{I} \left[\frac{\text{voltage}}{\text{amperage}}\right]$$

V (voltage) = I (amperage) x R (resistance)

$$\text{I (amperage)} = \frac{V}{R} \left[\frac{\text{voltage}}{\text{resistance}}\right]$$

Figure 14-2.13 Ohm's law in a simple circuit.

14-2.14 When electrons are moved (electrical current) through a resistance, electrical energy is spent. This energy may appear in a variety of ways such as light in a lamp or heating of a conductor. The rate at which energy is used is called power. The amount of power is expressed in watts. A 100-W lightbulb generates more light and heat than a 60-W lightbulb. *(See Figure 14-2.14.)*

Energy may be expressed in many different ways. For electrical applications, energy is usually measured in watt-seconds or watt-hours. A watt-second is equal to 1 joule, and a watt-hour is equal to 3600 joules (3.413 Btu).

14-2.15 Power in electrical systems is measured in watts *(P).* Resistive appliances such as a hair dryer or lightbulb are rated in watts. Power is computed as shown in the Ohm's law wheel, in Figure 14-2.15. The relationships among power, current, voltage, and resistance are important to fire investigators because of the need to find out how many amperes were drawn in a specific case. See Figure 14-2.15 for a summary of these relationships. If, for example, several appliances were found plugged into one extension cord or many appliances were plugged into several receptacles on the same circuit, the investigator could calculate the current draw to find whether the ampacity of the conductor was exceeded.

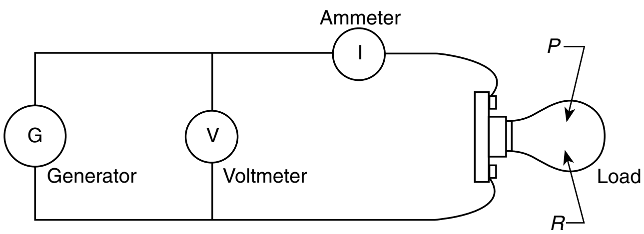


Figure 14-2.14 The power, in watts (*P*), consumed by a lightbulb is a product of the current (*I*) squared and the resistance (*R*) of the lightbulb.

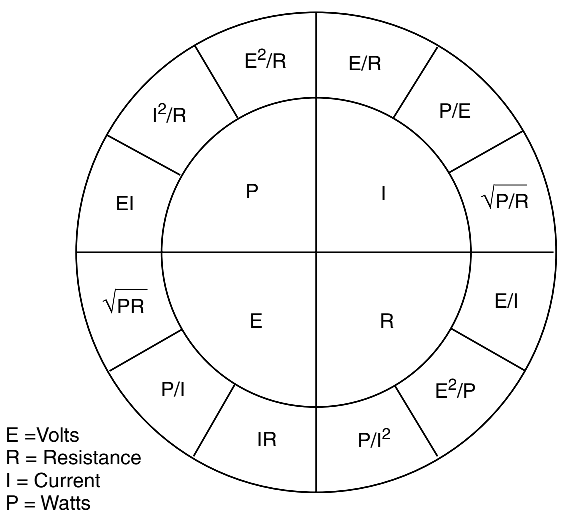


Figure 14-2.15 Ohm's law wheel for resistive circuits.

For example, a hair dryer designed to operate on 120 volts draws 1500 watts.

$$\text{current } (I) = \frac{\text{watts}}{\text{volts}} = \frac{1500}{120} = 12.5 \text{ A}$$

$$\text{resistance } (R) = \frac{(\text{volts})^2}{\text{watts}} = \frac{(120)^2}{1500} = 9.6 \text{ ohms}$$

To check results, do the following computation:

$$\text{volts } (E) = I \times R = 12.5 \times 9.6 = 120 \text{ V}$$

$$\text{watts } = (I)^2 \times R = (12.5)^2 \times 9.6 = 1500 \text{ W}$$

14-2.16 The following example will show how to find the total amperes, assuming the heater and circuit protection are turned on and are carrying current. A portable electric heater and cooking pot are plugged into an 18 AWG extension cord. The heater is rated at 1500 W and the cooking pot is 900 W. The previous relationships showed that current equaled power divided by voltage.

$$\text{amperes } (I) = \frac{\text{watts } (P)}{\text{volts } (V)} \quad \text{or} \quad \frac{1500}{120}$$
$$= 12.5 \text{ A for the heater}$$

$$\text{amperes } (I) = \frac{\text{watts } (P)}{\text{volts } (V)} \quad \text{or} \quad \frac{900}{120}$$
$$= 7.5 \text{ A for the pot}$$

The total amperage of a circuit is the sum of the amperage of each device that is plugged into the circuit. The total amperage for a circuit consisting of three receptacles is the total amperage of all devices plugged into these receptacles. Similarly, the total amperage on an extension cord is the sum of the amperage of each device plugged into the extension cord.

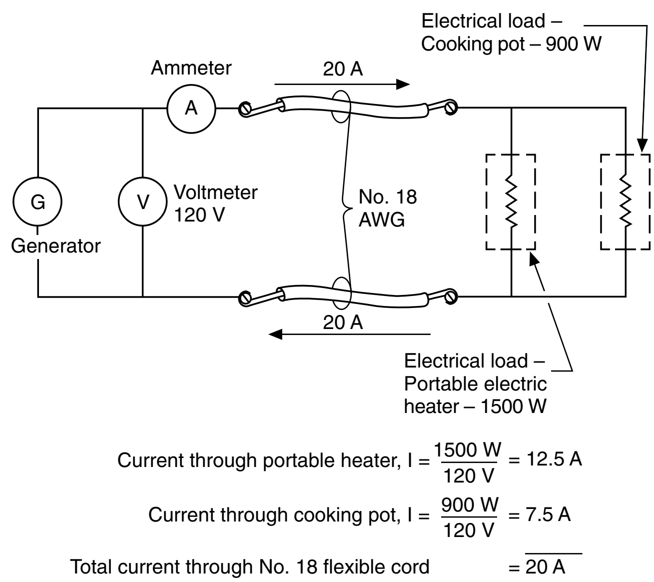


Figure 14-2.16 Total current calculation.

In this example *(see Figure 14-2.16),* the calculated amperages were 12.5 and 7.5, so the total amperage of that extension cord when both appliances were operating was 12.5 + 7.5 = 20.0 A. Tables of allowable ampacities [from NFPA 70, *National Electrical Code,* Table 400-5(a)] show that the maximum current should be 10 A in the No. 18 AWG extension cord. Therefore, the cord was carrying an overcurrent. The question to be determined is whether this created an overload. Did the overcurrent last long enough to cause dangerous overheating? In a situation such as shown in Figure 14-2.16 where it appears an overload existed, it is necessary to show that these conditions will create enough temperature rise to cause ignition. An overload is not absolute proof of a fire cause. If an overload occurred, this cord could be considered as a possible ignition source, particularly if the heat was confined or trapped, such as under a rug or between a mattress and box spring, preventing dissipation.

A similar situation exists when a short circuit occurs by conductor-to-conductor contact. This is by definition a connection of comparatively low resistance. As seen by Ohm's law, when the resistance goes down, the current goes up. Although a short circuit does cause a large current flow, the circuit overcurrent protection devices normally prevent this current from flowing long enough to cause overheating of the conductors.

14-3 Building Electrical Systems.

14-3.1* General. This section will provide a description of the electrical service into and through a building. It is intended to assist an investigator in recognizing the various devices and in knowing generally what their functions are. The main emphasis will be on the common 120/240-V, single-phase service with limited information on three-phase and higher voltage service. This section will not provide detailed information on codes. That information should come from the appropriate documents

14-3.2 Electrical Service.

14-3.2.1 Single-Phase Service. Most residences and small commercial buildings receive electricity from a transformer through three conductors, either overhead from a pole or underground. The two insulated conductors, called the hot legs or phases, have their alternating currents flowing in opposite directions (reversing 120 times per second for 60-cycle power) so that they go back and forth at the same instant but in opposite directions (180 out of phase). This alternating current is called single phase. The third conductor is grounded to serve as the neutral conductor, and it may be uninsulated. The voltage between either of the hot conductors and the grounded conductor is 120 V *[see Figure 14-3.2.1(a)]*. The voltage between the two hot conductors is 240 V. The incoming conductors are large multistranded cables intended to carry large currents safely. They all may hang separately, or the two hot conductors may be wrapped around the neutral in a configuration called a triplex drop. *[See Figure 14-3.2.1(b).]*

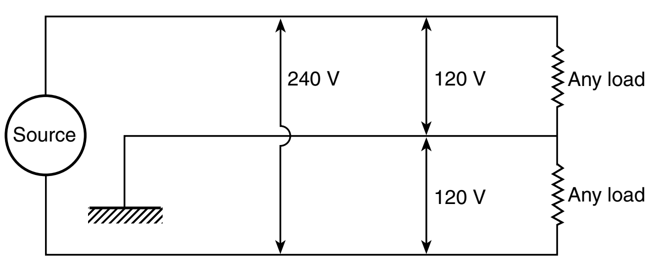


Figure 14-3.2.1(a) Relation of voltages in 120/240-V service.

If the cables come from a transformer on a pole, they are called a service drop. If they come from a transformer in or on the ground, they will be buried and are called a service lateral. *[See Figure 14-3.2.1(c).]*

The terms *hot, neutral,* and *ground* will usually be used in this document for installed conductors. The proper terms for them are *ungrounded, grounded,* and *grounding,* respectively.

14-3.2.2 Three-Phase Service. Industrial and large commercial buildings, large multifamily dwellings, and other large buildings normally are supplied with three-phase electrical service. Three-phase service consists of three alternating currents that go back and forth at different instants (out of phase with one another). There will be three current-carrying conductors and usually a fourth, which is the neutral and is at ground potential. The voltage between current-carrying conductors is typically 480 V, 240 V, or 208 V. The voltage between the conductors and ground depends on the wiring arrangement and may be 277 V, 208 V, or 120 V. The 480/277-V four-conductor system is a common service for large commercial and industrial buildings. Modern lighting systems in these buildings commonly operate at 277 V. In very large buildings, there might be more than one electrical service entrance. In some industrial buildings, the service entrance voltage may be very high (e.g., 4000 V). Transformers within buildings then reduce the voltage for utilization, including 120 V for lights and receptacles.

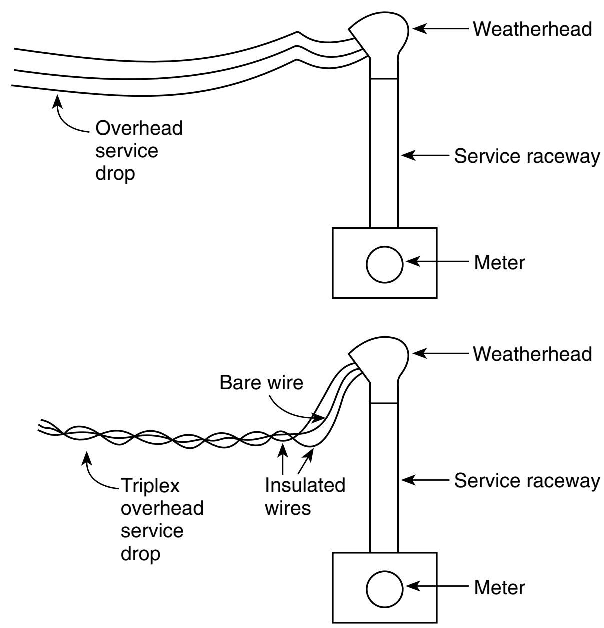


Figure 14-3.2.1(b) Overhead service.

14-3.3 Meter and Base. The cables of a service drop go into a weatherhead, which is designed to keep water from entering the system, and then down a service raceway to a meter base. A watt-hour meter plugs into the meter base and connects the service cables so that electricity can flow into the structure. In newer structures, the meter base is normally mounted on the outside. Cables go from the meter base to the service equipment in the structure. *(See Figure 14-3.3.)* In larger facilities, the entry cables may be connected directly to the service equipment without passing through the meter. In that case, the meter is operated from current transformers that surround each entry cable and sense current flow.

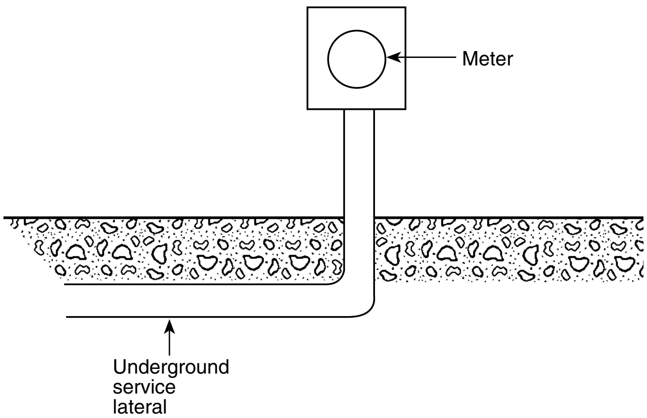


Figure 14-3.2.1(c) Underground service.

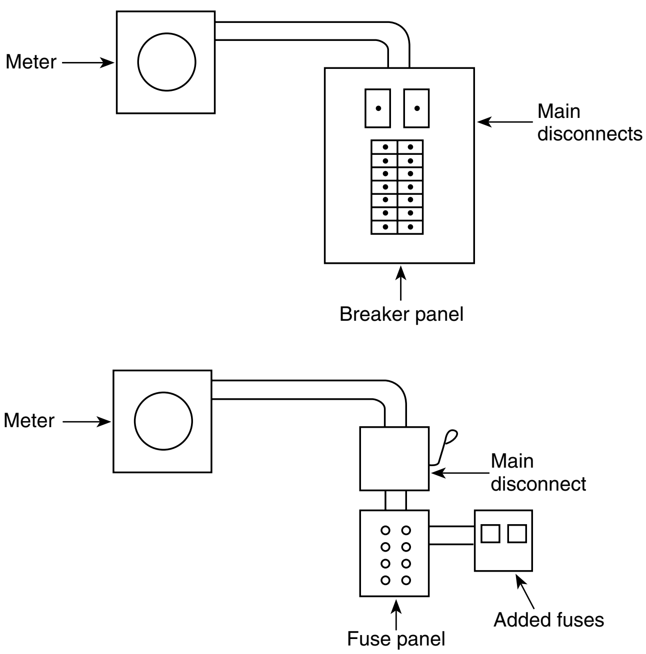


Figure 14-3.3 Service entrance and service equipment.

14-3.4 Significance. The service entry can be significant in fire investigations because damage to the insulation on the conductors can result in sustained high power faulting by either short circuits or ground faults that can ignite most combustibles. Between the utility transformer and the main protection in the structure, there is usually no overcurrent protection of the cables, and faulting may begin and continue. Once there are fault currents, either causing a fire or resulting from a fire, continued faulting can damage all or part of a service entrance.

14-4 Service Equipment. The cables from the meter base go to the service equipment, which consists of a main switch and fuses or circuit breakers. *(See Figure 14-3.3.)* The service equipment must be located close to where the cables enter the structure. The service equipment has three functions: to provide means for turning off power to the entire electrical system, to provide protection against electrical malfunctions, and to divide the power distribution into several branch circuits. Either a main switch or the main circuit breakers are the primary disconnects that can shut off all electricity to the building. From the cabinet of fuses or circuit breakers, electricity is distributed through branch circuits to the rest of the building.

14-5 Grounding. All electrical installations must be grounded at the service equipment. Grounding is a means of making a solid electrical connection between the electrical system and the earth. Grounding is accomplished by bonding the breaker or fuse panel to a metallic cold water pipe if the pipe extends at least 10 ft (3.048 m) into soil outside. In the absence of a suitable metallic cold water pipe, a grounding electrode must be used. The grounding electrode may be a galvanized steel rod or pipe or a copper rod of at least 8 ft (2.438 m) in length driven into soil to a level of permanent moisture.

In all installations, the service equipment must be bonded to the cold water piping. Bonding is the connecting of items of equipment by good conductors to keep the equipment bodies at the same voltage, which is essentially zero if bonded to ground. Bonding of the service equipment to ground is accomplished by a copper or aluminum conductor from the grounding block in the fuse or breaker cabinet to a clamp that is securely fixed to the cold water pipe or grounding electrode. *(See Figure 14-5.)* The purpose of grounding an electrical system is to make sure that any housings or exposed metal objects in the system or connected to it cannot become electrically charged. If an ungrounded conductor (the hot conductor) contacts a grounded object, the resulting surge of ground-fault current will open the protection.

All parts of the system must be grounded including cabinets, raceways, fittings, junction and outlet boxes, switches, receptacles, and any conductive objects attached to or plugged into the system. That is usually accomplished with a grounding conductor that accompanies the circuit conductors, although grounding can be accomplished through metallic conduit. Flexible metallic conduit may be used for grounding only if its length does not exceed 6 ft (1.829 m).

14-5.1 Floating Neutral. An electrical installation that is not properly grounded can continue to be used, but there will not be a fixed zero point of voltage (ground) between the two legs. There will still be 240 V between the two legs, but instead of the voltages of the two legs being fixed at 120 V to ground each, they may vary to some other values that add to 240 V. *(See Figure 14-5.1.)* All circuits will be affected. The actual voltages in the legs will depend on the loads on the two legs at any particular time. For example, the voltages might be 60 and 180 as in Figure 14-5.1. The higher voltage can overheat or burn out some equipment, and the lower voltage can damage some electronic equipment. Occupants would have seen incandescent lights that were too bright or too dim or appliances that overheated or malfunctioned in some way.

14-6 Overcurrent Protection. Fuses and circuit breakers provide protection against electrical short circuits, ground faults, and load currents that might be damaging (i.e., overloads). In general, such an overcurrent device must be installed where each ungrounded (hot) branch conductor is connected to the power supply, and the device must function automatically. Overcurrent devices are attached to bus bars in cabinets that are mounted in or on a wall. *[See Figures 14-6 (a), (b), (c), and (d).]*

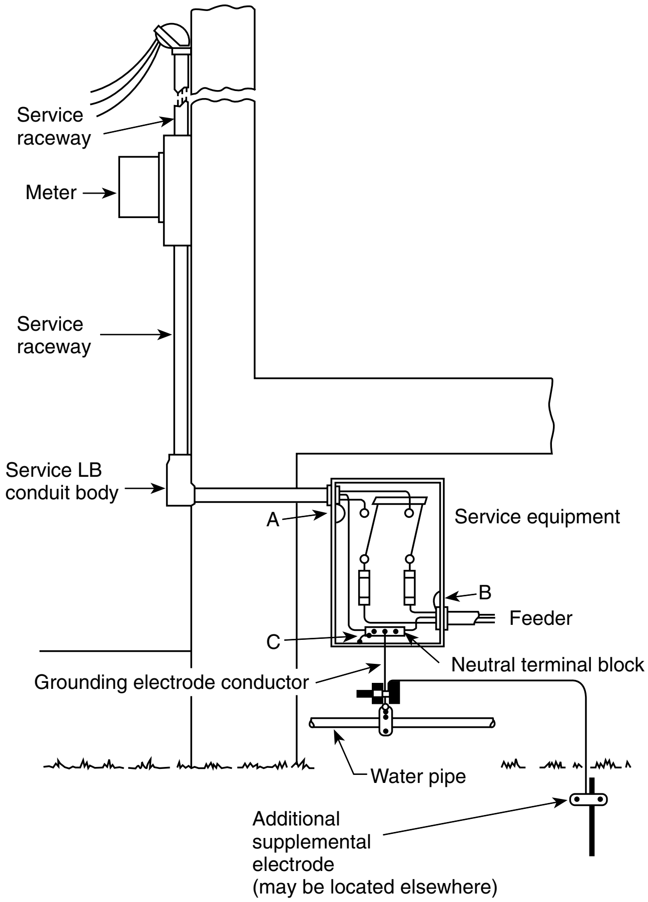


Figure 14-5 Grounding at a typical small service. A, B, and C are bonding connections that provide a path to ground.

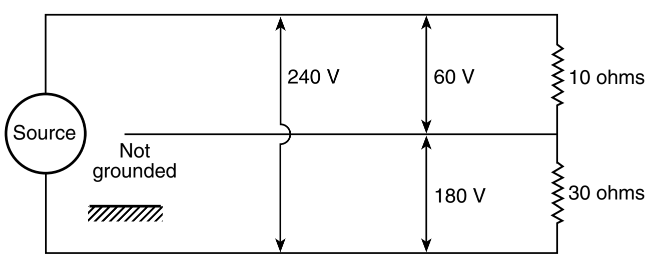


Figure 14-5.1 An example of the relation of voltages in 120/240-V services with an ungrounded neutral.

Protective devices have two current ratings, the regular current rating and the interrupting current rating. The regular rating is the level of current above which the device will open, such as 15 A, 20 A, or 50 A. The interrupting rating is the level of current that the device can safely interrupt. A common value for circuit breakers is 10,000 A.

14-6.1 Fuses. Fuses are basically nonmechanical devices with a fusible element in a small enclosure. The fusible element is made of a metal conductor or strip with enough resistance so that it will heat to melting at a selected level of current. Fuses have essentially no mechanical action; they operate only on the electrical and physical properties of the fuse element. Some fuses may contain a spring to help the separation of the fuse element on melting. Dual element fuses contain one element that operates most effectively with overloads and the other element that operates most effectively with short circuits. Ordinary fuses are single-use but some large fuses have replaceable elements. There are two types of fuses: the plug type that screws into a base and the cartridge type that fits into a holder. *[See Figures 14-6.1(a), (b), and (c).]* Fuses are not resettable.

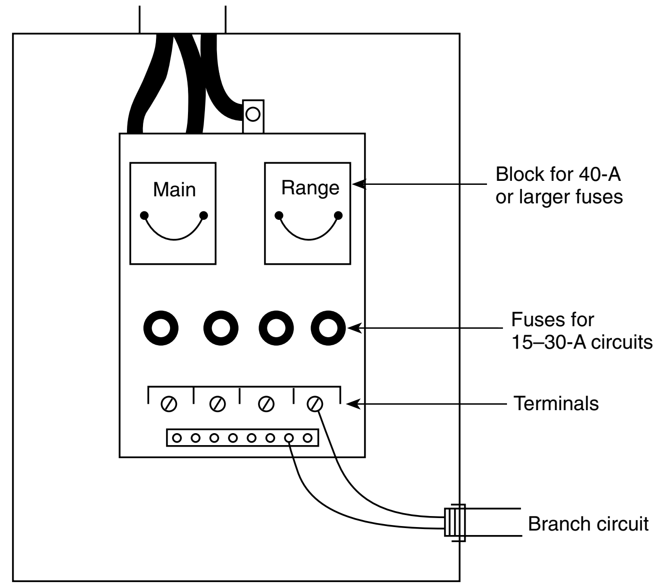


Figure 14-6(a) Fuse panel.

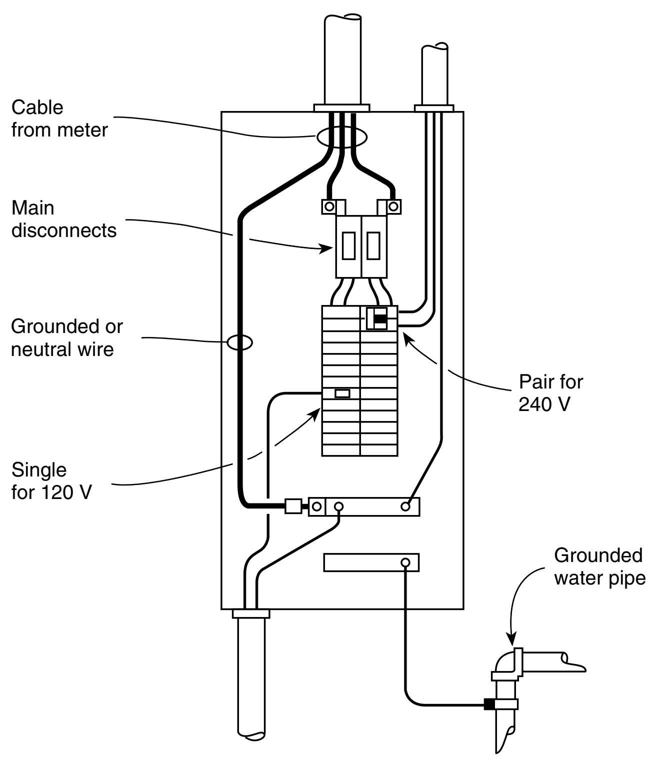


Figure 14-6(b) Common arrangement for a circuit-breaker panel.

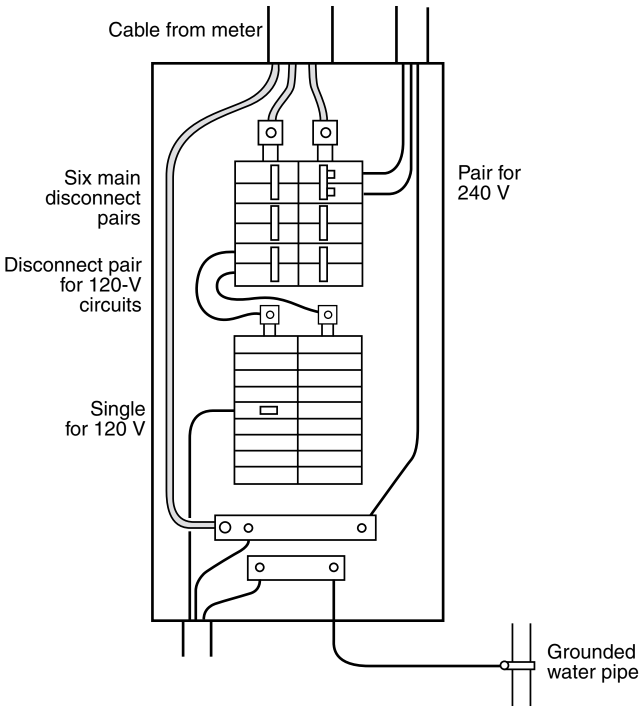


Figure 14-6(c) Common arrangement for a split-bus circuit-breaker panel.

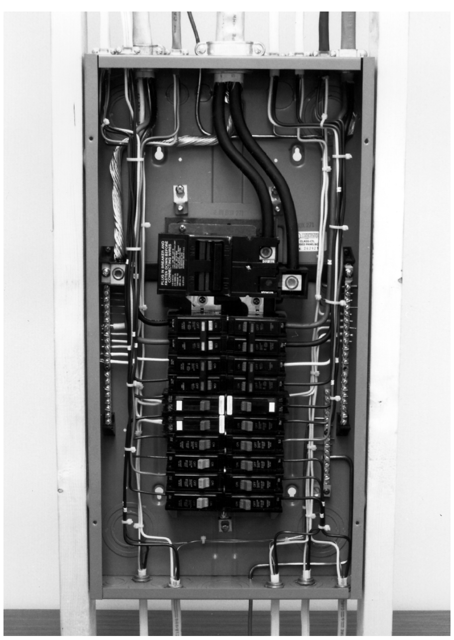


Figure 14-6(d) Photograph of a circuit-breaker panel.

Fuses are mounted in a panel board consisting of bus bars, connecting lugs, fuse holders, and supporting structures. Residential installations will usually be a combination of plug fuses for circuits of 30 A or less and cartridge fuses in removable holders for fuses with regular ratings greater than 30 A. The interrupting ratings on nontime-delay fuses are in the order of 100,000 A because they clear the fault in less than one-half cycle.

14-6.1.1 Plug Fuses. For circuits intended for 30 A or less, plug-type fuses have been used. The fuses have Edison bases so that all ampacities would fit in the same base. Thirty-ampere fuses could be put in where only 15-A fuses had been intended. Because of that overfusing and the ease with which the fuses could be bypassed (e.g., with a penny), they are not allowed in new installations. Such fuses are still available for replacement of burned out fuses in existing installations.

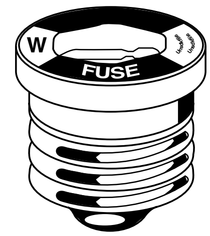


Figure 14-6.1(a) A typical, Edison-based nonrenewable fuse, single element. For replacement purposes only.

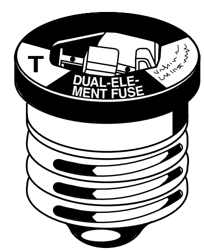


Figure 14-6.1(b) Another Edison-based nonrenewable fuse, dual element. For replacement purposes only.

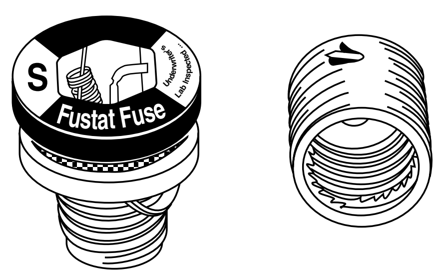


Figure 14-6.1(c) A Type S nonrenewable fuse and adapter. The time lag type of fuse is acceptable but not required.

14-6.1.2 Type S Fuses. In an effort to minimize improper fusing, Type S fuses were developed. They are designed to make tampering or bypassing more difficult. They screw into adapters that fit into Edison bases. After an adapter has been properly installed, it cannot be removed without damaging the fuse base. The adapter prevents a larger-rated fuse from being used with a lower-rated circuit and makes bypassing the fuse more difficult.

NFPA 70, *National Electrical Code,* specifies that fuse holders for plug fuses of 30 A or less shall not be used unless they are designed to use this Type S fuse or are made to accept a Type S fuse through use of an adapter.

14-6.1.3 Time-Delay Fuses. Whether a fuse is Type S or has an Edison base, the time-delay type of fuse permits overcurrents of short duration, such as starting currents for motors, without opening the circuit. While these momentary surges can be up to six times greater than the normal running current, they are harmless because they last only a short time. This makes it possible to use time-delay fuses in sizes small enough to give better protection than a type without time delay. The latter would have to be oversized to allow for such surges. In the event of short circuits or high-current ground faults, however, the time-delay type will operate and open the circuit as rapidly as the nontime-delay type. Time-delay fuses can be designed with dual elements or by modification of the fusing element.

14-6.1.4 Cartridge Fuses. For circuits intended for greater than 30 A, cartridge fuses are used. They consist of a cylinder containing the fusing element and either caps or blades on each end to make electrical contact in its holder. Cartridge fuses may be made for either fast action or time delay. They also come in single-use or replaceable-element types. Cartridge fuses may be found in fuse panels of residential installations for high current loads, such as water heaters and ranges, and at the main disconnect. Large fuses of 100-A rating or greater are more common in commercial or industrial installations. *[See Figures 14-6.1.4(a) and (b).]*

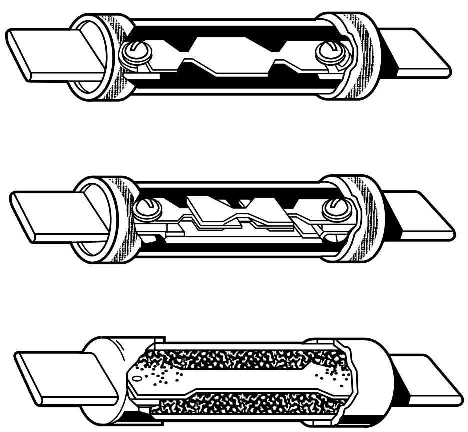


Figure 14-6.1.4(a) Three types of cartridge fuses. Top, an ordinary drop-out link renewable fuse; center, a super lag renewable fuse; and bottom, a one-time fuse.

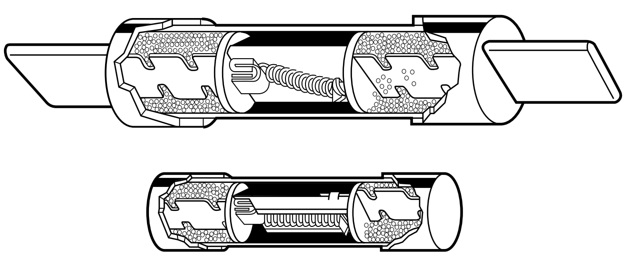


Figure 14-6.1.4(b) Dual-element cartridge fuses, blade and ferrule types.

14-6.2 Circuit Breakers. A circuit breaker is a switch that opens either automatically with overcurrent or manually by pushing a handle. The current rating of the breaker is usually, but not always, given on the face of the handle. Breakers are designed so that the internal workings will trip with excessive current even if the handle is somehow held in the on position. The on and off positions are indicated either on the handle or on the body. *[See Figure 14-6.2(a) and (b).]* The tripped position is in the center on most breakers. *[See Figure 14-6.2(c).]* A circuit breaker cannot be manually placed in the tripped position. However, if the fault has been corrected, it can be reset to the on position each time it has been tripped by overcurrent. A typical interrupting rating for circuit breakers is 10,000 A.

Most residential circuit breakers are of the thermal-magnetic type. The thermal element, usually a bimetal, provides protection for moderate levels of overcurrent. The magnetic element provides protection for short circuits and for low-resistance ground faults during which the fault currents are very high. Circuit breakers are mechanical devices that require movement of its components for operation. It is possible for them to fail to open, especially if they have not been operated either manually or by overcurrent in a long time and especially if they have been in a corrosive atmosphere.

The bodies of circuit breakers are usually made of molded phenolic plastic, which does not melt and does not sustain burning but which can be destroyed by fire impingement. Circuit breakers on a panel board are directly connected to bus bars that are fed from the main disconnect. A cover plate over the rows of breakers exposes only the tops of the breakers so that no energized parts of the panel or wiring are exposed.

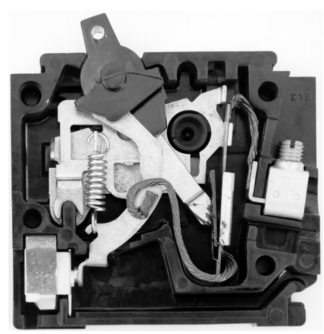


Figure 14-6.2(a) A 15-A residential-type circuit breaker in the closed (on) position.

Figure 14-6.2(b) A 15-A residential-type circuit breaker in the open (off) position.

Figure 14-6.2(c) A 15-A residential-type circuit breaker in the open (tripped) position.

14-6.2.1 Main Breakers. The main disconnect in a breaker panel is a pair of circuit breakers of ampacity large enough to carry the entire current draw of the installation, commonly 100 A to 200 A in residences. The handles of the two breakers (one on each leg) are fastened together or are molded as one unit so that only one motion is needed to turn off both legs. Also, if one leg has a fault that trips the one breaker, the fastener will pull off the other breaker. Three-phase service uses three main breakers in a single body or with the handles fastened together and three bus bars to feed the breakers.

There are many split-bus panel boards in use. *[See Figure 14-6(c).]* They usually have six 2-pole breakers or pairs of breakers fastened together to make 240-V circuits. All of them must be off to cut off all power to the installation. One of the breaker pairs serves as a main for the lower bus bars that feed the 120-V circuits. Split-bus panel boards are not allowed in new installations.

14-6.2.2 Branch Circuit Breakers. The circuit breakers for individual branch circuits are rated for the maximum intended current draw (ampacity). Circuits of 120 V will be fed from a single breaker, whereas circuits of 240 V will be fed from a double pole breaker or a pair of breakers of equal ampacity with the handles fastened together. General lighting and receptacle circuits will be 15 A or 20 A. Large appliances such as ranges and water heaters will have 30-A, 40-A, or 50-A breakers. Some small permanent appliances might have dedicated circuits with 15-A or 20-A breakers.

Three-phase service uses three bus bars to feed the breakers. Motors and other equipment that use three-phase power will be fed by three branch circuit breakers of equal ampacity with the handles fastened together.

14-6.2.3 Ground Fault Circuit Interrupter (GFCI). On newer installations a breaker might have a button labeled “push to test.” This breaker houses a ground fault circuit interrupter. It trips with a slight ground fault of about 5 milliamperes to give better protection for persons against electric shock at any level of amperage in the circuit. In addition, the breaker operates with overcurrents as an ordinary circuit breaker. The GFCI circuits are intended for bathrooms, patios, kitchens, or other locations where a person might be electrically grounded while near or using electrical appliances.

14-7 Branch Circuits. The individual circuits that feed lighting, receptacles, and various fixed appliances are the branch circuits. Each branch circuit should have its own overcurrent protection. The circuit consists of an ungrounded conductor (hot conductor) attached to a protective device and a grounded conductor (neutral conductor) attached to the grounding block in the cabinet. Both of those conductors carry the current that is being used in the circuit. In addition, there should be a grounding conductor (i.e., the ground). It normally does not carry any current but is there to allow fault current to go to ground and thereby open the protection. Some installations might have the grounding through metallic conduit, and some very old installations might not have a grounding conductor at all. The lack of a separate means of grounding has no effect on the operation of devices powered by that circuit.

14-7.1 Conductors. Conductors in electrical installations usually consist of copper or aluminum because they are economical and good conductors of electricity. Conductors made of other metals for special uses are covered in Chapter 18.

14-7.2 Sizes of Conductors. The sizes of conductors are measured in the American Wire Gauge (AWG). The larger the AWG number, the smaller the conductor. The branch circuit conductors for lighting and small appliances are usually solid copper, 14 AWG for 15-A circuits and 12 AWG for 20-A circuits. Circuits of larger ampacity will have larger conductors such as 10 or 8 AWG. *(See Table 14-7.2.)* Conductors of 6 AWG or larger size will be multistranded to give adequate flexibility.

Aluminum branch wiring has been used and might be found in some installations. Because of problems with heating at the connections, aluminum conductors are not used in branch circuits without approved connectors, although aluminum cables such as 3/0 and 4/0 cables are used for service drops and service entry.

The conductor size allowed in a circuit depends mainly on the ampacity of the protective device. In addition, the type of insulation and the bundling of conductors affect the allowed sizes. The conductor must not be smaller than the allowed size but may be larger. The basic reason for regulating the allowed size is to prevent heating of the conductor enough to damage its insulation. Because conductors have some resistance, heat will be generated as current passes through them. Small conductors have more resistance than large conductors and so heat more. The NFPA *National Electrical Code* tables show how much current is allowed in various size conductors with various kinds of insulation.

Table 14-7.2 Ampacity and Use of Branch Circuits

Wire Size			
Copper	Copper-Clad Aluminum and Aluminum	Ampacity	Use
14	12	15	Branch circuit conductors supplying other than kitchen
12	10	20–25	Small-appliance circuit conductors supplying outlets in kitchen for refrigerators, toasters, electric frying pans, coffee makers, and similar appliances
10	8	30	Large appliances such as ranges and dryers
8	6	40	
6	4	55	

14-7.3 Copper Conductors. The chemical element copper is used in a pure form to make conductors. The copper is heated and drawn through progressively smaller holes to squeeze it down to the desired size. There is no identifiable crystal structure in such copper. Impurities or alloying elements would make the copper less conductive to electricity. Pure copper melts at 1980°F (1082°C). In fires, copper melts along the surface of the conductor at temperatures somewhat below 1980°F (1082°C) because of mixing of the metal with copper oxide that forms on the surface in air. That is why, when copper conductors melt in a fire, they tend to melt along their surfaces to form pointed ends, globules, and thinned areas.

Copper conductors oxidize in fires when the insulation has been lost. The surface usually becomes blackened with cupric oxide. For some conductors in a chemically reducing condition, such as glowing char before cooling, the surface may appear either to be bare of oxide or to be coated with a reddish cuprous oxide.

14-7.4 Aluminum Conductors. The chemical element aluminum is used in a pure form to make conductors. Pure aluminum melts at 1220°F (660°C). A skin of aluminum oxide forms on the surface, but the oxide does not mix with the metallic aluminum. Therefore, the melting temperature is not reduced, and the aluminum tends to melt through the whole cross section at one time instead of leaving an unmelted core as copper does. Melted aluminum can flow through the skin of oxide and have odd shapes when it solidifies.

Aluminum has a lower conductivity than does copper. Thus, for the same ampacity of a circuit, an aluminum conductor must be two AWG sizes larger than a copper conductor. For example, 10 AWG aluminum is equivalent in ampacity to 12 AWG copper.

14-7.4.1 Copper-Clad Aluminum. Copper-clad aluminum conductors have been used but are not common. Because they are aluminum conductors with just a skin of copper, their melting characteristics are essentially the same as for aluminum conductors.

14-7.5 Insulation. Conductors are insulated to prevent current from taking unwanted paths and to protect against dangerous voltages in places that would be hazardous to people. Insulation could be made of almost any material that can be applied readily to conductors, does not conduct electricity, and retains its properties for a long time even at elevated temperatures. For a summary of the types of insulation in use, see Table 310-13 in NFPA 70, *National Electrical Code.* Air serves as an insulator when bare conductors and energized parts are kept separated. At high voltage, air contamination by dust, pollution, or products of combustion can break down the insulating effects of air, resulting in arcs.

The type of insulation on individual conductors is marked in a code along with the temperature rating, the manufacturer, and other information. Nonmetallic sheathed cable has the identifications printed on the sheath. The coding for the insulation material is given in Table 310-13 of NFPA 70.

Insulation on individual conductors is made in a variety of colors, some of which indicate specific uses. A grounding conductor must be green. A grounded conductor (neutral) may be white or light gray. An ungrounded conductor (hot) may be any color except green, white, or gray. In 120-V circuits it is commonly black. In 240-V circuits with nonmetallic cable the two hot legs are commonly black and red. Where individual conductors are pulled through the conduit, the colors might vary more widely, especially if more than one circuit is in the conduit.

14-7.5.1 Polyvinyl Chloride. Polyvinyl chloride, or PVC, is a commonly used thermoplastic insulating material for wiring. PVC must be blended with plasticizers to make it soft. Pigments and other modifiers may also be added. PVC, on aging, can slowly lose the plasticizers and become hard and brittle. In a fire, PVC may char and give off hydrogen chloride, a corrosive gas.

14-7.5.2 Rubber. Rubber was the most common insulating material until approximately the 1950s. Rubber insulation contains pigments and various modifiers and antioxidants. In time it may become oxidized and brittle, especially if it was hot for long periods. Embrittled rubber has little strength and can be broken off the conductor if it is bent or scraped. Rubber insulation chars when exposed to fire or very high temperatures and leaves an ash when the rubber is burned away.

14-7.5.3 Other Materials. Polyethylene and other closely related polyolefins are used as insulation, more commonly on large cables than on insulation for residential circuits. Nylon jackets are put around other insulating materials (usually PVC) to increase the thermal stability of the insulation.

Silicone and fluorinated polyolefin (e.g., Teflon®) insulations are used on conductors that are expected to be installed where elevated temperatures will persist, particularly in appliances.

14-8 Outlets and Devices.

14-8.1 Switches. Switches are installed to turn the current on or off in parts of circuits that supply installed lights and equipment. Sometimes one or more receptacles are fed from a switch so that a table lamp can be turned on or off. The hot (black) conductor goes to both terminals of the switch while the neutral (white) conductor goes on to the light or device being controlled. The switch should always be put in the run of the black conductor for safety, although the switch will perform properly if put in the run of the white conductor. The switches may have screw terminals or push-in terminals.

14-8.2 Receptacles. Receptacles for 15-A and 20-A circuits are usually duplex. Receptacles for large appliances (30 A or more) are single. Receptacles now must be polarized and of the grounding type, although there are still many nongrounding and nonpolarized receptacles in older installations. The grounding type has a third hole that allows any appliance with a grounding prong in its plug to ground that appliance. In polarized receptacles, the neutral slot is longer than the hot slot. A two-prong plug with a wide neutral prong (polarized plug) can be inserted into the receptacle only with the wide prong in the wide slot and not in the reverse way. All grounding receptacles and plugs are inherently polarized. *[See Figures 14-8.2(a) and (b).]*

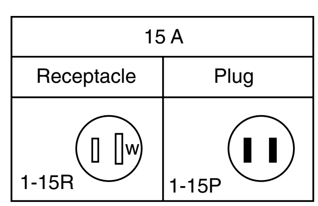


Figure 14-8.2(a) Nongrounding type receptacle.

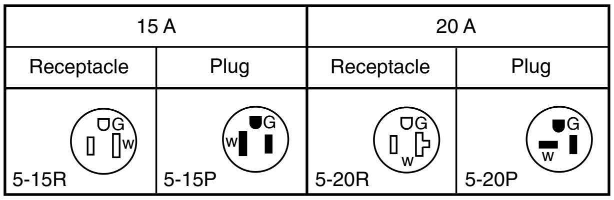


Figure 14-8.2(b) Grounding type receptacle.

In bathrooms or other areas where personal safety is a concern, receptacles may have a built-in ground fault circuit interrupter. *(See 14-6.2.3.)*

Receptacles may have either screw terminals or push-in terminals and sometimes both. The hot conductor (usually black insulation) should be connected to the brass screw, and the neutral conductor (white insulation) to the colorless metal screw. On grounding-type receptacles there is a screw with a green head for connecting the grounding conductor of the wiring cable.

14-8.3 Other Outlets, Devices, or Equipment. Permanent lighting fixtures are attached to electrical boxes in the wall or ceiling as appropriate with a wall switch in its individual part of the circuit. Thermostats may be mounted in walls to control permanently installed heating units.

In commercial and industrial installations, much of the electrically powered equipment is permanently connected to the basic wiring. Because of the large current draws, much of the equipment may be switched on and off by contactors rather than directly by switches.

In installations where explosive atmospheres might occur, explosionproof outlets and fixtures must be used. The outlet boxes, fittings, and attached devices are designed so that even if explosive concentrations of gases get into the system, an internal ignition will not let a flame front out to ignite the surrounding atmosphere.

14-9 Ignition by Electrical Energy.

14-9.1 General. For ignition to be from an electrical source, the following must occur:

(a) The electrical wiring, equipment, or component must have been energized from a building's wiring, an emergency system, a battery, or some other source.

(b) Sufficient heat and temperature to ignite a close combustible material must have been produced by electrical energy at the point of origin by the electrical source.

Ignition by electrical energy involves generating both a sufficiently high temperature and heat (i.e., competent ignition source) by passage of electrical current to ignite material that is close. Sufficient heat and temperature may be generated by a wide variety of means, such as short circuit and ground fault parting arcs, excessive current through wiring or equipment, resistance heating, or by ordinary sources such as lightbulbs, heaters, and cooking equipment. The requirement for ignition is that the temperature of the electrical source be maintained long enough to bring the adjacent fuel up to its ignition temperature with air present to allow combustion.

The presence of sufficient energy for ignition does not assure ignition. Distribution of energy and heat loss factors need to be considered. For example, an electric blanket spread out on a bed can continuously dissipate 180 W safely. If that same blanket is wadded up, the heating will be concentrated in a smaller space. Most of the heat will be held in by the outer layers of the blanket, which will lead to higher internal temperatures and possibly ignition. In contrast to the 180 W used by a typical electric blanket, just a few watts used by a small flashlight bulb will cause the filament to glow white hot, indicating temperatures in excess of 4000°F (2204°C).

In considering the possibility of electrical ignition, the temperature and duration of the heating must be great enough to ignite the initial fuels. The type and geometry of the fuel must be evaluated to be sure that the heat was sufficient to generate combustible vapors and for the heat source still to be hot enough to ignite those vapors. If the suspect electrical component is not a competent ignition source, other causes should be investigated.

14-9.2 Resistance Heating.

14-9.2.1 General. Whenever electric current flows through a conductive material, heat will be produced. See 14-2.13 for the relationships of current, voltage, resistance, and power (i.e., heating). With proper design and compliance with the codes, wiring systems and devices will have resistances low enough that current-carrying parts and connections should not overheat. Some specific parts such as lamp filaments and heating elements are designed to become very hot. However, when properly designed and manufactured and when used according to directions, those hot parts should not cause fires.

The use of copper or aluminum conductors of sufficient size in wiring systems (e.g., 12 AWG for up to 20 A for copper) will keep the resistance low. What little heat is generated should be readily dissipated to the air around the conductor under normal conditions. When conductors are thermally insulated and operating at rated currents, enough energy may be available to cause a fault or ignition.

14-9.2.2 Heat-Producing Devices. Common heat-producing devices can cause fires when misused or when certain malfunctions occur during proper use. Examples include combustibles placed too close to incandescent lamps or to heaters or coffee makers and deep-fat fryers whose temperature controls fail or are bypassed. *(See Chapter 18.)*

14-9.2.3 Poor Connections. When a circuit has a poor connection such as a loose screw at a terminal, increased resistance causes increased heating at the contact, which promotes formation of an oxide interface. The oxide conducts current and keeps the circuit functional, but the resistance of the oxide at that point is significantly greater than in the metals. A spot of heating develops at that oxide interface that can become hot enough to glow. If combustible materials are close enough to the hot spot, they can be ignited. Generally, the connection will be in a box or appliance, and the probability of ignition is greatly reduced. The wattage of well-developed heating connections in wiring can be up to 30–40 W with currents of 15–20 A. Heating connections of lower wattage have also been noted at currents as low as about 1 A.

14-9.3 Overcurrent and Overload. Overcurrent is the condition in which more current flows in a conductor than is allowed by accepted safety standards. The magnitude and duration of the overcurrent determines whether there is a possible ignition source. For example, an overcurrent at 25 A in a 14-AWG copper conductor should pose no fire danger except in circumstances that do not allow dissipation of the heat such as when thermally insulated or when bundled in cable applications. A large overload of 120 A in a 14-AWG conductor, for example, would cause the conductor to glow red hot and could ignite adjacent combustibles.

Large overcurrents that persist (i.e., overload) can bring a conductor up to its melting temperature. There is a brief parting arc as the conductor melts in two. The melting opens the circuit and stops further heating.

In order to get a large overcurrent, either there must be a fault that bypasses the normal loads (i.e., short circuit) or far too many loads must be put on the circuit. To have a sustained overcurrent (i.e., overload), the protection (i.e., fuses or circuit breakers) must fail to open or must have been defeated. Ignition by overload is rare in circuits that have the proper size conductors throughout the circuit, because most of the time the protection opens and stops further heating before ignition conditions are obtained. When there is a reduction in the conductor size between the load and the circuit protection, such as an extension cord, the smaller size conductor may be heated beyond its temperature rating. This can occur without activating the overcurrent protection. For an example, see 14-2.16.

14-9.4 Arcs. An arc is a high-temperature luminous electric discharge across a gap. Temperatures within the arc are in the range of several thousand degrees depending on circumstances including current, voltage drop, and metal involved. For an arc to jump even the smallest gap in air spontaneously, there must be a voltage difference of at least 350 V. In the 120/240-V systems being considered here, arcs do not form spontaneously under normal circumstances. *(See Section 14-12.)* In spite of the very high temperatures in an arc path, arcs may not be competent ignition sources for many fuels. In most cases, the arcing is so brief and localized that solid fuels such as wood structural members cannot be ignited. Fuels with high surface-area-to-mass ratio, such as cotton batting and tissue paper and combustible gases and vapors, may be ignited when in contact with the arc.

14-9.4.1 High-Voltage Arcs. High voltages can get into a 120/240-V system through accidental contact between the distribution system of the power company and the system on the premises. Whether there is a momentary discharge or a sustained high voltage, an arc may occur in a device for which the separation of conductive parts is safe at 240 V but not at many thousands of volts. If easily ignitible materials are present along the arc path, a fire can be started.

Lightning can send extremely high voltage surges into an electrical installation. Because the voltages and currents from lightning strikes are so high, arcs can jump at many places, cause mechanical damage, and ignite many kinds of combustibles. *(See 14-12.8.)*

14-9.4.2 Static Electricity. Static electricity is a stationary charge that builds up on some objects. Walking across a carpet in a dry atmosphere will produce a static charge that can produce an arc when discharged. Other kinds of motion can cause a build-up of charge, including the pulling off of clothing, operation of conveyor belts, and the flowing of liquids. *(See Section 14-12.)*

14-9.4.3 Parting Arcs. A parting arc is a brief discharge that occurs as an energized electrical path is opened while current is flowing, such as by turning off a switch or pulling a plug. The arc usually is not seen in a switch but might be seen when a plug is pulled while current is flowing. Motors with brushes may produce a nearly continuous display of arcing between the brushes and the commutator. At 120/240-V ac, a parting arc is not sustained and will quickly be quenched. Ordinary parting arcs in electrical systems are usually so brief and of low enough energy that only combustible gases, vapors, and dusts can be ignited.

In arc welding, the rod must first be touched to the workpiece to start current flowing. Then the rod is withdrawn a small distance to create a parting arc. If the gap does not become too great, the arc will be sustained. A welding arc involves enough power to ignite nearly any combustible material. However, the sustained arc during welding requires specific design characteristics in the power supply that are not present in most parting arc situations in 120/240-V wiring systems.

Another kind of parting arc occurs when there is a direct short circuit or ground fault. The surge of current melts the metals at the point of contact and causes a brief parting arc as a gap develops between the metal pieces. The arc quenches immediately but can throw particles of melted metal (i.e., sparks) around. *(See 14-9.5.)*

14-9.4.4* Arc Tracking. Arcs may occur on surfaces of nonconductive materials if they become contaminated with salts, conductive dusts, or liquids. It is thought that small leakage currents through such contamination causes degradation of the base material leading to the arc discharge, charring or igniting combustible materials around the arc. Arc tracking is a known phenomenon at high voltages. It has also been reported in experimental studies in 120/240-V ac systems.

Electrical current will flow through water or moisture only when that water or moisture contains contaminants such as dirt, dusts, salts, or mineral deposits. This stray current may promote electrochemical changes that can lead to electrical arcing. Most of the time the stray currents through a contaminated wet path cause enough warming that the path will dry. Then little or no current flows and the heating stops. If the moisture is continuously replenished so that the currents are sustained, deposits of metals or corrosion products can form along the electrical pathway. That effect is more pronounced in direct current situations. A more energetic arc through the deposits might cause a fire under the right conditions. More study is needed to more clearly define the conditions needed for causing a fire.

14-9.5 Sparks. Sparks are luminous particles that can be formed when an arc melts metal and spatters the particles away from the point of arcing. The term *spark* has commonly been used for a high voltage discharge as with a spark plug in an engine. For purposes of electrical fire investigation, the term *spark* is reserved for particles thrown out by arcs, whereas an arc is a luminous electrical discharge across a gap.

Short circuits and high-current ground faults, such as when the ungrounded conductor (i.e., hot conductor) touches the neutral or a ground, produce violent events. Because there may be very little resistance in the short circuit, the fault current may be many hundreds or even thousands of amperes. The energy that is dissipated at the point of contact is sufficient to melt the metals involved, thereby creating a gap and a visible arc and throwing sparks. Protective devices in most cases will open (i.e., turn off the circuit) in a fraction of a second and prevent repetition of the event.

When just copper and steel are involved in arcing, the spatters of melted metal begin to cool immediately as they fly through the air. When aluminum is involved in faulting, the particles may actually burn as they fly and continue to be extremely hot until they burn out or are quenched by landing on some material. Burning aluminum sparks, therefore, may have a greater ability to ignite fine fuels than do sparks of copper or steel. However, sparks from arcs in branch circuits are inefficient ignition sources and can ignite only fine fuels when conditions are favorable. In addition to the temperature, the size of the particles is important for the total heat content of the particles and the ability to ignite fuels. For example, sparks spattered from a welding arc can ignite many kinds of fuels because of the relatively large size of the particles and the total heat content. Arcing in entry cables can produce more and larger sparks than can arcing in branch circuits.

14-9.6 High-Resistance Faults. High-resistance faults are long-lived events in which the fault current is not high enough to trip the circuit overcurrent protection, at least in the initial stages. A high-resistance fault on a branch circuit may be capable of producing energy sufficient to ignite combustibles in contact with the point of heating. It is rare to find evidence of a high-resistance fault after a fire. An example of a high-resistance fault is an energized conductor coming into contact with a poorly grounded object.

14-10 Interpreting Damage to Electrical Systems.

14-10.1 General. Abnormal electrical activity will usually produce characteristic damage that may be recognized after a fire. Evidence of this electrical activity may be useful in locating the area of origin. The damage may occur on conductors, contacts, terminals, conduits, or other components. However, many kinds of damage can occur from nonelectrical events. This section will give guidelines for deciding whether observed damage was caused by electrical energy and whether it was the cause of the fire or a result of the fire. These guidelines are not absolute, and many times the physical evidence will be ambiguous and will not allow a definite conclusion. Figure 14-10.1 illustrates some of the types of damage that may be encountered.

14-10.2* Short Circuit and Ground Fault Parting Arcs. Whenever an energized conductor contacts a grounded conductor or a metal object that is grounded with nearly zero resistance in the circuit, there will be a surge of current in the circuit and melting at the point of contact. This event may be caused by heat-softened insulation due to a fire. The high current flow produces heat that can melt the metals at the points of contact of the objects involved, thereby producing a gap and the parting arc. A solid copper conductor typically appears as though it had been notched with a round file. *[See Figure 14-10.2(a).]* The notch may or may not sever the conductor. The conductor will break easily at the notch upon handling. The surface of the notch can be seen by microscopic examination to have been melted. Sometimes, there can be a projection of porous copper in the notch.

The parting arc melts the metal only at the point of initial contact. The adjacent surfaces will be unmelted unless fire or some other event causes subsequent melting. In the event of subsequent melting, it may be difficult to identify the site of the initial short circuit or ground fault. If the conductors were insulated prior to the faulting and the fault is suspected as the cause of the fire, it will be necessary to determine how the insulation failed or was removed and how the conductors came in contact with each other. If the conductor or other metal object involved in the short circuit or ground fault was bare of insulation at the time of the faulting, there may be spatter of metal onto the otherwise unmelted adjacent surfaces.

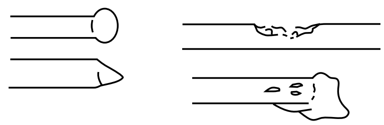
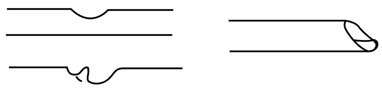
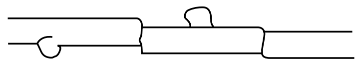
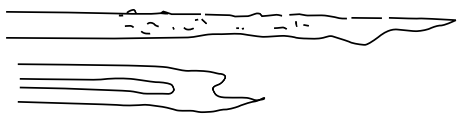
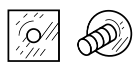
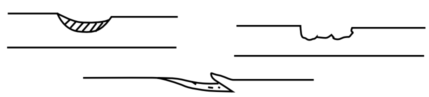
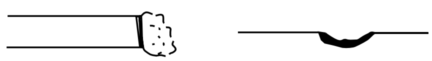
Mode of damage	Effects	Result of	Cause of fire?
Arcing-through-char		Direct fire heating	No, always a result of fire
Parting arcing		Heating at about 400°F (205°C) but no direct fire	Usually not
Overcurrent		Short circuit or failure in a device plus failure of overcurrent protection	Yes, but also may be a result of fire
Fire		Cable exposed to existing fire	N/A
Heating connection		Connection not tight	Yes
Mechanical		Scraping or gouging by something	No
Alloying		Melted aluminum on the wire	No

Figure 14-10.1 Guide for interpreting damage to electrical wires.

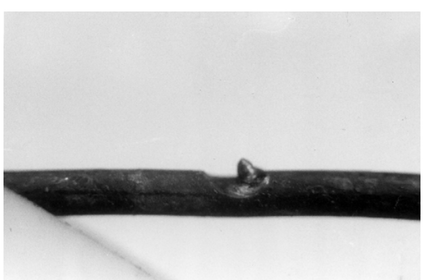


Figure 14-10.2(a) A solid copper conductor notched by a short circuit.

Stranded conductors, such as for lamp and appliance cords, appear to display effects from short circuits and ground faults that are less consistent than those in solid conductors. A stranded conductor may exhibit a notch with only some of the strands severed, or all of the strands may be severed with strands fused together or individual strands melted. *[See Figure 14-10.2(b).]*

14-10.3* Arcing Through Char. Insulation on conductors, when exposed to direct flame or radiant heat, may be charred before being melted. That char, when exposed to fire, is conductive enough to allow sporadic arcing through the char. That arcing can leave surface melting at spots or can melt through the conductor, depending on the duration and repetition of the arcing. There often will be multiple points of arcing. Several inches of conductor can be destroyed either by melting or severing of several small segments.

Figure 14-10.2(b) Stranded copper lamp cord that was severed by a short circuit.

When conductors are subject to highly localized heating, such as from arcing through char, the ends of individual conductors may be severed. When severed, they will have beads on the end. The bead may weld two conductors together. If the conductors are in conduit, holes may be melted in the conduit. Beads can be differentiated from globules, which are created by nonlocalized heating such as overload or fire melting. Beads are characterized by the distinct and identifiable line of demarcation between the melted bead and the adjacent unmelted portion of the conductor. *[See Figures 14-10.3(a), (b), and (c).]*

The conductors downstream from the power source and the point where the conductors are severed become de-energized. Those conductors will likely remain in the debris with part or all of their insulation destroyed. The upstream remains of the conductors between the point of arc-severing and the power supply may remain energized if the overcurrent protection does not function. Those conductors can sustain further arcing through the char. In a situation with multiple arc-severing on the same circuit, arc-severing farthest from the power supply occurred first. It is necessary to find as much of the conductors as possible to determine the location of the first arcing through char. This will indicate the first point on the circuit to be compromised by the fire and may be useful in determining the area of origin. In branch circuits, holes extending for several inches may be seen in the conduit or in metal panels to which the conductor arced.

Figure 14-10.3(a) Copper conductors severed by arcing through the charred insulation.

If the fault occurs in service entrance conductors, several feet of conductor may be partly melted or destroyed by repeated arcing because there is usually no overcurrent protection for the service entrance. An elongated hole or series of holes extending several feet may be seen in the conduit.

Figure 14-10.3(b) Copper conductors severed by arcing through the charred insulation with a large bead welding the two conductors together.

14-10.4* Overheating Connections. Connection points are the most likely place for overheating to occur on a circuit. The most likely cause of the overheating will be a loose connection or the presence of resistive oxides at the point of connection. Metals at an overheating connection will be more severely oxidized than similar metals with equivalent exposure to the fire. For example, an overheated connection on a duplex receptacle will be more severely damaged than the other connections on that receptacle. The conductor and terminal parts may have pitted surfaces or may have sustained a loss of mass where poor contact has been made. This loss of mass can appear as missing metal or tapering of the conductor. These effects are more likely to survive the fire when copper conductors are connected to steel terminals. Where brass or aluminum are involved at the connection, the metals are more likely to be melted than pitted. This melting can occur either from resistance heating or from the fire. Pitting also can be caused by alloying. *(See 14-10.6.3.)*

Figure 14-10.3(c) Stranded copper conductors severed by arcing through charred insulation with the strands terminated in beads.

14-10.5* Overload. Currents in excess of rated ampacity produce effects in proportion to the degree and duration of overcurrent. Overcurrents that are large enough and persist long enough to cause damage or create a danger of fire are called overloads. Under any circumstance, suspected overloads require that the circuit protection be examined. The most likely place for an overload to occur is on an extension cord. Overloads are unlikely to occur on wiring circuits with proper overcurrent protection.

Overloads cause internal heating of the conductor. This heating occurs along the entire length of the overloaded portion of the circuit and may cause sleeving. Sleeving is the softening and sagging of thermoplastic conductor insulation due to heating of the conductor. If the overload is severe, the conductor may become hot enough to ignite fuels in contact with it as the insulation melts off. Severe overloads may melt the conductor. If the conductor melts in two, the circuit is opened and heating immediately stops. The other places where melting had started may become frozen as offsets. This effect has been noted in copper, aluminum, and Nichrome® conductors. *(See Figure 14-10.5.)* The finding of distinct offsets is an indication of a large overload. Evidence of overcurrent melting of conductors is not proof of ignition by that means.

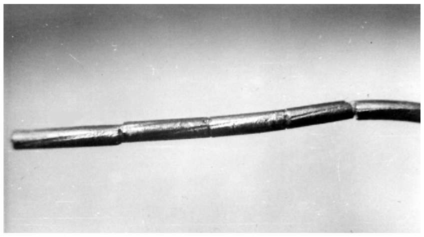


Figure 14-10.5 Aluminum conductor severed by overcurrent showing offsets.

Overload in service entrance cables is more common than in branch circuits but is usually a result of fire. Faulting in entrance cables produces sparking and melting only at the point of faulting unless the conductors maintain continuous contact to allow the sustained massive overloads needed to melt long sections of the cables.

14-10.6 Effects Not Caused by Electricity. Conductors may be damaged before or during a fire by other than electrical means and often these effects are distinguishable from electrical activity.

14-10.6.1 Conductor Surface Colors. When the insulation is damaged and removed from copper conductors by any means, heat will cause dark red to black oxidation on the conductor surface. Green or blue colors may form when some acids are present. The most common acid comes from the decomposition of PVC. These various colors are of no value in determining cause because they are nearly always results of the fire condition.

14-10.6.2 Melting by Fire. When exposed to fire, copper conductors may melt. At first, there is blistering and distortion of the surface. *[See Figure 14-10.6.2(a).]* The striations created on the surface of the conductor during manufacture become obliterated. The next stage is some flow of copper on the surface with some hanging drops forming. Further melting may allow flow with thin areas (i.e., necking and drops). *[See Figure 14-10.6.2(b).]* In that circumstance, the surface of the conductor tends to become smooth. The resolidified copper forms globules. Globules caused by exposure to fire are irregular in shape and size. They are often tapered and may be pointed. There is no distinct line of demarcation between melted and unmelted surfaces.

Figure 14-10.6.2(a) Copper conductors fire-heated to the melting temperature, showing regions of flow of copper, blistering, and no surface distortion.

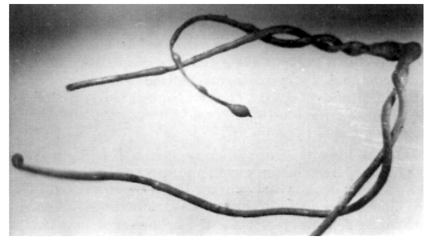


Figure 14-10.6.2(b) Fire-heated copper conductors, showing globules.

Stranded conductors that just reach melting temperatures become stiffened. Further heating can let copper flow among the strands so that the conductor becomes solid with an irregular surface that can show where the individual strands were. *[See Figure 14-10.6.2(c).]* Continued heating can cause the flowing, thinning, and globule formation typical of solid conductors. Magnification is needed to see some of these effects. Large-gauge stranded conductors that melt in fires can have the strands fused together by flowing metal or the strands may be thinned and stay separated. In some cases, individual strands may display a bead-like globule even though the damage to the conductor was from melting.

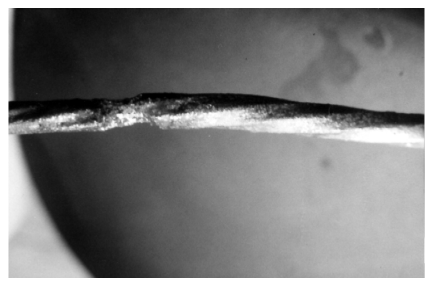


Figure 14-10.6.2(c) Stranded copper conductor in which melting by fire caused the strands to be fused together.

Aluminum conductors melt and resolidify into irregular shapes that are usually of no value for interpreting cause. *[See Figure 14-10.6.2(d).]* Because of the relatively low melting temperature, aluminum conductors can be expected to melt in almost any fire and rarely aid in finding the cause.

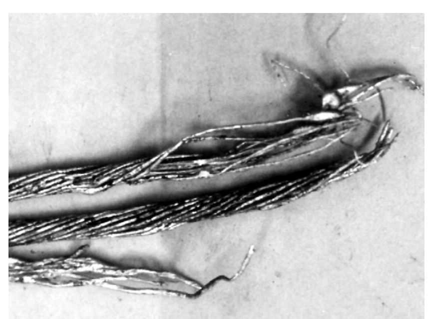


Figure 14-10.6.2(d) Aluminum cables that were melted by fire showing thinned areas, bulbous areas, and pointed ends.

14-10.6.3* Alloying. Metals such as aluminum and zinc can form alloys when melted in the presence of other metals. If aluminum drips onto a bare copper conductor during a fire and cools, the aluminum will be just lightly stuck to the copper. If that spot is further heated by fire, the aluminum can penetrate the oxide interface and form an alloy with the copper that melts at a lower temperature than does either pure metal. After the fire, an aluminum alloy spot may appear as a rough gray area on the surface, or it may be a shiny silvery area. The copper-aluminum alloy is brittle, and the conductor may readily break if it is bent at the spot of alloying. If the melted alloy drips off the conductor during the fire, there would be a pit that is lined with alloy. The presence of alloys can be confirmed by chemical analysis.

Aluminum conductors that melt from fire heating at a terminal may cause alloying and pitting of the terminal pieces. There is no clear way of visually distinguishing alloying from the effects of an overheating connection. Zinc forms a brass alloy readily with copper. It is yellowish in color and not as brittle as the aluminum alloy.

14-10.6.4* Mechanical Gouges. Gouges and dents that are formed in a conductor by mechanical means can usually be distinguished from arcing marks by microscopic examination. Mechanical gouges will usually show scratch marks from whatever caused the gouge. Dents will show deformation of the conductors beneath the dents. Dents or gouges will not show the fused surfaces caused by electrical energy.

14-11 Considerations and Cautions. Laboratory experiments, combined with the knowledge of basic chemical, physical, and electrical sciences, indicate that some prior beliefs are incorrect or are correct only under limited circumstances.

14-11.1 Undersized Conductors. Undersized conductors, such as a 14 AWG conductor in a 20-A circuit, are sometimes thought to overheat and cause fires. There is a large safety factor in the allowed ampacities. Although the current in a 14 AWG conductor is supposed to be limited to 15 A, the extra heating from increasing the current to 20 A would not necessarily indicate a fire cause. The higher operating temperature would deteriorate the insulation faster but would not melt it or cause it to fall off and bare the conductor without some additional factors to generate or retain heat. The presence of undersized conductors or overfused protection is not proof of a fire cause. *(See 14-2.16.)*

14-11.2 Nicked or Stretched Conductors. Conductors that are reduced in cross section by being nicked or gouged are sometimes thought to heat excessively at the nick. Calculations and experiments have shown that the additional heating is negligible. Also, it is sometimes thought that pulling conductors through conduit can stretch them like taffy and reduce the cross section to a size too small for the ampacity of the protection. Copper conductors do not stretch that much without breaking at the weakest point. Whatever stretching can occur before the range of plastic deformation is exceeded would not cause either a significant reduction in cross section or excessive resistance heating.

14-11.3 Deteriorated Insulation. When thermoplastic insulation deteriorates with age and heating, it tends to become brittle and will crack if bent. Those cracks do not allow leakage current unless conductive solutions get into the cracks. Rubber insulation does deteriorate more easily than thermoplastic insulation and loses more mechanical strength. Thus, rubber insulated lamp or appliance cords that are subject to being moved can become hazardous because of embrittled insulation breaking off. However, simple cracking of rubber insulation as with thermoplastic insulation does not allow leakage of current unless conductive solutions get into the cracks.

14-11.4* Overdriven or Misdriven Staple. Staples driven too hard over nonmetallic cable have been thought to cause heating or some kind of faulting. The suppositions range from induced currents because of the staple being too close to the conductors to actually cutting through the insulation and touching the conductors. A properly installed cable staple with a flattened top cannot be driven through the insulation. If the staple is bent over, the edge of it can be driven through the insulation to contact the conductors. In that case, a short circuit or a ground fault would occur. That event should be evident after a fire by bent points of the staple and by melt spots on the staple or on the conductors unless obliterated by the ensuing fire. A short circuit should cause the circuit overcurrent protection to operate and prevent any further damage. There would not be any continued heating at the contact, and the brief parting arc would not ignite the insulation on the conductor or the wood to which it was stapled.

If a staple is misdriven so that one leg of the staple penetrates the insulation and contacts both an energized conductor and a grounded conductor, then a short circuit or ground fault will result. If the staple severs the energized conductor, a heating connection may be formed at that point.

14-11.5 Short Circuit. A short circuit (i.e., low resistance and high current) in wiring on a branch circuit has been thought to ignite insulation on the conductors and allow fire to propagate. Normally, the quick flash of a parting arc prior to operation of the circuit protection cannot heat insulation enough to generate ignitible fumes even though the temperature of the core of the arc may be several thousand degrees. If the overcurrent protection is defeated or defective, then a short circuit may become an overload and, as such, may become an ignition source.

14-11.6 Beaded Conductor. A bead on the end of a conductor in and of itself does not indicate the cause of the fire.

14-12 Static Electricity.

14-12.1 Introduction to Static Electricity. Static electricity is the electrical charging of materials through physical contact and separation and the various effects that result from the positive and negative electrical charges formed by this process. This is accomplished by the transfer of electrons (negatively charged) between bodies, one giving up electrons and becoming positively charged and the other gaining electrons and becoming oppositely, but equally, negatively charged.

Common sources of static electricity include the following:

(a) Pulverized materials passing through chutes or pneumatic conveyors
(b) Steam, air, or gas flowing from any opening in a pipe or hose, when the steam is wet or the air or gas stream contains particulate matter
(c) Nonconductive power or conveyor belts in motion
(d) Moving vehicles
(e) Nonconductive liquids flowing through pipes or splashing, pouring, or falling
(f) Movement of clothing layers against each other or contact of footwear with floors and floor coverings while walking
(g) Thunderstorms that produce violent air currents and temperature differences that move water, dust, and ice crystals creating lightning
(h) Motions of all sorts that involve changes in relative position of contacting surfaces, usually of dissimilar liquids or solids

14-12.2 Generation of Static Electricity. The generation of static electricity cannot be prevented absolutely, but this is of little consequence because the development of electrical charges may not in itself be a potential fire or explosion hazard. For there to be an ignition there must be a discharge or sudden recombination of the separated positive and negative charges in the form of an electric arc in an ignitible atmosphere.

When an electrical charge is present on the surface of a nonconducting body, where it is trapped or prevented from escaping, it is called static electricity. An electric charge on a conducting body that is in contact only with nonconductors is also prevented from escaping and is therefore nonmobile or *static*. In either case, the body is said to be *charged*. The charge may be either positive (+) or negative (-).

14-12.2.1* Ignitible Liquids. Static is generated when liquids move in contact with other materials. This commonly occurs in operations such as flowing through pipes, and in mixing, pouring, pumping, spraying, filtering, or agitating. Under certain conditions, particularly with liquid hydrocarbons, static may accumulate in the liquid. If the accumulation of charge is sufficient, a static arc may occur. If the arc occurs in the presence of a flammable vapor/air mixture, an ignition may result.

Filtering with some types of clay or microfilters substantially increases the ability to generate static charges. Tests and experience indicate that some filters of this type have the ability to generate charges 100 to 200 times higher than achieved without such filters.

The electrical conductivity of a liquid is a measure of its ability to create, accumulate, and hold a charge. The lower the conductivity, the greater the ability of the liquid to create and hold a charge. Common liquids that have low conductivity and therefore represent a hazardous static potential are given in Table 14-12.2.1. For comparison, distilled water has a conductivity of 100,000,000 pico-siemen.

Table 14-12.2.1 Common Liquids that Have Low Conductivity

Typical Conductivity Product	Conductance per Meter in Pico-Siemen*
Highly purified hydrocarbons[a]	0.01
Light distillates[a]	0.01 to 10
Commercial jet fuel[b]	0.2 to 50
Kerosene[b]	1 to 50
Leaded gasoline[b]	above 50
Fuel with antistatic additives[b]	50 to 300
Black oils[a]	1000 to 100,000

*Pico-siemen is the reciprocal of ohms. One pico-siemen is 1 trillionth (1×10^{-12}) of a siemen.

[a]API 2003, *Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents.*

[b]W. M. Bustin and W. G. Duket, *Electrostatic Hazards in Petroleum Industry.*

14-12.2.2 Charges on the Surface of a Liquid. If an electrically charged liquid is poured, pumped, or otherwise transferred into a tank or container, the unit charges of similar polarity within the liquid will be repelled from each other toward the outer surfaces of the liquid, including not only the surfaces in contact with the container walls but also the top surface adjacent to the air or vapor space, if any. It is the latter charge, often called the *surface charge,* that is of most concern in many situations. In most cases the container is of metal, and hence electrically conductive.

Even if the tank shell is grounded, the time for the charge to dissipate, known as relaxation time, may be as little as a few seconds up to several minutes. This relaxation time is dependent on the conductivity of the liquid and the rate and manner that the liquid is being introduced into the tank, therefore, the rate at which the electrostatic charge is being accumulated.

If the electrical potential difference between any part of the liquid surface and the metal tank shell should become high enough, the air above the liquid may become ionized and an arc may discharge to the shell. However, an arc to the tank shell is less likely than an arc to some projection or to a conductive object lowered into the tank. These projections or objects are known as spark (i.e., arc) promoters. No bonding or grounding of the tank or container can remove this internal charge.

If the tank or container is ungrounded, the charge can also be transmitted to the exterior of the tank and can arc to any grounded object brought into proximity to the now charged tank external surface.

14-12.2.3* Switch Loading. *Switch loading* is a term used to describe a product being loaded into a tank or compartment that previously held a product of different vapor pressure and flash point. Switch loading can result in an ignition when a low vapor pressure/higher flash point product, such as fuel oil, is put into a cargo tank containing a flammable vapor from a previous cargo, such as gasoline. Discharge of the static normally developed during the filling can ignite the vapor/air mixture remaining from the low flash point liquid.

14-12.2.4 Spraying Operations. High-pressure spraying of ignitible liquids, such as in spray painting, can produce significant static electric charges on the surfaces being sprayed and the ungrounded spraying nozzle or gun.

If the material being sprayed can create an ignitible atmosphere, such as with paints utilizing flammable solvents, a static discharge can ignite the fuel/air mixture.

In general, high-pressure airless spraying apparatus have a higher possibility for creating dangerous accumulations of static than low-pressure compressed air sprayers.

14-12.2.5 Gases. When flowing gas is contaminated with metallic oxides or scale particles, dust, or with liquid droplets or spray, static electric accumulations may result. A stream of particle-containing gas directed against a conductive object will charge the object unless the object is grounded or bonded to the liquid discharge pipe. If the accumulation of charge is sufficient, a static arc may occur. If the arc occurs in the presence of an ignitible atmosphere, an ignition may result.

14-12.2.6 Dusts and Fibers. Generation of a static charge can happen during handling and processing of dusts and fibers in industry. Dust dislodged from a surface or created by the pouring or agitation of dust-producing material, such as grain or pulverized material, can result in the accumulation of a static charge on any insulated conductive body with which it comes in contact.

The minimum electrical energy required to ignite a dust cloud is typically in the range of 10 to 100 millijoules. Thus, many dusts can ignite with less energy than might be expended by a static arc from machinery or the human body.

14-12.2.7 Human Body. The human body can accumulate an electric charge that in dry atmospheres (e.g., less than 50 percent relative humidity) can be as high as several thousand volts.

14-12.2.8 Clothing. Outer garments can build up considerable static charges when layers of clothing are separated, moved away from the body, or removed entirely, particularly when of dissimilar fabrics. For some materials (particularly synthetic polymers) and/or low humidity conditions, an electrostatic charge may be accumulated. The use of synthetic fabrics and the removal of outer garments in ignitible atmospheres can become an ignition source.

14-12.3* Incendive Arc. An arc that has enough energy to ignite an ignitible mixture is said to be incendive. A nonincendive arc does not possess the energy required to cause ignition even if the arc occurs within an ignitible mixture. An ignitible mixture is commonly a gas, vapor of an ignitible liquid, or dust.

When the stored energy is high enough, and the gap between two bodies is small enough, the stored energy is released, producing an arc. The energy so stored and released by the arc is related to the capacitance of the charged body and the voltage in accordance with the following formula:

$$E_s = \frac{CV^2}{2}$$

where:
E_s = energy in joules

C = capacitance in farads

V = voltage in volts

Static arc energy is typically reported in thousandths of a joule (millijoules or mJ).

14-12.4* Ignition Energy. The ability of an arc to produce ignition is governed largely by its energy and the minimum ignition energy of the exposed fuel. The energy of the static arc will necessarily be some fraction of its total stored energy. Some of the total stored energy will be expended in heating the electrodes. With flat plane electrodes, the minimum arc voltage to jump a gap (0.01 mm) is 350 V. Increased gap widths require proportionately larger voltages; for example, 1 mm requires approximately 4500 V.

Though as little as 350 V is required to arc across a small gap, it has been shown by practical and experimental experience that because of heat loss to the electrodes, arcs arising from electrical potential differences of at least 1500 V are required to be incendive.

Dusts and fibers require a discharge energy of 10 to 100 times greater than gases and vapors for arc ignitions of optimum mixtures with air. See Table 3-3.4 and Table 13-13.2 for additional minimum ignition energies.

14-12.5 Controlling Accumulations of Static Electricity. A static charge can be removed or can dissipate naturally. A static charge cannot persist except on a body that is electrically insulated from its surroundings.

14-12.5.1 Humidification. Many commonly encountered materials that are not usually considered to be electrical conductors — such as paper, fabrics, carpet, clothing, and cellulosic and other dusts — contain certain amounts of moisture in equilibrium with the surrounding atmosphere. The electrical conductivity of these materials is increased in proportion to the moisture content of the material, which depends on the relative humidity of the surrounding atmosphere.

Under conditions of high relative humidity, 50 percent or higher, these materials and the atmosphere will reach equilibrium and contain enough moisture to make the conductivity adequate to prevent significant static electricity accumulations. With low relative humidities of approximately 30 percent or less, these materials dry out and become good insulators, so static accumulations are more likely.

Materials such as plastic or rubber dusts or machine drive belts, which do not appreciably absorb water vapor, can remain insulating surfaces and accumulate static charges even though the relative humidity approaches 100 percent.

The conductivity of the air itself is not appreciably increased by humidity.

14-12.5.2 Bonding and Grounding. Bonding is the process of electrically connecting two or more conductive objects. Grounding is the process of electrically connecting one or more conductive objects to ground potential and is a specific form of bonding.

A conductive object may also be grounded by being bonded to another conductive object that is already at ground potential. Some objects, such as underground metal pipe or large metal tanks resting on the earth, may be inherently grounded by their contact with the earth.

Bonding minimizes electrical potential differences between objects. Grounding minimizes potential differences between objects and the earth. Examples of these techniques include metal-to-metal contact between fixed objects and pickup brushes between moving objects and earth.

Investigators should not take the conditions of bonding or grounding for granted just by the appearance or contact of the objects in question. Specific electrical testing should be done to confirm the bonding or grounding conditions.

If static arcing is suspected as an ignition source, examination and testing of the bonding, grounding, or other conductive paths should be made by qualified personnel using the criteria in NFPA 77, *Recommended Practice on Static Electricity.*

14-12.6 Conditions Necessary for Static Arc Ignition. In order for a static discharge to be a source of ignition, five conditions must be fulfilled:

(a) There must be an effective means of static charge generation.

(b) There must be a means of accumulating and maintaining a charge of sufficient electrical potential.

(c) There must be a static electric discharge arc of sufficient energy. *(See Section 12-3.)*

(d) There must be a fuel source in the appropriate mixture with a minimum ignition energy less than the energy of the static electric arc. *(See Section 12-4.)*

(e) The static arc and fuel source must occur together in the same place and at the same time.

14-12.7 Investigating Static Electric Ignitions. Often the investigation of possible static electric ignitions depends on the discovery and analysis of circumstantial evidence and the elimination of other ignition sources, rather than on direct physical evidence.

In investigating static electricity as a possible ignition source, the investigator should identify whether or not the five conditions necessary for ignition existed.

An analysis must be made of the mechanism by which static electricity was generated. This analysis should include the identification of the materials or implements that caused the static accumulation, the extent of their electrical conductivity, and their relative motion, contact and separation, or means by which electrons are exchanged.

The means of accumulating charge to sufficient levels where it can discharge in the form of an incendive arc should be identified. The states of bonding, grounding, and conductance of the material that accumulates the charge or to which the arc discharges should be identified.

Local records of meteorological conditions, including relative humidity, should be obtained and the possible influence on static accumulation or dissipation (relaxation) considered.

The location of the static electric arc should be determined as exactly as possible. In doing so, there is seldom any direct physical evidence of the actual discharge arc, if it occurred. Occasionally, there are witness accounts that describe the arc taking place at the time of the ignition. However, the investigator should endeavor to verify witness accounts through analysis of physical and circumstantial evidence.

The investigator should determine whether the arc discharge could have been of sufficient energy to be a competent ignition source for the initial fuel.

The potential voltage and energy of the arc in relation to the size of the arc gap should be calculated to determine whether the incendive arc is feasible.

The possibility for the incendive arc and the initial fuel (in the proper configuration and mixture) to exist in the same place at the same time should be established.

14-12.8* Lightning. Lightning is another form of static electricity in which the charge builds up on and in clouds and on the earth below. Movement of water droplets, dust, and ice particles in the violent winds and updrafts of a thunderstorm build up a polarized electrostatic charge in the clouds. When sufficient charge builds up, a discharge occurs in the form of a lightning stroke between the charged cloud and objects of different potential.

Lightning strokes may occur between clouds or between clouds and the earth. In the latter, charges of opposite polarity are generated in the cloud while the charge in the ground below the cloud is induced by the cloud charge. In effect, the result is a giant capacitor, and when the charge builds up sufficiently, a discharge occurs.

14-12.8.1 Lightning Bolt Characteristics. Typically lightning bolts have a core of energy plasma $\frac{1}{2}$ to $\frac{3}{4}$ in. (1.27 to 1.9 cm) in diameter, surrounded by a 4-in. (10.2-cm) thick channel of superheated ionized air. Lightning bolts average 24,000 A but can exceed 200,000 A, and potentials can range up to 15,000,000 V.

14-12.8.2 Lightning Strikes. Lightning tends to strike the tallest object on the ground in the path of its discharge. Lightning enters structures in four ways:

(a) By striking a metallic object like a TV antenna, a cupola, or an air-conditioning unit extending up and out from the building roof

(b) By directly striking the structure

(c) By hitting a nearby tree or other tall structure and moving horizontally to the building

(d) By striking nearby overhead conductors and by being conducted into buildings along the normal power lines

The bolt generally follows a conductive path to ground. At points along its path, the main bolt may divert — for example, from wiring to plumbing, particularly if underground water piping is used as a grounding device for the structure's electrical system.

14-12.8.3 Lightning Damage. Damage by lightning is caused by two characteristic properties: first, the extremely high electrical potentials and energy in a lightning stroke; and second, the extremely high heat energy and temperatures generated by the electrical discharge. Examples of these effects are as follows:

(a) A tree may be shattered by the explosive action of the lightning stroke striking the tree and the heat immediately vaporizing the moisture in the tree into steam, causing explosive effects.

(b) Copper conductors not designed to carry the thousands of amperes of a lightning stroke may be melted, severed, or completely vaporized by the overcurrent effect of a lightning discharge. It is also characteristic for electrical conductors that have experienced significant overcurrents to become severed and disjointed at numerous locations along their length, due to the extremely powerful magnetic fields generated by such overcurrents.

(c) When lightning strikes a steel reinforced concrete building, the electricity may follow the steel reinforcing rods as the least resistive conductive path. The high energy and high temperature may destroy the surrounding concrete with explosive forces.

Chapter 15 Investigation of Motor Vehicle Fires

15-1 Introduction. This chapter deals with factors related to the investigation of fires involving motor vehicles. Included in this discussion are automobiles, trucks, and recreational vehicles (e.g., motor homes). While vehicles that travel by air, on water, or on rails are not covered, there are many factors relating to incident scene documentation, fuels, ignition sources, and ignition scenarios that may apply.

The burn or damage patterns remaining on the body panels and in the interior of the vehicle are often used to locate the point(s) of origin and for cause determination.

It was once felt that rapid fire growth and extensive damage was indicative of an incendiary fire. However, the type and quantity of combustible materials found in automobiles today, when burned, can produce this degree of damage without the intentional addition of another fuel such as gasoline. In the case of a total burnout, one cannot normally conclude whether the fire was incendiary on the basis of observations of the vehicle alone. The use of fire patterns or degree of fire damage to determine a point of origin or cause should be used with caution. The interpretations drawn from these patterns should be verified by witness evidence, laboratory analysis, service records indicating mechanical or electrical faults, or factory recall notices. The investigator should also be familiar with the composition of the vehicle and its normal operation. *(See Chapter 4.)*

The relatively small compartment sizes of vehicles may result in more rapid fire growth given the same fuel and ignition source scenario, when compared to the larger compartments normally found in a structure fire. However, the principles of fire dynamics are the same in a vehicle as in a structure and, therefore, the investigative methodology should be the same. *(See Chapters 2 and 3.)*

15-2 Fuels in Vehicle Fires. A wide variety of materials and substances may serve as the first materials ignited in motor vehicle fires. These include engine fuels, transmission fluids, coolants, and the vehicle interior materials or cargo. Once a fire is started, any of these materials may contribute as a secondary fuel affecting the fire growth rate and the ultimate damage sustained.

15-2.1* Liquid Fuels. Liquid fuels are often associated with vehicle fires, as they are almost universally present. These fuels may come in contact with an ignition source as the result of a malfunction of one of the vehicle systems, an accident involving fuel release, or an incendiary act. Table 15-2.1 provides some of the properties of commonly encountered liquid fuels.

Whether a given fuel can actually be ignited depends on the properties of the fuel, its physical state, the nature of the ignition source, and other variables. Flash point is of little or no significance when a fuel is released in spray form. Ignition on hot external surfaces may require temperatures of 200°C (360°F) above published ignition temperatures. See Chapter 3 for additional information on the process of ignition.

Table 15-2.1 Properties of Ignitible Liquids in Motor Vehicle Fires

Liquid	Flash Point °F (°C)	Ignition Temperature °F (°C)	Flammability Range (%)		Boiling Point °F (°C)	Vapor Density (air = 1)
			Lower	Upper		
Brake fluid[c]	240–355 (115–179)					
Brake fluid[d]	298 (148)				485 (252)	
Ethylene glycol (100%)[b]	232 (111)	775 (413)	3.3	—	387 (197)	
Ethylene glycol (90%)[b]	270 (132)					
Diesel #2D[e]	126–204 (52–96)	494 (257)	—	—		
Kerosene #1 fuel oil[e]	100–162 (38–72)	410 (210)	0.7	5.0	304–574 (151–301)	
Gasoline — 100 octane[e]	–36 (–38)	853 (456)	1.4	7.6	100–400 (38–204)	3–4
Methanol[e]	52 (11)	867 (464)	7.8	86.0	147 (64)	1.1
Motor oil[a]	410–495 (210–257)	500–700 (260–371)				
Trans fluid[a]	350 (177)					
Trans fluid[d] dextron IIE	361–379 (183–193)	410–417 (210–214)				
Dextron II	367 (186)	414 (212)				
Type F (Ford)	347 (175)					
Power steering fluid[a]	350 (177)					

Sources: The above information is from various sources within published literature:
[a]SAE 7411 80, Severy et al., *Automobile Collision Fires.*
[b]Flick, *Industrial Solvents Handbook*, p. 416.
[c]NFPA SPP 51, *Flash Point Index of Trade Name Liquids*, p. 182.
[d]Data provided by UNOCAL Lubricating Oils and Greases Division.
[e]NFPA 325, *Guide to Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids.*
Note: The data in this table are for generic or typical products when tested in a specific way. The test methods may not be the same for each material.

15-2.2 Gaseous Fuels. Alternate motor fuels, notably propane and compressed natural gas, are finding increasing use in fleets of automobiles and in trucks as well as in some privately owned vehicles. The use of these fuels is expected to increase in the future, along with the introduction of hydrogen. Propane is also found aboard the majority of recreational vehicles as a cooking, heating, and refrigeration fuel. Hydrogen and oxygen can be found in association with wet cell lead acid batteries and may be released during charging or as a consequence of a collision. Some properties of gaseous fuels are given in Table 15-2.2.

15-2.3 Solid Fuels. Solid fuels are less common than liquids and gases as the first materials ignited in motor vehicle fires, except in scenarios where overloaded wiring or smoking materials are possible ignition sources or the vehicle is subjected to an exposure fire. Frictional heating may also be an ignition source involving drive belts, bearings, or tires. Given even a small initial fire, solid fuels may significantly contribute to the speed of the fire growth and spread the extent of damage. Plastic materials can burn with heat release rates similar to those of ignitible hydrocarbon liquids. A metal such as magnesium and its alloys can also burn in vehicle fires, adding additional fuel.

Investigators should not interpret the presence of melted metals to be an indication of the use of an ignitible liquid as an accelerant in the belief that only an ignitible liquid can produce sufficiently high temperatures. Melting temperatures given in handbooks and in this guide are for pure metals unless otherwise stated. In many cases, alloys are used rather than pure metals. The melting temperature of an alloy is generally less than that of its constituents. The actual composition of a metal part and its melting temperature should be determined before drawing any conclusions from the fact that it has melted. Some properties and uses of solid fuels are given in Table 15-2.3.

15-3 Ignition Sources in Motor Vehicle Fires. In most instances, the sources of ignition energy in motor vehicle fires are the same as those associated with structural fires, arcs, overloaded wiring, open flames, and smoking materials, for example. There are, however, some unique sources that should be considered, such as the hot surfaces of the catalytic converter, turbocharger, and manifold. Because some of these ignition sources may be difficult to identify following a fire, the following descriptions are provided to assist in their recognition

Table 15-2.2 Gaseous Fuels in Motor Vehicles

Gas	Ignition Temperature °F (°C)	Boiling Point °F (°C)	Flammability Range (%)		Vapor Density (air = 1)
			Lower	Upper	
Hydrogen	932 (500)	–422 (–252)	4.0	75.0	0.1
Natural gas (methane)	999 (537)	–259 (–162)	5.0	15.0	0.6
Propane gas	842 (450)	–44 (–42)	2.1	9.5	1.6

Source: From NFPA 325, *Guide to Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids.*
Note: The data in this table are for generic or typical products and may not represent the values for a specific product. When possible, values specific to the product involved should be obtained from a material safety data sheet or by test.

Table 15-2.3 Solid Fuels in Motor Vehicle Fires

Material	Ignition Temperature °F (°C)	Melting Point °F (°C)	Comment
Acrylic fibers	1040 (560)[b]	122 (50)[b]	
Aluminum (pure)		1220 (660)[d*]	
ABS	871 (466)[b]	230–257 (110–125)[c]	Body panels — may be completely consumed
Fiberglass (polyester resin)	1040 (560)[b]	428–500[c]	Resin burns but not glass body panels
Magnesium (pure)	1153 (623)[d*]	1202 (650)[d*]	
Nylon[a]	790 (421)[b]	349–509 (176–265)[c]	Trim, window gears, timing gears
Polyethylene	910 (488)[e]	251–275 (122–135)[f]	Wiring insulation
Polystyrene	1063 (573)[e]	248–320 (120–160)[f]	Insulation, padding, trim
Polyurethane — foam	852–074 (456–579)[e]		Seats, arm rests, padding
Polyurethane — rigid	590 (310)[b]	248–320 (120–160)[c]	Trim
Vinyl (PVC)	945 (507)[e]	167–221 (75–105)[f]	Wire insulation, upholstery

Sources:
[a]Lide, *Handbook of Chemistry and Physics.*
[b]Hilado, *Flammability Handbook for Plastics.*
[c]*Guide to Plastics.*
[d]NFPA *Fire Protection Handbook,* Table 3-13A, 17th edition, 1991.
[e]NFPA *Fire Protection Handbook,* Table A-6, 18th edition, 1997.
[f]*Plastics Handbook.*
*Pure metal.
Note: The data provided in this table are for generic or typical products and may not represent the values for a specific product. When possible, values specific to the product involved should be obtained from the manufacturer or by test.

15-3.1 Open Flames. The most common open flame in a carburetted vehicle is caused by a backfire through the carburetor. Ignition will rarely occur if the air cleaner is properly in place. Most vehicles today, however, use a fuel injection system that eliminates the need for a carburetor. Lighted matches in ash trays may ignite debris in the ash tray, resulting in a fire that exposes combustible plastic dashboard or seat materials. In recreational vehicles, appliance pilot flames or operating burners and ovens are open flame ignition sources.

15-3.2 Electrical Sources. The primary source of electrical power in a vehicle is the battery. With no battery, there can be no other electrical source of energy. With a battery, however, consistent energy can be produced by the generator or alternator, which is more than sufficient to cause a fire. Overcurrent protection devices, such as fuses, circuit breakers, or fusible links, are used on motor vehicles to provide safety. However, in some cases, breakdown of parts, improper use, or installation of additional equipment can defeat these safeguards.

15-3.2.1 Overloaded Wiring. Unintended high-resistance faults in wiring can raise the conductor temperature to the ignition point of the insulation, particularly in bundled cables such as the wiring harnesses or the accessory wiring under the dash where the heat generated is not readily dissipated. This can occur without activating the circuit protection. Faults and mechanical failures of high-current devices such as power seat or window motors can also result in ignition of insulation, carpet materials, or combustible debris that may accumulate under seats. Pre-fire history of electrical malfunction may be a clue.

15-3.2.2 Electrical Arcing. In postcrash situations, arcs can be generated through the crushing or cutting of wires, particularly battery and starter cables, which are not electrically protected and are designed to carry high currents.

The large amount of energy available in a battery can be enough to ignite materials such as engine grease, some plastic materials, and electric insulation. Significant arcing can also occur along with the crushing of the battery or batteries.

15-3.2.3* Lamp Filaments of Broken Bulbs. Lamp filaments of broken bulbs are also a source of ignition energy especially for gases, vapors, or liquid fuels in a spray or mist form. Normally operating head lamp filaments have temperatures on the order of 2550°F (1400°C).

15-3.2.4 External Electrical Sources Used in Vehicles. While most electrical sources in vehicles are self-contained, in some situations electrical power is provided from commercial facilities. Examples of these sources are electrical hook-ups used in recreational vehicles and trailers and electric heaters for engines and vehicle interiors. Inspection for electrical power cords should be made when applicable, since an overload of the cord or failure of the appliance could be the cause of the fire. Where recreational vehicles are connected to commercial power, the branch circuit wiring should be inspected for indications that it was a possible ignition source.

15-3.3* Hot Surfaces. Exhaust manifolds and components can generate sufficient temperatures to ignite diesel spray and to vaporize gasoline. Automatic transmission fluid, particularly if heated due to an overloaded transmission, can ignite on a hot manifold. Engine oil and certain brake fluids (DOT 3 and 4) dropping on a hot manifold can also ignite. The internal components of a catalytic converter have operating temperatures in the range of 1292°F (700°C) under normal operation and can be much higher if unburned fuel is introduced due to a fuel or ignition system malfunction. External temperatures of these converters can reach temperatures of 600°F (315°C) under normal operation and higher where ventilation or air circulation is restricted.

15-3.4* Mechanical Sparks. Metal (e.g., steel and magnesium) to pavement sparking can generate enough energy to ignite liquid fuel vapors or gaseous fuels. Sparks generated at speeds as low as 8 km/h (5 mph) have been determined to have temperatures of 1470°F (800°C) (orange sparks). Higher speeds have produced temperatures of 2190°F (1200°C) (white sparks). Aluminum to pavement sparks are not an ignition source. Sparks can also be caused by moving parts such as pulleys rubbing against other metallic objects. Sparks from tools striking metals seldom cause ignition.

15-3.5 Smoking Materials. Modern upholstery fabrics and materials are treated with flame retardant and are generally difficult to ignite with a cigarette. Ignition may occur if a lit cigarette becomes buried in a crevice between seat cushions, paper, or other debris or if the seat material comes in contact with open flame.

15-4 Recording Motor Vehicle Fires. The same general techniques are employed for vehicles that are used for structural fires. Whenever possible, the vehicle should be examined in place at the scene. However, the investigator may not have the opportunity to view the vehicle in place or at the fire scene. For many reasons, the vehicle may have to be moved before the investigator reaches the scene. Frequently, part of the documentation takes place at a salvage yard, repair facility, or warehouse.

As the investigator commences the investigation, he or she should determine the following:

(a) Identify the vehicle to be inspected and record the information. This will entail describing it by make, model, model year, and any other identifying features. The vehicle should be accurately identified by means of the vehicle identification number (VIN). The composition of the VIN provides information on such things as the manufacturer, country of origin, body style, engine type, model year, assembly plant, and production number. The VIN plate is most commonly placed on the dash panel in front of the driver's position. It is affixed with rivets. If this plate survives the fire, the number should be recorded accurately. If it is rendered unreadable or appears to have been tampered with, then the assistance of one of the following should be requested:

1. A police auto theft unit
2. A member of the National Insurance Crime Bureau in the United States
3. A member of the Canadian Automobile Theft Bureau in Canada

These persons have the necessary expertise to identify the vehicle by means of confidential numbers located elsewhere on the vehicle. The VIN should be checked on either the National Crime Information Center (NCIC) or the Canadian Police Information Centre (CPIC) to ensure there is no record outstanding on it.

(b) Once the vehicle has been positively identified, the mechanical functions of that particular vehicle, its composition, and its fire susceptibility should be reviewed. To ensure that no details are overlooked, the investigator may examine a vehicle of similar year, make, model, and equipment, or the appropriate service manuals.

(c) Information regarding fires and fire causes in vehicles of the same make, model, and year can be obtained from the National Highway Safety Administration or from the Insurance Institute for Highway Safety, both located in Washington, DC. The Auto Safety Hotline number is 1-800-424-9393 or (202) 366-0123. In Canada, contact the Department of Transport, Ottawa; phone: (613) 998-1992.

15-4.1 Recording at the Scene. The investigator should make a diagram of the fire scene, showing points of reference and distances relative to the vehicle. The diagram should be of sufficient detail to pinpoint the location of the vehicle before its removal. The overall scene should be photographed showing surrounding buildings, highway structures, vegetation, other vehicles, and impressions left by tires or footprints. All fire damage to any of the above or any signs of fuel discharge that might help in the analysis of the fire spread should be photographed and documented. The location and condition of any parts or debris that are detached should be documented.

The vehicle should be photographed. The photographs should include all surfaces, including the top and underside. Both the damaged and undamaged areas, including the interior and exterior damage, should be photographed.

Any evidence showing the path of fire spread either into or out of any compartment (e.g., engine, passenger, trunk, cargo) or within any compartment should be photographed. As with structure fires, the path of fire travel may be difficult to determine in a totally burned out vehicle.

The cargo spaces should be photographed. The type and quantity of cargo and any involvement in the fire should be noted.

If possible, the removal of the vehicle(s) and any damage that may result from the removal process should be photographed. Also, the scene after removal of the vehicle(s) should be photographed, while noting burns on the earth or roadway and the location of glass and other debris.

Drawings and notes should be prepared to augment the photographs.

15-4.2 Recording the Vehicle Away from the Scene. If the vehicle has been removed from the scene, a visit should be made to the scene and any photographs that were taken at the scene should be reviewed. The basic process of documenting the condition of the vehicle is the same regardless of where it is. When the inspection is delayed and when it is located at a remote location, parts may be missing or damaged. Additionally, the vehicle(s) may have been damaged by the elements, and fire patterns, most notably those on metal surfaces, may be obscured. If outdoor storage is likely, arrangements should be made for the vehicle to be covered with a tarp or other suitable material.

Even if the vehicle was examined at the scene, there are advantages to inspecting a vehicle away from the scene. For example, it is easier to move or remove body panels that may be blocking a view of critical parts. Power is often available as are tools for disassembly if needed. Frequently, arrangements can be made to have equipment such as a forklift available to raise the vehicle for a more detailed inspection.

The vehicle should be thoroughly photographed as it is examined at locations away from the scene.

15-5 Examination of Vehicle Systems. For ease of discussion, the detailed examination is broken down by components or areas that have a common function. It is suggested that an attempt be made to develop a scenario of the events leading up to the fire as well as the progression of the fire itself. To do this, it is suggested that the operator of the vehicle, passengers, bystanders, the fire department personnel, and the police be interviewed separately. This information should be used to assist with the examination. Information regarding the operation of the vehicle immediately prior to the fire should be obtained from the operator and/or owner to determine the following:

(a) When the vehicle was last driven and how far
(b) The total mileage on the vehicle
(c) Whether the vehicle was operating abnormally (e.g., stalling, electrical malfunctions)
(d) When the vehicle was last serviced (e.g., oil change, repairs)
(e) When the vehicle was last fueled and the amount of fuel added
(f) When and where the vehicle was parked
(g) Whether the vehicle was seen again prior to the fire
(h) With what equipment the vehicle was equipped (e.g., radio, CD, CB, mobile phone, electrical windows, seats, customized wheels)
(i) What personal items were in the vehicle (e.g., clothing, tools)

If the vehicle was being driven at the time the fire occurred, the following additional points should be covered:

(a) How far the vehicle had been driven
(b) What the route of travel was
(c) If it was loaded, towing a trailer, being driven fast, and so forth
(d) When and where the smell, smoke, or flame was noticed first
(e) How the vehicle reacted (e.g., stalling, racing erratically, or showing indications of electrical malfunctions)
(f) What the operator did
(g) What was observed
(h) What attempts were made to put the fire out and how
(i) The length of time the fire burned before help arrived
(j) The total length of time the fire burned until it was extinguished

15-5.1 Type of Fuel Systems. Three main fuel systems provide the motive power for vehicles in use today. Fuels may be liquid or gaseous. Although electricity is not a fuel, its use as an energy source for vehicles is increasing.

15-5.1.1 Gasoline-Powered Vehicles. Inspect the gas tank for crushing or penetrations. Note the condition of the fuel filler pipe. Filler pipes are often two-piece systems with a rubber or flexible polymeric connection. This connection may release fuel by failing mechanically during an accident or may burn through from an exposure fire. Some filler systems are inserted into the tank through a rubber or polymeric bushing or gasket. Accident impacts may result in disconnection of the filler neck assembly from the tank and release of fuel.

The presence or absence of the fuel tank cap and any fire or mechanical damage at the end of the filler should be noted and recorded. Many fuel tank caps have plastic or low melting temperature metal components that may be destroyed during the fire, resulting in the metal parts being dislodged, missing, or found in the fuel tank.

Fuel tanks exposed to heat or flame generally exhibit a line of demarcation that represents the fuel level at the time the fire was extinguished.

Fuel supply and vapor return lines should be inspected for ruptures and indications of fire damage. These lines usually have rubber or flexible polymeric connection hoses at one or more points along their length that may be points of fuel release. Examine and record the condition of lines passing near the catalytic converter, lines in any location where nonmetallic fuel supply or vapor return lines pass near exhaust manifolds or other source of heat, or lines in locations subject to abrasion.

15-5.1.2 Diesel-Powered Vehicles. In a diesel engine, ignition is caused by compression of a fuel/air mixture in the cylinder. Spark plugs are not used. While diesel fuel is not as volatile as gasoline, diesel fuel leaking onto a hot manifold can ignite. Diesel-powered vehicles share similarities with fuel system components of fuel injected gasoline-powered vehicles.

15-5.1.3 Natural Gas and Propane Gas.

15-5.1.3.1 These fuels are used both as an engine fuel and for appliances. Appliances are most often found in recreational vehicles and motor homes. Regardless of the use for the fuel, the investigator should look for the same evidence and information.

These fuels are stored under pressure. Leakage can result in a flaming gas jet fire. Rupture of the pressure tank can result in the release of large quantities of fuel that, if ignited, can cause a large fire.

Examination of the tank should include noting any physical damage, the position of valve(s) (e.g., open or closed), and the fuel level if a gauge is present and undamaged. Fuel level can also be determined by weighing the tank.

The condition of the pressure regulator should be noted.

Fuel lines should be checked for evidence of loose fittings that may have permitted gas to escape, initiating or contributing to the fire. Presence of heat damage concentrated at or near fittings can be a clue. Fittings may be loosened as a result of the fire due to differential expansion and cooling. "Leaks" found by post-fire pressure testing may not necessarily indicate a pre-fire leak.

Appliances should be examined and the position of control valves noted to determine whether any were open at the time of the fire. Appliances can include stoves and ovens, water heaters, and refrigerators.

15-5.1.3.2 Information on natural gas systems can be found in NFPA 54, *National Fuel Gas Code.* Information on propane systems can be found in NFPA 58, *Standard for the Storage and Handling of Liquefied Petroleum Gases.*

15-5.2 Auxiliary Fuel Equipment. The equipment used to distribute, store, or mix fuels can be a contributor to a fire; therefore, their part in the system as a whole should be considered.

15-5.2.1 Mechanical Fuel Pumps. Mechanical fuel pumps are mounted on the engine block and will pump fuel only when the engine is running. The mechanical fuel pump should be inspected for leaking diaphragms or accident-related mechanical damage or tampering or for heat damages from exposure.

15-5.2.2 Electric Fuel Pumps. Many modern motor vehicles, particularly those that are fuel injected, are equipped with electric fuel pumps. The operation of these pumps is electronically controlled and not directly powered by the running of the vehicle engine.

These fuel pumps can be found mounted within fuel tanks, attached to vehicle frames as an intermediate component of fuel lines, or in the vehicle engine compartment. In fuel-injected gasoline engines, electric fuel pumps are designed to produce fuel gauge pressures of approximately 40 psi (276 kPa). Some designs may utilize higher fuel pressures.

Some fuel injection systems involve two electric fuel pumps, a primary and a secondary pump, which increase the fuel pressure in two stages respectively. In such a system, the primary upstream fuel pump generally contains a fuel reservoir holding a few liquid ounces of gasoline.

As a safety feature, in order to prevent the operation of fuel pumps after collisions or when an engine is not running, vehicle manufacturers have used inertial switches, which are designed to de-energize the fuel pump in the event of a collision or of an extreme sudden stop. These inertial switches are commonly mounted in the trunks of automobiles or, in some cases, under the dashboard. Engine operation sensors or oil pressure switches designed to de-energize the fuel pumps when the engine is not running are also utilized. However, collisions have been known to cause damage that can negate the operation of these switches and accidental fires have been known to compromise electrical wiring causing the electric fuel pump to activate and provide fuel, spreading the fire.

After the electric fuel pump has been de-energized, there may be residual pressure in the fuel lines. Breaks in the pressurized fuel lines can allow the escape of as much as one quart or more of gasoline as the pressure in the fuel system is relieved.

15-5.2.3 Carburetors. The automobile carburetor is a source of a small amount [5 oz (148 ml)] of gasoline and could be damaged during an impact. The carburetor should be inspected for damage. It should be noted whether the air cleaner is in place and whether there is any burn damage to the filter element or any soot inside that might point to the carburetor as the origin of the fire.

15-5.2.4 Fuel Injection. There are a number of fuel injection systems in use in today's automobiles. It is suggested that the type of system being used be determined from the manufacturer or dealer. Most fuel injection systems, including the lines, operate at approximately 40 psi (276 kPa) although some may operate at higher pressures. Fuel injection systems also involve return fuel lines that convey unused gasoline liquids and vapors back to the fuel storage tank. A leak of even minute proportions, for example, a pinhole in the line or a loose fitting, will result in a fine spray of fuel in the engine compartment. A small spark could cause a fire. Even if the engine is not running, residual pressure can remain in the system.

15-5.2.5 Turbocharger. Turbocharging is the utilization of a turbine to add to the power output of an engine by increasing the amount of the air being forced into the cylinder. The turbine used to drive the compressor turns at up to 100,000 rpm, and the heat created can ignite fuels or other ignitible materials that come in contact with the unit. Both gasoline- and diesel-fueled engines can be turbocharged.

15-5.3 Exhaust System. The exhaust system, in particular, the exhaust manifold area and the catalytic converter, should be examined. The investigator should look for concentrations of damage near possible fuel sources. The catalytic converter or the exhaust manifold, muffler, and exhaust pipe can ignite trash, leaves, or dry vegetative ground cover under a parked car, especially if the circulation around these exhaust components is blocked. A catalytic converter that is being fed raw or poorly burned fuel can generate sufficient heat to ignite carpet or padding inside the vehicle.

15-5.4 Emission Control System. The fuel tank, and indeed the entire fuel system in today's vehicle, is sealed. This is to prevent fuel vapors from escaping into the atmosphere. The method used to collect these vapors is called the vapor control system. The vapors travel from the gas tank and gas reservoir in the engine compartment into a canister, which is located in the engine compartment. The collected vapors form part of the air/gasoline mixture when the engine is started.

A fire involving the canister can be severe. On occasion, gasoline fluid entering the canister can cause flooding. This concentration of fuel can be ignited by an electrical arc.

The presence of gasoline in the vapor canister can be caused by overfilling the fuel tank, which in turn forces gasoline into the vapor line and then into the canister.

In the case of recreational vehicles, vans, trucks, and so forth, an extra fuel tank may be installed without making allowance for the increased amount of fuel and fuel vapor being forced through the vapor canister.

15-5.5 Windshield Washer System. Windshield washer solvent, if sprayed on a hot surface, can form a vapor that may become ignited. The condition of the windshield washer fluid reservoir(s) should be documented, noting crushing or rupture. The windshield washer solvent reservoir is usually a plastic material and may be consumed in a fire. If this is the case, the investigator should note whether body parts have penetrated the space that would have been occupied by the reservoir. Solutions sufficiently diluted by water may not ignite.

15-5.6 Brake System. When brakes are applied, the fluid is under pressure. A small leak in the line or couplings could produce a spray that could be ignited if it came in contact with an adequate heat source.

15-5.7 Electrical System. The electrical system, starting with the battery, should be examined in detail. If the insulation has not been consumed in the fire, evidence of burned insulation, severance of the wire, or other damage may be located that could be the origin of the fire. An overloaded wire heats uniformly along its entire length between its connection points or between the location of a short circuit and the energy source. It does not heat at a particular point along that length unless there is another connection there. Overloaded wiring can result in localized open flames at the connections. The location of these flames relative to other combustible materials is critical.

Damage to the insulation from the point of the short to the source of the electrical current can assist in locating the short.

Most electrical circuits are protected by fuses, fusible links, or circuit breakers. Check for any tampering of these devices or any attempt to bypass them as is often the case where amateur repairs or installations are made. A short circuit in the primary wiring may leave evidence of arcing or fusing of the metal. *(See also 15-3.2.)*

Hydrogen and oxygen are present in motor vehicle batteries. Hydrogen can be released during charging operations or as the result of a direct short of an unfused wire such as the starter cable. Small amounts of hydrogen and oxygen are also present inside sealed (i.e., no maintenance) batteries and can be released due to mechanical damage during a collision. Hydrogen gas has a very wide explosive range and is easily ignited by low energy sources. However, it is difficult to ignite hydrogen by a hot surface.

15-5.8 Power Steering System. Power steering fluid is an ignitible liquid and is under high pressure when the steering is being utilized. Leaks can produce sprays or mists that can be ignited.

15-5.9 Transmission. Transmission fluid can be heated significantly under conditions of heavy loads and insufficient cooling. Discharge of the hot fluid from the filler tube or a ruptured or leaking line or seal can result in a fire. If the vehicle was operating under a heavy load at the time of the fire, the investigator should note whether there was an auxiliary transmission cooler or leaks in the lines. A check for cracks in the transmission casing or for signs of overheated components inside the transmission should be made.

15-5.10 Body System. Many body panels of modern motor vehicles are made of plastic, polymers, or fiberglass materials and will burn during a fire. Often the entire cab of a tractor will be consumed or door and hood panels will be gone. The inside panels of the front fenders in many cars are plastic; when they burn through, additional ventilation will be available for engine compartment fires. It should be noted that aluminum, magnesium, and their alloys are being used in panels in some vehicles. These panels will burn, often with great intensity.

The partition between the engine compartment and the passenger compartment is commonly referred to as either the "fire wall," cowling, or bulkhead. In modern motor vehicles this partition may have numerous penetrations, some associated with the heating and air conditioning system ducts. The ducts are usually made of reinforced plastic and can burn, resulting in a path for fire spread into the passenger compartment. Fire can also spread by conduction through the metal partition to combustibles under the dash. During the examination, damage to plastic body panels should be noted.

15-5.11 Switches, Handles, Levers. During inspection of the vehicle interior, the position of switches should be noted to determine whether they were in the on position. An attempt should be made to determine whether windows were up or down and to determine their condition prior to the fire. The position of the gear shift mechanism should be noted and the ignition switch should be examined, if possible, for any signs of a key, tampering, or breaking of the lock. Most of these elements are made of material that will be easily consumed in a fire; however, there may be enough residue left to assist in the investigation.

15-5.12 Interior Finishes and Accessories. The interior finishes and furnishings (e.g., seats and padding) of most modern motor vehicles represent a significant fuel load. If the vehicle is burned out, the investigator should try to determine what the original interior fuel load was and how it was arranged. The presence (or absence) of seats and accessory equipment such as radios, CD players, and telephones should be documented.

15-5.13 Cargo Areas. A motor vehicle fire may involve the trunk of an automobile, the storage areas of a motor home, or the cargo compartment of a truck. It is important to determine whether the fire originated in or spread to these areas. The investigator should make an inventory of the materials that were present in these areas. Inspection of the debris may be sufficient, or it may be necessary to interview owners or occupants to obtain the information needed.

15-6 Recreational Vehicles. Recreational vehicles and motor homes, and fires in them, are similar in many ways to houses and mobile homes. Plywood flooring and paneling may be present, and there will often be large fuel items like polyurethane foam couches or mattresses. The examination should note the appliances present. Obtaining catalogues or sales brochures for these vehicles can help determine which appliances and furniture were present before the fire.

Chapter 16 Management of Major Investigations

16-1 Introduction. This chapter is principally concerned with the investigation of major fire and explosion incidents as a management function with an organizational and managerial perspective. Major fire management characteristics include the control of the scene, in which many interests participate simultaneously. This may include multiple public and private agencies and likely an investigation team for each interested party. A protocol should be developed to meet these objectives. This chapter provides guidance for these purposes.

A major fire or explosion incident may include fatal fires, fires in high-rise buildings, incidents involving major damage to large complexes or multiple buildings, conflagrations involving a large dollar loss, or fires resulting in a large number of personal injuries. While major incidents are not always large in size or magnitude, they do tend to be more complex. As a result, the primary goal in such circumstances is to preserve the evidence and preserve the interests of the different parties involved. Thorough investigations do not just happen, but instead are the result of careful planning, organization, and the ability to anticipate problems before they arise. Prior to actually beginning the scene investigation, numerous events, facts, and circumstances should be identified and considered before decisions are made as to how the investigation will flow. *(See Chapter 6.)*

16-2 Understanding Between the Parties. Interested parties should be allowed to participate in the investigation and examine the evidence in its undisturbed condition. No party should remove evidence or materials without adequate notice to other interested parties.

Different parties can conduct a joint investigation and still have separate and independent examinations. A joint investigation allows recording and examination of the scene as it is altered or examined or as evidence is collected. Allowing all interested parties an equal opportunity to establish the facts should eliminate future accusations of wrongdoing, such as altering the evidence or hiding facts. The parties should work together through coordination of the investigation. Personal interests should be subjugated to the truth.

Public officials conducting an investigation may have concerns about allowing other investigators to participate during a criminal investigation, but these concerns can be alleviated through proper planning and communication. Other investigators may be able to assist the public officials by providing their expertise, other experts, equipment, and personnel. The purpose of any investigation is to seek the facts.

16-3 Agreement Between Parties. An understanding or agreement should be developed through a consensus of the interested parties prior to conducting the investigation. The agreement should cover the following issues, where appropriate:

(a) Control and access to the site

(b) How and which information discovered during the investigation will be shared (such as through public agencies, interviews, or research)

(c) Joint custody and examination of evidence is usually a requirement for all parties. All parties should be notified prior to destructive examination. A sign-in sheet should be required to gain access to the evidence.

(d) The acquisition and processing of needed nonproprietary information from the parties through their identified representative

(e) Release of information to the public, which may be coordinated through one spokesperson, usually the public official

(f) A protocol for the scene examination and debris removal. This may require regular scheduled meetings to discuss the progress and the activities that are to be conducted. A person may be selected to chair the meetings and "lead" the scene examination.

(g) The development of a "flow chart" to provide guidance for the general scope of the investigation

Figure 16-3 is an example of a "Memorandum of Understanding" as an agreement for a joint investigation. It should be accompanied by Figure 16-5.

16-4 Organization of the Investigation. Each of the representative parties may develop a team, with its members conducting various aspects of their investigation. Interested parties may share the costs and services of specialized personnel such as evidence technicians, photographers, air quality people, safety coordinator, laborers, and so forth. Each of the teams should have a team leader who will participate in the "Team Leader Committee." Many functions of the "Team" and "Team Leader Committee" are similar in organization of their responsibilities. The Team Leader Committee organizes the investigation as a whole and coordinates the access to the evidence and the scene.

16-5 Team Leader Committee. The Team Leader Committee should coordinate access to the site through whoever has control of the scene. This may be the building owner, the insurance company, the public authorities, or the courts. The Committee should hold regular meetings to discuss the status of the investigation and to obtain a consensus from the parties regarding actions to be taken. It may be helpful for the Committee to develop a flow chart or plan to manage the investigation. Changes in the plan should be discussed with the participants in the investigation, so the Committee is aware of the changes and why the changes were made. Figure 16-5 is an example of a flow chart that could be used as a starting point in organizing an investigation.

A person should be selected to chair and organize the meetings. This person should have the responsibility to keep the meetings and the investigation moving, using the flow chart as a guide. The team leader may coordinate reports, documents, interviews, and so forth, and may write a report on his or her observations. In investigations with more than one interested party, the person selected usually has the same voting authority as the other investigators. The team leader should be an experienced fire investigator with the ability to identify problems that may be encountered by the team and to solicit solutions from the group. Oftentimes the public official or whoever has control of the site may be the most likely person for this position.

The person selected as Team Committee Leader is generally one of the following:

This Memorandum of Understanding relates to the investigation of the fire that occurred on July 1, 1998, at the Tall Building and Storage Facility, 1007 Main Ave., Any City, State, USA. It recognizes that a number of independent investigations are being conducted simultaneously and coincidentally and all with a common goal—to determine the origin and cause of the fire. All interested parties recognize that cooperation with one another will be beneficial to each party and will produce an efficient, quality outcome.

The parties agree to the following:

An origin and cause investigation is being conducted.

The investigation is being conducted by the Yourtown Fire Department, The Federal Fire Investigations, Payall Insurance Company, Any Storage Company, and the Tall Building Company.

All investigation procedures and the physical collection of the evidence will be coordinated through regular meetings. The evidence will be collected and stored in a location where access is monitored. No testing or examination of the evidence shall be conducted until all parties are notified.

All requests for data of a nonproprietary nature from the Tall Building Company or tenants should be processed through their identified representatives. Nonproprietary information provided by any party will be shared by all parties if requested.

All releases of information regarding the origin and cause of the fire will be coordinated through the Yourtown Fire Department, and no predisclosure of information will be made by any party.

The protocol recognizes that to remove material or conduct testing will require the permission of the Yourtown Fire Department and the undersigned parties. The request should be in writing; however, verbal agreement followed by written request and approval of the parties is acceptable when time frames are short.

Testing and examination protocol of materials associated with this investigation are as follows:

(1) All parties agree as to who will perform each examination and each test.

(2) All parties agree to allow any other party to observe each test.

(3) All parties agree to return any material remaining after each test to the storage facility.

Attached is an investigation flow chart to provide guidance for the general scope of the investigation.

Figure 16-3 Memorandum of understanding.

(a) Representative of an agency or department having responsibility to investigate the incident

(b) Person selected by consensus of fellow team leaders

(c) Representative of the private sector who has an interest in determining the origin and cause of the incident

It is recommended that the team select a secretary to take minutes of the meetings. Minutes should include the date, time, location, persons at the meeting, subjects discussed, and decisions reached. This record can be a tape recording with accompanying attachments.

A meeting should take place prior to an on-scene investigation. Personnel should be advised of the condition of the scene and the safety precautions required. Jurisdictional responsibilities and interests should be identified. Federal or state Occupational Safety and Health Administration (OSHA) compliance and safety concerns should be discussed.

Each of the interested parties should have one spokesperson at the meetings. Other representatives/investigators should be allowed to attend the meetings but they should voice their concerns through their representative so the meetings run efficiently.

It is reasonable to expect disputes, and efforts should be made to resolve these issues through proper planning and meetings or other communications. Disputes concerning access to the scene, scene alterations, evidence collection, evidence preservation, and evidence disposition should be anticipated.

Some of the committee issues that need to be resolved may be as follows:

(a) The purpose of the investigation
(b) The expected role of the committee and teams
(c) What agencies or parties are involved (e.g., local, state, federal, or private)
(d) Identification of team members (e.g., identification cards, patch, or hats)
(e) Number of persons from each party or agency
(f) Control of entry to the scene

16-6 Planning. A plan, such as a systematic order for the tasks, should be developed to conduct the investigation. Changes in the plan or flow chart may be required as the investigation moves forward. The plan should have some flexibility. *(See Chapter 6.)*

16-7 Occupant Access. If possible, the investigation should be conducted in such a manner to allow the occupants use of those portions of the facility not involved in the incident. This may require a delay in conducting some of the investigation until the situation can be stabilized for the occupants. Allowing the tenants/occupants to use space is important, but the fire or explosion scene should still be secured. This effort may help to lessen the interruption to business and the impact of the fire. Occupant access to any portions of the facility should be allowed only after the safety of the area has been established.

16-8* Organization of an Investigation Team. Organization of the team with the members' responsibilities and duties should be addressed. Some team members may have to assume/perform more than one function. The function should be identified in the flow chart or plan.

Responsibilities of an investigative team include the functions of air quality, structural safety, lighting, transportation, and safety. Some of these functions may be shared or organized with the other teams. The interested parties should share and organize the evidence removal and examination.

The team size, organization, and individual roles need to be addressed.

Having too many people at the scene may have a detrimental effect on the scene; likewise, too few may result in an incomplete or inefficient investigation. The number of individuals involved in the investigation depends on the size and complexity of the incident. Also, several responsibilities may fall under the same person.

A major loss team may include the following:

(a) Leader
(b) Secretary
(c) Evidence technician
(d) Photographer
(e) Diagramer
(f) Interviewer
(g) Searcher(s)

In addition, specialized personnel or skills should be used as necessary. *(See Section 6-5.)*

A successful major fire investigation requires proper management. One management system is known as the incident command system (ICS). ICS provides a management structure and system for on-site multidisciplinary operations.

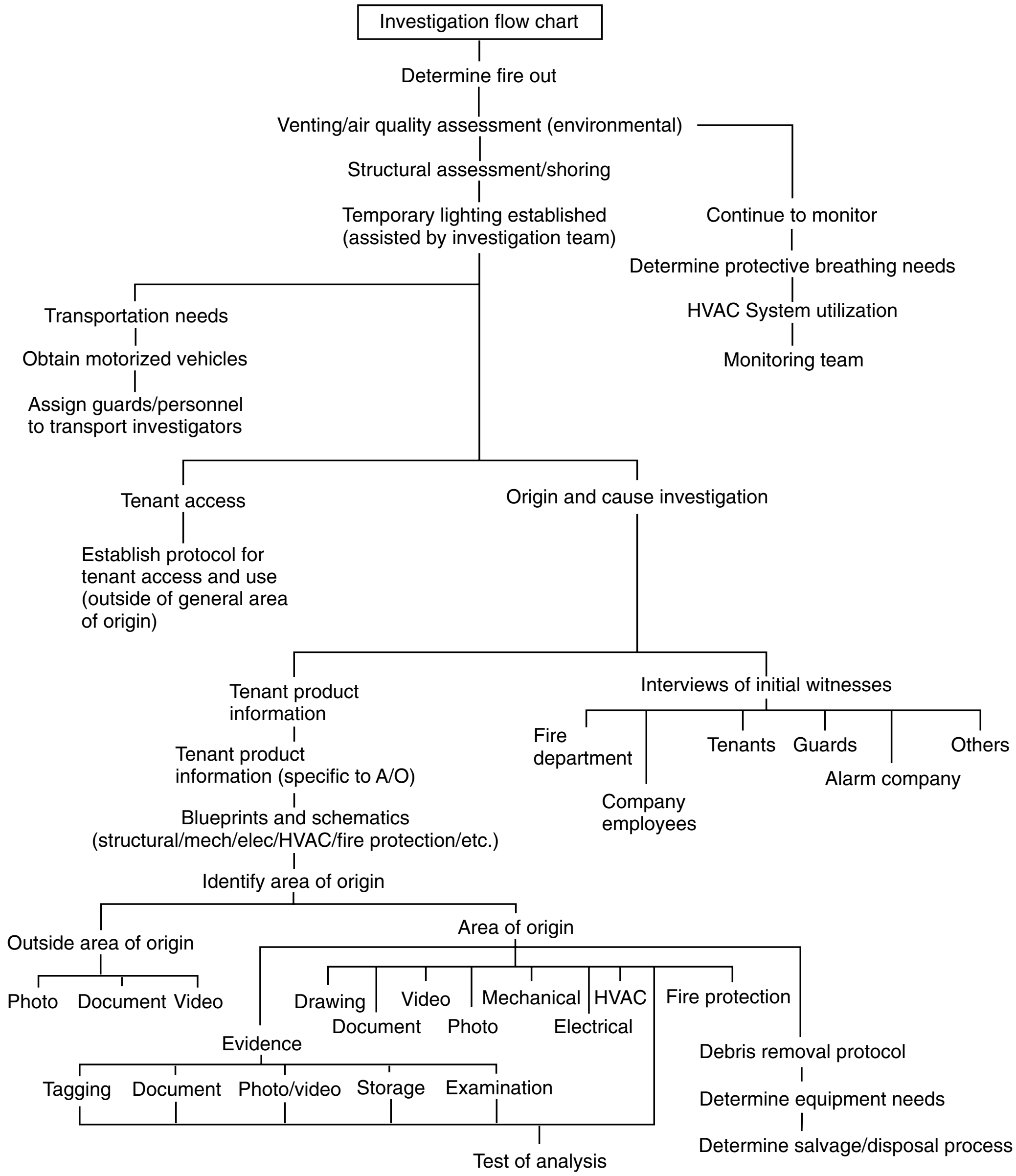


Figure 16-5 Investigation flow chart.

16-9 Regular Meetings. The Team Leader Committee should meet regularly to discuss the progress of the investigation, to discuss changes that may be required in the plan, and to inform the teams of what is going to happen and when. It is suggested that short meetings be held daily and that more thorough meetings be held weekly.

Each of the teams should also meet daily to coordinate their activities and to disseminate information to other team members. The regular team meetings provide the forum to share information developed by the team members such as information from interviews, the scene examination, document research, and safety conditions.

16-10 Resources. The investigators responsible for major loss investigations should identify resources at their disposal from within their department or company, or from outside sources (e.g., preplanning). Numerous fire investigators in rural areas and small investigation departments have surmounted their resource deficiencies by locating additional resources of both manpower and material when preplanning for major investigations. Unfortunately, the team concept, which can be utilized by both the public sector and the private sector, is often overlooked or disregarded because of budgetary constraints or because jurisdictional (i.e., turf) issues are allowed to take precedence over life safety and the need to conduct an organized investigation.

The investigator in charge at many incident scenes may be responsible for the entire investigation. A task force and team concept allows responsibilities to be delegated or conducted by more than one investigator.

16-11 Preliminary Information. The investigator should gain as much information as possible prior to developing the flow chart or plan (e.g., magnitude of the incident, the condition of the scene, information surrounding the incident, type of structure involved, use of the structure, and the nature and extent of damage). This will allow the development of a plan that will address areas of importance to the investigation without requiring major modification.

16-12 Safety. Safety is the responsibility of all team members but in some situations it may be necessary to designate one member as a safety monitor (i.e., safety officer) who will be responsible for monitoring conditions at the fire or explosion scene to ensure the safety of all personnel. The investigation plan should address safety for not only the investigators but for the tenants who will be utilizing the facility. The structure will need to be examined prior to conducting an investigation or removal of debris. Toxic gases or hazardous materials may have been present at the time of the incident or are there as a result of the fire.

It may be necessary to continue to monitor the air quality, environmental conditions, or structural stability while the investigation continues. The building's ventilation system should be evaluated for possible use in providing air quality. If the air or the environment may not be rendered safe, the investigator(s) may be required to wear protective clothes and an appropriate filter mask or self-contained breathing apparatus.

Investigator fatigue can be a safety consideration in major fires and should be avoided. *(See Chapter 10.)*

16-13 Lighting. Temporary lighting may be required. It is often better to have electricians install temporary lighting than to use portable lights and flashlights for extended periods of time. The temporary lighting will allow the investigators to view the scene more easily. The need to install temporary lighting will be a function of current lighting conditions, the estimated time the investigation will take, and the availability of other lighting and electrical power.

16-14 Access for Investigator. Transportation may be needed to allow ease of movement of materials and investigators. There may be long distances to travel or it may be difficult to move equipment and personnel to the area. The fire area may be on higher floors that are difficult to reach. If these issues are addressed early, it will make the task much easier.

Golf carts or small motorized vehicles, boats, four-wheel-drive vehicles, helicopters, or other means of transportation may be needed to provide transportation to areas that are difficult to reach. An elevator in an adjoining building, fire department ground or aerial ladders, or a man lift may assist in reaching upper floors.

16-15 Securing the Scene. One of the first duties of the team is to secure the scene. First responders to the scene should establish and maintain control. Access should be strictly monitored, and all personnel should log on and off the scene.

Access should be restricted to authorized personnel both to facilitate the quality of the investigation and to prevent possible injury to unauthorized or curious onlookers.

The decision regarding authorization rests with whoever has control of the site.

It may be necessary to hire private security personnel or to install physical barriers to ensure the level of security needed.

16-16 Sanitary and Comfort Needs. Provisions should be made for sanitary facilities and drinking water. An uncontaminated area should be available for eating, resting, and meeting.

16-17 Communications. A large incident area may create communication problems for the investigators. Communication may be provided through either mobile or fixed means. Portable radios, temporary hardwired phone systems, or cellular telephones may be used. A command post using temporary trailers or other facilities may be needed to act as a central point.

16-18 Interviews. Upon arrival at the scene, the team leader should ensure that interviews are conducted of at least the preliminary witnesses. Examples of preliminary witnesses are as follows: the fire chief; fire prevention personnel; suppression personnel; police officers; passersby; neighbors; property owner(s); employees, tenants, or people who may have information on fire discovery; events prior to fire department arrival; fire suppression efforts; movement of the fire; and the building construction and contents. (*See Chapter 7 on interviewing.)*

Interviews can be conducted while other activities are being performed. It is usually better to subject a person to one thorough interview than to many interviews. If more than one party is participating in the investigation, a joint interview with a representative from each of the interested parties will usually result in a more thorough interview and will not subject the person to several interviews. It is best to have one person from each party participating in the interview rather than multiple investigators from each party. This will limit the interview team to a manageable number, and the team size won't overwhelm the person being interviewed.

Joint interviews will allow investigators to work off one another's thoughts and questions, and the interview will cover more details and topics. There will be times when joint interviews may not be practical, such as suspect interviews by public officials. Summaries of the interviews should be made to facilitate the briefing of other team members. Transcripts of statements of significance may need to be prepared as soon as possible.

16-19 Plans and Drawings. Copies of blueprints and schematics may be obtained for the facility. The plans will assist in tracing the electrical system, determining the capabilities of the HVAC system, and reviewing the fire protection/detection systems. It may assist in developing accurate drawings of the investigation and in locating or determining the operation of equipment. The plans may be obtained from the building owner, contractor, architect, or the public building department.

16-20 Recording the Scene. Recording the scene and the artifacts is required and is discussed in Chapter 8. Documentation includes photographs, videos, diagrams, and sketches.

16-21 Search Patterns. The personnel assigned to the physical examination of the scene should be the team members with experience and expertise in determining origin and cause of fire/explosion incidents. A grid system may be developed to conduct the investigation by dividing the scene into specific areas. The search in each grid is documented and the evidence from each grid is identified. The geometry of the scene may determine the grid system, such as by floor or room.

Other methods include spiral, strip, or area searches. Regardless of the method used, the assigned search areas should overlap to ensure complete coverage.

16-22 Evidence. The removal of debris or evidence needs to be discussed with the interested parties/investigators prior to removal. The discussions may occur during the regular scheduled meetings, through correspondence, special meetings, or on the fire scene. The importance of reporting and properly securing evidence should be discussed with the team leader committee members.

One evidence technician should be selected to document the collection and preservation of all evidence. Evidence should be handled and secured as discussed. *(See Chapter 9.)*

A protocol regarding the evidence collection, processing, and storage should address the type and location of the storage facility that is acceptable to the parties and the methods of handling the evidence. This often requires a secured location with a log-in sheet for persons accessing the area. All evidence collected should be equally accessible to all teams involved in the investigation. Prior to any destructive examination or testing, all teams should be notified. Each of the interested parties may decide to have their own expert view or participate in the examination.

16-23 Release of Information. The team should be discrete when matters concerning the incident are discussed around persons other than team members. One person or agency should be designated to release information through the Team Leader Committee concerning the investigation. This may be the public information officer or the fire marshal.

16-24 Conducting the Scene Examination. Conducting the scene examination is discussed in other chapters. The investigation techniques for major fires remain the same, but the scene typically is larger, requiring more interviews, more data, and more documentation.

16-25 Preplan for Major Fire Investigations. In many communities or private companies, the responsibility for determining the origin and cause of a major fire or explosion will be assigned to one or two investigators. The need to preplan the investigation remains constant.

This team or task force concept allows the investigation to proceed more rapidly and allows more time and resources to be spent on each task by assigning tasks to the investigators on the team.

Chapter 17 Incendiary Fires

17-1 Introduction. An incendiary fire is a fire that has been deliberately ignited under circumstances in which the person knows the fire should not be ignited. The following section provides guidance to assist the investigator in identifying incendiary fires and documenting evidence regarding their origin and cause. In the event the investigator concludes that a fire was incendiary, other evidentiary factors are addressed regarding suspect development and identification.

The existence of a single indicator or a combination of indicators is not necessarily conclusive proof that a fire is of incendiary cause. However, the presence of indicators may suggest that the fire deserves further investigation.

17-2 Incendiary Fire Indicators. There are a number of conditions related to fire origin and spread that may provide physical evidence of an incendiary fire cause.

17-2.1 Multiple Fires. Multiple fires are two or more separate, nonrelated, simultaneously burning fires. The investigator should search to uncover any additional fire sets or points of origin that may exist. In order to conclude that there are multiple fires, the investigator should determine that any "separate" fire was not the natural outgrowth of the initial fire.

Fires in different rooms, fires on different stories with no connecting fire, or separate fires inside and outside a building are examples of multiple fires. A search of the fire building and its surrounding areas should be conducted to determine whether there are multiple fires.

Apparent multiple fires can result through spread by the following means:

(a) Conduction, convection, or radiation
(b) Flying brands
(c) Direct flame impingement
(d) Falling flaming materials (i.e., drop down) such as curtains
(e) Fire spread through shafts, such as pipe chases or air conditioning ducts
(f) Fire spread within wall or floor cavities within "balloon construction"
(g) Overloaded electrical wiring
(h) Utility system failures

Apparent multiple points of origin can also result from continued burning at remote parts of a building during fire suppression and overhaul, particularly when building collapse or partial building collapse is involved.

The earlier a fire is extinguished, the easier it is to identify multiple points of origin. Once full room involvement or room-to-room extension has occurred, identifying multiple fires becomes more difficult and a complete burnout or "black hole" may make identification impossible.

If there has been a previous fire in the building, care should be taken not to confuse earlier damage with a multiple fire situation.

Fire scene reconstruction *(see Section 11-7)*, an important aspect of the fire scene examination, is especially important when multiple fires are suspected.

A careful examination of the fire scene may reveal additional fire sets (which are intended to ignite additional fires), particularly in the same type of area. For example, if the investigator observes or discovers an area of origin in a closet, an examination of other closets for additional fires or fire sets is prudent. The investigator may be required to obtain legal authority to conduct a search in areas not affected or involved in the discovered fire. *(See 5-2.2 and 5-2.3.)*

Confirmation of multiple fires is a compelling indication that the fire was incendiary.

17-2.2 Trailers. After incendiary fires, when fuels have been intentionally distributed or "trailed" from one area to another, elongated patterns may be visible. Such fire patterns, known as "trailers," can be found along floors to connect separate fire sets, or up stairways to move fires from one story or level within a structure to another. Fuels used for trailers may be ignitible liquids, solids, or combinations of these. *(See Figure 4-18.1.)*

Materials such as clothing, paper, straw, and ignitible liquids are often used. Remnants of solid materials frequently are left behind and should be collected and documented.

Ignitible liquids may leave linear patterns, particularly when the fires are extinguished early. Radiant energy from the extension of flame or hot gases through corridors or up stairways can also produce linear patterns. As with suspected solid accelerants, samples of possible liquid accelerants should be collected and analyzed. *(See Section 9-5.)*

Often, when the floor area is cleared of debris to examine damage, long, wide, straight patterns will be found showing areas of extensive heat damage, bound on each side by undamaged or less damaged areas. These patterns have often been interpreted to be trailers. While this is possible, the presence of furniture, stock, counters, or storage may result in these linear patterns. These patterns may also result from fire impact on worn areas of floors and the floor coverings. Irregularly shaped objects on the floor, such as clothing or bedding, may provide protection to the floor, resulting in patterns that may be inaccurately interpreted.

For example, gasoline itself poured out to assist the fire is an accelerant. It is the deliberate use of the gasoline to spread the fire from one location to another that causes the stream of gasoline to be a trailer. Trailing gasoline from one room to another and up the staircase constitutes laying a trailer. Dousing a building with gasoline from cellar to rooftop or over a widespread area does not constitute laying a trailer; instead, it is considered using an accelerant. So it can be seen that the fuel does not constitute a trailer, but rather the manner in which the fuel or accelerant is used. This is similar to the "use" requirement in the definition of an accelerant. The burning action has no effect on whether there is a trailer. Gasoline, rags, or newspapers can all be used as trailers, but they burn differently. The pattern that is left by a trailer is evidence of the trailer; the pattern is not the trailer. If an arsonist lays a trailer but is arrested prior to ignition, there is still a trailer.

17-2.3 Lack of Expected Fuel Load or Ignition Sources. When the fire damage at the origin is inconsistent with the expected low fire loads, limited rates of heat release, or limited potential-accidental ignition sources, the fire may be incendiary. An example of all three is an isolated burn at floor level in a large, empty room. Examples of limited fire load areas include corridors and stairways. Stairways, while usually having limited fire loads, may promote rapid fire spread by allowing flames or hot gases to travel vertically to other areas. This action may cause severe damage on exposed stairway surfaces. Additional examples of areas with limited potential-accidental ignition sources include closets, crawl spaces, and attics.

17-2.4* Exotic Accelerants. Mixtures of fuels and Class 3 or Class 4 oxidizers *(see NFPA 430, Code for the Storage of Liquid and Solid Oxidizers)* may produce an exceedingly hot fire and may be used to start or accelerate a fire. Thermite mixtures also produce exceedingly hot fires. Such accelerants generally leave residues that may be visually or chemically identifiable.

Exotic accelerants have been hypothesized as having been used to start or accelerate some rapidly growing fires and were referred to in these particular instances as high temperature accelerants (HTA). Indicators of exotic accelerants include an exceedingly rapid rate of fire growth, brilliant flares (particularly at the start of the fire), and melted steel or concrete. A study of 25 fires suspected of being associated with HTAs during the 1981–1991 period revealed that there was no conclusive scientific proof of the use of such HTA.

In any fire where the rate of fire growth is considered exceedingly rapid, other reasons for this should be considered in addition to the use of an accelerant, exotic or otherwise. These reasons include ventilation, fire suppression tactics, and the type and configuration of the fuels.

17-2.5 Unusual Fuel Load or Configuration. If the investigation reveals the presence of an unusually large fuel load in the area of origin, or a fuel load in the area of origin that either would normally not be expected in that area or would not be expected to be in the configuration in which it was found, the fire may be incendiary. An example of an unusual configuration is where furniture, stock, or contents are deliberately stacked or piled in a configuration to encourage rapid or complete fire development. An example of an unusually large fuel load is where accumulations of trash, debris, or cardboard cartons are deliberately introduced into a room or space in order to encourage greater fire involvement.

17-2.6 Burn Injuries. The manner and extent of burn injuries may provide clues to the origin, cause, or spread of the fire. Burn injuries may be sustained while setting an incendiary fire. The investigator should ascertain whether the fire victim's burns and the nature and extent of the injuries are consistent with the investigative hypothesis regarding fire cause and spread. The investigator should check the local hospitals for the identification of any persons admitted or treated for burn injuries.

17-2.7 Incendiary Devices. *Incendiary device* is a term used to describe a wide range of mechanisms used to initiate an incendiary fire. In some cases, the fire setter may have used more than one incendiary device. Frequently, remains of the fuel used will be found with the ignition device. If an incendiary fire is suspected, the investigator should search for other fire sets that may have burned out or failed to operate.

WARNING: When an incendiary device is discovered that has not activated, *do not move it!* Such devices must be handled by specially trained explosive ordinance disposal personnel. Touching or moving such devices is extremely dangerous and can result in an ignition or explosion.

17-2.7.1 Examples of Incendiary Devices. Examples of some incendiary devices, and the evidence that may establish their presence or use, are as follows:

(a) Books of paper matches and cigarettes from which the striker from the matchbook, cigarette filters, remaining cigarette ash, and the combustible materials ignited by the matches or cigarettes may be found in the area of origin

(b) Candles from which their wax and the remains of any combustible material ignited by the candles may be found in the area of origin

(c) Wiring systems or electric heating appliances to initiate a fire (which may be evidenced by indications of tampering or modification of the wiring system, by the movement or arrangement of heat-producing appliances to locations near combustible materials, or by evidence of combustible materials being placed on or near heat-producing appliances)

(d) Fire bombs, commonly called Molotov cocktails (which leave evidence in the form of the ignitible liquid, chemicals, or compounds used within them, the broken containers, and wicks)

(e) Paraffin wax-sawdust incendiary device (which can be evidenced by remains of wax impregnated with sawdust, e.g., artificial fire logs)

17-2.7.2 Delay Devices. Timers or delay devices can be employed to allow the fire setter an opportunity to leave the scene and possibly establish an alibi prior to the ignition. Common delay devices include candles, cigarettes, and mechanical or electrical timers.