

NFPA®

1700

Guide for
Structural Fire Fighting

2021



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NFPA® 1700

Guide for

Structural Fire Fighting

2021 Edition

This edition of NFPA 1700, *Guide for Structural Fire Fighting*, was prepared by the Technical Committee on Fundamentals of Fire Control Within a Structure Utilizing Fire Dynamics and acted on by the NFPA membership during the 2020 NFPA Technical Meeting held June 8–29. It was issued by the Standards Council on August 11, 2020, with an effective date of August 31, 2020.

This edition of NFPA 1700 was approved as an American National Standard on August 31, 2020.

Origin and Development of NFPA 1700

NFPA 1700, *Guide for Structural Fire Fighting*, 2021 edition, is the first NFPA document connecting fire dynamics research and its application to strategy, tactics, and best practices for fire fighters in controlling fires within a structure.

Initiated through a project request in April 2015, the Standards Council requested input by June 21, 2015, on the proposed guide. Creation of the Technical Committee on Fundamentals of Fire Control Within a Structure Utilizing Fire Dynamics, the committee responsible for NFPA 1700, was approved at the August 2015 Standards Council meeting. This technical committee was charged with developing a document outlining techniques and methods used in fire fighting based on accepted scientific principles and research in fire dynamics. The committee includes a balance of representatives from the fire service, insurance industry, subject matter textbook publishers, special experts, and stakeholders actively engaged in fire dynamics research.

NFPA 1700 addresses fire control within a structure by establishing a basic understanding of fire science and fire dynamics. NFPA 921, *Guide for Fire and Explosion Investigations*, served as a model for how to translate fire dynamics understanding in practicable, applicable ways. Current information from recognized research efforts complements fundamental occupancy, building construction, and building service considerations. While acknowledging occupant life threats, the document further addresses the protection of fire fighters from the immediately dangerous to life and health environment by reinforcing the need for personal protective equipment and methodologies for contamination control.

The focus of the document is to provide guidance to individuals and organizations on interacting within a structure on fire with proven approaches based on documented fire investigations, research, and fire dynamics testing to achieve the most successful outcome. Chapters are dedicated to establishing strategies with tactical considerations to provide effective search, rescue, and fire suppression operations, as well as civilian and responder safety.

Technical Committee on Fundamentals of Fire Control Within a Structure Utilizing Fire Dynamics

Joseph M. Jardin, Chair

Fire Department City of New York, NY [E]
Rep. Fire Department City of New York

Michael J. Allen Anderson, Travis County Emergency Services
District #2, TX [C]

Rep. National Fallen Fire Fighters Foundation

Ian Bolton, District of North Vancouver Fire & Rescue Services,
Canada [U]

Cornelis Kees Both, PRTC Fire Laboratory, Belgium [RT]

John Brunacini, Blue Card, AZ [SE]

W. Edward Buchanan, Jr., Hanover Fire EMS Department, VA [E]

Rusty Dunham, Laramie County Fire District #2, WY [L]
Rep. National Volunteer Fire Council

Richard A. Dyer, Dyer Fire Consulting, MO [E]
Rep. International Association of Fire Chiefs

Andrew D. Ellison, Unified Investigations and Science, Inc., MA
[SE]

Gerard Fontana, Boston Fire Department, MA [E]

Brad French, Dayton Fire Department, OH [U]

James M. Golondzinier, Los Angeles County Fire Department, CA
[L]

Rep. International Association of Fire Fighters

Sean M. Gray, Cobb County Fire And Emergency Services, GA [U]

Gavin P. Horn, University of Illinois Fire Service Institute, IL [RT]

Stephen Kerber, UL LLC, MD [RT]
Rep. UL LLC

Kevin P. Kuntz, Jr., Verisk Analytics/Insurance Services Office, Inc.,
PA [I]

Nicolas J. Ledin, Eau Claire Fire Department, WI [C]

Peter J. McBride, Ottawa Fire Service, Canada [E]

Timothy R. Merinar, National Institute for Occupational Safety &
Health, WV [E]

Rep. National Institute for Occupational Safety & Health

Ryan O'Donnell, Whitehat Development, LLC, NY [SE]

John R. Schutt, Mesa Fire Medical Department, AZ [U]

Josh Matthew Stefancic, Safety Harbor Fire Department, FL [M]
Rep. International Fire Service Training Association

Jens Stiegel, Frankfurt Fire Department, Germany [E]

Jason A. Sutula, JENSEN HUGHES, MD [SE]

Devon J. Wells, Hood River Fire & EMS, OR [SE]

Rep. International Society of Fire Service Instructors

Richard White, Justice Institute of British Columbia Fire & Safety,
Canada [SE]

Steven Edward White, Prince George's County Fire Department
(Retired), MD [E]

Steve Young, Wolf Creek Fire Department/Travelers Insurance, MO
[I]

Alternates

Jonathan W. Bender, Prince George's County Fire/EMS
Department, MD [E]

(Alt. to Steven Edward White)

Bradley Bignucolo, Ottawa Fire Services, Canada [E]
(Alt. to Peter J. McBride)

Francesco Colella, Exponent, Inc., MA [SE]
(Voting Alt.)

Sean DeCrane, Underwriters' Laboratories, OH [L]
(Alt. to James M. Golondzinier)

Joseph M. Fleming, Boston Fire Department, MA [E]
(Alt. to Gerard Fontana)

Kenn Fontenot, LSU Fire & Emergency Training, LA [L]
(Alt. to Rusty Dunham)

Jeffrey Alan Grote, Central Jackson County Fire Protection District,
MO [E]
(Alt. to Richard A. Dyer)

George Healy, Fire Department City of New York, NY [E]
(Alt. to Joseph M. Jardin)

Xianxu (Sherri) Hu, Verisk Analytics/Insurance Services Office,
Inc., NJ [I]
(Alt. to Kevin P. Kuntz, Jr.)

James Tyler Johnson, Justice Institute of British Columbia, Canada
[U]

(Alt. to Richard White)

James M. Lord, JENSEN HUGHES, MD [SE]
(Alt. to Jason A. Sutula)

Daniel Madrzykowski, UL Firefighter Safety Research Institute, MD
[RT]

(Alt. to Stephen Kerber)

Richard L. Merrell, Fairfax County Fire & Rescue Department, VA
[M]

(Voting Alt.)

Michael Nixon, Strathcona County Emergency Services, Canada
[U]

(Alt. to Ian Bolton)

Sergio Romo, Mesa Fire Department, AZ [U]
(Alt. to John R. Schutt)

Timm Schabbel, Clay Fire Territory, IN [SE]
(Alt. to John Brunacini)

Brian Joseph Toonen, Eau Claire Fire Department, WI [C]
(Alt. to Nicolas J. Ledin)

Robert Fash, NFPA Staff Liaison

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

Committee Scope: This Committee shall have primary responsibility for documents relating to techniques and methods used in fire fighting based on accepted scientific principles and research in the field of fire dynamics.

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

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Information on referenced and extracted publications can be found in Chapter 2 and Annex D.

Chapter 1 Administration

1.1 Scope. This guide addresses structural fire-fighting strategy and tactics as supported by science-based research.

1.2 Purpose. The purpose of this document is to provide guidance for the development of policies, procedures, and guidelines, including strategies and tactics for structural fire-fighting supported by science-based research.

1.3 Application. The intent of this guide is to provide guidance on the application of science-based fire dynamics research supporting fire-fighting practices recognizing that life safety of the public and the first responder is the highest incident priority, followed by incident stabilization and property conservation.

1.4 Units of Measure. Metric units of measurement in this guide 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. These units are listed in Table 1.4.

Table 1.4 SI Units and Equivalent U.S. Customary Units

SI	U.S.
Distance	
1 cm	0.394 in.
2.54 cm	1 in.
1 m	3.28 ft
0.305 m	1 ft
Area	
1 cm ²	0.155 in. ²
6.45 cm ²	1 in. ²
1 m ²	10.8 ft ²
0.093 m ²	1 ft ²
Volume	
1 cm ³	0.34 fluid oz
29.6 cm ³	1 U.S. fluid oz
1 L	1.06 U.S. qt
0.95 L	1 U.S. qt
1 m ³	35.3 ft ³
0.028 m ³	1 ft ³
Mass	
1 g	0.353 oz
28.25 g	1 oz
1 kg	2.20 lb
0.454 kg	1 lb
Density	
1 g/cm ³	8.35 lb/U.S. gal
0.12 cm ³	1 lb/U.S. gal
1 kg/m ³	0.063 lb/ft ³
Flow	
1 L/sec	15.9 U.S. gal/min
0.063 L/sec	1 U.S. gal/min
Pressure	
1 bar (750 mmHg)	14.5 lb/in. ²
0.069 bar	1 lb/in. ² (27.7 in. water column)
1 kPa	0.145 lb/in. ²
Energy	
1 J	9.48 × 10 ⁻⁴ Btu
1055 J	1 Btu
1 kJ	0.948 Btu
Power	
1 kW	0.952 Btu/sec
1.06 kW	1 Btu/sec

Note: Converting from one system of measurement to another usually introduces additional significant figures to a value. The converted values should be rounded off, so that they include no more significant figures than the original measured or reported values.

1.5 Measurement Uncertainty. The reproducibility of measurements reported in this guide may be very high, such as density measurements of pure substances, or more variable, such as gas temperatures, heat release rates, or event times in test fires. Therefore, all reported measurements or factors in equations should be evaluated to assess whether the level of precision expressed is appropriate or broadly applicable.

Chapter 2 Referenced Publications

2.1 General. The documents or portions thereof listed in this chapter are referenced within this guide and should be considered part of the recommendations of this document.

2.2 NFPA Publications. National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02169-7471.

NFPA 12, *Standard on Carbon Dioxide Extinguishing Systems*, 2018 edition.

NFPA 13, *Standard for the Installation of Sprinkler Systems*, 2019 edition.

NFPA 13D, *Standard for the Installation of Sprinkler Systems in One- and Two-Family Dwellings and Manufactured Homes*, 2019 edition.

NFPA 13R, *Standard for the Installation of Sprinkler Systems in Low-Rise Residential Occupancies*, 2019 edition.

NFPA 14, *Standard for the Installation of Standpipe and Hose Systems*, 2019 edition.

NFPA 30, *Flammable and Combustible Liquids Code*, 2018 edition.

NFPA 72®, *National Fire Alarm and Signaling Code®*, 2019 edition.

NFPA 1407, *Standard for Training Fire Service Rapid Intervention Crews*, 2020 edition.

NFPA 1500™, *Standard on Fire Department Occupational Safety, Health, and Wellness Program*, 2018 edition.

NFPA 1584, *Standard on the Rehabilitation Process for Members During Emergency Operations and Training Exercises*, 2015 edition.

NFPA 1620, *Standard for Pre-Incident Planning*, 2020 edition.

NFPA 1801, *Standard on Thermal Imagers for the Fire Service*, 2018 edition.

NFPA 1851, *Standard on Selection, Care, and Maintenance of Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting*, 2020 edition.

NFPA 1931, *Standard for Manufacturer's Design of Fire Department Ground Ladders*, 2020 edition.

NFPA 1961 *Standard on Fire Hose*, 2020 edition.

NFPA 1964, *Standard for Spray Nozzles and Appliances*, 2018 edition.

NFPA 1971, *Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting*, 2018 edition.

NFPA 1975, *Standard on Emergency Services Work Apparel*, 2019 edition.

NFPA 1981, *Standard on Open-Circuit Self-Contained Breathing Apparatus (SCBA) for Emergency Services*, 2019 edition.

NFPA 1982, *Standard on Personal Alert Safety Systems (PASS)*, 2018 edition.

NFPA 1983, *Standard on Life Safety Rope and Equipment for Emergency Services*, 2017 edition.

2.3 Other Publications.

2.3.1 ASTM Publications. ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959.

ASTM D5/D5M, *Standard Test Method for Penetration of Bituminous Materials*, 2013.

ASTM D323, *Standard Test Method for Vapor Pressure of Petroleum Products (Reid Method)*, 2015a.

ASTM D4359, *Standard Test for Determining Whether a Material is a Liquid or a Solid*, 1990 (reapproved 2012).

ASTM D6413/D6413M, *Standard Test Method for Flame Resistance of Textiles (Vertical Test)*, 2015.

2.3.2 NIOSH Publications. National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, 1600 Clifton Road, Atlanta, GA 30329-4027.

DHHS (NIOSH) Publication No. 2005-132, *NIOSH Alert: Preventing Injuries and Deaths of Fire Fighters due to Truss System Failures*, May 2005. <https://www.cdc.gov/niosh/docs/2005-132/>.

2.3.3 UL Publications. Underwriters Laboratories Inc., 333 Pfingsten Road, Northbrook, IL 60062-2096.

UL 19, *Standard for Lined Fire Hose and Hose Assemblies*, 2013.

2.3.4 Other Publications.

Babrauskas, V. and Krasny, J., *Fire Behavior of Upholstered Furniture*, NBS Monograph 173, Fire Behavior of Upholstered Furniture.

Babrauskas, V., "Heat Release Rates," in *SFPE Handbook of Fire Protection Engineering*, 3rd edition, National Fire Protection Association.

Beyler, C. "Flammability Limits of Premixed and Diffusion Flames." In *SFPE Handbook of Fire Protection Engineering*, ed. P. DiNenno. Quincy, MA: National Fire Protection Association, 2002.

Fleischmann, Charles M., and ZhiJian Chen. "Defining the Difference Between Backdraft and Smoke Explosions." The 9th Asia-Oceania Symposium on Fire Science and Technology, Procedia Engineering 62, p. 324–330. 2013.

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

Merriam-Webster's Collegiate Dictionary, 11th edition, Merriam-Webster, Inc., Springfield, MA, 2003.

2.3.5 References from Chapter 4.

1. Madrzykowski, D. *Fire Fighter Equipment Operational Environment (FFEOE): Evaluation of Thermal Conditions*. UL Firefighter Safety Research Institute, Columbia, MD, August 2017.

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NFPA 5000®, *Building Construction and Safety Code®*, 2018 edition.

Chapter 3 Definitions

3.1 General. The definitions contained in this chapter apply to the terms used in this guide. Where terms are not defined in this chapter or within another chapter, they should be defined using their ordinarily accepted meanings within the context in which they are used. *Merriam-Webster's Collegiate Dictionary*, 11th edition, is the source for the ordinarily accepted meaning.

3.2 NFPA Official Definitions.

3.2.1* Approved. Acceptable to the authority having jurisdiction.

3.2.2* Authority Having Jurisdiction (AHJ). An organization, office, or individual responsible for enforcing the requirements of a code or standard, or for approving equipment, materials, an installation, or a procedure.

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

3.2.4 Labeled. Equipment or materials to which has been attached a label, symbol, or other identifying mark of an organization that is acceptable to the authority having jurisdiction and concerned with product evaluation, that maintains periodic inspection of production of labeled equipment or materials, and by whose labeling the manufacturer indicates compliance with appropriate standards or performance in a specified manner.

3.2.5* Listed. Equipment, materials, or services included in a list published by an organization that is acceptable to the authority having jurisdiction and concerned with evaluation of products or services, that maintains periodic inspection of production of listed equipment or materials or periodic evaluation of services, and whose listing states that either the equipment, material, or service meets appropriate designated standards or has been tested and found suitable for a specified purpose.

3.2.6 Should. Indicates a recommendation or that which is advised but not required.

3.3 General Definitions.

3.3.1 Abandoned Building. A building that is unoccupied/unused with no intention of re-occupying and reusing. [1620, 2020]

3.3.2 Accident. An unplanned event that interrupts an activity and sometimes causes injury or damage or a chance occurrence arising from unknown causes; an unexpected happening due to carelessness, ignorance, and the like. [921, 2017]

3.3.3 Aerial Fire Apparatus. A vehicle equipped with an aerial ladder, elevating platform, or water tower that is designed and equipped to support fire fighting and rescue operations by positioning personnel, handling materials, providing continuous egress, or discharging water at positions elevated from the ground. [1901, 2016]

3.3.4 Ambient. Someone's or something's surroundings, especially as they pertain to the local environment; for example, ambient air and ambient temperature. [921, 2017]

3.3.5 Atmospheric Pressure. The pressure of the weight of air on the surface of the earth, approximately 14.7 pounds per square inch (psia) (101 kPa absolute) at sea level. [54, 2018]

3.3.6 Backdraft. A deflagration resulting from the sudden introduction of air into a confined space containing oxygen-deficient products of incomplete combustion.

3.3.7 Basement. Any story of a building wholly or partly below grade plane that is not considered the first story above grade plane.

3.3.8 Bidirectional Vent. A building opening that serves as both an intake and exhaust vent of a flow path at the same time.

3.3.9 BLEVE. Boiling liquid expanding vapor explosion. [921, 2017]

3.3.10 Blitz Attack. A coordinated fire attack from the exterior with a master stream (300+ gpm).

3.3.11 Blowers. Powered fans that are used to push air into a structure to increase the pressure of the gases inside a structure to move the gases to an area of lower pressure, usually the exterior.

3.3.12 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; a British thermal unit is equal to 1055 joules, 1.055 kilojoules, and 252.15 calories. [921, 2017]

3.3.13 Broken Stream. See 3.3.205.1.

3.3.14 Buoyancy. (1) The tendency or capacity to remain afloat in a liquid. (2) The upward force of a fluid upon a floating object. [1405, 2016]

3.3.15 Calorie. The amount of heat necessary to raise 1 gram of water 1°C at the pressure of 1 atmosphere and temperature of 15°C; a calorie is 4.184 joules, and there are 252.15 calories in a British thermal unit (Btu). [921, 2017]

3.3.16 Carcinogen/Carcinogenic. A cancer-causing substance that is identified in one of several published lists, including, but not limited to, those prepared by the U.S. National Toxicology Program, the International Agency for Research on Cancer (IARC), the National Institute for Occupational Safety and Health (NIOSH), and the American Conference of Governmental Industrial Hygienists (ACGIH). [1851, 2020]

3.3.17 Ceiling Jet. A relatively thin layer of flowing hot gases that develops under a horizontal surface (e.g., ceiling) as a result of plume impingement and the flowing gas being forced to move horizontally. [921, 2017]

3.3.18 Ceiling Layer. A buoyant layer of hot gases and smoke produced by a fire in a compartment. [921, 2017]

3.3.19 Char. Carbonaceous material that has been burned or pyrolyzed and has a blackened appearance. [921, 2017]

3.3.20 Cold Zone. See 3.3.99.1.

3.3.21 Combustible. Capable of undergoing combustion. [921, 2017]

3.3.22 Combustible Liquid. See 3.3.135.1.

3.3.23 Combustion. A chemical process of oxidation that occurs at a rate fast enough to produce heat and usually light in the form of either a glow or flame. [921, 2017]

3.3.24 Combustion Products. The heat, gases, volatilized liquids and solids, particulate matter, and ash generated by combustion. [921, 2017]

3.3.25 Command Post. The location where the incident commander and associated staff are located during an emergency incident. [610, 2019]

3.3.26 Company. The basic fire-fighting organizational unit staffed by various grades of fire fighters under the supervision of an officer and assigned to one or more specific pieces of apparatus. [1410, 2020]

3.3.26.1 Engine Company. A piece of fire apparatus along with fire fighters that have the primary responsibility to deliver a fire stream or streams to extinguish the fire in coordination with ventilation (truck company) and rescue operations.

3.3.26.2 Rescue Company. A piece of fire apparatus along with fire fighters that are generally utilized for search and rescue at fire incidents.

3.3.26.3 Truck (Ladder) Company. A group of fire fighters who work as a unit and are equipped with one or more pieces of aerial fire apparatus.

3.3.27 Compartmentation. The interposing of a physical barrier that is not required to be fire or explosion resistant in order to limit combustible particulate solid migration and hence to control the size of a hazard area. [654, 2020]

3.3.28 Concealed Space. That portion(s) of a building behind walls, over suspended ceilings, in pipe chases, and in attics whose size might normally range from 44.45 mm (1¾ in.) stud spaces to 2.44 m (8 ft.) interstitial truss spaces and that might contain combustible materials such as building structural members, thermal and/or electrical insulation, and ducting. [96, 2017]

3.3.29 Conduction. Heat transfer to another body or within a body by direct contact. [921, 2017]

3.3.30 Conductive and Compressive Heat Resistance (CCHR) Test. A test used to evaluate the properties of the garment shoulder and knee areas, which are more likely to become compressed, because thermal insulation is reduced under compression.

3.3.31 Construction Type. The combination of materials used in the construction of a building or structure, based on the varying degrees of fire resistance and combustibility. [5000, 2018]

3.3.32 Contaminant. Smoke, fumes, and particulates deposited on personnel, PPE, apparatus, tools, and equipment.

3.3.33 Convection. Heat transfer by circulation within a medium such as a gas or a liquid. [921, 2017]

3.3.34 Decay Stage. The stage of fire development within a structure characterized by either a decrease in the fuel load or available oxygen to support combustion, resulting in lower temperatures and lower pressure in the fire area. [1410, 2020]

3.3.35* Decontamination. The process of removing contaminants such as soot, particulate, and fireground chemicals to clean fireground tools and equipment and prevent the spread of contamination to other persons or equipment.

3.3.35.1 Dry Decontamination. Utilizing forced airflow or brushing off of personnel, PPE, apparatus, tools, and equipment to reduce contaminants.

3.3.35.2 Gross Decontamination. The initial phase of the decontamination process during which the amount of surface contaminant is significantly reduced by removing bulk contaminants and substances from the surface of the equipment or tools using some form of brushing, wetting agent, and/or detergents.

3.3.35.3 Wet Decontamination. Utilizing water or a water and soap solution to reduce contaminants on personnel, PPE, apparatus, tools, and equipment.

3.3.36 Defensive Strategy. The plan for the actions or movements of fire department units to protect exposures and contain the main body of fire to the already affected areas.

3.3.37 Deflagration. Propagation of a combustion zone at a velocity that is less than the speed of sound in the unreacted medium. [68, 2018]

3.3.38 Density. The mass of a substance per unit volume, usually specified at standard temperature and pressure. The density of water is approximately 1 gram per cubic centimeter. The density of air is approximately 1.275 grams per cubic meter. [921, 2017]

3.3.39 Detection. (1) Sensing the existence of a fire, especially by a detector from one or more products of the fire, such as smoke, heat, infrared radiation, and the like. (2) The act or process of discovering and locating a fire. [921, 2017]

3.3.40 Detonation. Propagation of a combustion zone at a velocity greater than the speed of sound in the unreacted medium. [68, 2018]

3.3.41 Differential Pressure. The difference between pressures at different points along a flow path that creates a flow of gases or fluids from an area of higher pressure to an area of lower pressure.

3.3.42 Diffuse Fuel. A gas, vapor, dust, particulate, aerosol, mist, fog, or hybrid mixture of these, suspended in the atmosphere, which is capable of being ignited and propagating a flame front. [921, 2017]

3.3.43 Diffusion Flame. A flame in which fuel and air mix or diffuse together at the region of combustion. [921, 2017]

3.3.44 Direct Application. Fire-fighting operations involving the application of extinguishing agents directly onto the burning fuel surface.

3.3.45 Doffing. The process of properly removing a member's PPE and respiratory protection to limit additional contamination and exposure.

3.3.46 Donning. The process of properly dressing in full PPE, ensuring all exposed skin and airway are protected.

3.3.47 Door Control. Using a door to limit the amount of air available to the fire, or to isolate a part of the building from the flow path.

3.3.48 Drop Down. The spread of fire by the dropping or falling of burning materials. Synonymous with "fall down." [921, 2017]

3.3.49 Dry Decontamination. See 3.3.35.1.

3.3.50 Dynamic Flow. A unidirectional or bidirectional flow of smoke/air that presents irregular stratification and shape or alternates in direction (i.e., pulsations).

3.3.51* Energy Storage System (ESS). One or more components assembled together capable of storing energy and providing electrical energy into the premises wiring system or an electric power production and distribution network. [70:706.2]

3.3.52 Engine Company. See 3.3.26.1.

3.3.53 Entrainment. The process of air or gases being drawn into a fire, plume, or jet. [921, 2017]

3.3.54 Exclusion Zone. See 3.3.99.2.

3.3.55 Exhaust Vent. The outlet of a flow path that allows the gases to move out of the structure.

3.3.56 Explosion. The sudden conversion of potential energy (chemical or mechanical) into kinetic energy with the production and release of gases under pressure, or the release of gas under pressure. These high-pressure gases then do mechanical work such as moving, changing, or shattering nearby materials. [921, 2017]

3.3.57 Explosive. Any chemical compound, mixture, or device that functions by explosion. [921, 2017]

3.3.58 Exposure — Personnel. The process by which people, animals, and equipment are subjected to or come in contact with a hazardous environment or material.

3.3.59 Exposure — Structure. The side of a structural assembly or separate part of the fireground that is directly exposed to the fire to which the fire could spread.

3.3.60 Exposure Protection. Using an extinguishing agent to coat the exposure, and/or remove the fuel(s), to prevent fire spread.

3.3.61 Extinguish. To cause to cease burning. [921, 2017]

3.3.62 Failure. Distortion, breakage, deterioration, or other fault in an item, component, system, assembly, or structure that results in unsatisfactory performance of the function for which it was designed. [921, 2017]

3.3.63 Fire. A rapid oxidation process, which is a gas phase chemical reaction resulting in the evolution of light and heat in varying intensities. [921, 2017]

3.3.64 Fire Alarm System. A system or portion of a combination system that consists of components and circuits arranged to monitor and annunciate the status of fire alarm or supervisory signal-initiating devices and to initiate the appropriate response to those signals. [72, 2019]

3.3.65 Fire Apparatus. A vehicle designed to be used under emergency conditions to transport personnel and equipment or to support the suppression of fires or mitigation of other hazardous situations. [1901, 2016]

3.3.66 Fire Command Center. The principal attended or unattended room or area where the status of the detection, alarm communications, control systems, and other emergency

systems is displayed and from which the system(s) can be manually controlled. [72, 2019]

3.3.67 Fire Control. The coordinated tasks of delivering an extinguishing agent (e.g., water) to fire and heat and managing the flow of air, smoke, heat, and fuel(s).

3.3.68 Fire Department Connection (FDC). A connection through which the fire department can pump supplemental water into the sprinkler system, standpipe, or other water-based fire protection systems, furnishing water for fire extinguishment to supplement existing water supplies. [24, 2019]

3.3.69 Fire Dynamics. The detailed study of how chemistry, fire science, and the engineering disciplines of fluid mechanics and heat transfer interact to influence fire behavior. [921, 2017]

3.3.70 Fire Propagation. See 3.3.73, Fire Spread.

3.3.71 Fire Resistive Construction. Construction designed to provide reasonable protection against fire.

3.3.72 Fire Science. The body of knowledge concerning the study of fire and related subjects (such as combustion, flame, products of combustion, heat release, heat transfer, fire and explosion chemistry, fire and explosion dynamics, thermodynamics, kinetics, fluid mechanics, fire safety) and their interaction with people, structures, and the environment. [921, 2017]

3.3.73 Fire Spread. The movement of fire from one place to another. [921, 2017]

3.3.74 Flame. A body or stream of gaseous material involved in the combustion process and emitting radiant energy at specific wavelength bands determined by the combustion chemistry of the fuel. In most cases, some portion of the emitted radiant energy is visible to the human eye. [921, 2017]

3.3.75 Flame Front. The flaming leading edge of a propagating combustion reaction zone. [921, 2017]

3.3.76 Flameover. The condition where unburned fuel from a fire has accumulated in the ceiling layer to a sufficient concentration (i.e., at or above the lower flammable limit) that it ignites and burns; can occur without ignition of, or prior to, the ignition of other fuels separate from the origin. [921, 2017]

3.3.77 Flammable. Capable of burning with a flame. [921, 2017]

3.3.78 Flammable Gas. A material that is a gas at 68°F (20°C) or less at an absolute pressure of 14.7 psi (101.3 kPa), that is ignitable at an absolute pressure of 14.7 psi (101.3 kPa) when in a mixture of 13 percent or less by volume with air, or that has a flammable range at an absolute pressure of 14.7 psi (101.3 kPa) with air of at least 12 percent, regardless of the lower limit. [55, 2020]

3.3.79 Flammable Limit. The upper or lower concentration limit at a specified temperature and pressure of a flammable gas or a vapor of an ignitable liquid and air, expressed as a percentage of fuel by volume that can be ignited. [921, 2017]

3.3.80 Flammable Liquid. See 3.3.135.2.

3.3.81 Flammable Range. The range of concentrations between the lower and upper flammable limits. [68, 2018]

3.3.82 Flash Fire. A fire that spreads by means of a flame front rapidly through a diffuse fuel, such as dust, gas, or the

vapors of an ignitable liquid, without the production of damaging pressure. [921, 2017]

3.3.83 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. [921, 2017]

3.3.84 Flashover. A transition phase in the development of a compartment fire in which surfaces exposed to thermal radiation reach ignition temperature more or less simultaneously and fire spreads rapidly throughout the space, resulting in full room involvement or total involvement of the compartment or enclosed space. [921, 2017]

3.3.85* Flow Path. The route followed by smoke, air, heat, or flame toward or away from an opening; typically, a window, door, or other leakage points, due to differences in pressure.

3.3.86 Flow Path Control. The tactic of controlling or closing ventilation points to limit additional oxygen into the space thereby limiting fire development, heat release rate, and smoke production, and to control the movement of the heat and smoke conditions out of the fire area to the exterior and to other areas within the building. [1410, 2020]

3.3.87 Fog Stream. See 3.3.205.2.

3.3.88 Fuel. A material that will maintain combustion under specified environmental conditions. [53, 2016]

3.3.89 Fuel Gas. Natural gas, manufactured gas, LP-Gas, and similar gases commonly used for commercial or residential purposes such as heating, cooling, or cooking. [921, 2017]

3.3.90 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. [921, 2017]

3.3.91 Fuel Package. A single item of fuel.

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

3.3.93 Fully Developed Stage. The stage of fire development where heat release rate has reached its peak within a compartment based on available fuel or ventilation.

3.3.94 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. [921, 2017]

3.3.95 Glowing Combustion. Luminous burning of solid material without a visible flame. [921, 2017]

3.3.96 Gross Contamination. See 3.3.35.2.

3.3.97 Growth Stage. The stage of fire development where the heat release rate from an incipient fire has increased to the point where heat transferred from the fire and the combustion products are pyrolyzing adjacent fuel sources and the fire begins to spread across the ceiling of the fire compartment (rollover). [1410, 2020]

3.3.98 Hazard. Any arrangement of materials that presents the potential for harm. [921, 2017]

3.3.99 Hazard Control Zones. The physical or conceptual demarcation of an emergency scene according to levels of risk and the associated personal protective equipment (PPE) usage that identifies the exclusion, hot, warm, and cold zones are all zones within the “hazard control zone” classification.

3.3.99.1 Cold Zone. A hazard-free area where PPE is not required and that is suitable for locating command, rehabilitation, medical functions, and public access.

3.3.99.2 Exclusion Zone. An area where no personnel may enter due to imminent hazard(s), where issued PPE will not protect against the hazard, or where there is a need to protect potential evidence.

3.3.99.3* Hot Zone. The primary incident hazard area deemed immediately dangerous to life and health (IDLH) and where personnel wear PPE suitable for the hazards encountered.

3.3.99.4 Warm Zone. A limited-access area for personnel directly aiding or in support of operations in the hot zone where personnel wear PPE suitable for the hazards present.

3.3.100 Heat. A form of energy characterized by vibration of molecules and capable of initiating and supporting chemical changes and changes of state. [921, 2017]

3.3.101 Heat and Flame Vector. An arrow used in a fire scene drawing to show the direction of heat, smoke, or flame flow. [921, 2017]

3.3.102 Heat Flux. The measure of the rate of heat transfer to a surface or an area, typically expressed in kW/m², or W/cm². [921, 2017]

3.3.103 Heat of Combustion. The total amount of thermal energy that could be generated by a fuel if it were to burn completely and which is typically measured in kilojoules per gram (kJ/g) or mega joules per kilogram (MJ/kg).

3.3.104 Heat of Ignition. The heat energy that brings about ignition. [921, 2017]

3.3.105 Heat Release Rate (HRR). The rate at which heat energy is generated by burning. [921, 2017]

3.3.106 Heat Transfer. The exchange of thermal energy from the *source* to the *fuel* by the mechanisms of *conduction*, *convection*, or *radiation*, or all three.

3.3.107 High-Pressure Side or Upwind Side. The side of the building that the wind is impacting on.

3.3.108 High-Rise Building. A building where the floor of an occupiable story is greater than 75 ft (23 m) above the lowest level of fire department vehicle access. [5000, 2018]

3.3.109 Horizontal Ventilation. A method of utilizing natural ventilation currents to manage the flow of heat and smoke from the interior to the exterior while entraining fresh air from an intake on the same level of the structure.

3.3.110 Hoseline. A hose extended from fire apparatus or a standpipe system designed to flow between 90 gpm and 300 gpm.

3.3.111 Hot Zone. See 3.3.99.3.

3.3.112 Hydraulic Ventilation. Use of a water stream to remove gases from a compartment through an exhaust vent while entraining fresh air from an intake.

3.3.113 HVAC Ventilation. Air flows due to fixed building heating ventilation and air conditioning systems.

3.3.114 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 burned. [921, 2017]

3.3.115 Ignition. The process of initiating self-sustained combustion. [921, 2017]

3.3.116 Ignition Energy. The quantity of heat energy that should be absorbed by a substance to ignite and burn. [921, 2017]

3.3.117 Ignition Temperature. Minimum temperature a substance should attain in order to ignite under specific test conditions. [921, 2017]

3.3.118 Ignition Time. The time between the application of an ignition source to a material and the onset of self-sustained combustion. [921, 2017]

3.3.119 Immediately Dangerous to Life or Health (IDLH). Any condition that would pose an immediate or delayed threat to life, cause irreversible adverse health effects, or interfere with an individual's ability to escape unaided from a hazardous environment. [1670, 2017]

3.3.120 Incendiary Fire. A fire that is intentionally ignited in an area or under circumstances where and when there should not be a fire. [921, 2017]

3.3.121* Incident Action Plan. The correct actions that match, take control of, and mitigate the incident hazards within the overall incident strategy.

3.3.122 Incident Command System (ICS). A component of an incident management system (IMS) designed to enable effective and efficient on-scene incident management by integrating organizational functions, tactical operations, incident planning, incident logistics, and administrative tasks within a common organizational structure. [472, 2018]

3.3.123 Incident Commander (IC). The individual responsible for all incident activities, including the development of strategies and tactics and the ordering and the release of resources. [1410, 2020]

3.3.124 Incipient Stage. The early stage of fire development where the fire's progression is limited to a fuel source and the thermal hazard is localized to the area of the burning material. [1410, 2020]

3.3.125 Independent Service Provider (ISP). See 3.3.243, Verified Independent Service Provider (ISP).

3.3.126 Indirect Attack. Fire-fighting operations involving the application of extinguishing agents to reduce the buildup of heat released from a fire with the intention of suppressing the fire without applying the agent directly onto the burning surface.

3.3.127 Intake Vent. An inlet of a flow path that allows fresh air to move into the structure.

3.3.128 Joule. The preferred SI unit of heat, energy, or work. A joule is the heat produced when one ampere is passed through a resistance of one ohm for one second, or it is the work required to move a distance of one meter against a force of one newton. There are 4.184 joules in a calorie and 1055 joules in a British thermal unit (Btu). A watt is a joule/second. [See also 3.3.12, *British Thermal Unit (Btu)*, and 3.3.15, *Calorie*.] [921, 2017]

3.3.129 Knee Wall. A short wall, typically under 3 ft (1 m) in height, used to create a room, such as a living space within an attic, and whose creation results in a void space behind the knee wall and the underside of the roof.

3.3.130 Knockdown. The reduction of flame and heat to a point where further extension of a fire has been abated and the overhaul stage can begin. [402, 2019]

3.3.131* Latent Heat. The energy that causes a change in state of matter of an object.

3.3.132 Layering. The systematic process of removing debris from the top down and observing the relative location of artifacts at the fire scene. [921, 2017]

3.3.133 Life Safety. The protection of human life, including all persons within a structure, civilians, and fire-fighting personnel.

3.3.134* Lightweight Construction. Structures that have framework made out of wood or other lightweight materials.

3.3.135 Liquid. Any material that (1) has a fluidity greater than that of 300 penetration asphalt when tested in accordance with ASTM D5, *Standard Test Method for Penetration of Bituminous Materials*, or (2) is a viscous substance for which a specific melting point cannot be determined but that is determined to be a liquid in accordance with ASTM D4359, *Standard Test for Determining Whether a Material is a Liquid or a Solid*. [30, 2018]

3.3.135.1 Combustible Liquid. Any liquid that has a closed-cup flash point at or above 100°F (37.8°C), as determined by the test procedures and apparatus set forth in Section 4.4 of NFPA 30. Combustible liquids are classified according to Section 4.3 of NFPA 30. [30, 2018]

3.3.135.2 Flammable Liquid. Any liquid that has a closed-cup flash point below 100°F (37.8°C), as determined by the test procedures and apparatus set forth in Section 4.4 of NFPA 30 and a Reid vapor pressure that does not exceed an absolute pressure of 40 psi (276 kPa) at 100°F (37.8°C), as determined by ASTM D323, *Standard Test Method for Vapor Pressure of Petroleum Products (Reid Method)*. Flammable liquids are classified according to Section 4.3 of NFPA 30. [30, 2018]

3.3.136 Low Explosive. An explosive that has a reaction velocity of less than 1000 m/sec (3000 ft/sec). [921, 2017]

3.3.137 Low-Pressure Side or Downwind Side. The side of the building opposite the side of the building that the wind is impacting on.

3.3.138 Lower Explosive Limit or Lower Flammable Limit. The minimum concentration of combustible vapor or combustible gas in a mixture of the vapor or gas and gaseous oxidant above which propagation of flame will occur on contact with an ignition source. [115, 2020]

3.3.139 Master Stream. See 3.3.205.3.

3.3.140 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. [921, 2017]

3.3.141 Mechanical Ventilation. The use of powered blowers, fans, smoke ejectors, or hydraulic ventilation to exchange gases inside the structure with fresh air.

3.3.142 Natural Ventilation. The use of convection currents and winds to ventilate a structure without the use of powered blowers, fans, smoke ejectors, or hose streams.

3.3.143 Negative-Pressure Ventilation. The use of powered blowers, fans, or smoke ejectors to remove gases from a compartment through an exhaust vent while entraining fresh air from an intake.

3.3.144 Neutral Plane. Marks the level at a bi-directional vent, such as a doorway or window opening, between the hot gas (smoke) flowing out of a fire compartment and the cool air flowing into the compartment.

3.3.145 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. [921, 2017]

3.3.146 Nonflammable. (1) Not readily capable of burning with a flame. (2) Not liable to ignite and burn when exposed to flame. Its antonym is *flammable*. [921, 2017]

3.3.147 Nozzle.

3.3.147.1 Penetrating Nozzle. A nozzle that is designed to penetrate a building membrane such as a roof, wall, or floor to deliver a water stream from one area to another area.

3.3.147.2 Spray Nozzle. A nozzle intended for connection to a hose line or monitor to discharge water in either a spray pattern or a straight stream pattern as selected by the operator. [1964, 2018]

3.3.147.3 Straight Tip Nozzle. A smooth-bore nozzle for producing a solid stream. [1963, 2019]

3.3.148 Nozzle Pressure. The pressure at the point where water flows from a nozzle and is described in pounds per square inch (psi).

3.3.149 Offensive Strategy. The plan for the actions and movements of arriving fire department units to control the fire, effect rescues, start searches for occupants, and extinguish the fire with the intent to commence operations inside the fire building.

3.3.150 Origin. The general location where a fire or explosion began. [921, 2017]

3.3.151 Overhaul. A fire-fighting term involving the process of final extinguishment after the main body of the fire has been knocked down. All traces of fire must be extinguished at this time. [921, 2017]

3.3.152 Overload. Operation of equipment in excess of normal, full-load rating or of a conductor in excess of rated ampacity that, where it persists for a sufficient length of time would cause damage or dangerous overheating. A fault, such as a short circuit or ground fault, is not an overload. [921, 2017]

3.3.153 Oxidizer. Any solid or liquid material that readily yields oxygen or other oxidizing gas or that readily reacts to

promote or initiate combustion of combustible materials and that can, under some circumstances undergo a vigorous self-sustained decomposition due to contamination or heat exposure. [400, 2019]

3.3.154 Oxygen Deficiency. Insufficiency of oxygen to support combustion. (See also 3.3.240, *Ventilation-Controlled Fire*.) [921, 2017]

3.3.155 Penetrating Nozzle. See 3.3.147.1.

3.3.156 Personal Protective Equipment (PPE). Protective equipment tested and approved for fire fighting, including, but not limited to, coat, pants, gloves, boots, hood, helmet, and self-contained breathing apparatus.

3.3.157 Photovoltaic (PV) System. The total components, circuits, and equipment up to and including the PV system disconnecting means that, in combination, convert solar energy into electric energy. [70:100]

3.3.158 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. [921, 2017]

3.3.159 Plume. The column of hot gases, flames, and smoke rising above a fire; also called *convection column*, *thermal updraft*, or *thermal column*. [921, 2017]

3.3.160 Positive Pressure Attack. The utilization of powered blowers or fans, prior to fire control, as a means to control and reduce the heat in the intake portion of the flow path and exhaust heat and smoke from the fire area.

3.3.161 Positive Pressure Isolation. The utilization of powered blowers or fans to pressurize sections of buildings or exposures adjacent to the fire area with the intent to prevent smoke and fire spread into the pressurized sections.

3.3.162 Positive Pressure Ventilation. The utilization of powered blowers or fans, post-fire control, to exhaust heat and smoke from the fire area.

3.3.163 Preservation. Application or use of measures to prevent damage, change or alteration, or deterioration. [921, 2017]

3.3.164 Pressure. A measure of force per unit area, given in pounds per square inch (psi) or Pascals (Pa), exerted on a surface at 90 degrees to that surface.

3.3.165 Products of Combustion. See 3.3.24, Combustion Products.

3.3.166 Pyrolysis. A process in which material is decomposed, or broken down, into simpler molecular compounds by the effects of heat alone; pyrolysis often precedes combustion. [921, 2017]

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

3.3.168 Radiation. Heat transfer by way of electromagnetic energy. [921, 2017]

3.3.169* Rapid Fire Development. A transient phase in fire behavior accompanied by a rapid increase in heat release rate

of the fire and temperature in the environment, sometimes accompanied by the generation of over-pressure.

3.3.170 Rapid Intervention Crew (RIC). A dedicated crew of at least one officer and three members, positioned outside the IDLH, trained and equipped as specified in NFPA 1407, who are assigned for rapid deployment to rescue lost or trapped members. [1710, 2020]

3.3.171 Rate of Heat Release. See 3.3.105, Heat Release Rate (HRR).

3.3.172 Recirculation. Ineffective ventilation where smoke continues to circulate within the structure instead of being exhausted from the structure.

3.3.173 Rekindle. A return to flaming combustion after apparent but incomplete extinguishment. [921, 2017]

3.3.174 Rescue. The process of searching, evacuating, and removing occupants from the fire building and providing emergency medical care.

3.3.175 Rescue Company. See 3.3.26.2.

3.3.176 Risk. The degree of peril; the possible harm that might occur that is represented by the statistical probability or quantitative estimate of the frequency or severity of injury or loss. [921, 2017]

3.3.177 Rollover. See 3.3.76, Flameover.

3.3.178 Salvage. The process of protecting the contents within a building during and following the fire incident.

3.3.179 Scene. The general physical location where an emergency is occurring.

3.3.180 Self-Contained Breathing Apparatus (SCBA). Protective equipment that consists of an air supply, a facepiece, and a regulator.

3.3.181 Sensible Heat. The energy that causes a change in the temperature of an object.

3.3.182 Size Up. The ongoing observation and evaluation of factors that are used to develop strategic goals and tactical objectives. [1006, 2017]

3.3.183 Smoke. The airborne solid and liquid particulates and gases evolved when a material undergoes pyrolysis or combustion, together with the quantity of air that is entrained or otherwise mixed into the mass. [921, 2017]

3.3.184 Smoke Condensate. The condensed residue of suspended vapors and liquid products of incomplete combustion. [921, 2017]

3.3.185 Smoke Cooling. Fire-fighting operations involving the application of extinguishing agents to reduce the flammability of the smoke.

3.3.186 Smoke Ejectors. A powered fan that is designed to remove gases from the interior of a structure using negative pressure.

3.3.187 Smoke Explosion. A rapid fire development that occurs when a smoke-air mixture falls within its flammable range, either external or internal to the room of origin, and is ignited, resulting in a significant pressure front.

3.3.188* Smoke Ignition. The ignition of the products of pyrolysis and incomplete combustion interior or exterior to the fire compartment due to the accumulated smoke layer falling within its flammability range and either autoigniting or igniting due to an ignition source.

3.3.189 Smoldering. Combustion without flame, usually with incandescence and smoke. [921, 2017]

3.3.190 Soot. Black particles of carbon produced in a flame. [921, 2017]

3.3.191 Spalling. Chipping or pitting of concrete or masonry surfaces. [921, 2017]

3.3.192 Special Amusement Building. A building that is temporary, permanent, or mobile and contains a device or system that conveys passengers or provides a walkway along, around, or over a course in any direction as a form of amusement arranged so that the egress path is not readily apparent due to visual or audio distractions or an intentionally confounded egress path, or is not readily available due to the mode of conveyance through the building or structure. [101, 2018]

3.3.193 Specific Gravity (air) (vapor density). The ratio of the average molecular weight of a gas or vapor to the average molecular weight of air. [921, 2017]

3.3.194 Specific Gravity (of a liquid or solid). The ratio of the mass of a given volume of a substance to the mass of an equal volume of water at a temperature of 4°C. [921, 2017]

3.3.195 Spontaneous Heating. Process whereby a material increases in temperature without drawing heat from its surroundings. [921, 2017]

3.3.196 Spontaneous Ignition. Initiation of combustion of a material by an internal chemical or biological reaction that has produced sufficient heat to ignite the material. [921, 2017]

3.3.197 Sprinkler System. A system, commonly activated by heat from a fire and discharges water over the fire area, that consists of an integrated network of piping designed in accordance with fire protection engineering standards that includes a water supply source, a water control valve, a waterflow alarm, and a drain. The portion of the sprinkler system aboveground is a network of specially sized or hydraulically designed piping installed in a building, structure, or area, generally overhead, and to which sprinklers are attached in a system pattern. [13, 2019]

3.3.198 Stack Effect. The vertical airflow within buildings caused by the temperature-created density differences between the building interior and exterior or between two interior spaces. [92, 2018]

3.3.199 Standard Operating Guideline (SOG). A written directive that establishes recommended strategies/concepts of emergency response to an incident. [475, 2017]

3.3.200 Standard Operating Procedure (SOP). A written directive that established specific operation or administrative methods to be followed routinely for the performance of a task or for the use of equipment. [475, 2017]

3.3.201 Steam Conversion. The physical event where water is delivered to the heat of a fire and the water is converted from a liquid to a vapor in the form of steam.

3.3.202 Straight Stream. See 3.3.205.4.

3.3.203 Straight Tip Nozzle. See 3.3.147.3.

3.3.204 Strategy. The general plan or direction selected to accomplish incident objectives. [1026, 2018]

3.3.205 Stream.

3.3.205.1 Broken Stream. A stream of water that has been broken into coarsely divided drops.

3.3.205.2 Fog Stream. A stream of water that is flowed in the form of small water droplets.

3.3.205.3 Master Stream. A ground or aerial device designed to flow in excess of 300 gpm.

3.3.205.4 Straight Stream. A water stream that flows from a solid bore nozzle or a stream that flows from a combination nozzle with the stream setting placed in the narrowest stream setting that is available.

3.3.206 Support Personnel. Any personnel on the fireground in support of fire operations to assist with rehabilitation, decontamination medical treatment, and monitoring.

3.3.207 Suppression. The sum of all the work done to extinguish a fire, beginning at the time of its discovery. [921, 2017]

3.3.208 Surfactants. Compounds that lower the surface tension (or interfacial tension) between two liquids, between a gas and a liquid, or between a liquid and a solid, and which can act as detergents, wetting agents, emulsifiers, foaming agents, and dispersants.

3.3.209 Tactics. Deploying and directing resources on an incident to accomplish the objectives designated by the strategy.

3.3.210 Target Fuel. A fuel that is subject to ignition by thermal radiation such as from a flame or a hot gas layer. [921, 2017]

3.3.211 Temperature. The degree of sensible heat of a body as measured by a thermometer or similar instrument. [921, 2017]

3.3.212 Thermal Column. See 3.3.159, Plume.

3.3.213 Thermal Decomposition. A chemical decomposition caused by heat.

3.3.214 Thermal Expansion. The increase in length, volume, or surface area of a body with rise in temperature. [921, 2017]

3.3.215 Thermal Inertia. The properties of a material that characterize its rate of surface temperature rise when exposed to heat; related to the product of the material's thermal conductivity (k), its density (ρ), and its heat capacity (c). [921, 2017]

3.3.216 Thermal Protective Performance (TPP). A numerical value indicating the resistance of materials to a convective and radiant heat exposure. [1977, 2016]

3.3.217 Thermometry. The study of the science, methodology, and practice of temperature measurement. [921, 2017]

3.3.218 Thermoplastic. Plastic materials that soften and melt under exposure to heat and can reach a flowable state. [921, 2017]

3.3.219 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 form char in a fire. [921, 2017]

3.3.220 Time Line. Graphic representation of the events in a fire incident displayed in chronological order. [921, 2017]

3.3.221 Total Burn. A fire scene where a fire continued to burn until most combustibles were consumed and the fire self-extinguished due to a lack of fuel or was extinguished when the fuel load was reduced by burning and there was sufficient suppression agent application to extinguish the fire.

3.3.222 Transitional Attack. The application of a fire stream from the exterior of a structure to improve conditions prior to interior fire control.

3.3.223 Travel Distance. The length measured on the floor or other surface along the centerline of the natural path of travel.

3.3.224 Truck (Ladder) Company. See 3.3.26.3.

3.3.225 Turnout Components. The interval that begins when the emergency response facilities (ERFs) and emergency response units (ERUs) notification process begins by either an audible alarm or visual annunciation, or both, and ends at the beginning point of travel time.

3.3.226 Unidirectional Vent. A building opening that serves as either an intake and exhaust vent of a flow path at a given time.

3.3.227 Upper Layer. See 3.3.18, Ceiling Layer.

3.3.228 Vacant. No furnishings or equipment present. [901, 2016]

3.3.229 Vapor. The gas phase of a substance, particularly of those that are normally liquids or solids at ordinary temperatures. (See also 3.3.94, Gas.)

3.3.230 Vapor Density. See 3.3.193, Specific Gravity (air) (vapor density).

3.3.231 Vaporization. Also known as *vapourisation*, is a phase transition of an element or compound from the liquid phase to vapor.

3.3.232 Vent. An opening for the passage of, or dissipation of, fluids, such as gases, fumes, smoke, and the like. [921, 2017]

3.3.233 Vent Profile. The visual evaluation of the condition (stratification-neutral plane) presented at a specific ventilation opening relating to a unidirectional, bidirectional, or dynamic flow integrated with the four fire development assessment indicators (smoke, air, heat, and flame [SAHF]).

3.3.234 Ventilation. Circulation of air in any space by natural wind or convection or by fans blowing air into or exhausting air out of a building; a fire-fighting operation of removing smoke and heat from the structure by opening windows and doors or making holes in the roof. [921, 2017]

3.3.235 Ventilation Control Device. Using an object to limit the amount of air available to the fire.

3.3.236 Ventilation for Extinguishment. The controlled and coordinated ventilation tactic that should coincide with the engine company extinguishment of the fire. [1410, 2020]

3.3.237 Ventilation for Search. The controlled and coordinated ventilation tactic performed to facilitate the movement of a firefighter into an area to conduct a search for victims. [1410, 2020]

3.3.238 Ventilation Induced Flashover. A flashover initiated by the introduction of oxygen into a preheated, fuel-rich (smoke filled), oxygen-deficient area. [1410, 2020]

3.3.239 Ventilation Profile. The visual evaluation of the entire fire building's ventilation openings, indicating air movement into the structure as well as smoke, heat, or flame out of the structure.

3.3.240 Ventilation-Controlled Fire. A fire in which the heat release rate or growth is controlled by the amount of air available to the fire. [921, 2017]

3.3.241 Ventilation-Limited Fire. A fire in which the heat release rate or growth is controlled by the amount of air (oxygen) available to the fire. [1410, 2020]

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

3.3.243 Verified Independent Service Provider (ISP). An independent service provider verified by a third-party certification organization to conduct an advanced inspection, advanced cleaning and sanitization, basic repair, and advanced repair service. [1851, 2020]

3.3.244 Vertical Ventilation. A method of using buoyancy to permit smoke and convected heat to flow upward to be exhausted from the building through vents above the fire while being replaced with intake air through other vents at the same level of the fire or lower.

3.3.245 Virgin Fuels. Fuel that is new and previously unused.

3.3.246 Void Space. Cofferdams and spaces not normally accessible or used for storage.

3.3.247 Water Supply. The amount of water described in terms of gallons per minute that is available at a fire incident for fire control.

3.3.248* Watt (W). Unit of power, or rate of work, equal to one joule per second, or the rate of work represented by a current of one ampere under the potential of one volt. [921, 2017]

3.3.249 Wet Decontamination. See 3.3.35.3.

Chapter 4 General

4.1 Scope.

4.1.1 This chapter will provide a brief overview of the research conducted with the fire service that applied fire dynamics principles to structural fire fighting and demonstrated the impact that changes in fuel loads and construction methods have had on the fire environment.

4.1.2 These changes have altered the model of fire behavior taught to the fire service for decades. In addition, fire fighter protective and safety equipment has also changed over the years. All these factors led to an assessment that fire-fighting tactics needed to evolve to improve the effectiveness of fire-fighting strategies and tactics.

4.1.3 Additional information has been made available to support selection of strategies and tactics that are based on evidence (i.e., knowledge) developed as part of research projects and as a result of line-of-duty death and injury after-action reports. The overarching objectives of all of these

research endeavors was to increase the effectiveness of fire fighters and increase the safety of the public and fire fighters.

4.2 Purpose.

4.2.1 An understanding of fire dynamics applied within the context of structure fires can provide a fire officer or a fire fighter with means to assess how a fire will grow and spread within a structure and how best to control that growth.

4.2.2 During the past two decades, experimental results have been translated to tactical considerations. NFPA 1700 is a direct result of that body of research and the evidence-based results. This chapter provides a timeline and a brief summary of the body of knowledge, which focused on research results that had application on the fireground, used in this guide. The data taken from each study will be noted and referenced in the appropriate section of NFPA 1700.

4.3 The Need for Research.

4.3.1 Changing Technology. Technology is constantly changing the world around us as well as changing how we work and live. This is true for the fire service as well. Research that has a direct impact on the fire service comes from a wide range of disciplines — engineering, textile science, the military, and many others. For example, the development of thermal imagers by the military enabled the use of thermal imagers for the fire service.

4.3.2 Changes in the Fire Fighters' Work Environment. Over the past 50 years, changes in construction materials, construction methods, insulation, and furnishings have changed the means and the speed of fire growth within a structure. Both research experiments and line-of-duty death (LODD) and line-of-duty injury (LODI) investigations have demonstrated the importance of understanding how ventilation affects fire behavior. Fires in today's fire environment, fueled predominantly by synthetic materials, commonly become ventilation-limited. How, where, and when a fire receives oxygen greatly impacts the fire dynamics and the resulting thermal environment inside the structure. As outlined in Figure 4.3.2, many factors in the construction methods, building materials, fuel loads, and power technologies have transformed the fire fighters' working environment. The construction techniques and materials used to build a house over the past 50 years have changed. Engineered wood products have enabled long spans and open areas for improved use of living space in houses. Gypsum board interior linings have been reduced en masse by 30 percent in recent years. In order to increase the energy efficiency of houses, insulation has improved, walls are wrapped in plastic to limit incursion of air and water, and multipane, low-emissivity windows are now the norm. The objects and materials inside our homes have changed as well. Some areas have seen more of these changes than others. It is important to note that even though a jurisdiction may have very few newly built homes, many structures are being renovated using new building materials, construction methods, and design features.

4.3.3 Furnishings. In the 1950s a wide range of synthetic materials called polymers became available for use in clothing, furniture, interior finish, and insulation. Today, the use of polyester, polystyrene, polyethylene, nylon, and polyurethane foam has become commonplace in homes, vehicles, and industry. Durability, comfort, and economics all play a role in the design and manufacturer of furnishings that people choose to buy. Flexible polyurethane foam is one of the most common materi-

als used in upholstered furniture. Figure 4.3.3 illustrates the speed of fire development, fire size, and heat release rate between a sofa with cotton cushions and a sofa with polyurethane foam cushions.

4.3.4 Fire-Fighting Equipment Enables Changes in Fire-Fighting Tactics.

4.3.4.1 During the same 50-year period, the tactics fire fighters use on the fireground have also changed. The reliance on indirect, or exterior, attack prior to entry changed to a focus on interior, direct fire control.

4.3.4.2 This change occurred largely due to the improvements in protective equipment and clothing that fire fighters rely on to enter high-temperature atmospheres considered immediately dangerous to life or health (IDLH). Just as the use of synthetic materials has overtaken the use of natural materials such as cotton, wool, or wood in homes, the same trend is true for fire-fighter protective clothing and equipment. In the past, fire-fighting coats were wool lined and had an outer layer of cotton canvas or a layer of rubber. Fire fighters protected their feet and legs with long rubber boots. Hoses used to be cotton jacketed with rubber liners. Starting in the 1960s, new materials, such as aramid fibers and polybenzimidazole, were introduced. These materials did not melt and had a high resistance to ignition. These materials are now in common use as part of fire fighters' protective clothing and equipment.

4.3.4.3 The use of self-contained breathing apparatus (SCBA) has improved conditions for fire fighters. The continued development of SCBAs with lighter materials, increased air supply, electronic monitoring, and warning devices also have made working in a smoke-filled building safer. Early versions of respiratory protective equipment have been around for more than 100 years as shown in Figure 4.3.4.3, however routine use of SCBA did not begin for many fire departments until the 1980s. Continued developments in the fields of electronics and sensing have produced improvements in situational awareness for fire fighters in the form of thermal imaging and fire fighter tracking and accountability systems.

4.3.4.4 Currently the fire fighter has the most advanced protective ensemble and a wider range of tools and equipment for fighting fire than ever before. The synthetic materials currently used in fire-fighting gear have improved performance over the natural materials in many ways.

4.3.4.5 Fire-fighting equipment, such as the two apparatus shown in Figure 4.3.4.5, have also changed over the years. Technology has improved the capabilities of fire fighters and provided for more safety.

4.3.5 Thermal Exposure Capabilities of Fire-Fighting Gear.

4.3.5.1 Understanding the measured thermal exposures from research fire experiments and considering the thermal exposures in the aftermath of fire-fighter LODDs and LODIs we understand that fire conditions can overtake the protective capabilities of the fire-fighter protective clothing and safety equipment. Therefore, the protective capabilities of fire-fighter protective clothing and safety equipment must be understood in terms of tactical assignments to ensure that level of protection matches the potential hazards in the fire fighters' work place.

Today's Fire Environment

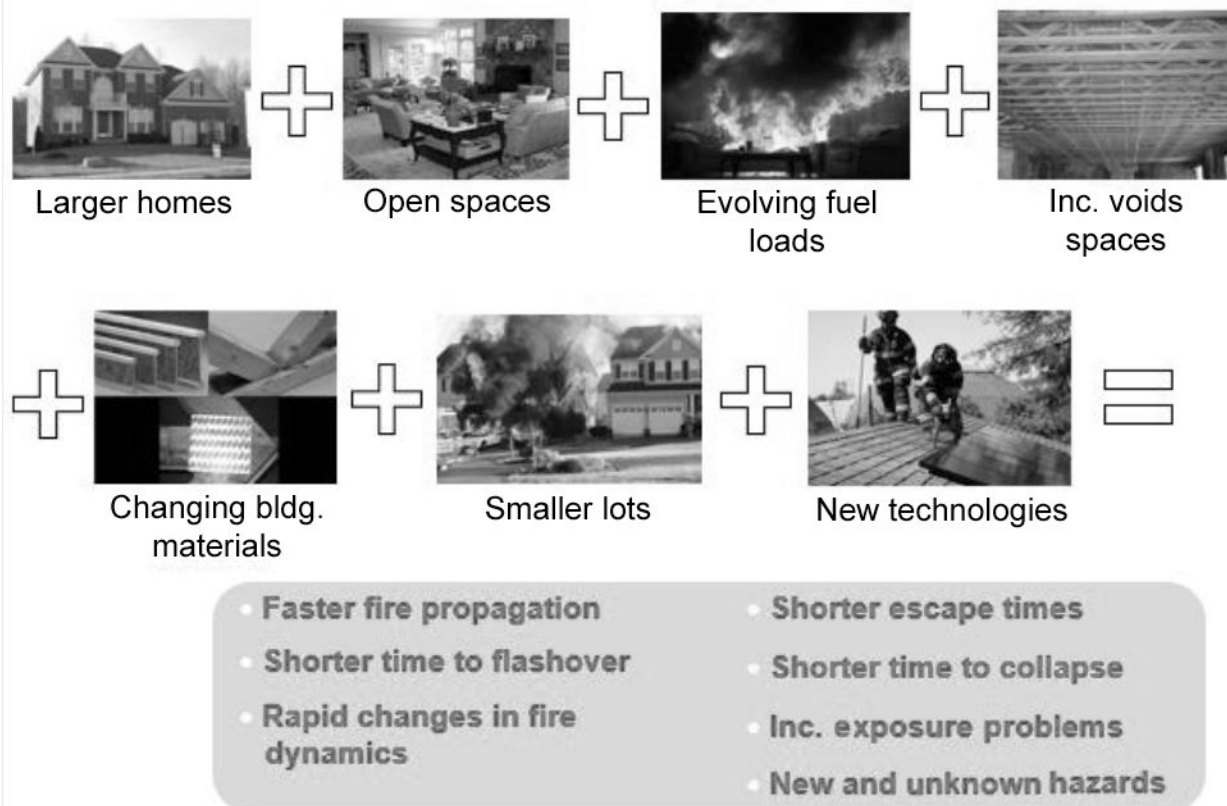


FIGURE 4.3.2 Today's Fire Environment. (Source: UL FSRI.)

4.3.5.2 The Fire Protection Research Foundation report, *Fire Fighter Equipment Operational Environment (FFEOE): Evaluation of Thermal Conditions*, is a summary of the thermal exposure research to date and studies from the 1970s to present that supported the development of the structural fire-fighter protective clothing [1].

4.4 America Burning. The release of *America Burning* [2] in 1973 generated funding and programs that resulted in studies focused on fire dynamics in a compartment, toxicity of fire gases, flammability of furniture (available at the time), plastics, fire detection, suppression and fire-fighting PPE. In addition to federal and industrial research, and top-ranked engineering schools across the U.S. [3], there were also significant fire research efforts underway in Canada, Japan, Sweden, and the United Kingdom, to name a few. The collective findings of these efforts were incorporated into the development of the *SFPE Handbook of the Fire Protection Engineering* [4] and additions to the *NFPA Fire Protection Handbook* [5]. These major gains in fire knowledge in the 1970s, 1980s, and 1990s led to improvements in fire measurements and the development of quantitative methods of predicting or simulating fire behavior. The first text book on fire dynamics was authored by Dougal Drysdale and published in 1985 [6]. The scope of the information contained in these books is beyond the scope of this guide, but it is important to note that the fundamentals of fire behavior

and analytical methods for the interaction between fire, buildings, and people are presented in these books.

4.5 Fire Research.

4.5.1 Fire research has been conducted for many reasons such as improved fire safety, understanding fire dynamics within a compartment, the development of fire-fighter protective equipment, and the study of fire-fighting tactics.

4.5.2 Research topics covered by fire-fighting tactics have a broad range, but for purposes of this guide the focus is on the operational environment for fire fighting. Recent fire-fighting studies address the concepts of fuel-limited fires and ventilation-limited fires within a compartment or structure, based on fuel load, ventilation, and building construction.

4.5.3 Madrzykowski provides an overview in the paper, "Fire Dynamics: The Science of Fire Fighting" [7]. One of the factors regarding the thermal environment fire fighters may work in is time. It makes sense that the longer a fire fighter is exposed to a hazard, the less time the fire fighter may have to continue to operate. However, there are other time considerations, such as how long the fire has been burning and what stage the fire is in.

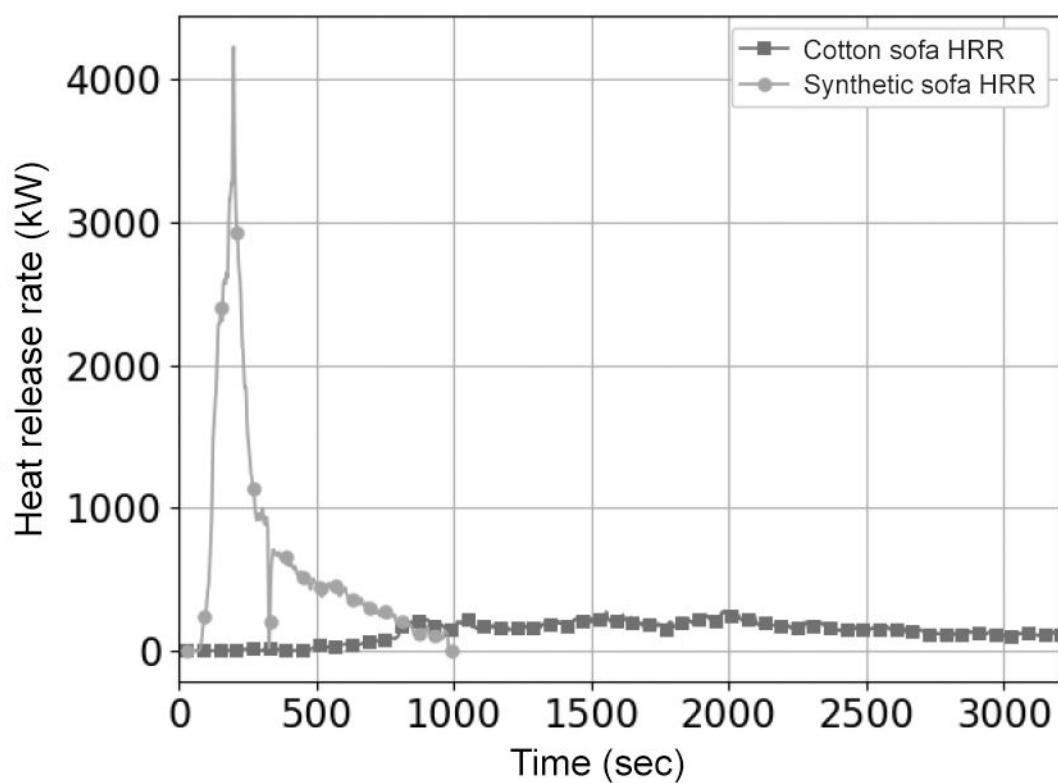


FIGURE 4.3.3 Cotton Versus Synthetic Furnishings. (Source: UL FSRI.)



FIGURE 4.3.4.3 Fire Fighter Protective Equipment Changed Significantly. (Source: UL FSRI.)



FIGURE 4.3.4.5 Technology Has Changed Fire Apparatus in Terms of Safety and Capabilities. (Source: UL FSRI.)

4.6 Summary of Structural Fire Dynamics Research.

4.6.1 Time to Flashover. The paper, “Analysis of Changing Residential Fire Dynamics and Its Implications on Firefighter Operational Timeframes,” by Kerber discusses many of the changes that have occurred on the fireground [8]. These changes include home size, geometry, contents, construction materials, and construction methods. As a result, the fire development in structures and the fire’s response to traditional fire-

fighting tactics has also changed. Kerber conducted a series of compartment fire experiments to examine the difference in time to flashover between a room furnished with legacy fuels and a room furnished with modern fuels. Legacy fuels meant furnishings made from wood, steel, and cotton. Modern fuels are characterized by polyurethane foam, polyester fiber and fabric, engineered wood, and plastics in many different forms. Each room was ignited by a small open flame from a candle on the sofa. The flashover times for the modern room averaged

235 seconds after ignition. Only two of the three legacy room fires resulted in flashover. The average flashover times for the two legacy rooms was 1912 seconds after ignition. It took eight times longer for the cotton sofa, compared to the sofa comprised of synthetic materials, to generate enough heat release rate to spread fire throughout the room [8]. The driving difference in these experiments was the sofa with cushions made from polyurethane foam and polyester batting. These synthetic fuels can significantly change the thermal environment fire fighters respond to.

4.6.2 Structural Collapse Studies.

4.6.2.1 Phoenix FD and NIST Roof Collapse Studies.

4.6.2.1.1 Ordinary Construction Warehouse. In 2001, the Phoenix Fire Department obtained a 135 ft (41 m) by 50 ft (15 m) warehouse that was scheduled for demolition. The building was a single story with a peaked roof. The peak of the roof was 18 ft (5.5 m) above the floor. The main chords of the wood roof trusses were full-dimension 2 in. (50 mm) by 12 in. (305 mm) lumber. The warehouse was separated into two sections with a fire-rated wall constructed for these experiments. One fire experiment was conducted in each section. Stacks of wood pallets were used as the primary fuel source and were ignited using paper and an electric match. Some combustible debris and the building structural elements provided the remainder of the fuel load. Peak temperatures obtained at different elevations ranged from approximately 570°F (300°C) to 1470°F (800°C). Peak carbon monoxide volume fractions, measured at a height of 1 in. (25 mm) and 3 ft (0.9 m) above the floor, reached 4 percent in the first test and 5 percent during the second test. The roof of the front half of the structure collapsed approximately 18 minutes after ignition of the fire for the first test. The roof of the back half of the structure collapsed about 15 minutes after the start of the second test [9]. Assuming a 6- to 10-minute fire department response time, these collapses would have occurred within 5 to 12 minutes of the start of fireground operations.

4.6.2.1.2 Single Story, Residential. The Phoenix Fire Department built four similar-sized structures with overall dimensions of approximately 24 ft (7.3 m) by 18 ft (5.5 m). Each structure had a different roof construction: asphalt shingles over plywood, asphalt shingles over oriented strand board (OSB), cement tiles over plywood, and cement tiles over OSB. The roof trusses were built from nominal dimension 2 in. (50 mm) × 4 in. (100 mm) wood. Furniture items were placed in the front and back of each structure to simulate living room and bedroom areas. The living room and bedroom areas of each structure were ignited simultaneously using electric matches. Peak temperatures obtained during the tests ranged from approximately 1500°F (800°C) to 1800°F (1000°C). The roof of each structure collapsed approximately 17 minutes after ignition [10].

4.6.2.2 UL and NIST Floor Collapse Studies.

4.6.2.2.1 Floor Furnace Comparisons. UL published their research findings on the structural stability of engineered lumber in fire conditions in 2008 [11]. The experiments were conducted on a floor furnace. The research demonstrated that “modern” engineered wood floor assemblies failed faster than wood floor assemblies with “legacy” designs. This study also pointed out that modern tools like thermal imagers had limited use in determining the condition of the floor assembly or the fire conditions under the floor. Further, the study ques-

tioned the use of the time-honored means of “sounding the floor” as a way to determine if the floor was safe to operate on.

4.6.2.2.2 Townhouse Floor Comparisons. In 2012, UL and NIST released a study that examined four types of flooring systems in a townhouse-type arrangement, with a 720 ft² (67 m²) floor area and a 20 ft (6.1 m) span. These experiments were conducted to examine the time to collapse for residential floor systems constructed with dimensional lumber, wood I-joists, parallel chord wood trusses, and lightweight steel C-channel. The results from this study proved that any of the unprotected floor assemblies could collapse within the operational time frame of the fire department. The report again indicates that current fireground practices of entering on the floor above the fire and working down to the fire in the basement will not provide the fire fighter with the appropriate information to make decisions to enable a safe operating environment [12].

4.6.2.2.3 Two-Level Structure, Comparison of Thermal Imagers. NIST conducted experiments in two-level wood structures with a 16 ft (4.8 m) span that supported the findings of the UL study on the value of gypsum board to protect the floor assembly and the challenges for the thermal imagers. Three fire-fighting thermal imagers (TIs), each with a different type of sensor, were used to view and record the thermal conditions of the top of the floor assembly from the open doorway in the upper compartment. Times to collapse of each floor were also noted. Given the insulating effects of the OSB and the floor coverings, the temperature increase or thermal signatures viewed by the TIs were small given the fact that the ceiling temperatures below the OSB were in excess of 1110°F (600°C). These experiments demonstrated that TIs alone cannot be relied upon to determine the structural integrity of a wood floor system. Therefore, it is critical for the fire service to review their practice of size-up and other fireground tactics needed to enable the location of the fire prior to conducting fire operations inside a building. The study also highlighted the interaction of ventilation to the fire area in order to generate the energy needed to fail the floor assemblies [13].

4.6.3 Wind-Driven Fires in Structures. Two studies were conducted to measure the impact of wind on the thermal environment within a fire apartment and public access areas connected to the apartment.

4.6.3.1 Laboratory Study. The first study, started in 2007, was sponsored by the NFPA Fire Protection Research Foundation and the USFA and was conducted within a laboratory at NIST to gain insight into the heat release rate of the apartment [14]. In this study, a three-room apartment was attached to approximately 48 ft (14.6 m) of public corridor. The conditions in the corridor were of critical importance because that is the portion of the building that fire fighters would use to approach the fire apartment or that occupants from an adjoining apartment would use to exit the building. The fires were ignited in the bedroom of a three-room apartment. Prior to the failure or venting of the bedroom window, which was on the upwind side of the experimental apartment, the heat release rate from the fire was on the order of 1 MW. Prior to implementing any mitigating tactics, the heat release rates from the post-flashover structure fire were typically between 15 MW and 20 MW. When the door from the apartment to the corridor was open, temperatures in the corridor area near the open doorway, 5.0 ft (1.52 m) below the ceiling, were in excess of 1112°F (600°C) for each of the experiments. The heat fluxes measured in the

same location, during the same experiments, were in excess of 70 kW/m². These thermal conditions are not tenable, even for a fire fighter in fully protective gear. These conditions were attained within 30 seconds of the window failure. The study showed that wind speeds as low as 9 miles per hour (4 m/s) could create the unidirectional fire exhaust flows, floor to ceiling within the structure's flow path. These experiments demonstrated the thermal conditions that can be generated by a "simple room and contents" fire and how these conditions can be extended along a flow path within a structure when a wind condition is present. Two potential tactics that could be implemented from either the floor above the fire in the case of a wind control device (WCD) or from the floor below the fire in the case of the external water application were demonstrated to be effective in reducing the thermal hazard in the corridor. Other data and observations, such as the fire pulsing out of the window opening against the wind, can provide valuable information to the fire service for hazard recognition purposes [14].

4.6.3.2 High-Rise Study. The second study was supported by and conducted by the Fire Department of New York City (FDNY) in a high-rise apartment building on Governors Island in 2008. Fourteen experiments were conducted to evaluate the ability of positive pressure ventilation fans, wind control devices, and external water application to mitigate the hazards of a wind-driven fire in a structure. NIST instrumented components of the flow path throughout the building, which included the fire apartment, public corridor, and a stairwell. The results of the experiments provided a baseline for the hazards associated with a wind-driven fire and the impact of pressure, ventilation, and flow paths within a structure. Wind-created conditions that rapidly caused the fire hazard in the structure to increase by forcing hot fire gases through the apartment of origin and into the public corridor and stairwell. These conditions would be untenable for advancing fire fighters. Door control tactics, coupled with the tactical use of PPV fans, WCDs, and external water application were able to reduce the thermal hazard created by the wind-driven fire. Multiple tactics used in conjunction with each other were very effective at improving conditions for fire fighter operations and occupant egress [15].

4.6.4 Fire-Fighting Ventilation Studies.

4.6.4.1 A wide range of ventilation studies has been conducted in both purpose-built structures inside of laboratories and in acquired structures. Some of the studies focused on natural ventilation [16, 17] and other considered positive pressure ventilation (PPV) [18–23]. All of the studies show that providing additional oxygen to a ventilation-limited compartment fire resulted in an increase of heat release rate, temperature, and pressure in the structure and along the exhaust portions of the flow path.

4.6.4.2 The UL Firefighter Safety Research Institute team conducted several research studies in their laboratory, in structures built to resemble a 1200 ft² (112 m²) single-story home and a 3200 ft² (297 m²) two-story home [16, 17, 23]. The results of the experiments demonstrated that an upholstered furniture fire resulted in ventilation-limited fire conditions prior to fire department arrival and continued in the structures after venting, either horizontal or vertical, until suppression actions reduced the heat release rate of the fire. As the buildings were vented, oxygen entered the hot, fuel-rich, (ventilation-limited) environment within the structure, which resulted in rapid (30 second to 120 second) increases in heat and gas velocities within the exhaust portion of the flow path — in other words,

between the location of the fire and the exhaust vent. In these experiments, the temperature conditions ranged between ambient and those consistent with flames, as have been shown in previous studies. In these experiments the fire attack was started from the exterior of the structure.

4.6.5 Fire-Fighting Suppression Studies.

4.6.5.1 Governors Island 2012. The Fire Department of the City of New York, along with NIST and UL, conducted a series of experiments in abandoned townhouses with an approximately 600 ft² area per floor and unprotected dimensional lumber floor systems between the first level and the basement level. The live burn tests were aimed at quantifying emerging theories about how fires are different today. Tactics examined included vent enter Isolate and search (VEIS), horizontal and vertical ventilation, and interior and exterior fire attack. Fires attacked and controlled from exterior openings from the front and/or rear of the structure resulted in improved conditions throughout the structure [24]. In addition, fire professionals and experts will closely analyze how the introduction of oxygen into these scenarios impacts fire behavior and how this required consideration of new procedures on ventilation strategies during fire-fighting operations.

4.6.5.2 Spartanburg 2013 and 2014. The International Society of Fire Service Instructors (ISFSI) in co-operation with NIST, the South Carolina State Fire Academy and the Spartanburg Fire Department conducted two series of fire-fighting experiments in acquired structures were conducted as part of the AFG funded "Translating Fire Fighting Research Results into Fire Fighter Training Project". The experiments demonstrated the value of size-up, coordinated ventilation and offensive fire attacks which began on the exterior. These experiments and previous fire-fighting research, such as the Governors Island studies provided the basis for the ISFSI's Principles of Modern Fire Attack course [25].

4.6.5.3 UL FSRI Fire Attack Study. Between 2015 and 2017 UL FSRI, with the support of the DHS/FEMA Assistance to Firefighters Grant Research program, conducted three different series of experiments to develop knowledge of fire-fighting hose streams applied during an interior and transitional fire attack and their impact on victim survivability and fire-fighter safety. Objectives of the studies included developing an understanding of where the water goes and how air flows during interior and transitional fire attack and what that means to the fire dynamics within a structure, and advancing the understanding of victim survivability in the modern fire environment.

4.6.5.3.1 Water Distribution. The experiments conducted were intended to develop a fundamental knowledge of water distribution in compartments from fire service hose streams, without the presence of furniture. The stream locations were chosen to simulate an attack from a hallway into a room and an attack through a window into a room. Fundamental knowledge of water dispersion and distribution was gained from these experiments. The results of the water distribution made it clear that the hose streams' effectiveness was limited to "line of sight." The ability to apply water to all surfaces in a room is limited when the nozzle is located outside the compartment. Once inside the compartment a fire fighter can put water anywhere in the room by moving the nozzle. This is completely within the control of the fire fighter. When outside the room, this is not possible. However, understanding the dynamics of water hitting a surface at different angles provides the ability to extrapolate this knowledge to other locations [26].

4.6.5.3.2 Air Entrainment. The air entrainment tests were conducted without the presence of fire to gain a fundamental understanding of how hose streams entrain and move air. Each set of experiments was intended to add to the understanding of air entrainment and pressure from fire service hose streams by evaluating the differences caused by various application methods, hose stream types, nozzle movements, pressures/flowrates, manufacturers, and ventilation configurations. These experiments looked to quantify air entrainment by hand-held fire hose streams, expanding on work already done looking at hydraulic ventilation [27–30]. The results show that to increase entrainment, a fire fighter should have the water interact with as much air as possible. This can be done by using a fog pattern, moving the nozzle rapidly (any pattern), and providing the largest stream length. If the intent is to limit air entrainment, the nozzle fire fighter should limit nozzle movement, use a smooth bore or straight stream, and minimize the stream length where possible. No difference was seen between air entrainment in a smooth bore stream versus a straight stream. Understanding these key concepts of air entrainment can aid fire fighters in being more effective. Applying these concepts to structural fire fighting allows for better control of air entrainment during both interior and exterior operations [31].

4.6.5.3.3 Full-Scale Residential Fire Experiments. UL FSRI conducted 26 full-scale structure fire experiments in a single-story 1600 ft² (149 m²) ranch-style home test structure. Two of those structures were built inside UL's large fire lab in Northbrook, IL. The objective of the study was analyzing how fire-fighting tactics, specifically suppression methods, affect the thermal exposure and survivability of both building occupants and fire fighters in residential structures. This was accomplished by measuring the impact of different fire attacks on a fire in a bedroom(s) at the end of a hallway and understanding the effect it would have on the fire environment and any persons in the structure [32]. Most of the experiments involved fire fighters flowing water either before or shortly after they entered the structure. Two fire attack methods, interior and transitional, were used with three different structure ventilation configurations. To determine the thermal exposure within the test structure, it was instrumented for temperature, pressure, gas velocity, heat flux, gas concentration, and moisture content. Additionally, to provide information on occupant burn injuries, five sets of instrumented pig skin were located in predetermined locations in the structure. The results were evaluated by a fire service-based project technical panel, and 18 tactical considerations were developed. Common threads for the results were that rapid and effective water application into the fire compartment, either from the interior or exterior, reduced the thermal hazard throughout the structure and suppression operations, either from the interior or exterior, did not increase potential burn injuries to occupants [32].

4.6.5.4 Illinois Fire Service Institute (IFSI).

4.6.5.4.1 A series of experiments was conducted by research teams from the Illinois Fire Service Institute (IFSI), UL FSRI, NIOSH, and Skidmore College. The goal of this study was to investigate the effects of modern fire environments on the two most pressing concerns in the fire service today, cardiovascular and carcinogenic risks [33, 34]. As part of the study, 12-person teams performed realistic fire-fighting tactics in residential fire environments that contained common building materials and furnishings.

4.6.5.4.2 Specific to the thermal environment, one of the key areas of the IFSI study was the measurement of the production and transfer of heat through modern PPE and onto or into fire fighters' bodies. The variables that impacted that heat transfer included tactical decisions (interior only vs. transitional attack) and operating location (interior fire suppression/search vs. exterior operations vs. interior overhaul). The overall results showed the following:

- (1) Temperatures inside the fire structure decreased after water was applied
- (2) Transitional attack resulted in faster water application
- (3) Local temperatures were higher for fire fighters operating inside versus other positions (neck skin temperatures for inside-attack fire fighters were lower when exterior attack was used)
- (4) Higher body core temperatures were measured for the outside vent and overhaul positions

4.7 National Institute for Occupational Safety and Health (NIOSH).

4.7.1 The National Institute for Occupational Safety and Health is a part of the Centers for Disease Control and Prevention (CDC) of the U.S. Department of Health and Human Services. The mission of the NIOSH Fire Fighter Fatality Investigation and Prevention Program (FFFIPP) is to conduct investigations of fire fighter line-of-duty deaths to develop recommendations for preventing future deaths and injuries. The program does not seek to determine fault or place blame on fire departments or individual fire fighters, but to learn from these tragic events and prevent future similar events. These reports and recommendations have been the catalyst for most of the fire service research studies listed in this chapter.

4.7.2 The FFFIPP program, which started in 1998, is divided into two main areas of study: traumatic injury deaths and cardiovascular disease deaths (CVD). The traumatic injury deaths are investigated in accordance with the Fatality Assessment and Control Evaluation (FACE) model. Incidents investigated under this model include burns, diving accidents, electrocutions, falls, motor vehicle accidents, and structural collapse incidents. Heart attack and stroke are two of the most common types of line-of-duty deaths for fire fighters, accounting for almost half of the fire fighter deaths in the U.S. annually. FFFIPP investigations of CVD examine both the individual's risk factors for coronary artery disease and workplace factors. Workplace factors include what conditions the fire fighter was exposed to in terms of physical effort, exposure to hazardous chemicals, and thermal stress. In addition, NIOSH assesses the fire department's fitness and wellness program, as well as any screening program for coronary artery disease.

4.7.3 Since the program started, more than 600 investigation reports have been produced. Based on the trends discovered in the investigations, NIOSH has issued special reports such as "Preventing Injuries and Deaths of Fire Fighters Due to Structural Collapse," "Fire Fighter Fatality Investigation and Prevention Program: Leading Recommendations for Preventing Fire Fighter Fatalities, 1998–2005," and "Preventing Deaths and Injuries of Fire Fighters Working Above Fire-Damaged Floors." All of the completed investigations and the special reports can be downloaded from <https://www.cdc.gov/niosh/fire/default.html> [35].

4.8* Summary of Fire-Fighting Research. Building on the scientific body of knowledge that supports the fire protection engineering discipline, research specific to fire-fighting tactics has been conducted. The results of the studies, referenced here, have been used as a basis of change for fire department standard operating procedures or guides around the world. Experience in the field has shown positive results when tactics such as size-up, door control, coordinated ventilation, and exterior attack, prior to entry, have been used to accomplish the incident priorities of life safety, incident stabilization, and property conservation.

Chapter 5 Fundamentals of Fire Science

5.1 Scope. This chapter addresses the fundamentals of fire science knowledge.

5.2 Purpose. The purpose of this chapter is to provide fire service information that provides a basis for the application of fire dynamics for fire fighting.

5.3 Application.

5.3.1 The content in this chapter explains the fundamentals of basic fire science that is used for understanding and discussion in the next chapter on fire dynamics.

5.3.2 Chapter 3 provides the definitions for the terms used throughout this chapter.

5.4 General. Fire-fighting personnel should have an understanding of combustion and fire dynamic principles and be able to use them for fire scene size up and assessment of fire conditions both upon initial arrival and continuously over the course of the incident. This chapter addresses the basic and fundamental knowledge of fire science needed to assist the reader to sufficiently understand the following chapters. The user of this guide is urged to consult the reference material listed in Annex D for additional details.

5.5 Fire Tetrahedron. The combustion reaction can be characterized by four components: the fuel, the oxidizing agent, the heat, and the uninhibited chemical chain reaction. These four components have been classically symbolized by a four-sided solid geometric form called a tetrahedron (see Figure 5.5). Fires can be prevented or suppressed by controlling or removing one or more of the sides of the tetrahedron.

The difference between the fire tetrahedron model and the fire triangle model of combustion is the inclusion of the chemical chain reaction. The chemical chain reaction provides the ability to sustain flames. The fire triangle will only support a flash of flame or combustion in the condensed (solid) phase, such as glowing embers or hot charcoal.

5.5.1 Fuel. A fuel is any substance that sustains combustion under specified environmental conditions. The majority of fuels encountered are organic, which means that they are carbon-based and may contain other elements such as hydrogen, oxygen, and nitrogen in varying ratios. Examples of organic fuels include wood, wool, plastics, gasoline, alcohol, and natural gas. Inorganic fuels contain no carbon. Examples of inorganic fuels would include combustible metals, such as magnesium or sodium. The term *fuel load* is used to describe the amount of fuel present within a defined space, usually within a compartment. Fuel load can include contents, compartment linings, and structural materials. Increased

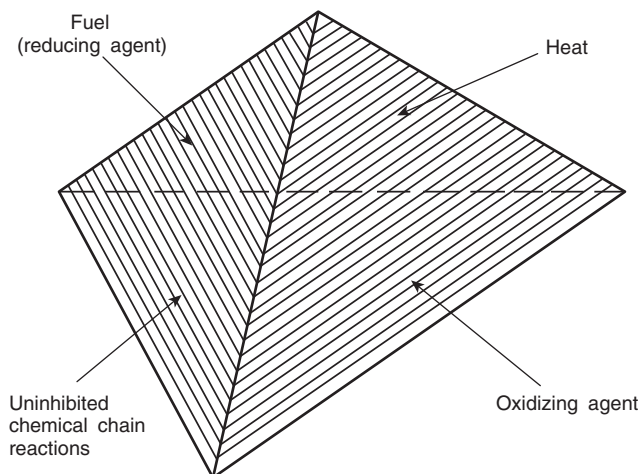


FIGURE 5.5 Fire Tetrahedron ([921:5.1.5]).

synthetic fuel loads and new construction materials with higher heat of combustion lead to higher heat release rate. Fuel loads vary greatly across occupancies; the nature of contents, amount, and configuration should be considered.

5.5.1.1 States of Matter. All matter can exist in one of three states: solid, liquid, or gas. The state of a given material depends on the temperature and pressure and can change as conditions vary. Fuels also exist in various states of matter under standard atmospheric temperature and pressure conditions. Under fire exposure conditions, a fuel can change phases.

5.5.1.2 Solid. A solid fuel has a fixed shape and volume. The molecules are generally in a fixed position and do not move unless acted upon by heat or a chemical reaction.

5.5.1.3 Liquid. A liquid fuel can take the shape of a container, except that it forms a flat, or slightly curved, surface due to gravity. The chemical bonds and spacing between molecules tends to be weaker and more distant relative to solids.

5.5.1.4 Gas. Gas is 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. So fuel gases that are released within a room will begin to disperse throughout the room and take the shape of the room. The chemical bonds and spacing between molecules tends to be weaker and more distant relative to liquids.

5.5.1.4.1 State of Change to Gas. For flames to exist, the fuel must be in a gaseous form to mix with oxygen in gaseous form to allow the combustion to occur. Therefore, fuels in solid and liquid form must be transformed to a gaseous state to support flaming combustion.

5.5.1.4.2 Pyrolysis. Since solids cannot burn in their current state, the solid must be pyrolyzed. Pyrolysis is a process in which the solid fuel is decomposed, or broken down, into simpler molecular compounds by the effects of heat alone. Pyrolysis precedes combustion and continues to support the combustion after ignition occurs. The application of heat causes vapors or pyrolysis products to be released where they can burn when in proper mixture with air and a sufficient ignition source is present, or if the fuel's autoignition temperature is reached. Observing a piece of wood that is "on fire," a gap can be seen