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NFPA 921
Fire and Explosion Investigations
1992 Edition

NFPA®

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Policy Adopted by NFPA Board of Directors on December 3, 1982

The Board of Directors reaffirms that the National Fire Protection Association recognizes that the toxicity of the products of combustion is an important factor in the loss of life from fire. NFPA has dealt with that subject in its technical committee documents for many years.

There is a concern that the growing use of synthetic materials may produce more or additional toxic products of combustion in a fire environment. The Board has, therefore, asked all NFPA technical committees to review the documents for which they are responsible to be sure that the documents respond to this current concern. To assist the committees in meeting this request, the Board has appointed an advisory committee to provide specific guidance to the technical committees on questions relating to assessing the hazards of the products of combustion.

Statement on NFPA Procedures

This material has been developed under the published procedures of the National Fire Protection Association, which are designed to assure the appointment of technically competent Committees having balanced representation. While these procedures assure the highest degree of care, neither the National Fire Protection Association, its members, nor those participating in its activities accepts any liability resulting from compliance or noncompliance with the provisions given herein, for any restrictions imposed on materials or processes, or for the completeness of the text.

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NFPA 921

Guide for

Fire and Explosion Investigations

1992 Edition

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 18-20, 1991 in Montréal, Québec, Canada. It was issued by the Standards Council on January 17, 1992, with an effective date of February 10, 1992.

The 1992 edition of this document has been approved by the American National Standards Institute.

Origin and Development of NFPA 921

This is the first edition of NFPA 921, *Guide for Fire and Explosion Investigations*. It was developed by the 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 civil litigation. Throughout the development of this document, it has been the goal of the Committee to provide guidance that is based on accepted scientific principles or scientific research.

The first edition is focused largely on the determination of origin and cause of fires and explosions involving structures. The Committee realizes this first edition is not complete and is continuing work on expanding this guide. Future editions will deal with the investigation of fires in vehicles and on wildlands, failure analysis, and the analysis of specific equipment or products when they are involved in fires.

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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 the membership may have occurred.

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.

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

Information on referenced publications can be found in Chapter 14 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 a recommended practice for the 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.

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.

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) where zero is the lowest possible temperature and 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 ignitable liquid, used to initiate or speed the spread of fire.

Accident. An unplanned event, sometimes but not necessarily injurious or damaging, that interrupts an activity. A chance occurrence arising from unknown causes; an unexpected happening due to carelessness, ignorance, and the like.

Ambient. Surrounding, especially pertaining to the local environment, as in ambient air and ambient temperature.

Approved. Acceptable to the "authority having jurisdiction."

NOTE: The National Fire Protection Association does not approve, inspect or certify any installations, procedures, equipment, or materials nor does it approve or evaluate testing laboratories. In determining the acceptability of installations or procedures, equipment or materials, the authority having jurisdiction may base acceptance on compliance with NFPA or other appropriate standards. In the absence of such standards, said authority may require evidence of proper installation, procedure or use. The authority having jurisdiction may also refer to the listings or labeling practices of an organization concerned with product evaluations which is in a position to determine compliance with appropriate standards for the current production of listed items.

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

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 (oxygen) into a confined space containing oxygen deficient superheated products of incomplete combustion.

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. See Fire Cause.

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 set of rules and standards that have been adopted as mandatory regulations having the force and effect of law.

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 including as examples 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 draw along with or after.

Explosion. A physical reaction characterized by the presence of high pressure gas, confinement of that high pressure gas, rapid production or release of that pressure, and change or damage to the confining (restricting) element, structure, container, or vessel caused by the pressure release.

Explosive. Any chemical compound, mixture, or device the primary purpose of which is to function 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 a structure, component, or system resulting in unsatisfactory performance of the function for which it was designed.

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

Fall Down. See Drop Down.

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

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

Fire Cause. The circumstances or agencies that bring a fuel and an ignition source together with proper air or oxygen.

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. Flaming leading edge of a combustion reaction, which can be stationary or moving.

Flammable. Capable of burning with a flame.

Flammable Limit. The extreme concentration limits of a combustible in an oxidant through which a flame, once initiated, will continue to propagate at the specified temperature and pressure.

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 with extreme rapidity, such as one that races over dust, over the surface of flammable liquids, or through gases.

Flashover. A stage in the development of a contained fire in which all exposed surfaces reach ignition temperature more or less simultaneously and fire spreads rapidly throughout the space.

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.

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, i.e., quantity and geometry. Adequate air for combustion is available.

Fuel Gas. Natural gas, manufactured gas, LP-Gas, and similar gases commonly used for commercial or residential purposes, i.e., 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.

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/sq ft/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: "equipment involved in ignition" and "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. An explosive that has a reaction velocity greater than 3300 ft/sec.

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

Ignitable 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 burn.

Ignition. The process of initiating self-sustained combustion.

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

Ignition Temperature. Minimum surface temperature a substance must attain in order to ignite under specific test conditions. Ignition after 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.

Low Order Explosion. A slow rate of pressure rise or low force explosion characterized by a pushing or dislodging effect upon 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.

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.

Pointer. The difference in height of a series of fire-damaged vertical wood members ranging from high being farthest away from a source of heating to the shortest being closer.

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.

Rekindle. A return to flaming combustion after incomplete extinguishment, such as a fire reigniting at some time after being put out. Residual heat and hidden embers may restart a fire several hours after it has been declared out if overhauling has not been sufficiently thorough.

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.

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 crater-like 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.

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) An official, detailed statement of specifications and requirements, such as for equipment or testing. (b) An object that serves as a basis for comparison or acceptance.

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

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), it density (rho or ρ), and its heat capacity (c).

Thermoplastic. Plastic materials that will 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.

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.

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 inch = 2.54 centimeters
1 foot = 0.3048 meter
1 sq. foot = 0.09290 sq meter
1 cubic foot = 7.481 gallons
1 cubic foot = 0.02832 cubic meter
1 U.S. gal = 3.785 liters
1 pound = 0.4536 kilogram
1 ounce (weight) = 28.35 grams
1 foot per sec. = 0.3048 meter per sec
1 pound per cubic foot = 16.02 kilograms per cubic meter
1 gallon per minute = 0.06308 liters per second
1 atmosphere = pressure exerted by 760 millimeters of mercury of standard density at 0°C, 14.7 pound per sq inch, 101.3 kilopascal
1 Btu/sec = 1.055 kilowatts
1 Btu = 1055 joules
1 kilowatt = 0.949 Btu/sec

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 upon 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.

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 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 must determine that a problem exists. In this case a fire or explosion has occurred and the cause must 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 must define in what manner the problem can be solved. In this case, a proper origin and cause investigation must 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 upon 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.

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

2-3.6 Test the Hypothesis (Deductive Reasoning). All other reasonable origins and causes must 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 must either be discarded as not provable and a new more adequate hypothesis tested or the fire cause must be listed as "unknown."

2-4 Basic Method of a Fire Investigation. Using the scientific method in most fire or explosion incidents should involve the following six 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.

2-4.2 Preparing for the Investigation. The investigator should marshal his or her forces and resources and plan the conduct of the investigation.

2-4.3 Examination of the Scene. The investigator should conduct the examination of the scene and collect basic data necessary to the analysis.

2-4.4 Recording the Scene. The scene should be photographed and diagrammed, and notes of the progress of the investigation should be made. Valuable empirical data should be noted and preserved.

2-4.5 Collecting and Preserving Evidence. Valuable physical evidence should be recognized, properly collected, and preserved for further testing and evaluation or courtroom presentation.

2-4.6 Analyzing the Incident. An incident scenario or failure analysis should be described, explaining the origin, cause, and responsibility for the incident. This analysis should be reported in the proper forum to help prevent reoccurrence.

2-5 Reporting Procedure. The reporting procedure may take many written or oral forms, depending upon the specific responsibility of the investigator.

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 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 a self-sustained chemical 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.

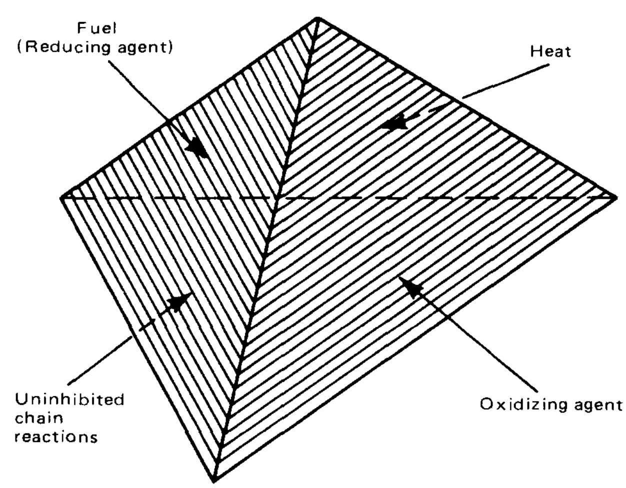


Figure 3-1.1 The tetrahedron of fire.

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 upon 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, and 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 will ignite easier and burn 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 will be 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 upon the fuel involved. As the temperature of the environment increases, the oxygen requirements are further reduced. 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 must be mixed in the correct ratio. In the case of solids and liquids, the pyrolysis products or vapors disperse away 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 will burn 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 will 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 or 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 or 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 Self-Sustained Chemical 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 upon the difference in temperature and the physical properties of the material. The properties are the thermal conductivity (k), the density (rho), 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/pound/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 (rho) 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) will 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 (rho), 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, rho, 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 (rho) 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).

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.

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.

NOTE: From *An Introduction to Fire Dynamics*, Douglas Drysdale, John Riley and Sons, 1985, pg. 36.

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 sixteen-fold increase in radiation between the two objects. *(See Figure 3-2.3 on the following page.)*

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 must 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 must 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 must 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, rho, 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 must 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.

Table 3-3
Reported Temperatures of Selected Ignition Sources

Source	Temperature °F	°C
Flames		
Benzene[A]	1690	920
Gasoline[A]	1798	1026
JP-4[B]	1700	927
Kerosene[A]	1814	990
Methanol[A]	2190	1200
Wood[C]	1800	1027
Ember[D]		
Cigarette (puffing)	1520-1670	830-910
Cigarette (free burn)	930-1300	500-700
Mechanical Spark[E]		
Steel Tool	2550	1400
Copper-nickel alloy	570	300

[A]*An Introduction to Fire Dynamics*, Dougal Drysdale, John Wiley and Sons, 1985.

[B]*The Heat Radiation from Petroleum Fires*, Hagglund and Persson, FOA Report C 20126-D6(A3) Forsvarerts Forskningsanstalt, Stockholm.

[C]*An Experimental Study of the Radiation from Wood Flames*, Hagglund and Persson, FOA Report C 4589-D6(A3) Forsvarerts Forskningsanstalt, Stockholm.

[D]*Cigarette Ignition of Soft Furnishings—A Literature Review with Commentary*, John Krasny, Center for Fire Research, National Bureau of Standards, June 1987.

[E]*Fire Protection Handbook*, 15th ed., NFPA, Quincy, MA. 1981, pp. 4-105.

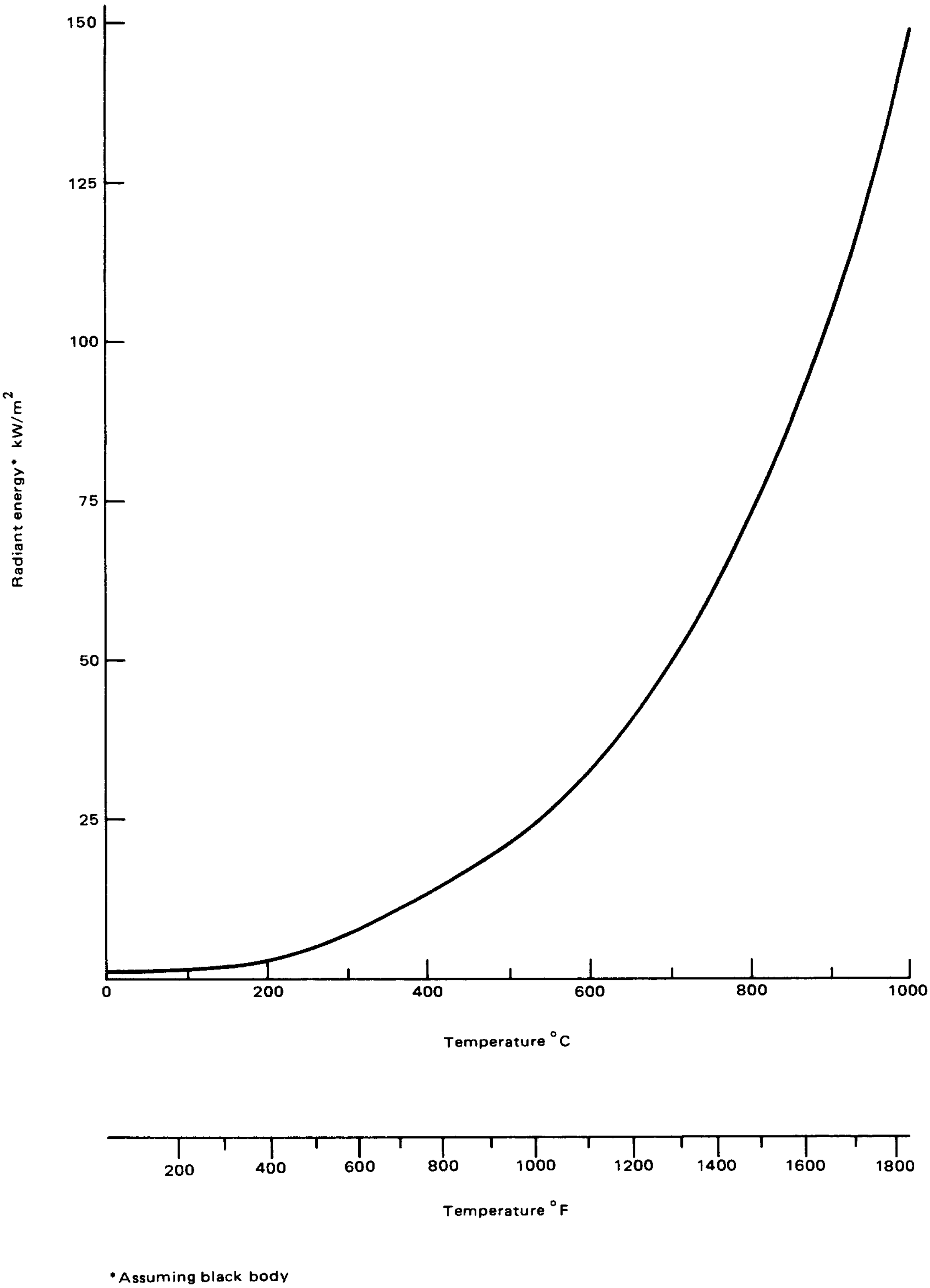


Figure 3-2.3 Relation of radiation to temperature.

3-3.1 Ignition of Solid Fuels. For solid fuels to burn with a flame, the substance must either be melted and vaporized (like thermoplastics) or be pyrolyzed into gases or vapors (i.e., wood or thermoset plastic). In both examples energy 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, will ignite 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 ignition of wood exposed to varying temperatures.

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

Table 3-3.1
Time Required to Ignite Wood Specimens

Wood 1¼ by 1¼ by 4 in. (32 × 32 × 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

NOTE: From *Fire Protection Handbook*, Table 3-3B, NFPA (17th edition 1991).

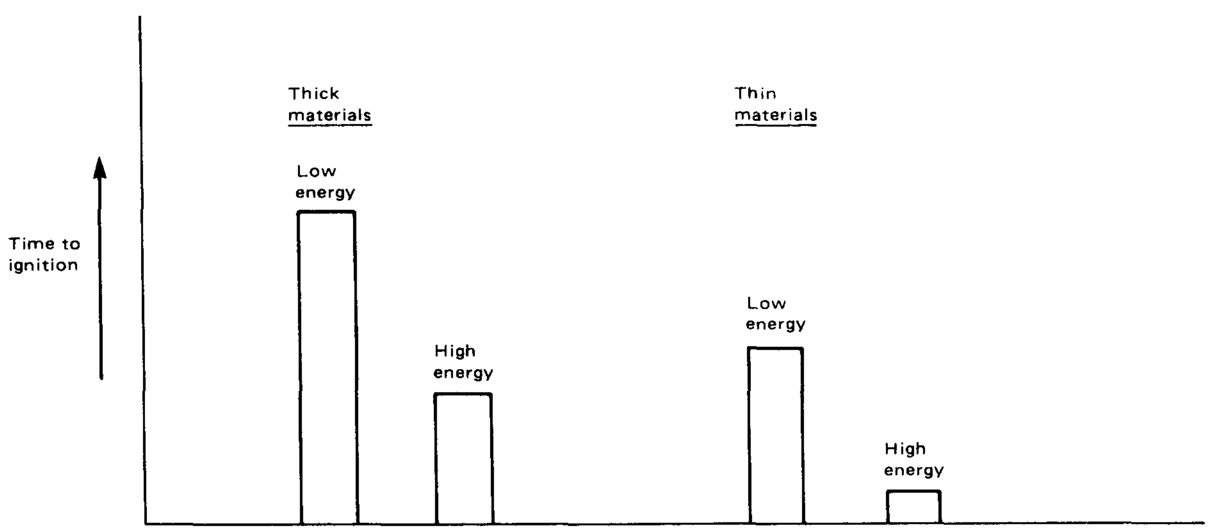


Figure 3-3.1(a) Relationship of energy source to ignition time for thick and thin materials.

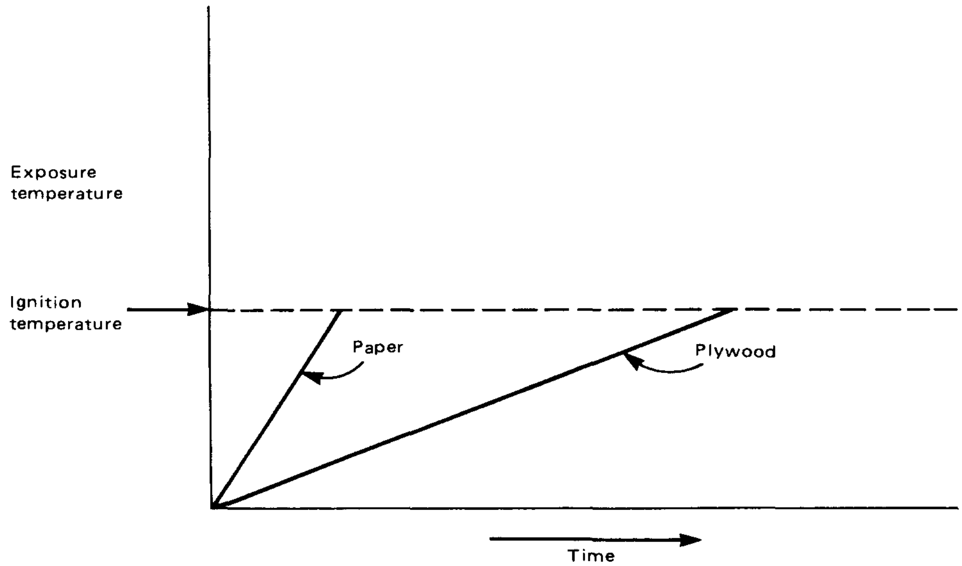


Figure 3-3.1(b) Relationship of material thickness to ignition time when exposed to ignition temperature.

3-3.2 Ignition of Liquids. In order for the vapors of a liquid to form an ignitable mixture, the liquid must 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.

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 must 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 must 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 must be sufficiently porous to allow for oxygen to permeate through the mass to the point of combustion and the material must 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.

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[F]
Toluene	896	480	—	—	2.5[F]
Gases[D]					
Acetylene	581	305	—	—	0.02[F]
Methane	999	537	—	—	0.28[F]
Natural Gas	900-1170	482-632	—	—	0.30[F]
Propane	842	450	—	—	0.25[E]

[A] *Fire Protection Handbook*, Table A-6, NFPA, (17th edition 1991)
[B] *Fire Protection Handbook*, pg 3-25, NFPA, (17th edition 1991)
[C] *Fire Protection Handbook*, Table 5-9A, NFPA, (16th ed. 1986)
[D] Ignition temperatures from NFPA 325M, *Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids*, 1991
[E] *The SFPE Handbook of Fire Protection Engineering*, Table 2-5.2, NFPA, 1988
[F] *Fire Protection Handbook*, Table 11-3B, NFPA, (15th edition 1981).

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.

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*, 17th edition. Omission of any material does not necessarily indicate that it is not subject to self-heating.

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

NOTE: Fire Protection Handbook, Table A-10, NFPA, 17th edition, 1991.

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 8,000 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."

Total fuel load in the room has no bearing on the rate of growth of a given fire in its pre-flashover stage. During this development stage, 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 above 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 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 light weight 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 (pounds)	Peak HRR (kW)
Wastebasket—small (1.5-3)	4-18
Trash Bags—11 gal with mixed plastic and paper trash (2½ - 7½)	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 sq foot 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

Values from:

Fire Behavior of Upholstered Furniture, Babrauskas and Krasny, NBS Monograph 173, National Bureau of Standards, November 1985

NFPA 72E, *Standard on Automatic Fire Detectors*, Table C-2-2.2.1(a), 1990 edition

Heat Release Rate Characteristics of Some Combustible Fuel Sources in Nuclear Power Plants, B. T. Lee, NBSIR 85-3195, National Bureau of Standards, 1985.

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. [*Figure 3-5.1(b).*]

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.

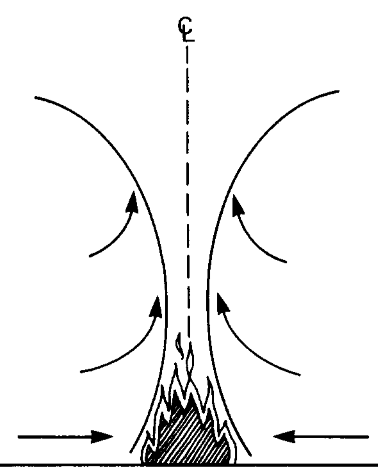


Figure 3-5.1(a) Fire plume in the open.

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.

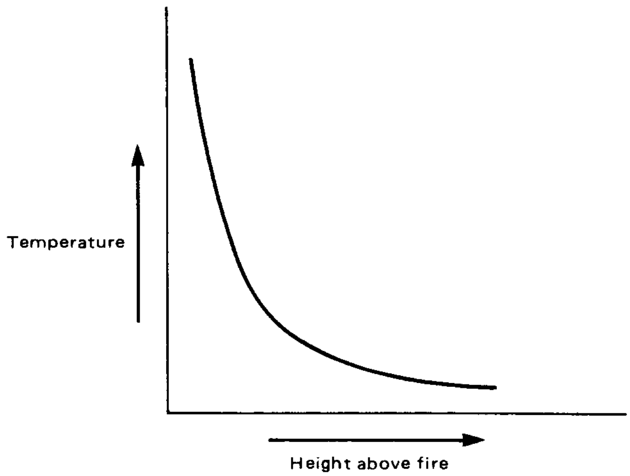


Figure 3-5.1(b) Temperature in a fire plume.

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) on the following page*].

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.

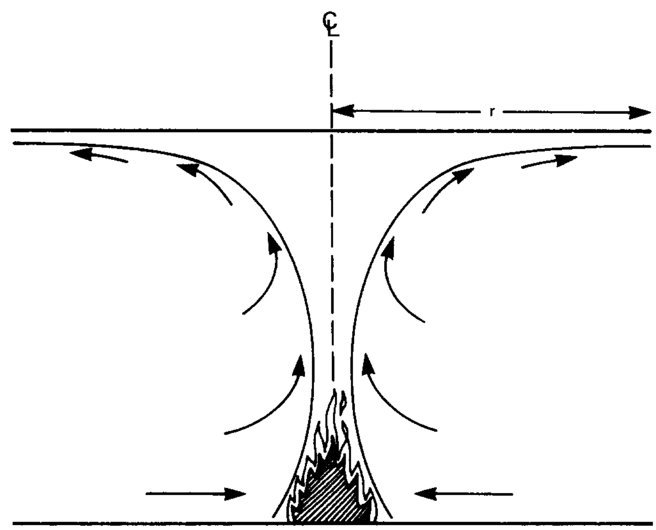


Figure 3-5.3.1(a) Fire confined by a ceiling in a large room.

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 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 suffi-

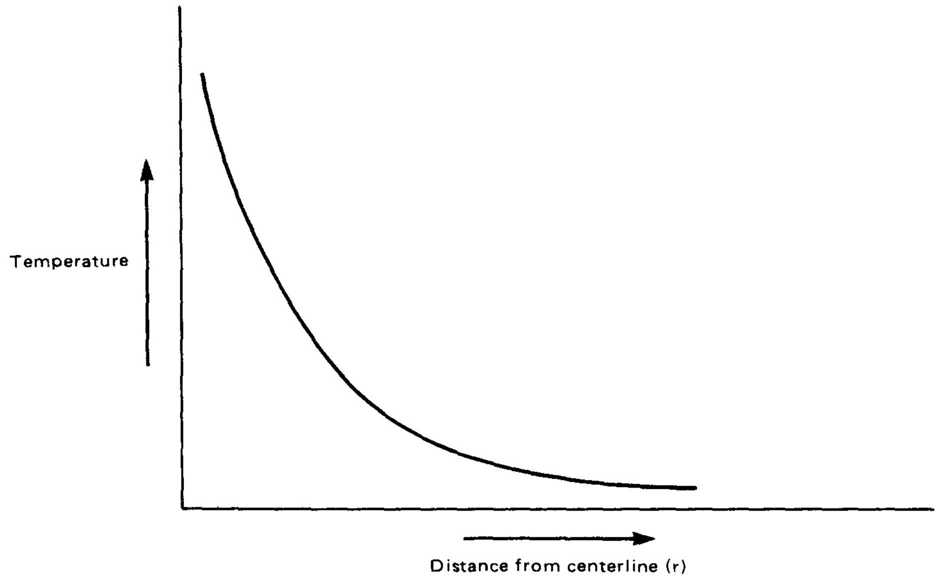


Figure 3-5.3.1(b) Ceiling layer temperature away from the plume.

cient 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.

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 upon 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.

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. From this stage until additional ventilation is provided by window or wall failure the fire will burn at a nearly steady rate controlled by the amount of air available.

Research has shown that time to flashover from open flame can be as short as 1½ 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 defined as the area of the opening (A_o) times the square root of the height of the opening (h_o).

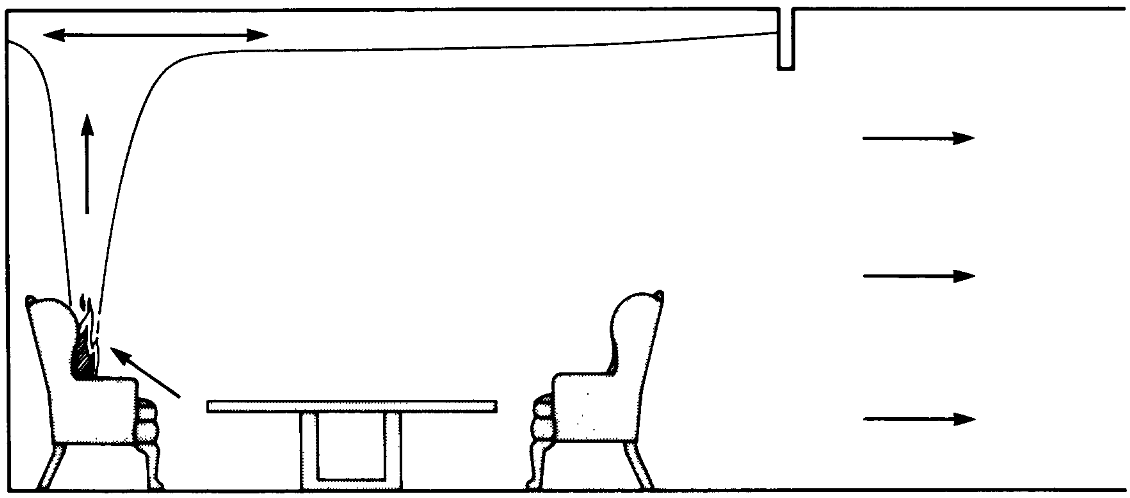


Figure 3-5.3.2(a) Early compartment fire development.

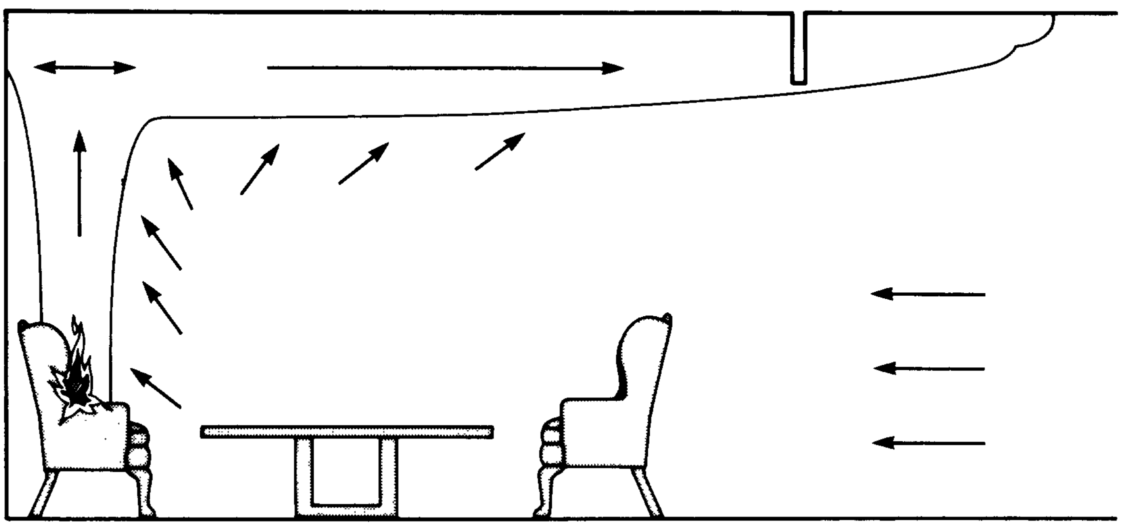


Figure 3-5.3.2(b) Ceiling layer development in compartment fire.

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

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

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

$$HRR_{fo}\ (Btu/sec) = 36.5\ A_o\ (h_o)^{0.5}$$

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

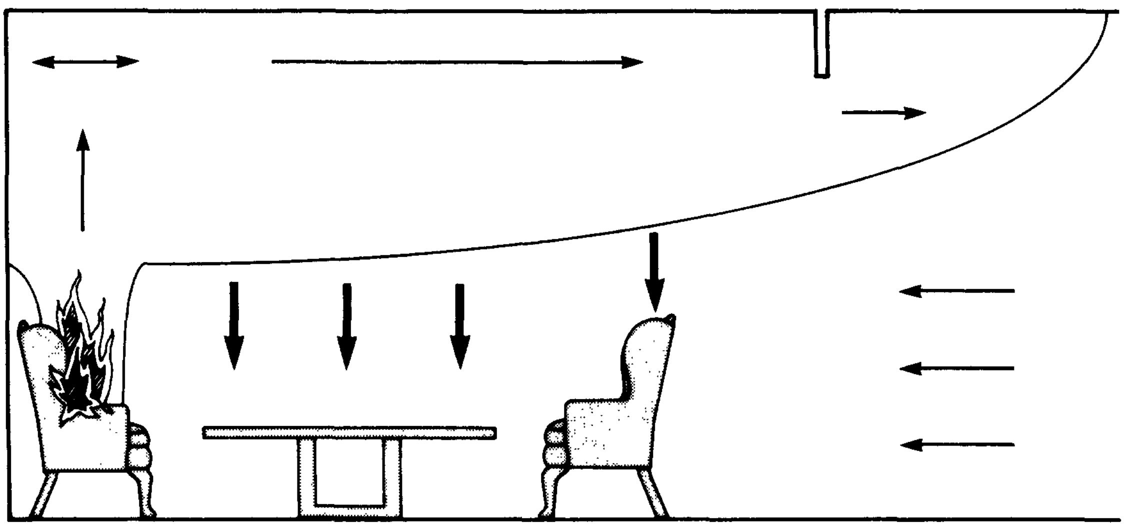
A log v. log graph of the HRR for a range of ventilation factors is shown in Figure 3-5.4.1 on page 23. If the room dimensions are known, a closer approximation can be found using the following relationship:

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

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 would be:

$$HRR_{fo}\ (Btu/sec) = 19\ A_o\ (h_o)^{0.5} + 0.74\ A_w$$

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



NOTE: Small arrows indicate airflow. Heavy arrows indicate radiation.

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

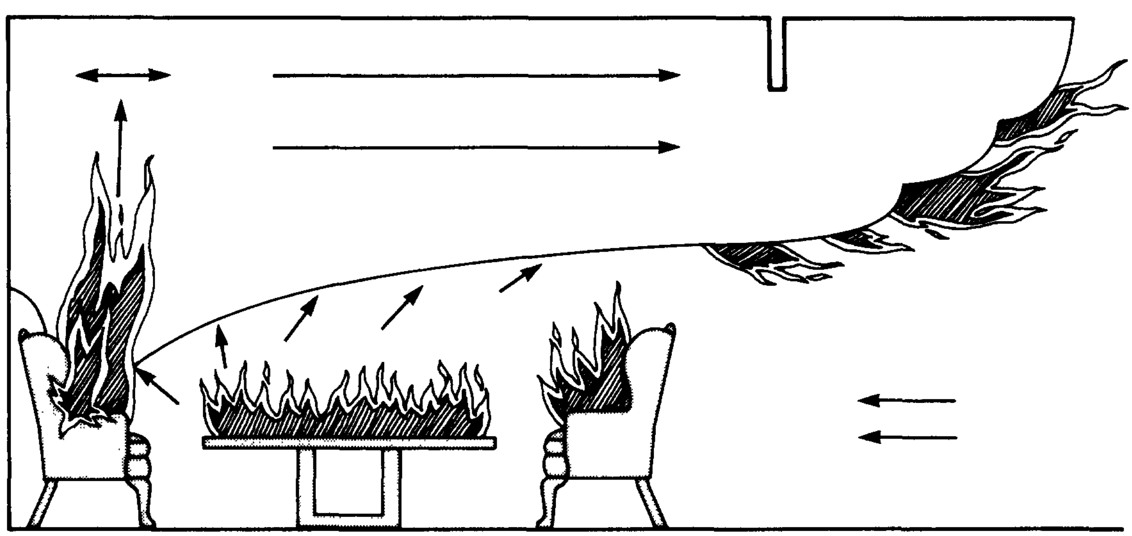
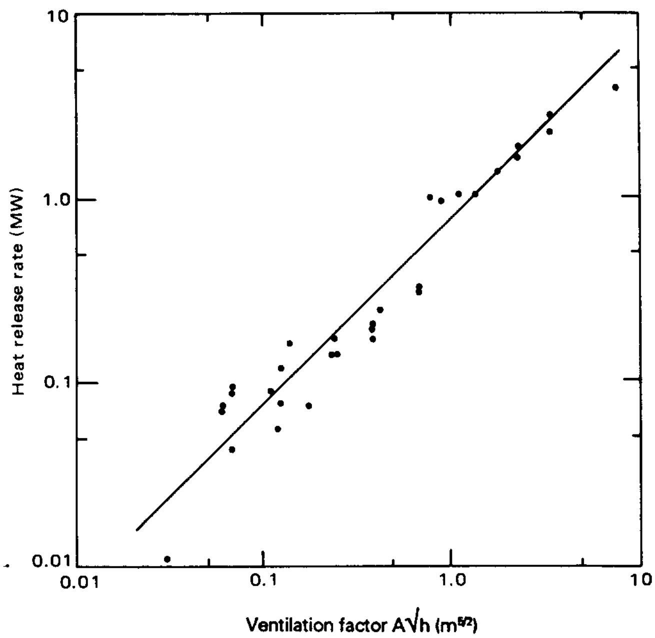


Figure 3-5.3.2(d) Flashover conditions in compartment fire.



NOTE: From "Estimating Room Flashover Potential," V. Babrauskas, *Fire Technology*, Vol. 16, No. 2 (May 1980), pp. 94-103.

Figure 3-5.4.1 Minimum heat release rate for flashover.

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, seventy-five percent (75%) 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 eliminated.

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.

3-6 Products of Combustion. The chemical products of combustion can vary widely depending upon 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 fire is gray or light colored, the same fuel under the low oxygen conditions of a post-flashover fire can be black. Black smoke can be produced by burning plastic materials as well as burning flammable 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 lower in the early stages of a fire but increase greatly with the onset of flashover.

3-7 Fire Pattern Development. 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 "V" pattern. Determining which pattern was produced at the point of origin by the first material ignited becomes more and 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.

3-7.1 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 3-7.1(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 3-7.1(b).*]

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.

3-7.2 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.

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. These types of patterns have often been erroneously attributed to ignitable liquids. It is more likely that holes in floors may be caused by glowing combustion or radiation. 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 ignitable liquids will probably only result when the ignitable liquid has soaked into the floor or accumulated below the floor level. Evidence other than shape alone is necessary to confirm that an ignitable liquid produced a given pattern.

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 3-7.2(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 3-7.2(b).*] This can also occur if glowing debris falls against the door either on the inside or the outside. [*See Figure 3-7.2(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.

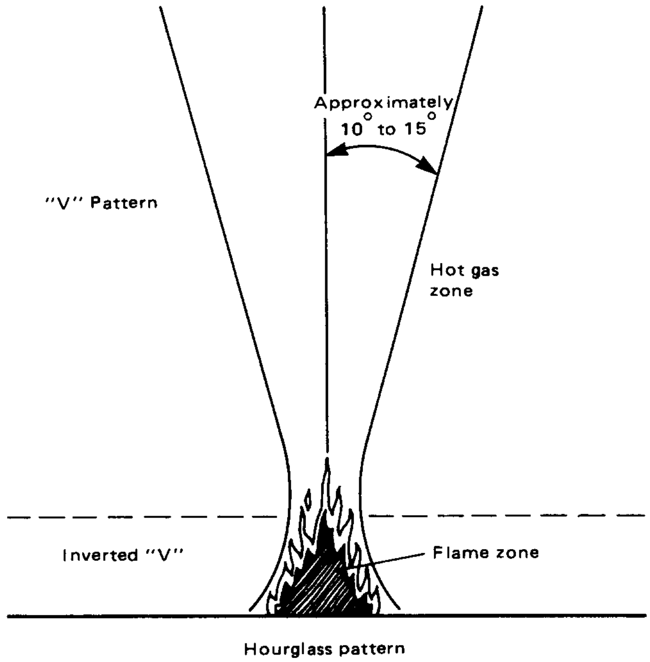


Figure 3-7.1(a) Hourglass pattern.

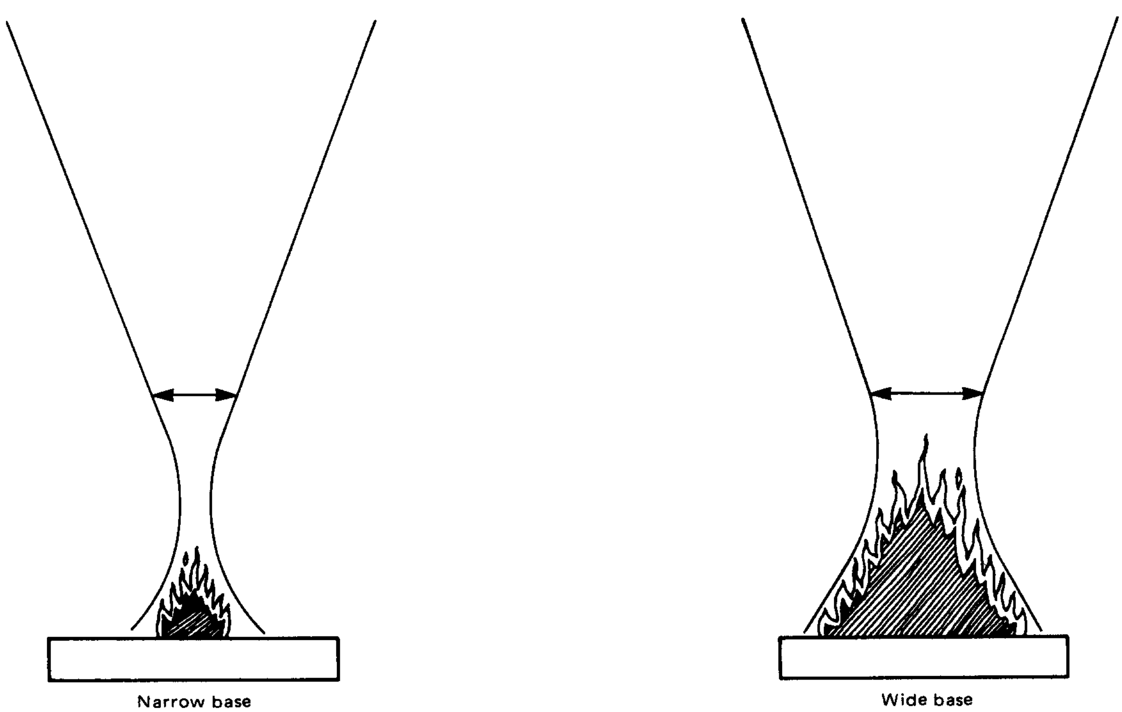


Figure 3-7.1(b) Effects of fire base on "V" width.

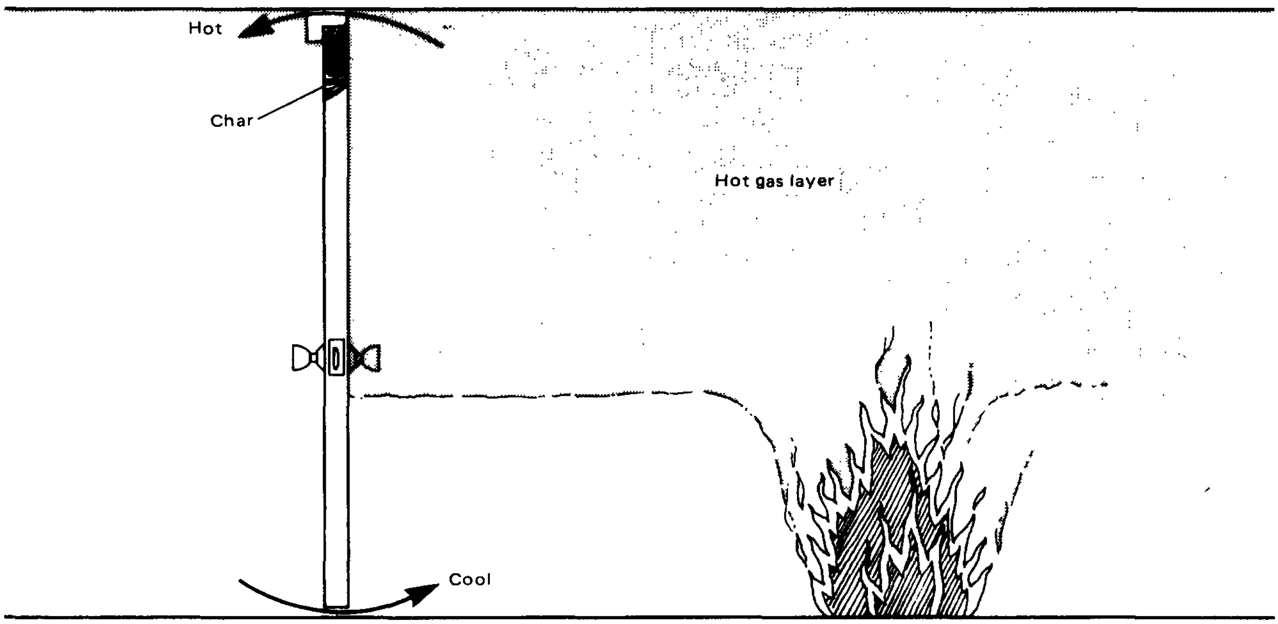


Figure 3-7.2(a) Airflow around door.

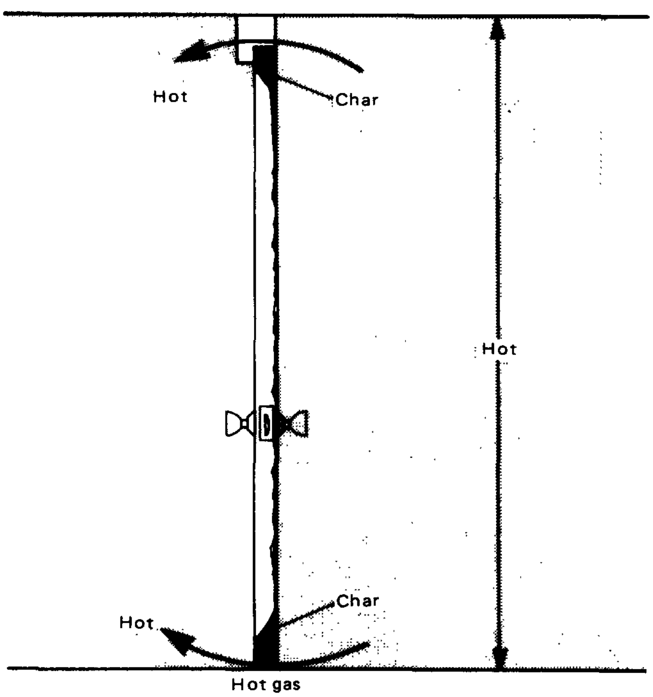


Figure 3-7.2(b) Hot gases under door.

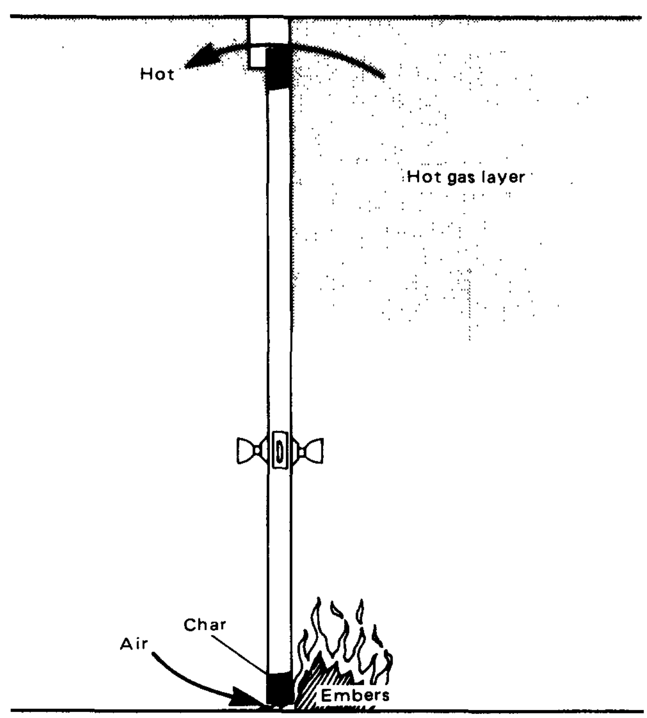


Figure 3-7.2(c) Glowing embers at base of door.

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 is dependent upon 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*).

4-3 Fire Patterns Defined. Fire patterns are the physical effects that are visible or measurable remaining 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 upon 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, are dependent upon 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, etc., may increase or decrease the rate of heat treatment or burning.

Combustible surfaces will be darkened by the beginnings of pyrolysis, 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, preexisting 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. Any downward penetration, such as a hole burned into a floor or a tabletop, should be carefully 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 on the following page*).

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.

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.

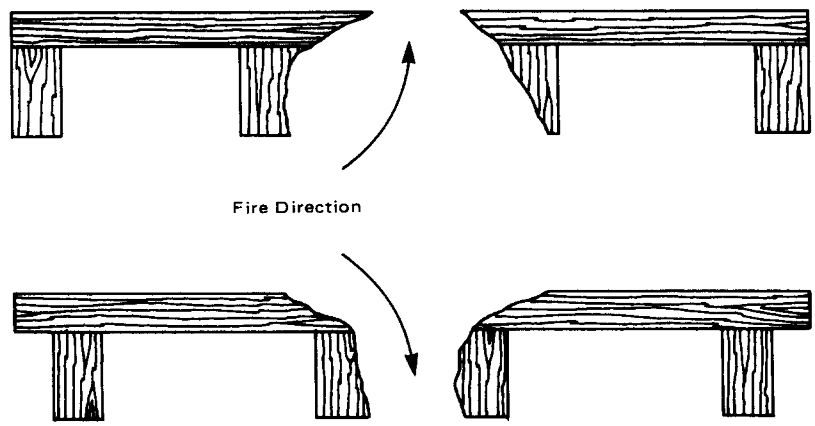


Figure 4-3.3. Burn pattern with fire from above and below.

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 char when heated. Vinyl and other plastic surfaces on walls, floors, tables, or counters also discolor and char. Wood surfaces also char, but, because of the greater significance of wood char, it is being treated in greater detail.

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. in 45 min 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. per hr at 750°F (390°C) to 10 in. per hr 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 had been 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 then 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:

(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) Char measurements should be compared only for identical materials. It would be invalid 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.

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.

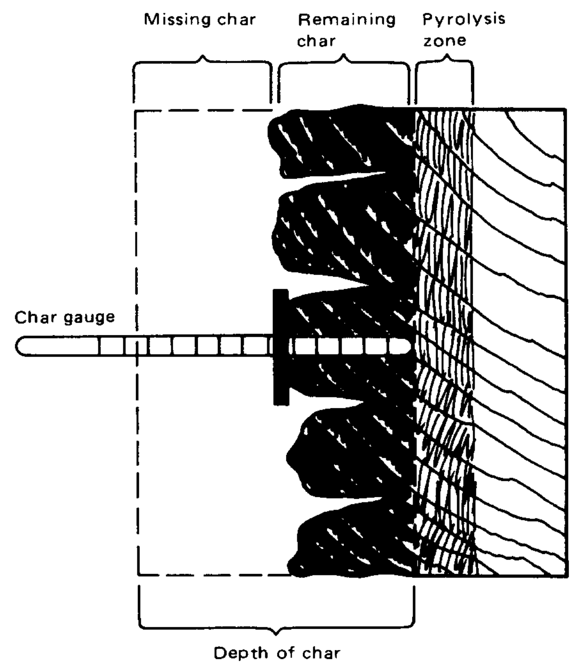


Figure 4-5.3.3 Measuring depth of char.

4-5.5 Misconceptions about 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. There is no scientific evidence of such a correlation, and the investigator is advised not to claim indications of accelerant 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:

(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 upon depth of char.

4-6 Spalling. Spalling, for use in fire investigations, 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, chipping, or 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 does involve high rates of heat release or a rapid rise in temperatures, accelerant need not be involved at all. 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.

4-6.1 Misconceptions about Spalling. The use of spalling evidence in fire investigations is one of the most misunderstood and improperly used evidential elements.

Among the misconceptions are that spalling is caused only by the presence of liquid accelerant. Exposure to any high rate of heating by flame or high levels of radiation from any fuel, whether solid, liquid, or gas, can cause spalling.

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 water.

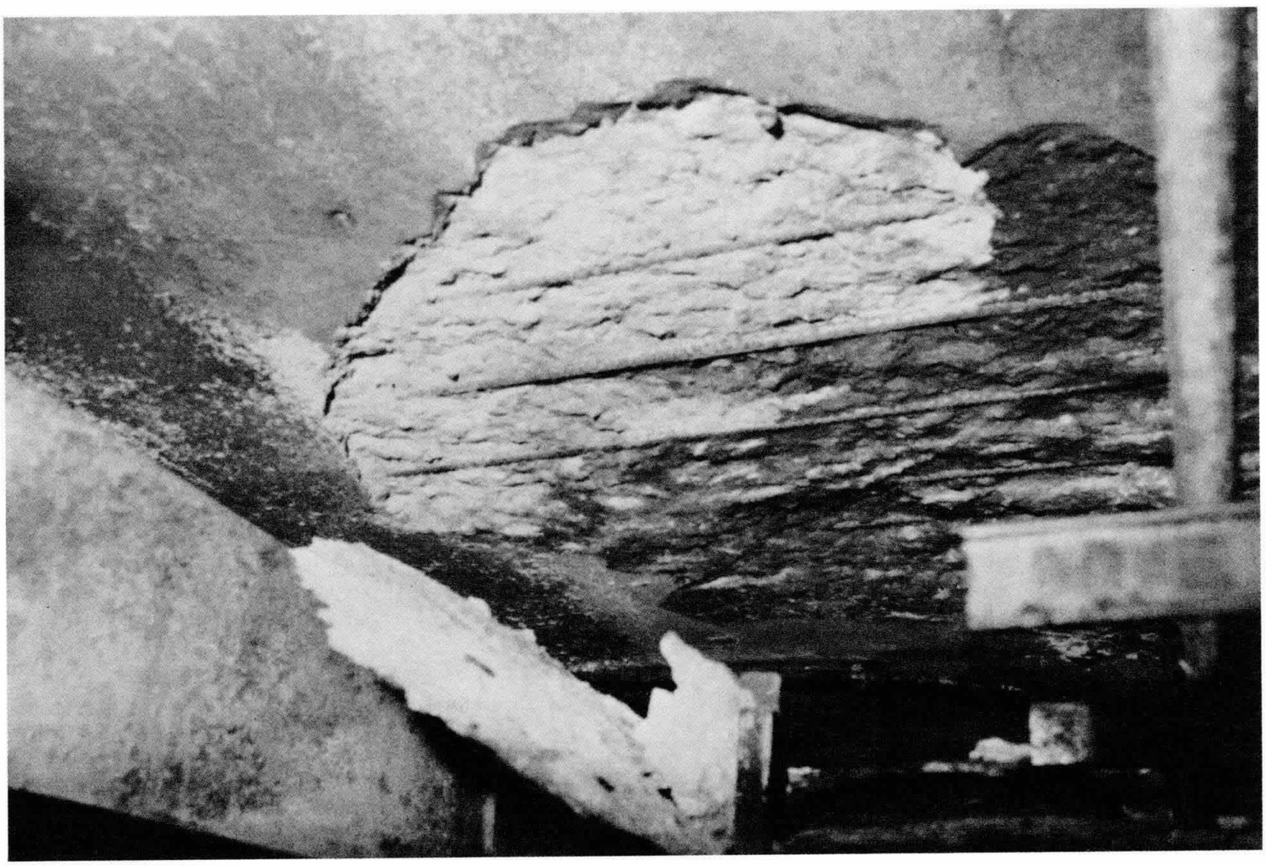


Figure 4-6 Spalling on ceiling.

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. Even the presence of high heat producing flammable liquids will not normally cause spalling. 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 ignitable liquid fire may cause spalling on adjacent surfaces, or a resultant fire may cause spalling on the surface after the ignitable liquid burns away.

In evaluating the significance of a spalled area, the investigator should identify the condition of the surface before 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.

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 temperatures to thousands of degrees. A specific melting temperature or range is characteristic for each material. (*See Table 4-8 on the following page.*)

Melting temperatures of common metals range from as low as 338-370°F (170-188°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 ignitable 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 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

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

Aluminum (Alloys)[B]	1050-1200°F	566-650°C
Aluminum[A]	1220°F	660°C
Brass (Yellow)[B]	1710°F	932°C
Brass (Red)[B]	1825°F	996°C
Bronze (Aluminum)[B]	1800°F	982°C
Cast Iron (Gray)[A]	2460-2550°F	1350-1400°C
Cast Iron (White)[A]	1920-2010°F	1050-1100°C
Chromium[A]	3350°F	1845°C
Copper[A]	1981°F	1082°C
Fire Brick (Insulating)[A]	2980-3000°F	1638-1650°C
Glass[A]	1100-2600°F	593-1427°C
Gold[A]	1945°F	1063°C
Iron[A]	2802°F	1540°C
Lead[A]	621°F	327°C
Magnesium (AZ31B alloy)[B]	1160°F	627°C
Nickel[A]	2651°F	1455°C
Paraffin[A]	129°F	54°C
Plastics (Thermo)		
ABS[D]	190-257°F	88-125°C
Acrylic[D]	194-221°F	90-105°C
Nylon[D]	349-509°F	176-265°C
Polyethylene[D]	251-275°F	122-135°C
Polystyrene[D]	248-320°F	120-160°C
Polyvinylchloride[D]	167-221°F	75-105°C
Platinum[A]	3224°F	1773°C
Porcelain[A]	2820°F	1550°C
Pot Metal[E]	562-752°F	300-400°C
Quartz (SiO_2)[A]	3060-3090°F	1682-1700°C
Silver[A]	1760°F	960°C
Solder (Tin)[A]	275-350°F	135-177°C
Steel (Stainless)[B]	2600°F	1427°C
Steel (Carbon)[B]	2760°F	1516°C
Tin[A]	449°F	232°C
Wax (Paraffin)[C]	120-167°F	49-75°C
White Pot Metal[E]	562-752°F	300-400°C
Zinc[A]	707°F	375°C

[A] *Marks' Standard Handbook for Mechanical Engineers*, Eighth edition, McGraw-Hill, Inc., New York.
[B] *Handbook of Chemistry and Physics*, 71st edition, CRC Press, Boca Raton, 1990-1991.
[C] NFPA 325M, *Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids*, 1991 edition.
[D] *Plastics Handbook*, 1986-1987 edition, McGraw-Hill, Inc., New York, October 1986.
[E] *Engineering Formulas, Kurt Gleck, 5th edition, McGraw-Hill, Inc., New York, 1986.*

"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 if 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.

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 wire that has been alloyed with aluminum will be very brittle at the spot of alloying and will likely break there if bent.

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.

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 onto them during and after sooty fires. When smoke deposits on a window are heated later in a fire, the brown deposit will be carbonized and turn black.

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. 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.

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

Figure 4-11 Clean burn on wall surface.

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 board 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 the fire. These include rate of heating, degree of insulation to the edges of the glass provided by glazing, degree of restraint provided by the window frame, history of flame contact, and cooling history. The following discussion relates to common flat or plate glass.

4-13.1* Breaking of Glass. Current research indicates that temperature gradients in the glass between the exposed glass and the insulated portions of 140°F (60°C) or greater will result in long, smoothly undulating cracks radiating from the edges of the frame to the center of the pane.

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

Although it would appear logical that very rapid heating would result in a complicated pattern of small cracks (generally called "crazing"), this has not been confirmed by research.

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

The investigator is urged to be careful not to make conclusions from glass breaking morphology alone. Both types of damage have been found in adjacent windows. The small craters or pits found in the surface of glass are believed to result from rapid cooling by water spray during fire suppression activities.

4-13.2 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 erroneously interpreted as positive proof of the presence or use of liquid accelerant. Such staining can also result from the incomplete combustion of wood or other cellulosic materials. Such staining, therefore, cannot be exclusively interpreted as having come from an accelerant.

4-14* Collapsed Furniture Springs. The collapse of springs cannot be used to indicate exposure to a specific heat source, such as "flaming accelerant" or "smoldering combustion." Actual laboratory testing has shown that the annealing of springs and the associated loss of spring tension are merely a function of the total heat treatment. Both short-term heating at high temperatures and long-term heating at moderate temperatures over about 750°F (about 400°C) can anneal furniture springs and cause them to loose their springiness. The presence of a weight load upon the springs at the time of heating increases the loss of spring tension.

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 upon 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 in 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 prohibiting the products of combustion from depositing on the material that the object protects.

The object prohibiting the depositing of products of combustion may be a solid or liquid, combustible or noncombustible. Any object that prohibits the settling of the products of combustion may cause the production of a pattern on the material it protects.

Patterns produced by protected areas may, however, assist the fire investigator in the process of reconstruction during the origin determination.

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 inside of walls.

Exterior surfaces would commonly include: walls, eaves, roofs, doors, windows, gutters and down spouts, 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.

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.*)

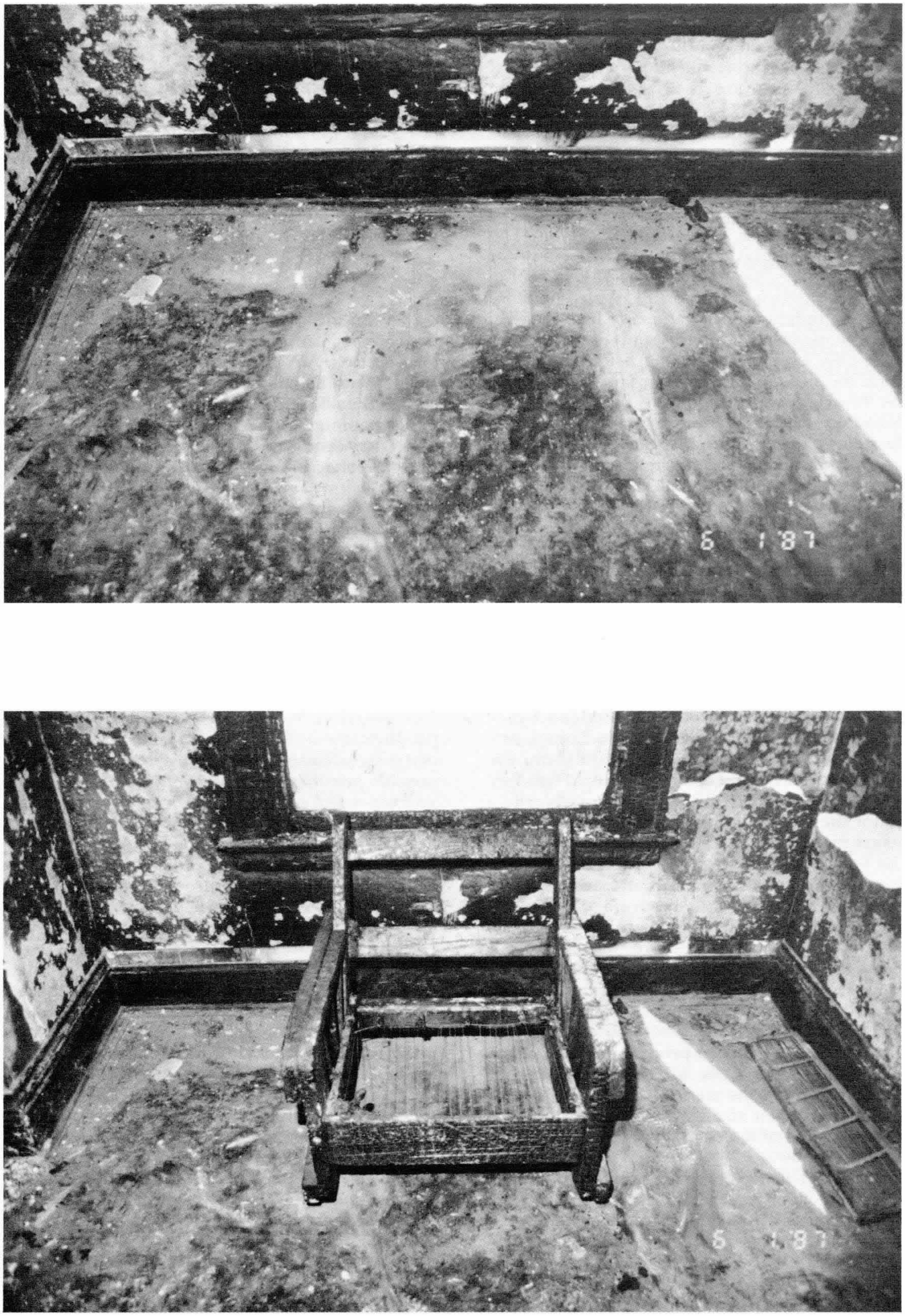


Figure 4-15.2 Photograph on top shows protected area while photograph at bottom shows how the chair was positioned during the fire.

4-16.1.1 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 Floors. Floors should not be ignored by the investigator. Patterns on floors and floor coverings are produced by the effects of intense radiation from flaming furniture, melted plastic, and burning liquids and from the hot gas layer produced by and after flashover. Flashover produces a radiant heat flux that exceeds 2 watts/cm^2, a typical value for the radiant ignition of common combustible construction materials.

Seams or cracks between floorboards and areas around door thresholds can show evidence of burning from radiation or collection of ignitable liquids within the space between boards. In cases where room flashover has not occurred, burning in the cracks between floorboards may indicate the presence of ignitable liquids and may be confirmed by laboratory tests.

Post-flashover burning can also produce holes in floors and around door thresholds due to the presence of hot combustible fire gases and the air source provided by the gaps in construction. Even small gaps can provide sufficient air for combustion of floors.

Fire-damaged vinyl floor tiles often exhibit curled tile edges exposing the floor beneath. This action has been attributed to the action of ignitable liquids dissolving the adhesive and burning in the resulting cracks.

The curling of tile edges can be frequently 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 ignitable 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.

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 longer 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 must 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 below 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 3-7, Fire Pattern Development.

Since the interpretation of all possible fire patterns cannot be directly traced 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.

4-17.1 "V" Shaped Patterns. The "V" shaped pattern is a common fire pattern displayed on vertical surfaces, such as walls, doors, and the sides of furnishings and appliances.

The lateral spread of the sides of the pattern is created by the radiated heat energy from above and by the upward and outward movement of flames and hot gases when encountering a horizontal obstruction, such as a ceiling, eaves, tabletop, or shelf.

The angled lines of demarcation, which produce the "V" pattern, can often be traced back, from the higher to lower levels, toward a point of origin. The low point or vertex of the "V" may often indicate the point of origin. Generally, the more obtuse or wide the angle of the "V," the longer the burned material will have been subjected to the heating where combustible walls are involved (*see 3-7.1*).

The angle of the "V" on a vertical combustible surface will be wider than on a noncombustible surface for a comparable heat source and time of burning.

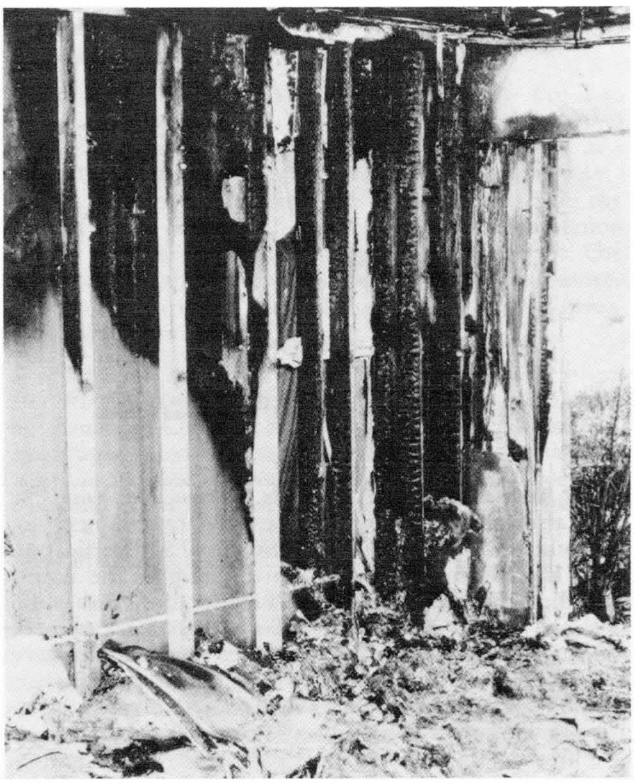


Figure 4-17.1 Typical "V" pattern showing wall and wood stud damage.

4-17.1.1 Misconceptions about "V" Patterns. A common misconception associated with the shape of "V" patterns is that narrow angle "Vs" are produced by "fast burning fires" and wide angle "Vs" are produced by "slow burning fires." The angles of lines of demarcation of a "V" pattern are actually associated with the size of the fire, burning rate, ventilation, and combustibility of walls rather than the relative rate of heat release alone (*see 3-7.1*). The value of these patterns lies in the direction of spread that they depict, not in what caused them.

4-17.2 Inverted Cone Patterns. Inverted cones, often called inverted "Vs" are triangular patterns, wider at their base than at the top. They are almost always displayed by lines of heat and temperature demarcation on vertical walls emanating from floor level. They are most commonly associated with volatile fuels, such as pooled flammable or combustible liquids or natural gas.

Inverted cones are commonly caused by the vertical flame plumes of the burning volatile fuels not reaching the ceiling. The type of fuel source combined with the geometry of the room in which they occur and the width of the fuel source base at floor level are the major factors in their formation.

4-17.2.1 Misconceptions about Inverted Cone Patterns. Many common misconceptions abound about the formation factors and significance of the inverted cone pattern. The term inverted cone is often used as a misnomer for the truncated cone pattern, but they are neither synonymous nor even directly related.

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.

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. 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

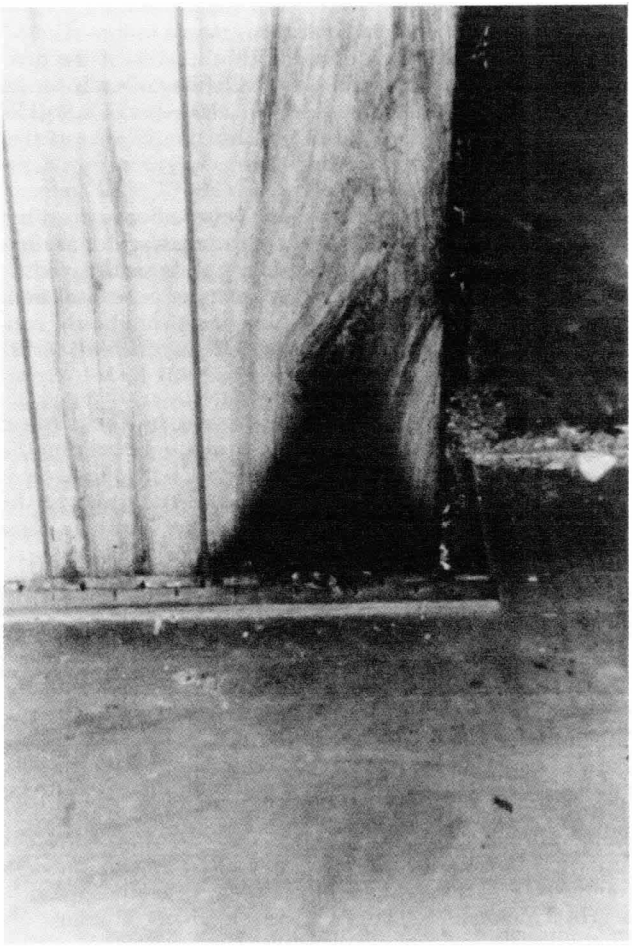


Figure 4-17.2.2 Inverted cone pattern at the floor level.

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 3-7.1*).

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. "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.

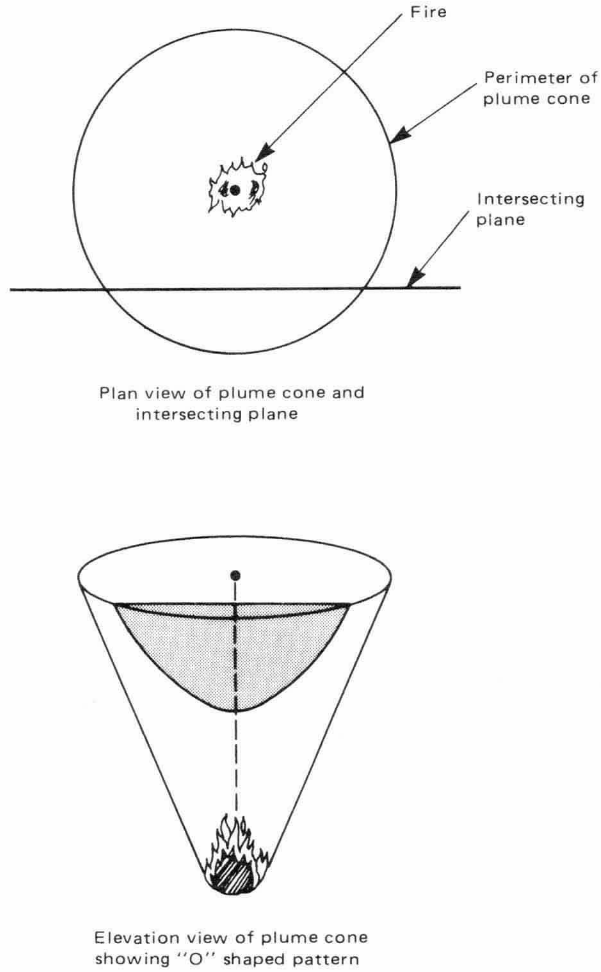


Figure 4-17.4 Development of "U" shaped pattern.

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. 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 "Vs," "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 2-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.

4-17.6 Pointer and Arrow Patterns. These fire patterns are commonly displayed on vertical wooden wall studs or furring strips of walls whose surface sheathing has been destroyed by fire. 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 sides of the studs.

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 towards the heat source that produces them.

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

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.

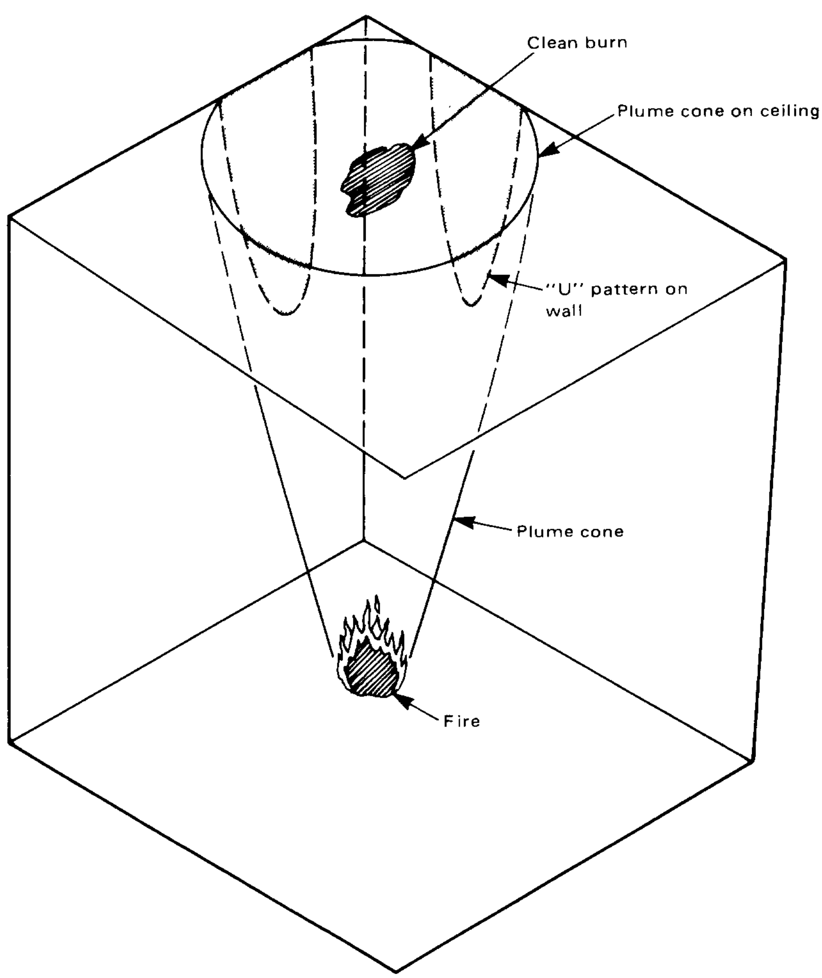


Figure 4-17.5 Truncated cone pattern.

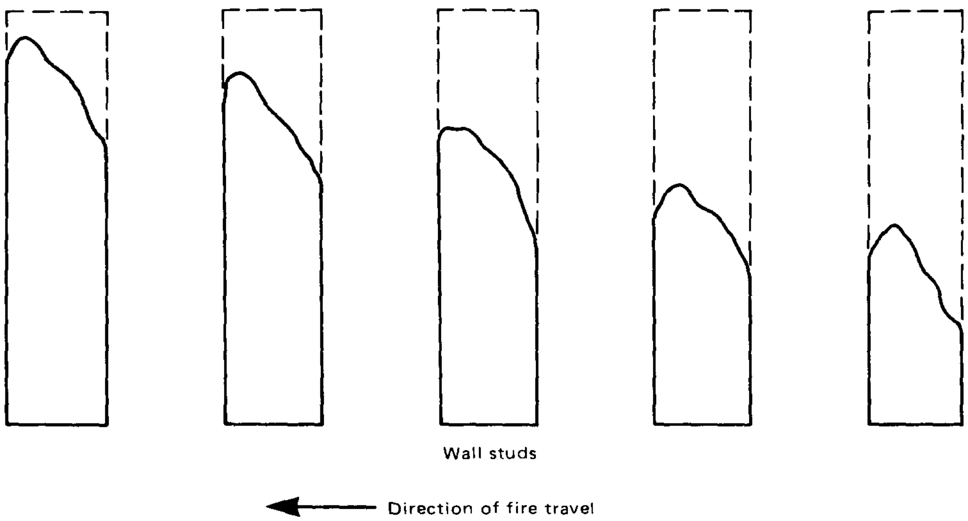


Figure 4-17.6(a) Wood wall studs showing decreasing damage as distance from fire increases.

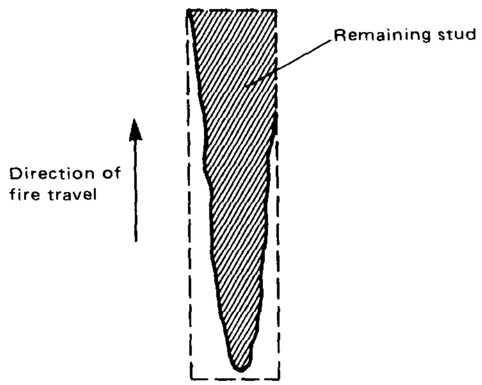


Figure 4-17.6(b) Cross section of wood wall stud pointing toward fire.

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 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 ignitable 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 upon 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 (nylon) carpet. The absence of a carpet pad often leads to sharper lines.

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 ignitable liquids. If the presence of ignitable 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 petroleum products and can be detected by combustible gas indicators when no ignitable liquid accelerant has been used. A "positive" reading should prompt further investigation and the collection of samples for more detailed chemical analysis. It should also be noted that chromatographic analysis of burned carpet made of petroleum-based materials can indicate the presence of hydrocarbons in the absence of accelerants.

However, when overall fire damage is limited and small or isolated irregular patterns are found, the presence of ignitable liquids may be more likely, although the use of supporting evidence is still recommended.

Pooled ignitable liquids that soak into flooring or floor covering materials as well as melted plastic can produce irregular patterns that are more deeply burned in the center than at the edges. These patterns can also be produced by localized heating after flashover or fallen fire debris.

4-17.7.3 Doughnut Shaped Patterns. A distinct "doughnut" pattern where a roughly ring shaped burn area surrounds a less burned area may result from an ignitable liquid. When a liquid caused 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 must be conducted as supporting evidence to the presence of ignitable liquids.

Holes burned in floors or burning under baseboards, door sills, and between floorboards are often attributed to the presence of ignitable liquids. These patterns can result with no liquids involved at all (*see 4-16.1.3*). In the absence of an otherwise explainable fuel and scenario, the use of an accelerant should be considered and samples should be taken.

In any situation where the presence of ignitable liquids is suggested, the effects of flashover, airflow, hot gases, melted plastics, and building collapse must be eliminated.

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 ignitable liquid with a particular irregular pattern has been ruled out on the presumption that ignitable 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 to air mixture (*see 3-1.1.2 and 13-8.3*). 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.

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 affected joist. "Saddle burns" display deep, heavy charring, and the fire patterns are highly localized and gently curved. (*See Figure 4-17.10.*)

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 ignitable 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 have been often 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.

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. When the flashover phenomenon occurs in a compartment, the spread of fire travel from one point in the compartment to another is very rapid, by definition. The entire compartment "flashes over" in a matter of seconds. Flashover can produce entire areas of relatively even burning, without good physical evidence of the direction of fire travel within the area affected. Flashover does not necessarily destroy previously created movement patterns from other sources, but the time and extent of burning, both before and after flashover, is an important consideration in the relationship between the movement patterns and flashover area patterns.

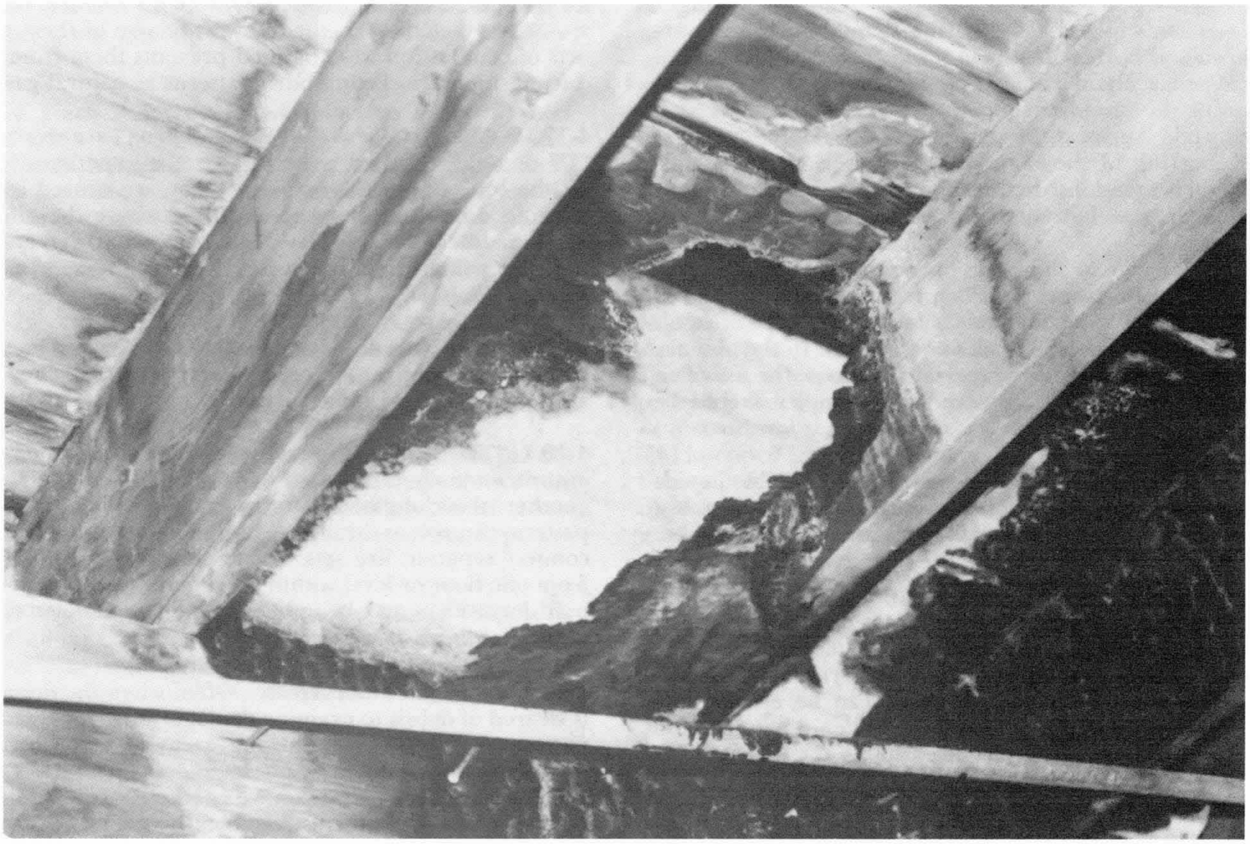


Figure 4-17.10 Saddle burn in a floor joist.

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 is dependent upon the location and concentration of fuel gas, and the geometry, venting, and strength of the confining structure.

If the fuel/air mixtures of the gases or vapors are near the lower flammable or explosive limit (LEL) and there is no explosion associated with ignition, the gases may burn as a flash fire, and there will be little or no subsequent burning. 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.

With bulbs of 25 watts or less, because they contain a vacuum, the distortion 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 must 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.*)

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 on page 46.*)

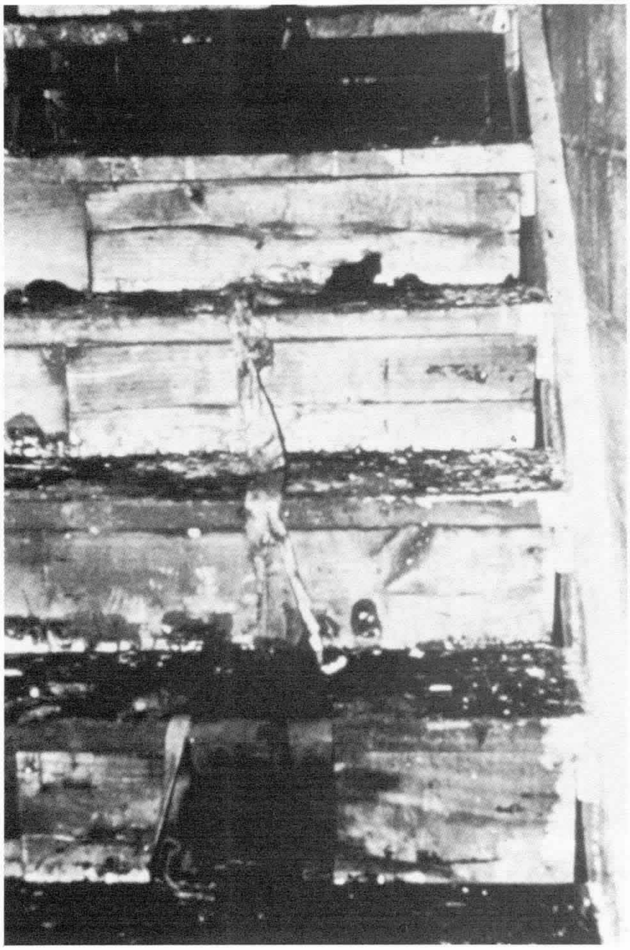


Figure 4-18.1 Trailer running up a stairway.

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

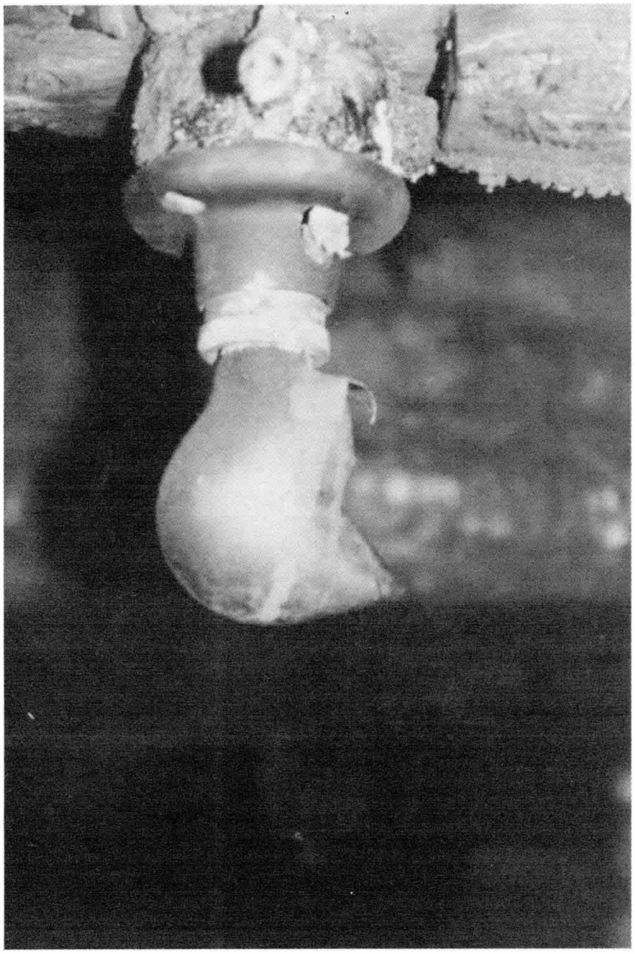


Figure 4-20.1 A typical "pulled" bulb showing that the heating was from the right side.

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 upon 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. This chapter does not attempt to state the law as it is applied in each 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 upon 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 any officer or authority then 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.

Remain aware that investigators and others may be required to produce evidence by order of court or pursuant to a subpoena. Exercise caution. The investigator should 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 as 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 upon 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 must 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 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 upon 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 purpose and scope of the search; the location; against whom the search is directed; the time in which the search is to be initiated and concluded; and the 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 upon 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 and are described in detail below.

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

Demonstrative evidence must be authenticated. Things are authenticated in one of two ways: witness identification (recognition testimony) or by establishing a chain of custody (establishing an unbroken chain of possession from the taking of the thing from the fire scene to the exhibiting of the thing).

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 must 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 must be established.

5-3.2.2 Documentary Evidence. Documentary evidence is any evidence in written form. It may include the fire investigator's report, the investigator's notes, the fire incident report, and any witness statement reduced to writing. 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 (i.e., 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.

5-3.3 Testimonial Evidence. Testimonial evidence is that which is elicited from a witness, in contrast to evidence consisting of documents or things. Testimonial evidence is that given by a competent live witness speaking under oath or affirmation. Investigators are frequently called upon to give testimonial evidence regarding the nature, scope, conduct, and results of their investigation. It is incumbent upon all witnesses to respond completely and honestly to all questions.

5-3.4 Postfire Interviews and Witness Statements. Postfire 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.

5-3.4.1 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. Constitutional protection need not be afforded by investigators functioning in a private 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 must be warned:

(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; and

(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" must be advised of their constitutional rights. Though interviews conducted on a fire scene are not generally considered to be custodial, dependent upon 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 must 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 upon 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 criminal actor 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 non-exclusive 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, 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 must, upon 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 are 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 upon allegations of negligence. A significant number of civil lawsuits are premised upon 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 must be established to impose legal liability for negligence may be stated briefly as follows:

Duty: A duty requiring an actor to conform to a certain standard of conduct, for the protection of others against unreasonable risks;

Failure: A failure by the actor to conform to the standard required;

Cause: A reasonably close causal connection between the conduct of the actor and resulting injury to another (generally referred to as "legal cause" or "proximate cause"); and

Loss: Actual loss or damage resulting to the interests of another.

A hypothetical example of the application of the elements of negligence is as 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 treble 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 upon a wholesaler or middleman, a bailor or lessor, and infrequently upon 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*, 5th ed. at 1089 (1979).]

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:

Design Defect — in which the basic design of the product contains a fault or flaw that has made the product unreasonably dangerous.

Manufacturing Defect — in which 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.

Inadequate Warnings — in which the consumer was not properly instructed in the proper or safe use of the product; or 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 must 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 manpower, 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 must 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, must 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 preexisting documentation and information, e.g., incident reports, photographs, building plans, and diagrams.

6-2.3 Weather Conditions. Weather conditions at the time of the fire must be determined in advance of the scene investigation in order to properly conduct the cause and origin determination. Factors such as wind direction and velocity, temperature, and rain can effect ignition and fire spread.

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 greater safety precautions be taken on behalf of the team members; for example, when the weight of snow on a structure weakens it.

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 the 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, a 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 must 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 manpower, 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 which 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 must 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*); and evidence collection and preservation (*see Chapter 9*).

In addition, specialized expertise in such fields as electrical, heating and air conditioning, or other engineering fields are 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 Pre-Investigation 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

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

Tools and Equipment

Evidence collecting container (*see 9-5.4 for recommendations*)
Writing/drawing equipment
Camera & film (*see 8-2.2.1 and 8-2.2.2 for recommendations*)
Shovel
Broom
Rake
Screwdrivers (multiple types)
Tape measure

Rulers
Directional compass
Paint brushes
Lighting
Tape recorder
Hydrocarbon detector
Pen knife
Axe
Saw
Pliers - wire cutters
Tongs
Tweezers
Magnet
Pry bar
Claw hammer
Hatchet
Sieve
Paper towels/wiping cloths
Styrofoam cups
Marking pens
Evidence labels (sticky)
Hand towels
Soap and hand cleaner
Ladder
Absorption material
Rope
Volt - Ohm meter
Twine

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 the investigator is unfamiliar with a particular aspect, they 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 sections list examples of professional or specific engineering and scientific disciplines along with areas where these personnel may help the fire investigator.

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.

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. A polymer scientist or chemist may offer assistance regarding how plastics react to heat and other conditions present during a fire; and 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 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.

6-5.6 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.

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. The fire investigation should not, however, end with a mere examination of the fire 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, the fire scene examination, interviewing, and the 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 source of the information. Certainly, no information should be considered to be accurate or reliable without such an evaluation of its source.

This evaluation may be based upon many varying factors depending upon 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 source of information's reputation, or the source of information'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. These forms include 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 must approach with caution, and interviews with those you must approach with an attitude of distrust.

7-4.3 Preparation for the Interview. The fire investigator must 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. This is important for two reasons. First, the scene examination may serve as the basis for specific questions relating to the incident. Secondly, if interviews are conducted before the scene examination, the investigator may be prejudiced during the later examination of the scene by the information obtained during the interview. 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 must 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 whatever other information 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 Must 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 must 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 Must 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 includes 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. 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, maps showing the locations of drains, maps showing the locations of sewers, maps showing the locations of 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, cause 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 U.C.C. 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, recreations 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 Environment 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 the monitoring of 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, vessel over 16 ft 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 who 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, technical and reference materials focusing on fire investigation, and coordinates the distribution of the Arson Information Management System (AIMS) software.

7-5.4.15 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. The National Fire Protection Association was organized in 1896 to promote the science 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. 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. The American Society for Testing 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. The National Association of Fire Investigators was organized in 1961. Its primary purposes are to increase the knowledge 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. The International Association of Arson Investigators is a group of public officials and private citizens from the ranks of the fire service, the insurance industry, and law enforcement. The purpose of the association is to strive to control the crime of arson and kindred crimes.

The association sponsors an annual meeting and seminar each year that fosters the exchange of ideas, discussions on the association's current and future programs, and the attainment of two of the association's founding principles, which are a focus on training and education.

7-6.6 Regional Fire Investigations Organizations. In additional 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 who 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, Arson Reporting Statutes.*)

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 who 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 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 developed and supported.

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 to be 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 video tapes, motion pictures, or slides is not recommended. They are more effectively used in conjunction with still photographs. Also, additional equipment is obviously required to review and utilize videos, films, and slides.

8-2.1 Timing. Photographs taken during or as soon as practical after a fire are an important means of recording the fire scene, as the scene may become altered, disturbed, or even destroyed. Some reasons why time is important include:

(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 must 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 flood light 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 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 as 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 vs. 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, most similar to the human eye) through 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 that the fire investigator needs to be familiar with. 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 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 with 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 flood light or from a strobe or flash unit integrated with the camera.

Because a burned area has poor reflective properties, artificial lighting using flood lights 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 will 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 concerned that glare from a flash or flood light 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 video tapes 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. The fire investigator should determine where this type of photography is available and make contact with persons or organization who have these special capabilities to learn about these techniques.

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.

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. An investigator needs to identify items (bench marks) 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 also. When the finished product of a floor plan is completed, 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 will assist in orientation when reviewed by someone unfamiliar with the fire scene. A diagram prepared to log a set of photographs might appear as shown in Figure 8-2.3.3.

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.

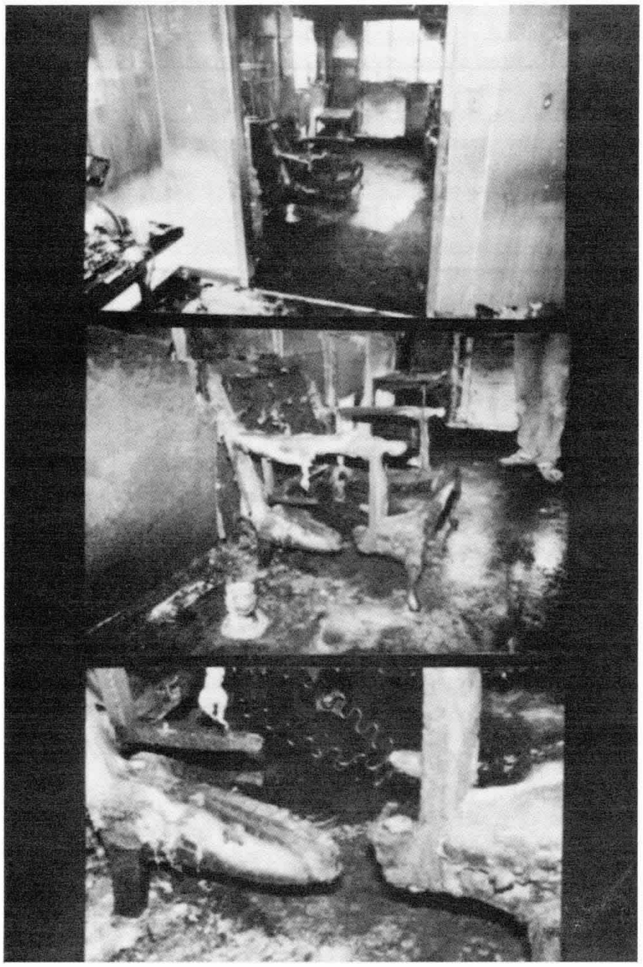


Figure 8-2.3.1 Sequential photographs of a chair.

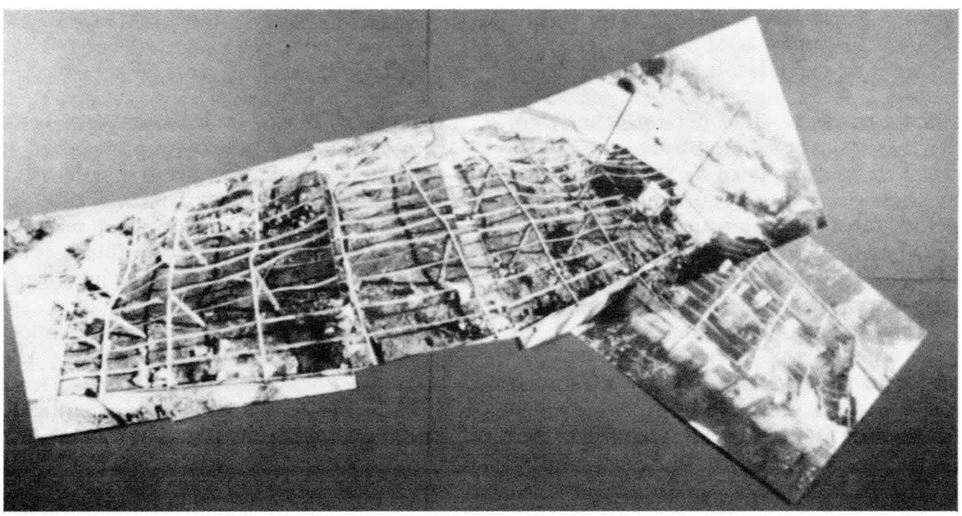


Figure 8-2.3.2 Mosaic of warehouse burn scene from aerial truck.

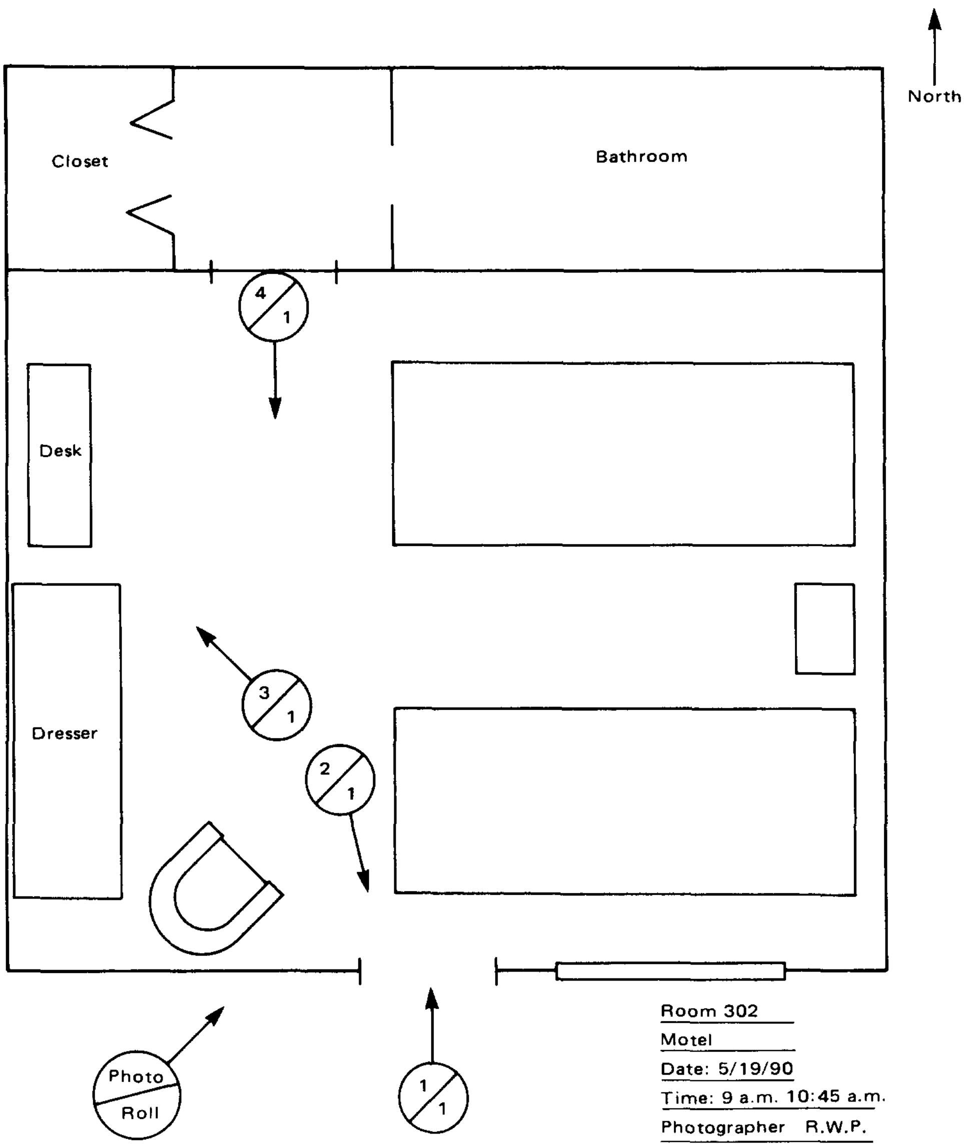


Figure 8-2.3.3 Diagram showing photo locations.

8-2.3.4 Assisting Photographer. If a person other than the fire investigator is taking the photographs, the angles and composition need to be supervised by the fire investigator to ensure the shots needed to document the fire are obtained. Investigators must 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 must be relevant to the testimony. There are other requirements that may exist in other jurisdictions, including non-inflammatory 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.

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 will sometimes reveal it.

The exclusive use of video tape 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.

8-2.5 Suggested Activities to Be Documented. An investigation can be enhanced if as many aspects of the fire ground activities can be documented as possible or practical. The documentation should include suppression activities, overhaul, and the origin and cause 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. All aspects pertinent to these, such as hydrant locations, engine company positions, hose lays, attack line locations, etc., 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.

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.

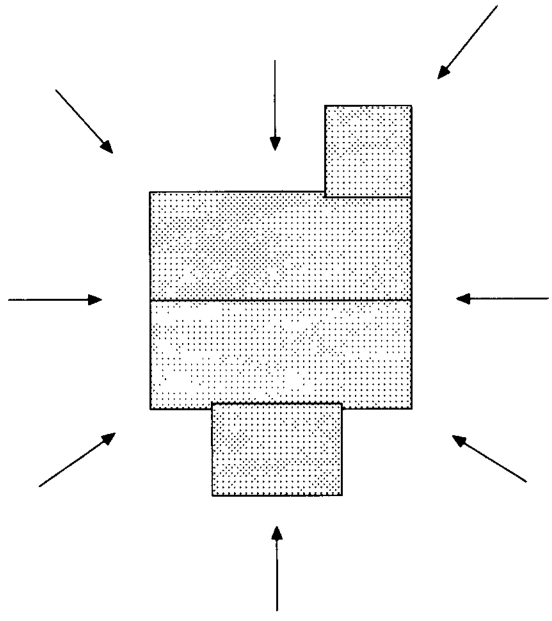


Figure 8-2.5.4 The scene should be photographed from all angles and corners.

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 ventilation points accessed or created by the fire should be photographed, as well as all smoke, heat, and burn patterns.

Rooms within the immediate area of the fire origin should be photographed even if there is no damage. 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.

All heat producing appliances or equipment, such as furnaces, in the immediate area of the origin or connected to

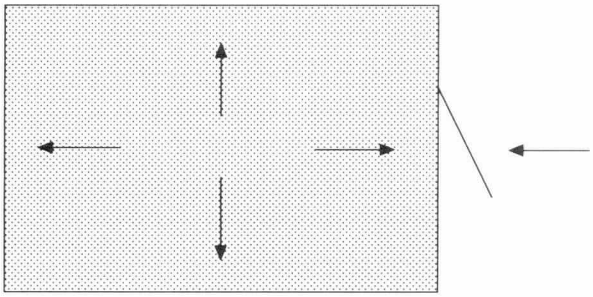


Figure 8-2.5.6(a) Photograph all four walls and both sides of each door.

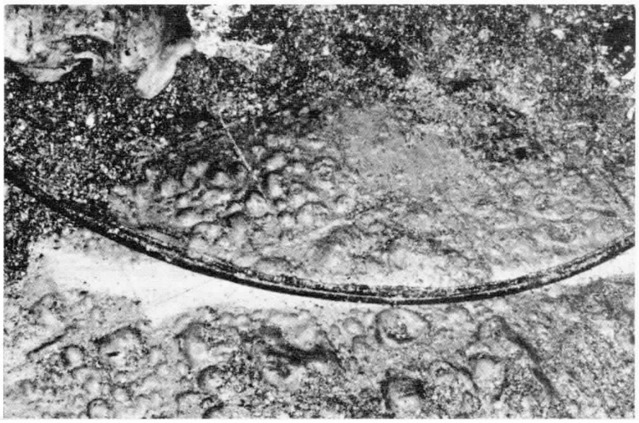


Figure 8-2.5.6(b) Floor tile protected from radiant heat by wire.

the area of origin should be photographed to document their role, if any, in the fire cause.

All furniture should be photographed in its original position before and after reconstruction as well as any protected areas left by any furnishings or other contents [*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 should be photographed to 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 Photographs. The utility (gas, electric) entrances and controls both inside and outside a structure should be photographed. This includes gas meters and their relational location to the structure, the electrical services coming into the structure, and the fuse or circuit breaker panels. If there are gas appliances in the fire area, the position of all knobs on gas appliances should be photographed. Likewise, all electrical cords and convenience outlets pertinent to the fire's location should be photographed.

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, i.e, 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. If there is a death involved, the body should photographed. Surviving victims' injuries and their clothing worn should also be photographed.

Figure 8-2.5.9 Protected area where body was located.

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 orientate all persons involved with the investigation as well as a jury to the direction of the witnesses' observation and could support or refute the possibility of them seeing what they said they saw.

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 can help themselves by remembering certain 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 many types of 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) The investigator should 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 if 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:

(a) Names and addresses

(b) Model/serial numbers

(c) Statements

(d) Photo log

(e) Identification of items

(f) Types of materials (examples — 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.

Dependent upon 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) on the following pages are illustrative of drawing documentation.

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 (2) 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."

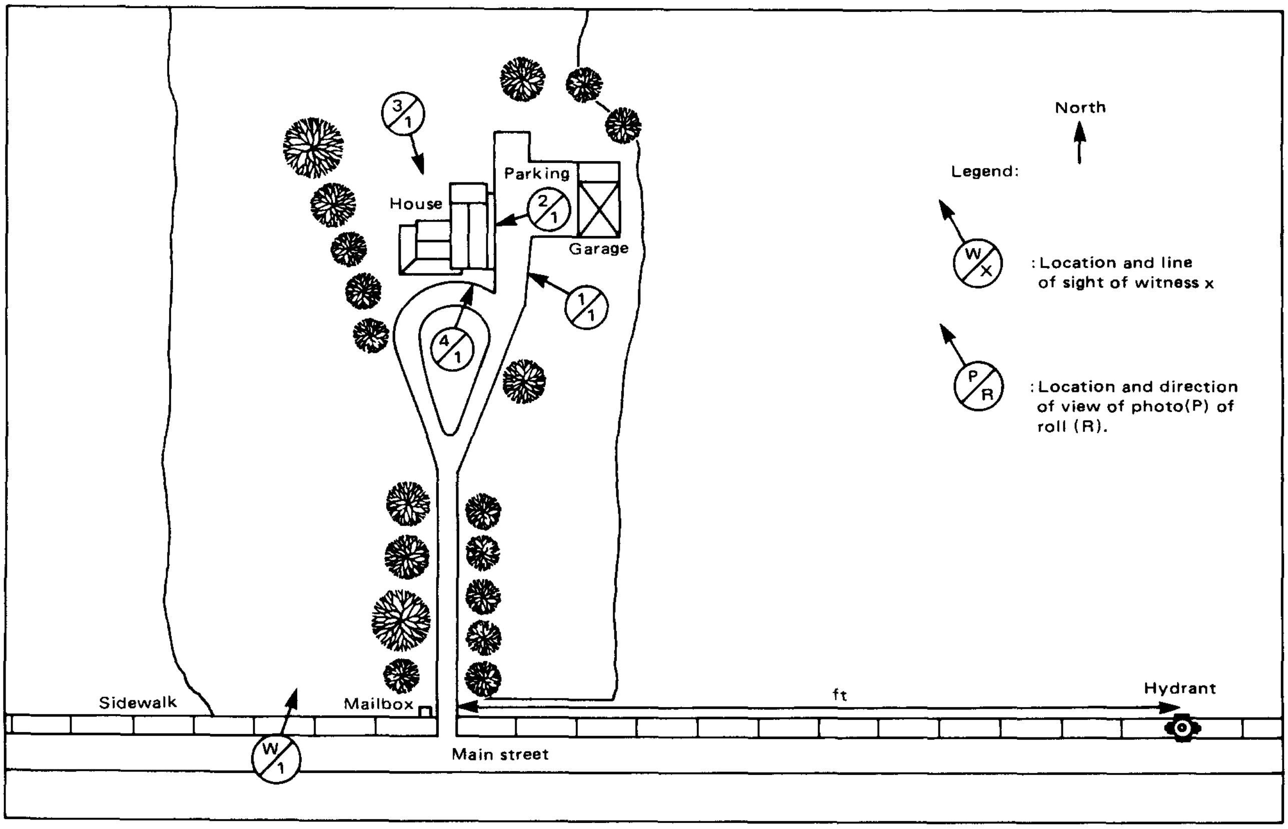


Figure 8-4.2(a) Site plan showing photo and witness locations.

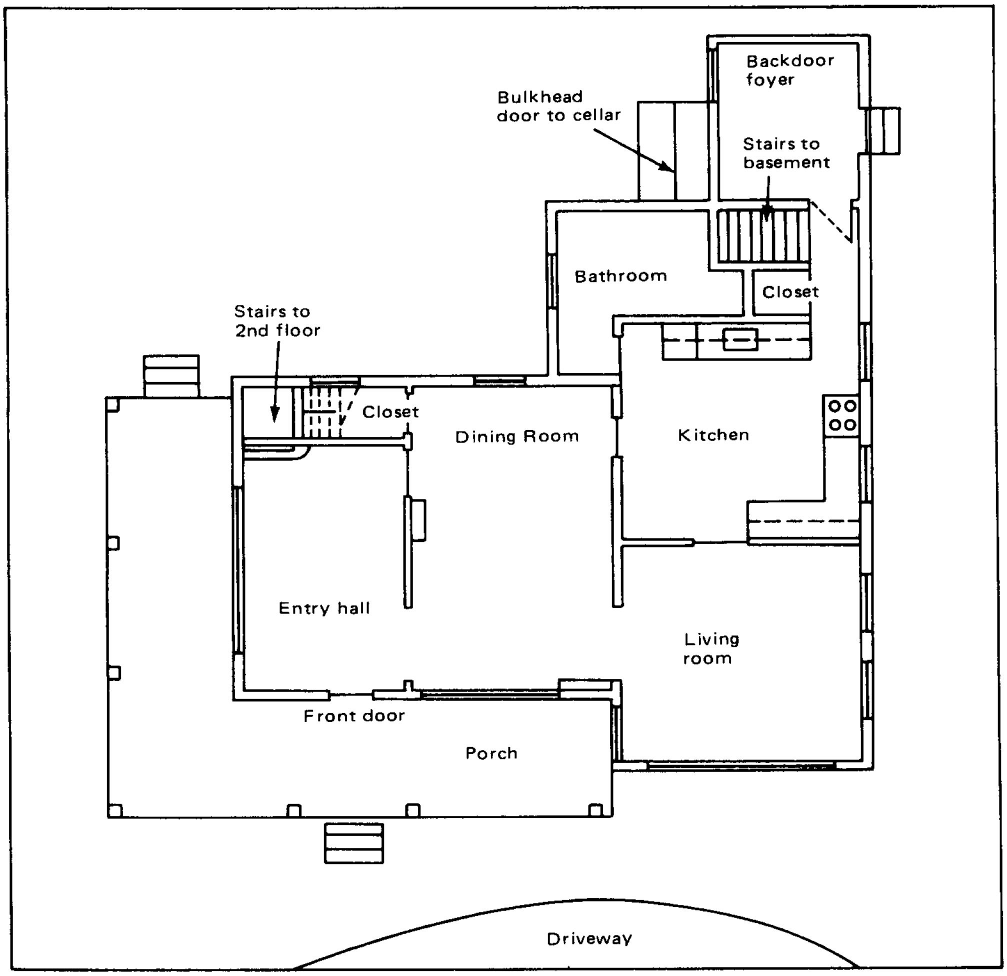


Figure 8-4.2(b) Detailed floor plan.

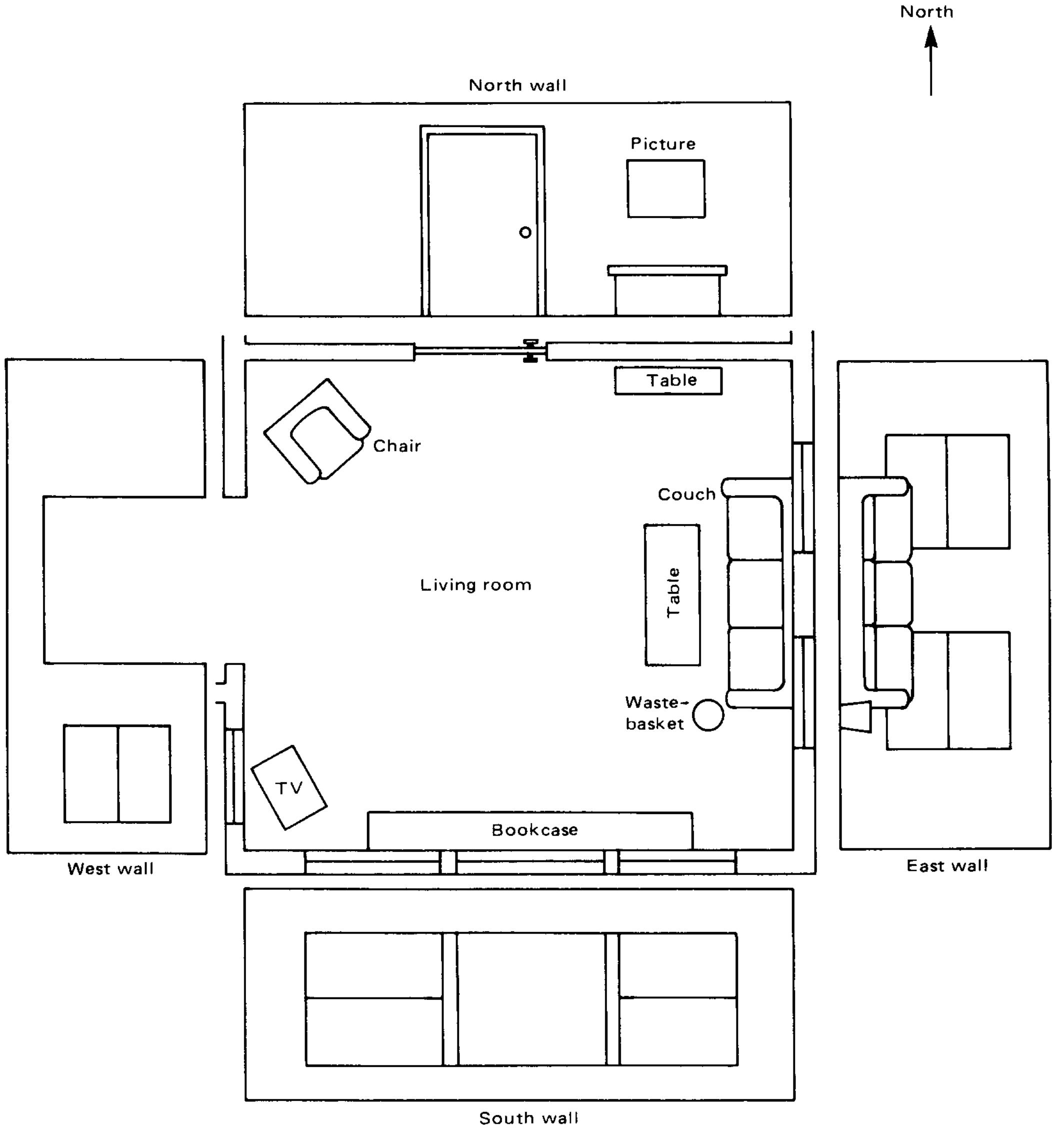


Figure 8-4.2(c) Pre-fire contents diagram.

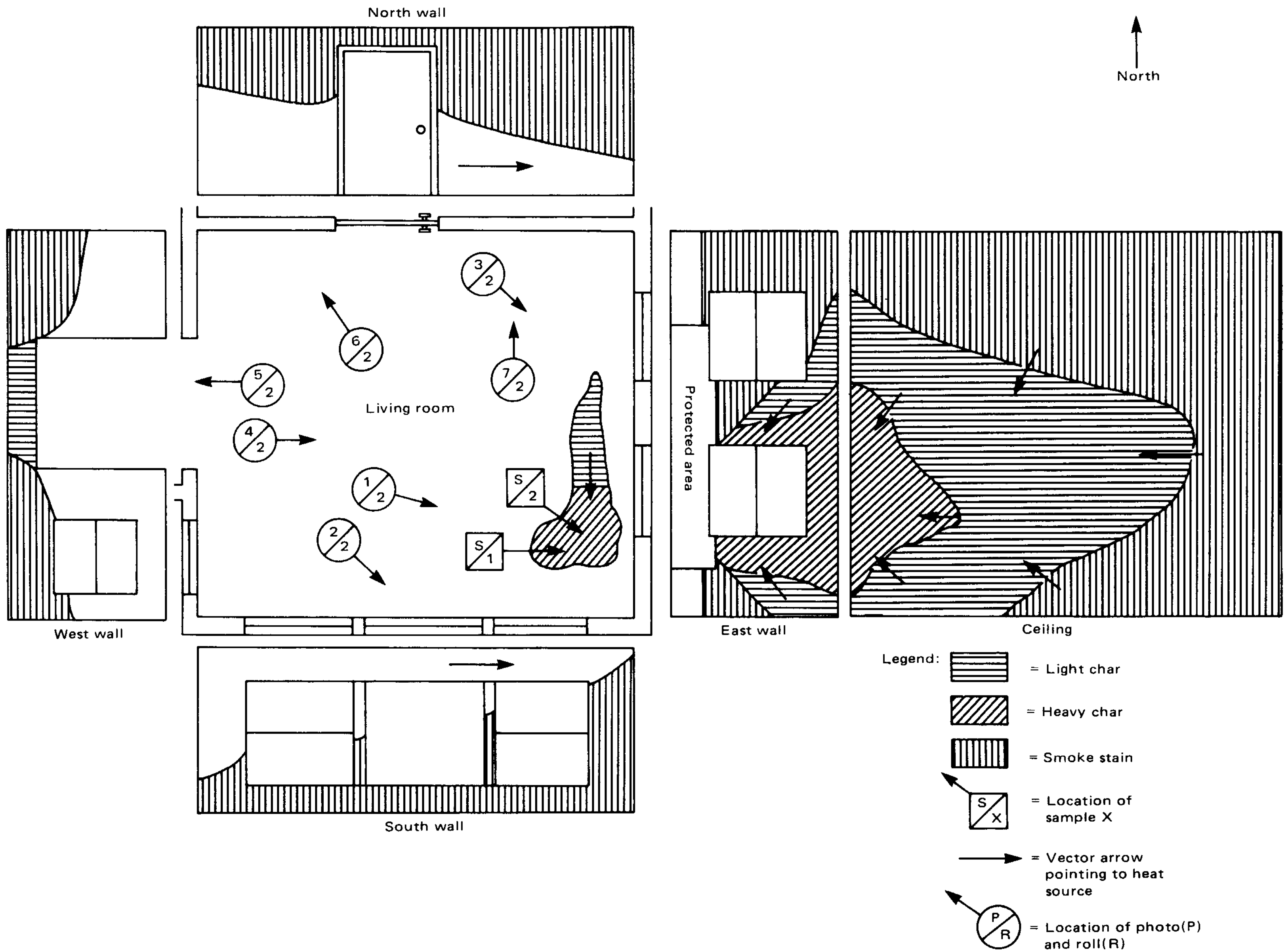


Figure 8-4.2(d) Exploded room diagram showing damage patterns, sample locations, and photo locations.

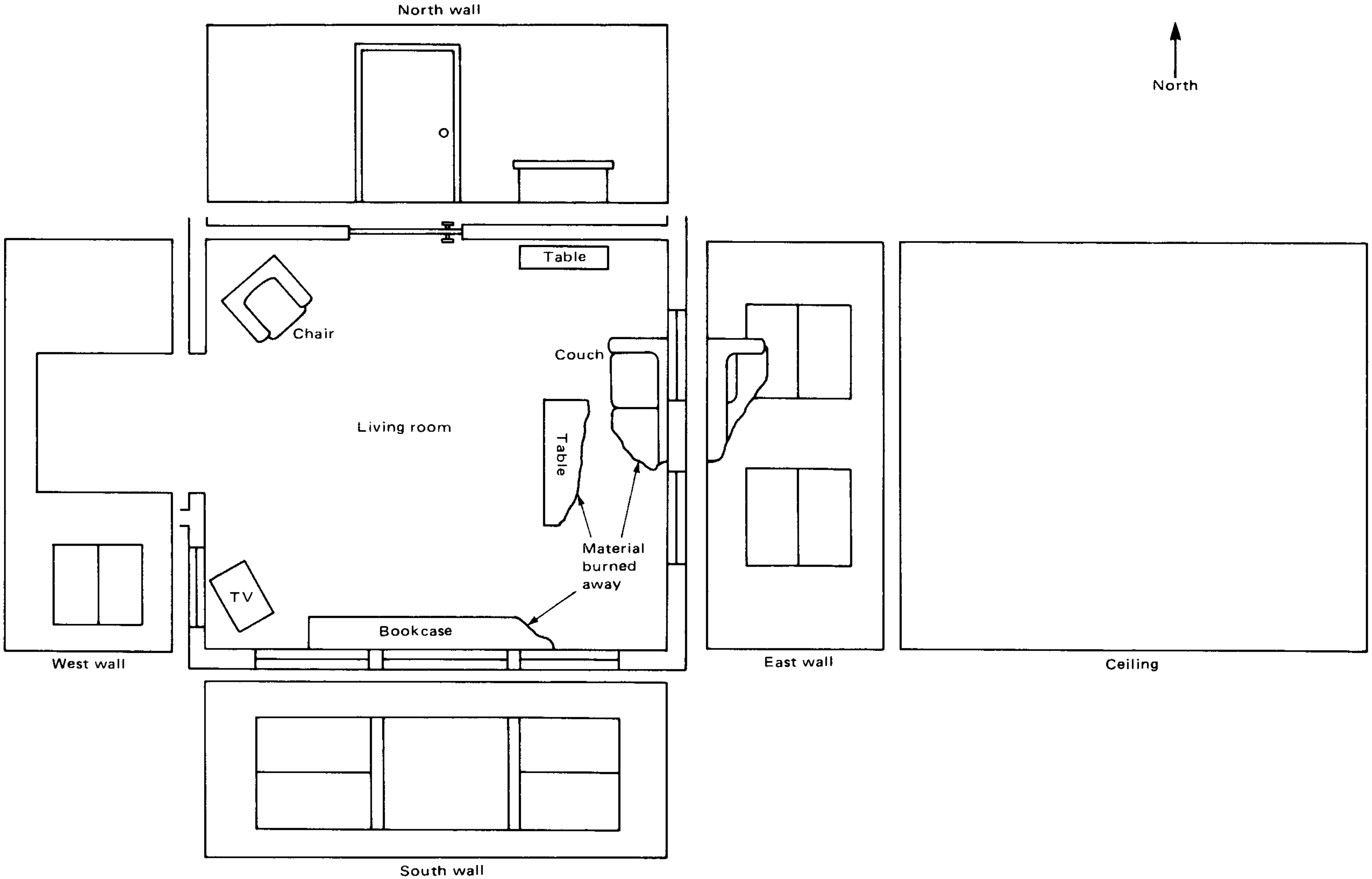
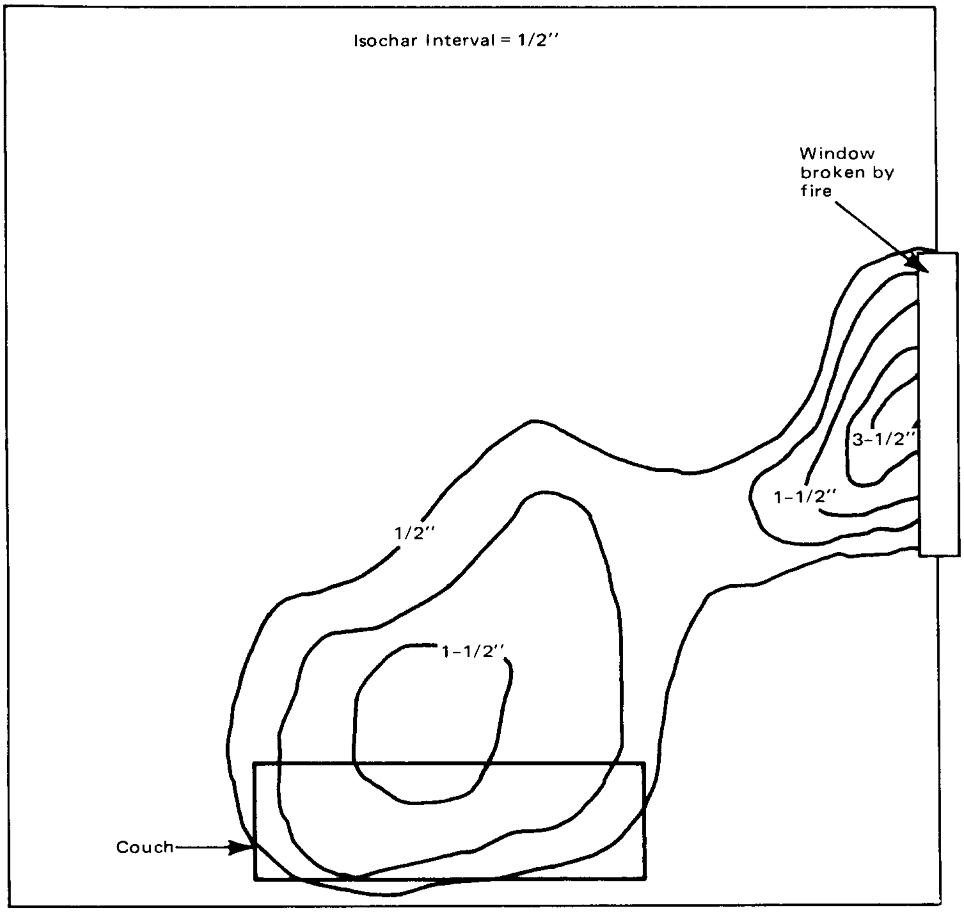


Figure 8-4.2(e) Contents reconstruction diagram showing damaged furniture in original positions.



NOTE: Deepest char is over the couch where a major fuel package was burning and at the window opening where rapid burning of the joists occurred due to ventilation.

Figure 8-4.2(f) An Isochar diagram showing lines of equal char depth on exposed floor joists.

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 conclusion(s) 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 and in order:

(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 specialty that generally prepare them, are shown in Table 8-4.6.1.

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.

Table 8-4.6.1 Design and Construction Drawing That May Be Available

Type	Information	Discipline
Topographical	Shows the various 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 thorough	Architect
Details	Show close-ups of complex areas	All Disciplines

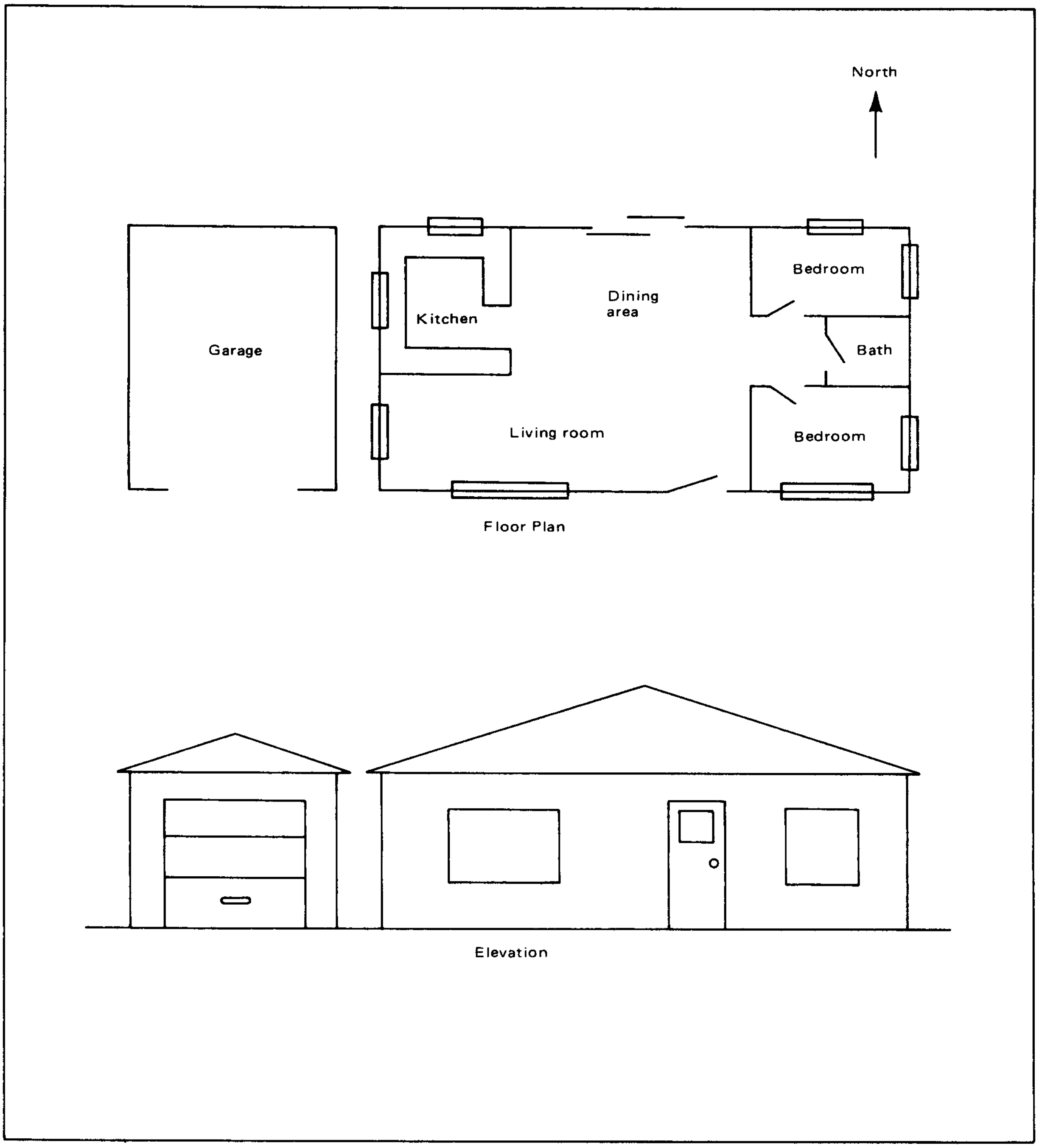


Figure 8-4.5 Minimum drawing for simple fire analysis.

Chapter 9 Physical Evidence Examination and Testing

9-1 General. During the course of any fire investigation, the fire investigator is likely to be responsible for the location, collection, identification, storage, and examination and testing of physical evidence. As such, the fire investigator must 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 of the fire, the cause of the fire, or the responsibility for the fire.

9-2.1 Decision to Collect Physical Evidence. The decision to collect physical evidence at the fire 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 upon a variety of considerations, such as the scope of the investigation, legal requirements, or prohibitions. 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.

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.

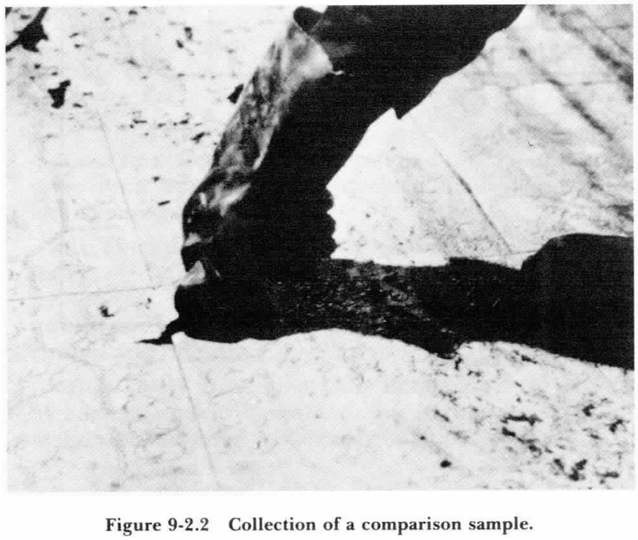


Figure 9-2.2 Collection of a comparison sample.

9-3 Preservation of the Fire Scene and Physical Evidence.

9-3.1 Preservation of the Fire Scene. The fire scene itself should be considered evidence because the examination and analysis of that fire scene is vitally important in determining the origin of the fire, the cause of the fire, and the responsibility for the fire. Improper preservation of the fire scene will usually result in the contamination, loss, or unnecessary movement of other physical evidence within that fire scene, any one of which may reduce the evidentiary value of the physical evidence. The fire investigator should, therefore, secure the fire scene from unauthorized intrusions. Access to the fire scene should be limited to only those persons who need to be there.

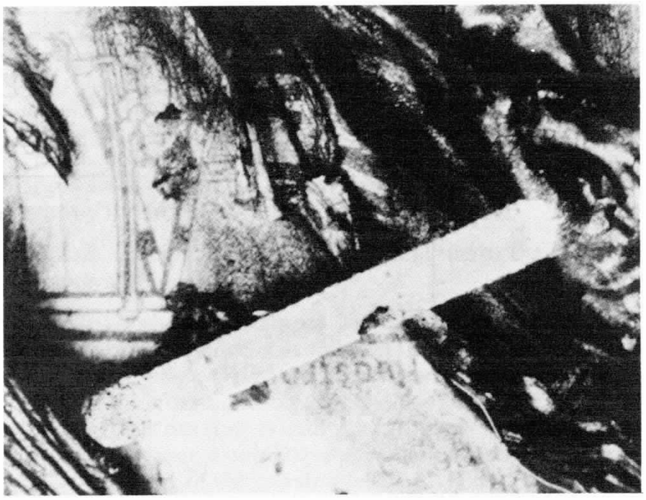


Figure 9-3.1 Physical evidence that could easily get destroyed or lost.

9-3.2 Preservation of Physical Evidence. The fire investigator will usually locate specific items of physical evidence within the fire scene. The movement of such physical evidence should be avoided whenever possible until it has been properly documented and collected.

Often, it will be necessary for the fire investigator to preserve and protect these specific items of physical evidence. Burn patterns on the floor, for example, may have to be roped off or covered with a tarp to prevent them from being walked on. Other physical evidence may have to be covered with cardboard boxes to protect it. Whatever type of physical evidence is encountered, the fire investigator should take every reasonable precaution to preserve and protect it.

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. Often, physical evidence becomes 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.

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. The gloves or bags should then be placed into the evidence container with the physical 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.

Likewise, any collection tools or instruments 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.

9-5 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:

(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 removed. This documentation can be best accomplished through field notes, written reports, sketches, and diagrams with accurate measurements and photography. The diagramming and photography should always be accomplished before the physical evidence is moved or disturbed.

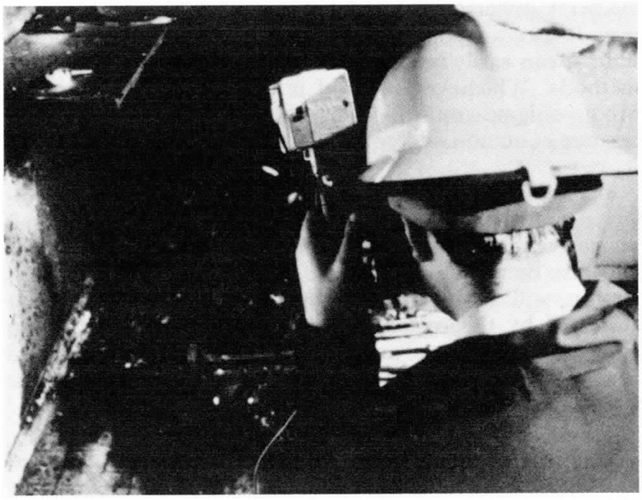


Figure 9-5.1 Using photography to document the collection of evidence.

The purpose of such documentation is two-fold. 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 relationship to the fire investigation. Secondly, the documentation should also assist the fire investigator in establishing that the physical evidence has not been contaminated or altered.

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, voiceprints, 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 varies 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 ignitable 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 E1387, *Standard Test Method for Flammable or Combustible Liquid Residue in Extracts from Samples of Fire Debris by Gas Chromatography*.

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.

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 must be certain that the evidence does not become contaminated.

If readily accessible, the liquid accelerant may be collected with a new syringe, 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 will result in the liquid accelerant 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 will be submitted to the laboratory for examination and testing.

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 flour. This method of collection involves spreading the absorbent onto the concrete surface, allowing it to stand for 20-30 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 for analysis as a comparison sample.

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 by scooping them with the evidence container itself or by cutting, sawing, or scraping. Core drilling may be useful in taking deep samples of wood or other porous materials.

9-5.3.3 Collection Of Solid Samples for Accelerant Testing. Solid accelerant may be common household materials and compounds or dangerous chemicals. When collecting solid accelerant evidence, the fire investigator must ensure that the solid accelerant evidence is maintained in the physical state in which it is found. Since some incendiary materials remain corrosive or reactive, care must 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.

9-5.4 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. 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.

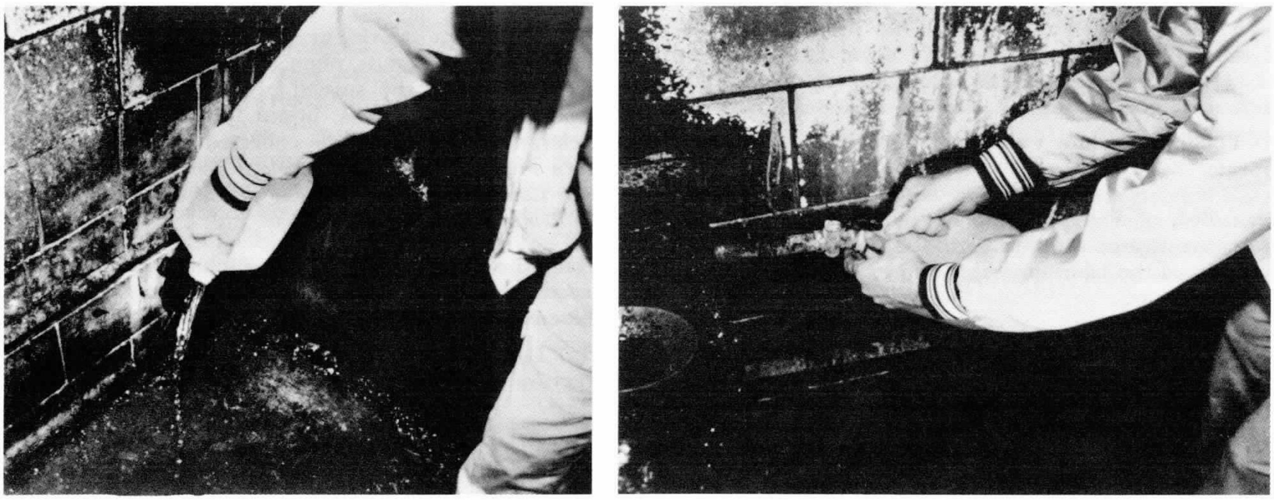


Figure 9-5.4 Gathering a gaseous sample.

9-5.5 Collection of Electrical Components. The fire investigator should exercise caution when handling electrical components as physical evidence. Electrical components may be collected as physical evidence to assist the fire investigator in determining whether or not 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. Before any electrical component is collected as physical evidence, it should be thoroughly documented, including being photographed and diagrammed. Electrical wiring can usually be easily cut 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 to:

(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 components are often collected as physical evidence. It is recommended that these types of electrical components be removed intact, in the condition in which they were found.

When practical, it is recommended that any fixtures housing such 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, and to carefully document their position and function in the overall electrical distribution system.

9-5.6 Collection of Appliances or 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 (furnaces, water heaters, stoves, washers, dryers) to the small (toasters, coffee pots, radios, irons, lamps).

Where practical, the entire appliance or piece 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 piece 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 piece of equipment may be collected as physical evidence. In that case, the fire investigator must 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 is also dependent upon 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 recommend container for the collection of liquid and solid accelerant evidence is an unused, unlined metal can. It is important that the can be unlined as the common lacquer linings in some cans may cause erroneous test results during laboratory examination and testing of the physical evidence contained in such cans. In order to allow space for vapor samples to be taken during such examinations and testing, the can should not be 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.

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

Figure 9-6.1.1 Various types of metal cans.

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, 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 will cause erroneous test results during laboratory examination and testing of the physical evidence contained in such bags.

The advantages of using special evidence bags include their ready availability in a variety of shapes and sizes, economic price, ability to view the evidence without opening the bag, ease of storage, and 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, they may be difficult to seal adequately, and they have a tendency to degrade or decompose when in contact with some types of liquid and solid accelerant.

9-6.1.4 Common Plastic Bags. Common plastic bags may also be used for the collection of liquid and solid accelerant evidence. However, they may have a chemical composition that may cause erroneous test results during laboratory examination and testing of the physical evidence contained in such bags. As such, common plastic bags should be used only when no other alternative is available.

The advantages of using common plastic bags include their ready availability in a variety of shapes and sizes, economic price, ability to view the evidence without opening the bag, and ease of storage.

The disadvantages, however, are their susceptibility to easy damage, resulting in the contamination of the physical evidence contained in them and their marked inability to retain light hydrocarbons, resulting in loss of the sample or misidentification.

9-7 Identification of Physical Evidence. All evidence must 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.

The fire investigator should be careful that the identification of the physical evidence cannot be easily damaged, lost, removed, or altered. The fire investigator should also 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.

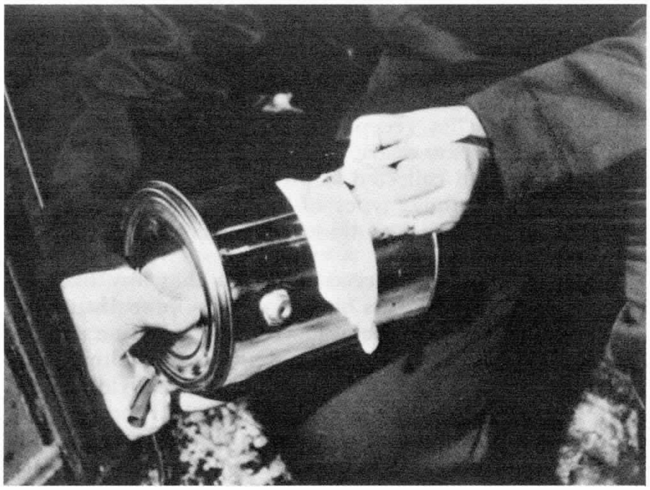


Figure 9-7 Marking of the evidence container.

9-8 Transportation of Physical Evidence. Transportation of physical evidence to the laboratory or testing facility can be done either by hand delivery or shipment. When dealing with volatile evidence it is important that the evidence be protected from extremes of temperature. Freezing or heating of the volatiles may affect lab test results.

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 upon 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.

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 cardboard box of sufficient size to adequately hold all of the individual evidence containers from a single investigation. Never place physical evidence from more than one investigation in the same shipment.

Package the individual evidence containers securely within the cardboard box. Seal the cardboard box with tamper-resistant tape to detect unauthorized opening. Conspicuously mark the outside of the cardboard box to indicate that it contains physical evidence.

Place a "Letter of Transmittal" in a sealed envelope and attach it to the sealed cardboard box. A 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, dependent upon 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.

Both the sealed cardboard box and the sealed envelope containing the letter of transmittal should then be wrapped in parcel wrapping paper. This outer wrapping should also be sealed with tamper-resistant tape. This outer wrapping allows review of the letter of transmittal before actual opening of the cardboard box containing the physical evidence. (*See Figure 9-8.2 on the following page.*)

Before shipment, it is recommended that the fire investigator perform a photographic survey of the sealed package. A photographic survey is simply a series of photographs that show the condition of the sealed package prior to its shipment.

Ship the sealed package by Registered United States Mail or any commercial courier service. The fire investigator should, however, always request return receipts and signature surveillance.

The fire investigator is cautioned about shipping volatile or hazardous materials. The investigator must ensure that such shipments are made in accordance with applicable federal, state, and local law.

9-9 Chain of Custody of Physical Evidence. The value of physical evidence depends entirely upon 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 must 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 on page 83 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 the fire's spread, or the responsibility for the 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 is available depending upon 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 will better assure that the results are valid and that they will be comparable to results from other laboratories or testing facilities.

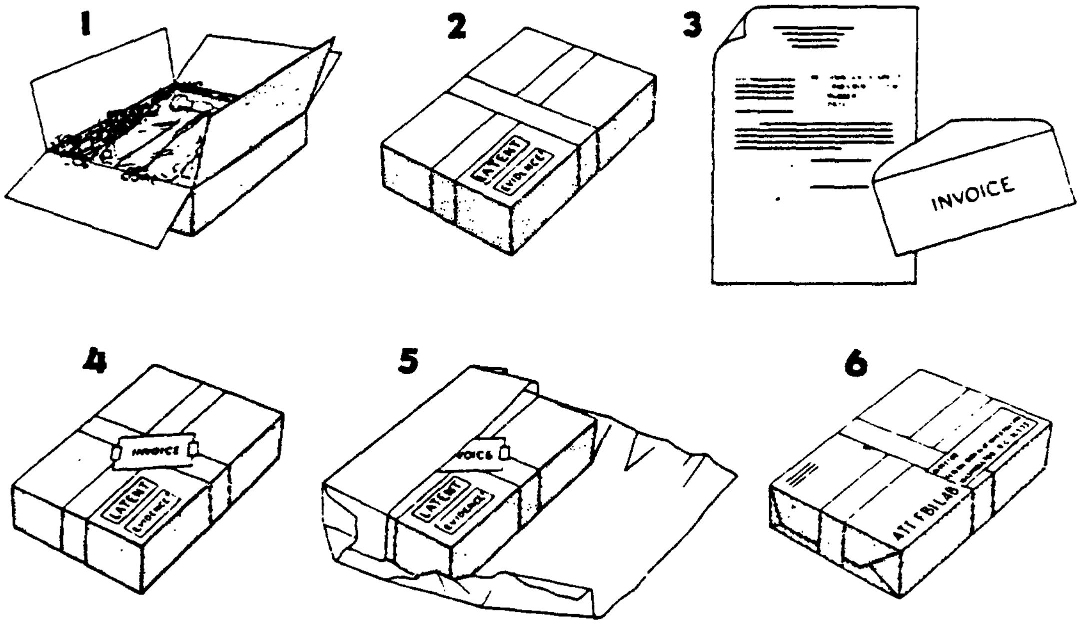
It should be noted that the results of many laboratory examinations and tests may be affected by a variety of factors. These factors include the abilities of the person conducting or interpreting the test, the capabilities of the particular test apparatus, the maintenance or condition of the particular test apparatus, sufficiency of the test protocol, and the quality of the sample or specimen being tested. Fire investigators must be aware of these factors when using the interpretations of test results.

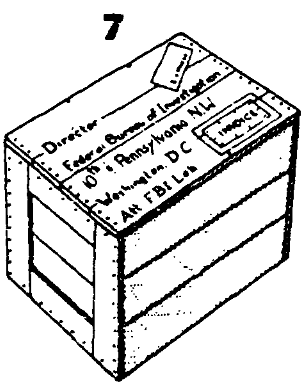
9-10.2 Test Methods. The following is a listing of selected analytical methods and tests that are applicable to certain fire investigations. When utilizing laboratories to perform any of these tests, investigators should be aware of the quality of the laboratory results that can be expected. Certified laboratories have been judged to be capable of performing accurate and credible tests.

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

Proper Sealing of Evidence

The method shown below permits access to the invoice letter without breaking the inner seal. This allows the person entitled to receive the evidence to receive it in a sealed condition just as it was packed by the sender.





1. Pack bulk evidence securely in box.
2. Seal box and mark as evidence. Mark "Latent" if necessary.
3. Place copy of transmittal letter in envelope and mark "Invoice."
4. Stick envelope to outside of sealed box.
5. Wrap sealed box in outside wrapper and seal with gummed paper.
6. Address to the laboratory that is doing the testing.
7. If packing box is wooden-tack invoice envelope to top under a clear plastic cover.

Figure 9-8.2 Shipping evidence.

CRIME SCENE SEARCH EVIDENCE REPORT

Name of Subject..

Offense..

Date of Incident..............................Time..............................AM-PM

Search Officer..

Evidence Description..

....

Location..

....

CHAIN OF POSSESSION

Received From..

By..

Date..............................Time..............................AM-PM

Received From..

By..

Date..............................Time..............................AM-PM

Received From..

By..

Date..............................Time..............................AM-PM

Received From..

By..

Date..............................Time..............................AM-PM

Figure 9-9 Chain of custody form.

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 E1387, *Standard Test Method for Flammable or Combustible Liquid Residues in Extracts from Samples of Fire Debris 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.

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 D56). 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 closed tester.

9-10.2.7 Flash and Fire Points by Cleveland Open Cup (ASTM D92). This test method covers determination of the flash and fire points of all petroleum products, except oils, and those having an open cup flash below 175°F (79°C).

9-10.2.8 Flash Point by Pensky-Martens Closed Tester (ASTM D93). These test methods cover the determination of the flash point by Pensky-Martens closed-cup tester of fuel oils, lube 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 D1310). 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 D3828). These test methods cover 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 E659). This 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 D2382). 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 D1230). 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 E1352). 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 E1353). These test methods are 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 D2859). 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 man-made 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 D3065). These methods cover the determination of flammability hazards for aerosol products.

9-10.2.18 Surface Burning Characteristics of Building Materials (ASTM E84). 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 E108). These methods cover the measurement of relative fire characteristics of roof coverings under simulated fire originating outside the building. They are 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 E648). 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, 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 E603). 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 E681). 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 one 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 E800). 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 E906). 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 Test Method for Pressure and Rate of Pressure Rise for Combustible Dusts (ASTM E1226). 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 Visable Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter (ASTM E1354). 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 Standard Test Method for Ignition Properties of Plastics (ASTM D1929). This test method covers a laboratory determination of the self-ignition and flash-ignition temperatures of plastics using a hot-air ignition furnace.

9-10.3 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 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 will require a certain minimum quantity of physical evidence to facilitate proper and accurate results. As such, the fire investigator must be familiar with these minimum requirements. The laboratory that will examine or test 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. Care should be taken that the sample is the same make and model as the product involved in the fire.

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. In that way, if an investigator should become trapped or injured, assistance would be at hand.

If it is impossible for the investigator to be accompanied, he or she should, at the least, notify a responsible person of where they will be and when they 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, self-contained breathing apparatus, 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 the equipment without that training.

10-1.3 Fire Scene Hazards. The investigator should remain aware of the general and particular dangers of the scene that is 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 must 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 may be required, such as rubber gloves, self-contained breathing apparatus (SCBA), and hazardous material suits.

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 ensure 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 must receive permission from the fire ground commander. The investigator must 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 extinguished, the investigator should be mindful of the possibility of a rekindle. The investigator should be alert for continued burning or a rekindle and 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 structural 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 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 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 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 (electric, gas, and water) within the structure under investigation. He or she must know, before entering, if electric lines are energized, fuel gas lines 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.

In many instances, the investigator may be working at fire scenes that have been equipped with temporary wiring by previous investigation interests or contractors. The investigator must be mindful that such temporary lighting or power arrangements are often improperly installed, improperly grounded, not properly insulated, and otherwise unsafe.

10-2.4 Standing Water. Standing water can provide 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 investigators head and pose the danger of drowning. Pools of water may also conceal hidden danger, such as holes or dangerous objects, that may trip or otherwise injure the investigator.

Investigators must be cognizant of these hidden dangers and take proper precautions to avoid injury.

10-2.5 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, must be addressed by the investigator.

The investigation scene should be secured from entry by the curious. This may be accomplished by the mere roping off of the area and the posting of "Keep Out" signs or 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 required to leave.

10-2.6 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 ignitable gas, vapors, and liquids. The investigator should refrain from introducing ignition sources into such atmospheres. 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 the fire. Chapter 12, "Cause Determination," will further develop the investigative effort based upon 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 will frequently involve the coordination of information derived from:

(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 must 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 the complete list of plausible explanations for the origin with the supporting evidence for each option.

The purpose of determining the origin of the fire is to identify the geographical location where the fire began. If the specific location where the heat source ignited the first fuel can be identified, then the point of origin can be determined. The process to determine the origin involves the identification of pertinent fire patterns, the documentation of these patterns, and the analysis of the patterns. The process almost always involves the plotting of fire movement from the areas of least damage to the areas of greatest damage.

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.

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, the development of a preliminary fire-spread scenario, an in-depth examination of the fire scene, fire scene reconstruction, a final fire-spread scenario, and the 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 not 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 upon 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 so as to effectively show their shape, size, relationship to other patterns, and the location within the fire scene. These photographs include changing the angle of viewing of the camera in documenting the pattern and using 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 including: 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 include an overall look at the structure, both exterior and interior, and 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.

Examine surrounding areas 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 that can provide information about the building that burned.

11-3.2 Weather. Determine the weather on the day of the loss. Analyze any weather factors that may have influenced the fire.

The surrounding area may also provide evidence of the weather conditions. Wind direction may be indicated by the fire damage on the surrounding structures or vegetation.

11-3.3 Structural Exterior. A walk around the entire structure will reveal the extent and location of damage and help determine the size of the scene that must be examined as well as the possibility of extension from an outside fire source. Note the construction and use of the structure. 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 being defined as the activities conducted, the manner in which such activities are undertaken, and the type, number, and condition of those 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 where further study is warranted. 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. Be observant of conditions of occupancy, including methods of storage, nature of contents, and living conditions. Note the type of construction and surface covering. Document smoke and heat movement, areas of fire damage, and extent of damage in each area — severe, moderate, minor, or none. Compare this damage with the damage seen on the exterior. Use this opportunity to assess the soundness of the structure. This aspect is critical to determine if the structure is safe to work in. 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, note any indication of postfire 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 manpower 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. 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 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

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 Prefire Conditions. The prefire conditions in the interior of the structure should be documented, especially in the areas where there was fire development and spread. Note the housekeeping or lack of it. Note the presence of any evidence of concentrations of easily ignitable materials, such as trash. Note if the electrical devices are properly utilized. Note any indications that might relate to electrical overloading, power cord abuse, appliance abuse, etc. These do not solely determine a fire cause, but they can be supportive, or contradictory, to subsequent cause determinations.

Locate any interior fire suppression or fire protection devices, such as smoke alarms, fire extinguishing systems, fire doors, etc. Determine if they are in working order and if they functioned properly during the fire. Note if they have been disabled or inadequately maintained.

Look at the fuel loads present in the structure. Note if they are consistent with what is expected in this structure and if they added to the fire's development. Include in the fuel load considerations the interior surface covering and furnishings.

The ultimate determination is whether or not the prefire conditions created the fire or greatly contributed to the fire's origin, cause, or spread.

11-6.2 Utilities. Locate and document the condition of the utility services in the structure. 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 documented.

The fuel gas utility should be identified and documented. The purpose of this examination is to assist in determining if 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 if 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 prefire explosion. Postfire 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 should enable 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.

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 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 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 prefire positions. Once the debris has been removed, the contents should be placed in their prefire positions for analysis of the fire patterns on them.

When the contents have been displaced during fire suppression activities, postfire 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 content 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 hand-held 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 he or she uses is appropriate, that the data they input is proper, and that the output is properly interpreted. Those who are not sufficiently informed to have a level of confidence sufficient that they can support the use of the fire models and their validity, if challenged, should not unilaterally use such methods. Users that 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 must be recognized and resolved. If resolution is not possible, then the scenario should be reevaluated to minimize the contradictions. To resolve contradictions, reexamine the data to see if 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 must be made to decide if the determination as to 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.

Although there are many reasons that a fire will burn itself out, for this discussion consider the isolated dwelling that burns until all combustible materials have been consumed, unimpeded by any extinguishment efforts and without witnesses. In such fires all available information should be gathered about the building, its occupancy, and weather conditions on the day of the fire. If at all possible, obtain photographs or floor plans of the building. See Chapter 7 for a discussion on sources of information.

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. Consult the local utilities for information on the building's past and recent utility requirements.

In the case of the occupancy of the building, consult the insurance carrier, real estate officials, and neighbors.

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, 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 will generally be found almost directly beneath their prefire location. This will generally 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 if 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 in 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 for 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. 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 so as to allow the fire to occur.

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.

12-2.1 Accidental Fire Cause. Accidental fires involve all those where 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 set fires can still be accidental. For example, a trash fire in a legal setting 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 set under circumstances in which the person knows that the fire should not be set.

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.

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.

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 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 must 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 must generate a level of energy sufficient to raise the fuel to its ignition temperature and must 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 must 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 must 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 must 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, and clothes dryers.

The investigator should also look for devices that may have malfunctioned. Such devices include many of the above 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 explosionproof, 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 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 gathering of information is especially important when the source of ignition does not survive the fire. That 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 NFPA 907M, *Manual for the Determination of Electrical Fire Causes*.

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 ignitable 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 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 must 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 table top. 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.

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 ignitable fuel and a potential ignition source were present. The sequence of events that allowed 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 are some that 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 min after a reliable witness passed through and saw no smoke.

12-6 Certainty of Opinions. When forming opinions or hypotheses about fires or explosions, the investigator must set a minimum standard for the proof of 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 (proof). (*See Chapter 2.*)

There are four levels of challenge that can be regularly applied to such opinions.

(a) A reasonable degree of scientific (engineering) certainty. This degree of challenge corresponds to the degree of proof applied in criminal legal proceedings, beyond a reasonable doubt. At this level of proof, all reasonable alternatives to the hypothesis are considered and eliminated.

(b) Probably true. This level of challenge corresponds to the degree of proof applied in civil legal proceedings; more probably true than not. At this level of proof, the chance of the data or hypothesis being true is more than 50 percent.

(c) Possibly true. This level of challenge corresponds to the degree of proof in which other data or hypothesis may be equally or as nearly as possible as others.

(d) Suspected to be true. This level of challenge corresponds to a perception that the data or hypothesis may be true, but there are insufficient data to draw a conclusion to the exclusion of any other reasonable conclusion.

Ultimately, the decision as to the truth of data collected in the investigation or any hypothesis drawn from an analysis of the data rests with the investigator. However, the scientific method precludes the use of "possibly true" or "suspected to be true" data. Only data that are true to a reasonable degree of scientific certainty or that are probably true should be used in an analysis or hypothesis. If the data collected are only possibly true or suspected, those data, or the cause should be listed as unknown, undetermined, or under investigation.

Chapter 13 Explosions

13-1 General. Historically, the term explosion has been difficult to define precisely. There are two general categories of definitions that are in common usage. Both include the extremely rapid and violent expansion of gases.

The first definition is: a sudden conversion of potential energy (chemical or mechanical) into kinetic energy in the form of rapidly expanding gases, often accompanied by heat and light. This definition, commonly used by the explosives industry and researchers in the theoretical sciences, does not take into account the effects of the explosion.

The second definition, particularly of fire and explosion investigations, relies upon damage or change brought about by the restriction of the expanding blast pressure wave as an integral element. These gases, expanding as a shock or pressure wave, produce physical effects on containers or nearby surfaces.

This effect can result from the confinement of the pressure wave or the impact of an unconfined pressure or shock wave upon an object, such as a person or structure.

Under the fire and explosion investigation definition, an explosion is a physical reaction characterized by the presence of four major elements: high pressure gas, confinement or restriction of the pressure, rapid production or release of that pressure, and change or damage to the confining (restricting) structure, container, or vessel caused by the pressure release. 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.

A phenomenon that lacks any one of these four major elements is not, by this definition, an explosion. For example: The ignition of a flammable vapor/air mixture within a can, which bursts the can or even only pops off the lid, is an explosion. However, the ignition of the same mixture in open field, while it is a deflagration, is not 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. Under this definition, the failure and bursting of a tank or vessel from hydrostatic pressure is not an explosion because the pressure is not created by gas. Explosions must be gas dynamic.

13-2* Types of Explosions. There are two major types of explosions: 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. These are explosions in which the high pressure gas is produced by purely physical reactions. None of the reactions involves changes in the basic chemical nature of the substances. The most commonly used example of a mechanical explosion is the bursting of a steam boiler. The source of over-pressure 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.

The boiling liquid expanding vapor explosion (BLEVE) is a type of mechanical explosion that will be encountered most frequently by the fire investigator. (The BLEVE will be discussed more in 13-2.5.)

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 can be either uniform reactions or propagating reactions. Uniform reactions occur essentially throughout the entire reactant (fuel) almost simultaneously. This is similar to the detonation of high explosives in which the triggering mechanism is a shock wave transmitted through the bulk of the explosive at extremely high velocities. This document will consider uniform chemical reactions as those that occur with such speed as to create the entirety of their exhaust gases almost simultaneously. In this case the speed of the resultant blast pressure wave does not increase after the initiation, though total pressures may increase with confinement.

More common are the cumulative reactions found with gases, vapors, and dusts. 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. Most chemical explosions, including combustion explosions, are the result of propagation rather than uniform chemical reactions.

13-2.3 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 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 upon 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:

(a) Flammable gases

(b) Vapors of flammable and combustible (ignitable) liquids

(c) Dusts

(d) Low explosives (those that undergo deflagration)

(e) High explosives (those that undergo detonation)

NOTE: The chemical structure of high explosives allows for oxidation reactions to occur during detonation. Detonation of a high explosive is not a combustion reaction in the usual sense. There is no separate oxidizer. Rather, the explosive compound decomposes as a shock wave travels through it at supersonic speed. The reaction is exothermic.

(f) Smoke and flammable products of incomplete combustion (backdraft explosions).

13-2.4 Nuclear Explosions. In nuclear explosions the high pressure element is created by the fusion or fission of the nuclei of atoms. The investigation of nuclear explosions is not covered by this document.

13-2.5 BLEVEs. The word "BLEVE" is the acronym for a boiling liquid expanding vapor explosion. These are explosions involving vessels that contain liquids under pressure at temperatures above their boiling points. The liquid need not be flammable. BLEVEs are a subtype of mechanical explosions. They are sufficiently 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 most often occurs when the temperature of the liquid and vapor within a confining tank or vessel is raised, often by external heat, to the point where the increasing internal pressure can no longer be contained and the vessel explodes. This rupture of the confining vessel releases the pressurized liquid and allows it to vaporize almost instantaneously. If the contents are ignitable, there is almost always a fire. If the contents are noncombustible, there can still be a BLEVE, but the ignition of the vapors and subsequent fire will not occur. 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.

13-3* Orders of Explosions. As an investigative tool, particularly for structures, explosions can be classified as low order and high order (not to be confused with low explosives and high explosives). These classifications are based on the nature of the damage created by the explosion. The differences in damage are more a factor of the rate of pressure rise and the strength of the confining structure, than of the total maximum pressures achieved.