NFPA® 1700

Guide for Structural Fire Fighting

2021

NFPA®

IMPORTANT NOTICES AND DISCLAIMERS CONCERNING NFPA® STANDARDS

REMINDER: UPDATING OF NFPA STANDARDS

Users of NFPA codes, standards, recommended practices, and guides ("NFPA Standards") should be aware that these documents may be superseded at any time by the issuance of a new edition, may be amended with the issuance of Tentative Interim Amendments (TIAs), or be corrected by Errata. It is intended that through regular revisions and amendments, participants in the NFPA standards development process consider the then-current and available information on incidents, materials, technologies, innovations, and methods as these develop over time and that NFPA Standards reflect this consideration. Therefore, any previous edition of this document no longer represents the current NFPA Standard on the subject matter addressed. NFPA encourages the use of the most current edition of any NFPA Standard [as it may be amended by TIA(s) or Errata] to take advantage of current experience and understanding. An official NFPA Standard at any point in time consists of the current edition of the document, including any issued TIAs and Errata then in effect.

To determine whether an NFPA Standard has been amended through the issuance of TIAs or corrected by Errata, visit the "Codes & Standards" section at www.nfpa.org.

ADDITIONAL IMPORTANT NOTICES AND DISCLAIMERS CONCERNING NFPA® STANDARDS

Updating of NFPA Standards

Users of NFPA codes, standards, recommended practices, and guides ("NFPA Standards") should be aware that these documents may be superseded at any time by the issuance of a new edition, may be amended with the issuance of Tentative Interim Amendments (TIAs), or be corrected by Errata. It is intended that through regular revisions and amendments, participants in the NFPA standards development process consider the then-current and available information on incidents, materials, technologies, innovations, and methods as these develop over time and that NFPA Standards reflect this consideration. Therefore, any previous edition of this document no longer represents the current NFPA Standard on the subject matter addressed. NFPA encourages the use of the most current edition of any NFPA Standard [as it may be amended by TIA(s) or Errata] to take advantage of current experience and understanding. An official NFPA Standard at any point in time consists of the current edition of the document, including any issued TIAs and Errata then in effect.

To determine whether an NFPA Standard has been amended through the issuance of TIAs or corrected by Errata, visit the "Codes & Standards" section at www.nfpa.org.

Interpretations of NFPA Standards

A statement, written or oral, that is not processed in accordance with Section 6 of the Regulations Governing the Development of NFPA Standards shall not be considered the official position of NFPA or any of its Committees and shall not be considered to be, nor be relied upon as, a Formal Interpretation.

Patents

The NFPA does not take any position with respect to the validity of any patent rights referenced in, related to, or asserted in connection with an NFPA Standard. The users of NFPA Standards bear the sole responsibility for determining the validity of any such patent rights, as well as the risk of infringement of such rights, and the NFPA disclaims liability for the infringement of any patent resulting from the use of or reliance on NFPA Standards.

NFPA adheres to the policy of the American National Standards Institute (ANSI) regarding the inclusion of patents in American National Standards ("the ANSI Patent Policy"), and hereby gives the following notice pursuant to that policy:

NOTICE: The user's attention is called to the possibility that compliance with an NFPA Standard may require use of an invention covered by patent rights. NFPA takes no position as to the validity of any such patent rights or as to whether such patent rights constitute or include essential patent claims under the ANSI Patent Policy. If, in connection with the ANSI Patent Policy, a patent holder has filed a statement of willingness to grant licenses under these rights on reasonable and nondiscriminatory terms and conditions to applicants desiring to obtain such a license, copies of such filed statements can be obtained, on request, from NFPA. For further information, contact the NFPA at the address listed below.

Law and Regulations

Users of NFPA Standards should consult applicable federal, state, and local laws and regulations. NFPA does not, by the publication of its codes, standards, recommended practices, and guides, intend to urge action that is not in compliance with applicable laws, and these documents may not be construed as doing so.

Copyrights

NFPA Standards are copyrighted. They are made available for a wide variety of both public and private uses. These include both use, by reference, in laws and regulations, and use in private self-regulation, standardization, and the promotion of safe practices and methods. By making these documents available for use and adoption by public authorities and private users, the NFPA does not waive any rights in copyright to these documents.

Use of NFPA Standards for regulatory purposes should be accomplished through adoption by reference. The term "adoption by reference" means the citing of title, edition, and publishing information only. Any deletions, additions, and changes desired by the adopting authority should be noted separately in the adopting instrument. In order to assist NFPA in following the uses made of its documents, adopting authorities are requested to notify the NFPA (Attention: Secretary, Standards Council) in writing of such use. For technical assistance and questions concerning adoption of NFPA Standards, contact NFPA at the address below.

For Further Information

All questions or other communications relating to NFPA Standards and all requests for information on NFPA procedures governing its codes and standards development process, including information on the procedures for requesting Formal Interpretations, for proposing Tentative Interim Amendments, and for proposing revisions to NFPA standards during regular revision cycles, should be sent to NFPA headquarters, addressed to the attention of the Secretary, Standards Council, NFPA, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101; email: stds_admin@nfpa.org.

For more information about NFPA, visit the NFPA website at www.nfpa.org. All NFPA codes and standards can be viewed at no cost at www.nfpa.org/docinfo.

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

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

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

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

Contents

NFPA 1700

Guide for

Structural Fire Fighting

2021 Edition

IMPORTANT NOTE: This NFPA document is made available for use subject to important notices and legal disclaimers. These notices and disclaimers appear in all publications containing this document and may be found under the heading "Important Notices and Disclaimers Concerning NFPA Standards." They can also be viewed at www.nfpa.org/disclaimers or obtained on request from NFPA.

UPDATES, ALERTS, AND FUTURE EDITIONS: New editions of NFPA codes, standards, recommended practices, and guides (i.e., NFPA Standards) are released on scheduled revision cycles. This edition may be superseded by a later one, or it may be amended outside of its scheduled revision cycle through the issuance of Tentative Interim Amendments (TIAs). An official NFPA Standard at any point in time consists of the current edition of the document, together with all TIAs and Errata in effect. To verify that this document is the current edition or to determine if it has been amended by TIAs or Errata, please consult the National Fire Codes® Subscription Service or the "List of NFPA Codes & Standards" at www.nfpa.org/docinfo. In addition to TIAs and Errata, the document information pages also include the option to sign up for alerts for individual documents and to be involved in the development of the next edition.

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

A reference in brackets [ ] following a section or paragraph indicates material that has been extracted from another NFPA document. Extracted text may be edited for consistency and style and may include the revision of internal paragraph references and other references as appropriate. Requests for interpretations or revisions of extracted text shall be sent to the technical committee responsible for the source document.

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.

2. *America Burning, the Report of The National Commission on Fire Prevention and Control.* Washington, DC, May 1973.

3. Gross, D. "Fire Research at NBS: The First 75 Years." In *Fire Safety Science – Proceedings of the Third International Symposium,* pages 119–133. International Association for Fire Safety Science, 1991.

4. Hurley, M. J., ed. *SFPE Handbook of Fire Protection Engineering.* Springer, NY, NY, 5th edition, 2016.

5. *Fire Protection Handbook.* National Fire Protection Association, Quincy, MA, 20th ed., 2008.

6. Drysdale, D. *An Introduction to Fire Dynamics.* John Wiley and Sons, New York, 2nd edition, 2002.

7. Madrzykowski, D. "Fire Dynamics: The Science of Fire Fighting." *International Fire Service Journal of Leadership and Management.* FPP/IFSTA, Stillwater, OK, vol 7, 2013.

8. Kerber, S. "Analysis of Changing Residential Fire Dynamics and Its Implications on Firefighter Operational Timeframes." *Fire Technology,* 48:865–891, October 2012.

9. Stroup, D. W., Madrzykowski, D., Walton, W.D. and Twilley, W. *Structural Collapse Fire Tests: Single Story, Ordinary Construction Warehouse*. National Institute of Standards and Technology, Gaithersburg, MD, NISTIR 6959, May 2003.

10. Stroup, D. W. Bryner, N.P., Lee, J., McElroy, J., Roadarmel, G., and Twilley, W.H. *Structural Collapse Fire Tests: Single Story, Wood Frame Structures*. National Institute of Standards and Technology, Gaithersburg, MD, NISTIR 7094, March 2004.

11. Izydorek, M. S., Zeeveld, P.A., Samuels, M. D., Smyser, J. P. *Report on Structural Stability of Engineered Lumber in Fire Conditions*. Underwriters Laboratories, Northbrook, IL, September 2008.

12. Kerber, S., Madrzykowski, D., Dalton, J., and Backstrom, R. *Improving Fire Safety by Understanding the Fire Performance of Engineered Floor Systems and Providing the Fire Service with Information for Tactical Decision Making. Underwriters Laboratories*, Northbrook, IL, March 2012.

13. Madrzykowski, D. and Kent, J. *Examination of the Thermal Conditions of a Wood Floor Assembly above a Compartment Fire*. National Institute of Standards and Technology, Gaithersburg, MD, NISTTN 1709, July 2011.

14. Madrzykowski, D. and Kerber, S. *Fire Fighting Tactics Under Wind Driven Conditions: Laboratory Experiments*. National Institute of Standards and Technology, Gaithersburg, MD, NISTTN 1618, January 2009.

15. Kerber, S. and Madrzykowski, D. *Fire Fighting Tactics Under Wind Driven Conditions: 7 Story Building Experiments*. National Institute of Standards and Technology, Gaithersburg, MD, NISTTN 1629, April 2009.

16. Kerber, S. *Impact of Ventilation on Fire Behavior in Legacy and Contemporary Residential Construction*. Underwriters Laboratories, Northbrook, IL, December 2010.

17. Kerber, S. *Study of the Effectiveness of Fire Service Vertical Ventilation and Suppression Tactics in Single Family Homes*. Underwriters Laboratories, Northbrook, IL, June 2013.

18. Kerber, S. and Walton, W. D. *Effect of Positive Pressure Ventilation on a Room Fire*. National Institute of Standards and Technology, Gaithersburg, MD, NISTIR 7213, March 2005.

19. Kerber, S. and Walton, W. D. *Full-Scale Evaluation of Positive Pressure Ventilation In a Fire Fighter Training Building*. National Institute of Standards and Technology, Gaithersburg, MD, NISTIR 7342, July 2006.

20. Kerber, S., Madrzykowski, D. and Stroup, D. W. *Evaluating Positive Pressure Ventilation In Large Structures: High-Rise Pressure Experiments*. National Institute of Standards and Technology, Gaithersburg, MD, NISTIR 7412, March 2007.

21. Kerber, S., and Madrzykowski, D. *Evaluating Positive Pressure Ventilation In Large Structures: High-Rise Fire Experiments*. National Institute of Standards and Technology, Gaithersburg, MD, NISTIR 7468, November 2007.

22. Kerber, S., and Madrzykowski, D. *Evaluating Positive Pressure Ventilation In Large Structures: School Pressure and Fire Experiments*. National Institute of Standards and Technology, Gaithersburg, MD, NISTTN 1498, July 2008.

23. Zevotek, R. and Kerber, S. *Study of the Effectiveness of Fire Service Positive Pressure Ventilation During Fire Attack in Single Family Homes Incorporating Modern Construction Practices*. UL Firefighter Safety Research Institute, Columbia, MD, May 2016.

24. Madrzykowski, D., Kerber, S., and Zipperer, J. *Scientific Research for the Development of More Effective Tactics — Governors Island Experiments Training: Governors Island Experiments*, July 2012. Accessed January 3 2018, from http://ulfirefightersafety.org/resources.

25. ISFSI. *The Principles of Modern Fire Attack Course*. Accessed January 3 2018, from http://www.isfsi.org/p/cl/et/cid=1000.

26. Weinschenk, C., Stakes, K., and Zevotek, R. *Impact of Fire Attack Utilizing Interior and Exterior Streams on Firefighter Safety and Occupant Survival: Air Entrainment*, Columbia, MD, December 2017.

27. Knapp, J., Pillsworth, T., and White, S. "Nozzle Tests Prove Fireground Realities, Part 1." *Fire Engineering*, February 2003.

28. Knapp, J., Pillsworth, T., and White, S. "Nozzle Tests Prove Fireground Realities, Part 2." *Fire Engineering*, September 2003.

29. Knapp, J., Pillsworth, T., and White, S. "Nozzle Tests Prove Fireground Realities, Part 3." *Fire Engineering*, September 2003.

30. Willi, J., Weinschenk, C., and Madrzykowski, D. *Impact of Hose Streams on Air Flows Inside a Structure*. NISTTN 1938, National Institutes of Standards and Technology, Gaithersburg, MD, 2016.

31. Weinschenk, C., Stakes, K., and Zevotek, R. *Impact of Fire Attack Utilizing Interior and Exterior Streams on Firefighter Safety and Occupant Survival: Water Mapping*. UL Firefighter Safety Research Institute, Columbia, MD, December 2017.

32. Zevotek, R., Stakes, K., and Willi, J. *Impact of Fire Attack Utilizing Interior and Exterior Streams on Firefighter Safety and Occupant Survival: Full Scale Experiments*. UL Firefighter Safety Research Institute, Columbia, MD, December 2017.

33. Horn, G. P., Kerber, S., Fent, K. W., Fernhall, B., and Smith, D.L. *Cardiovascular and Chemical Exposure Risks in Modern Firefighting*. Interim Technical report, Illinois Fire Service Institute, University of Illinois-Urbana/Champaign, 2016.

34. Horn, G. P., Kesler, R. M., Kerber, S., Fent, K. W., Schroeder, T. J., Scott, W. S., Fehling, P.C., Fernhall, B., and Smith, D. L. "Thermal Response to Firefighting Activities in Residential Structure Fires: Impact of Job Assignment and Suppression Tactic." *Ergonomics*, 0(0):1–16, 0. PMID:28737481.

35. CDC, NIOSH. *Fire Fighter Fatality Investigation and Prevention*. Accessed January 4, 2018, from https://www.cdc.gov/niosh/fire/default.html.

2.4 References for Extracts in Advisory Sections.

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

NFPA 24, *Standard for the Installation of Private Fire Service Mains and Their Appurtenances*, 2019 edition.

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

NFPA 53, *Recommended Practice on Materials, Equipment, and Systems Used in Oxygen-Enriched Atmospheres,* 2016 edition.

NFPA 54, *National Fuel Gas Code,* 2018 edition.

NFPA 55, *Compressed Gases and Cryogenic Fluids Code,* 2020 edition.

NFPA 68, *Standard on Explosion Protection by Deflagration Venting,* 2018 edition.

NFPA 70®, National Electrical Code®, 2020 edition.

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

NFPA 92, *Standard for Smoke Control Systems,* 2018 edition.

NFPA 96, *Standard for Ventilation Control and Fire Protection of Commercial Cooking Operations,* 2017 edition.

NFPA *101®, Life Safety Code®,* 2018 edition.

NFPA 115, *Standard for Laser Fire Protection,* 2020 edition.

NFPA 400, *Hazardous Materials Code,* 2019 edition.

NFPA 402, *Guide for Aircraft Rescue and Fire-Fighting Operations,* 2019 edition.

NFPA 472, *Standard for Competence of Responders to Hazardous Materials/Weapons of Mass Destruction Incidents,* 2018 edition.

NFPA 475, *Recommended Practice for Organizing, Managing, and Sustaining a Hazardous Materials/Weapons of Mass Destruction Response Program,* 2017 edition.

NFPA 610, *Guide for the Emergency and Safety Operations at Motorsports Venues,* 2019 edition.

NFPA 654, *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids,* 2020 edition.

NFPA 901, *Standard Classifications for Incident Reporting and Fire Protection Data,* 2016 edition.

NFPA 921 *Guide for Fire and Explosion Investigations,* 2017 edition.

NFPA 1006, *Standard for Technical Rescue Personnel Professional Qualifications,* 2017 edition.

NFPA 1026, *Standard for Incident Management Personnel Professional Qualifications,* 2018 edition.

NFPA 1405, *Guide for Land-Based Fire Departments That Respond to Marine Vessel Fires,* 2020 edition.

NFPA 1410, *Standard on Training for Emergency Scene Operations,* 2015 edition.

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

NFPA 1670, *Standard on Operations and Training for Technical Search and Rescue Incidents,* 2017 edition.

NFPA 1710, *Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments,* 2020 edition.

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

NFPA 1901, *Standard for Automotive Fire Apparatus,* 2016 edition.

NFPA 1963, *Standard for Fire Hose Connections,* 2019 edition.

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

NFPA 1977, *Standard on Protective Clothing and Equipment for Wildland Fire Fighting,* 2016 edition.

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 ignitible 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 ignitible 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/m^2, or W/cm^2. [**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 Ignitible Liquid. Any liquid or the liquid phase of any material that is capable of fueling a fire, including a flammable liquid, combustible liquid, or any other material that can be liquefied and burned. [**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 materials 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.

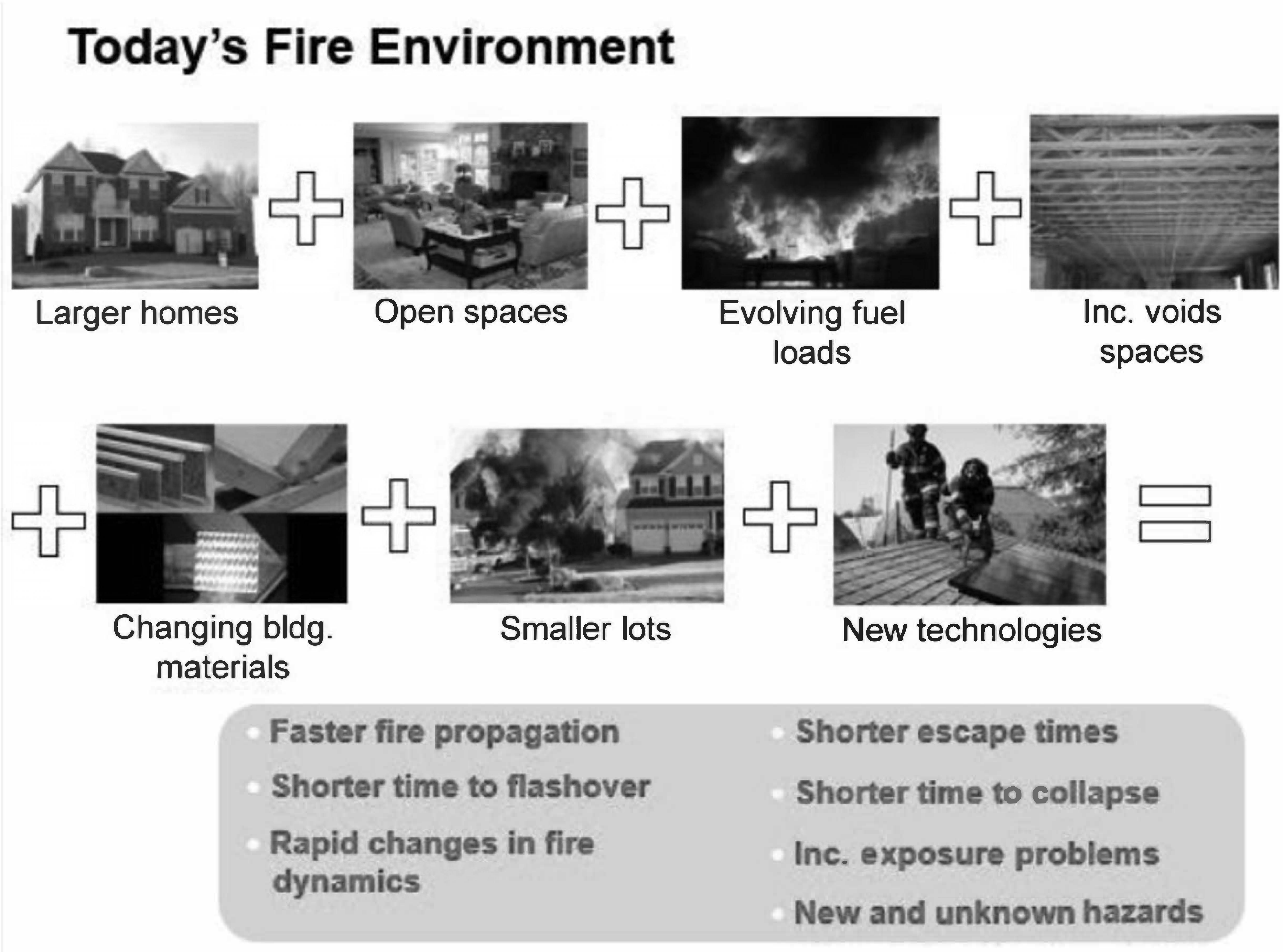

FIGURE 4.3.2 Today's Fire Environment. *(Source: UL FSRI.)*

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.

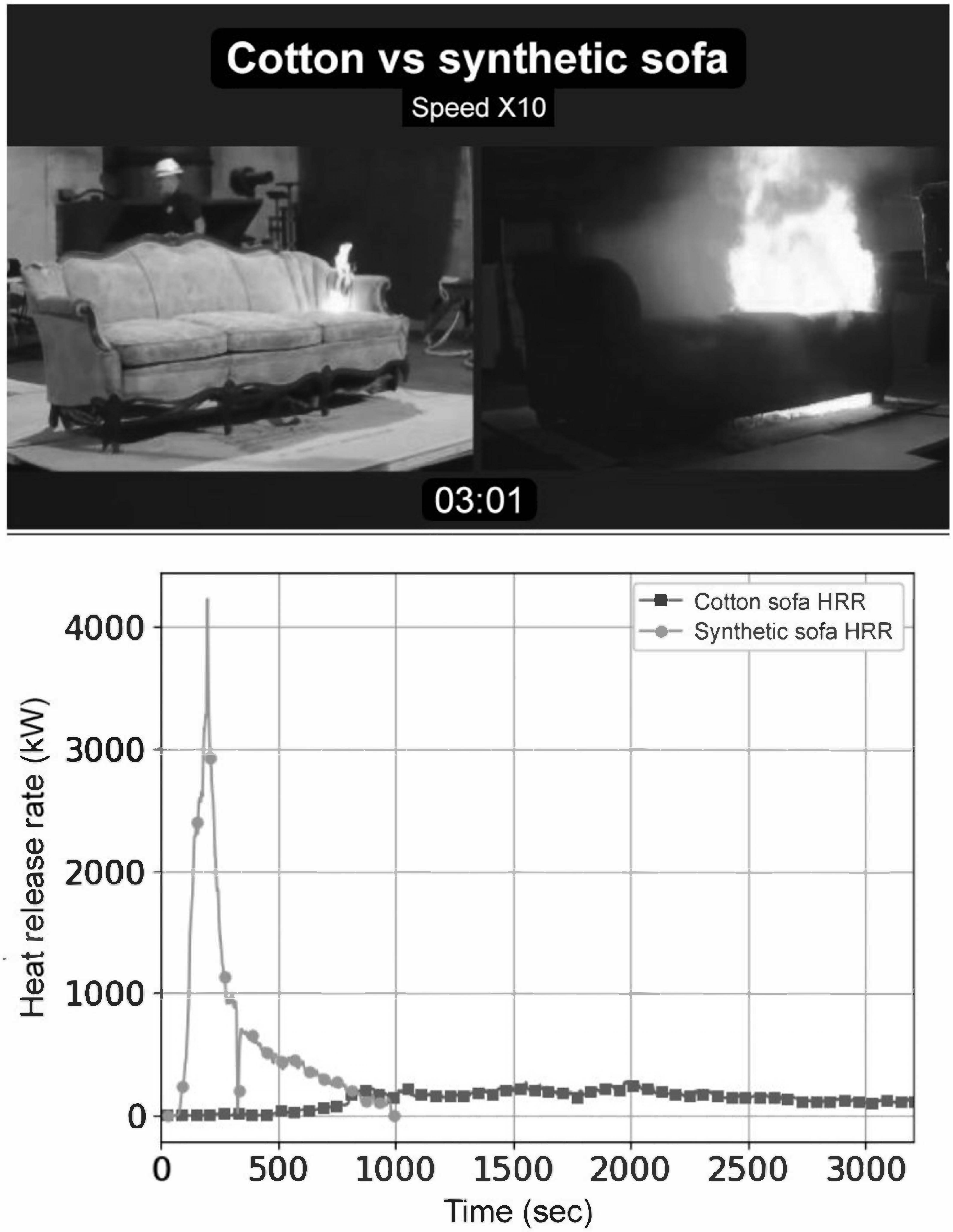

FIGURE 4.3.3 Cotton Versus Synthetic Furnishings. *(Source: UL FSRI.)*

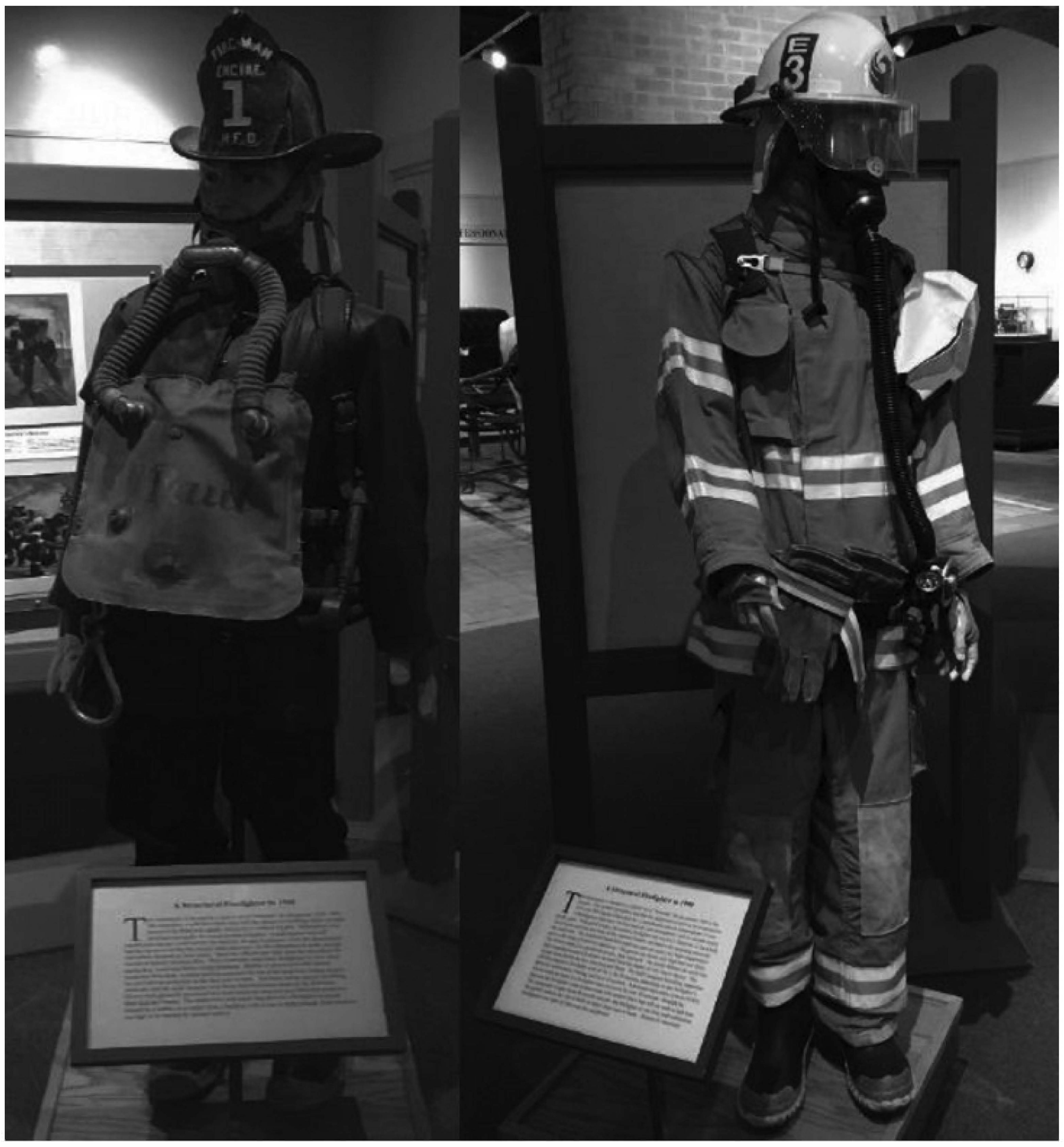

FIGURE 4.3.4.3 Fire Fighter Protective Equipment Changed Significantly. *(Source: UL FSRI.)*

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 firefighting 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 questioned 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 ft^2 (67 m^2) 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 ft^2 (149 m^2) 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 firefighting 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 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.

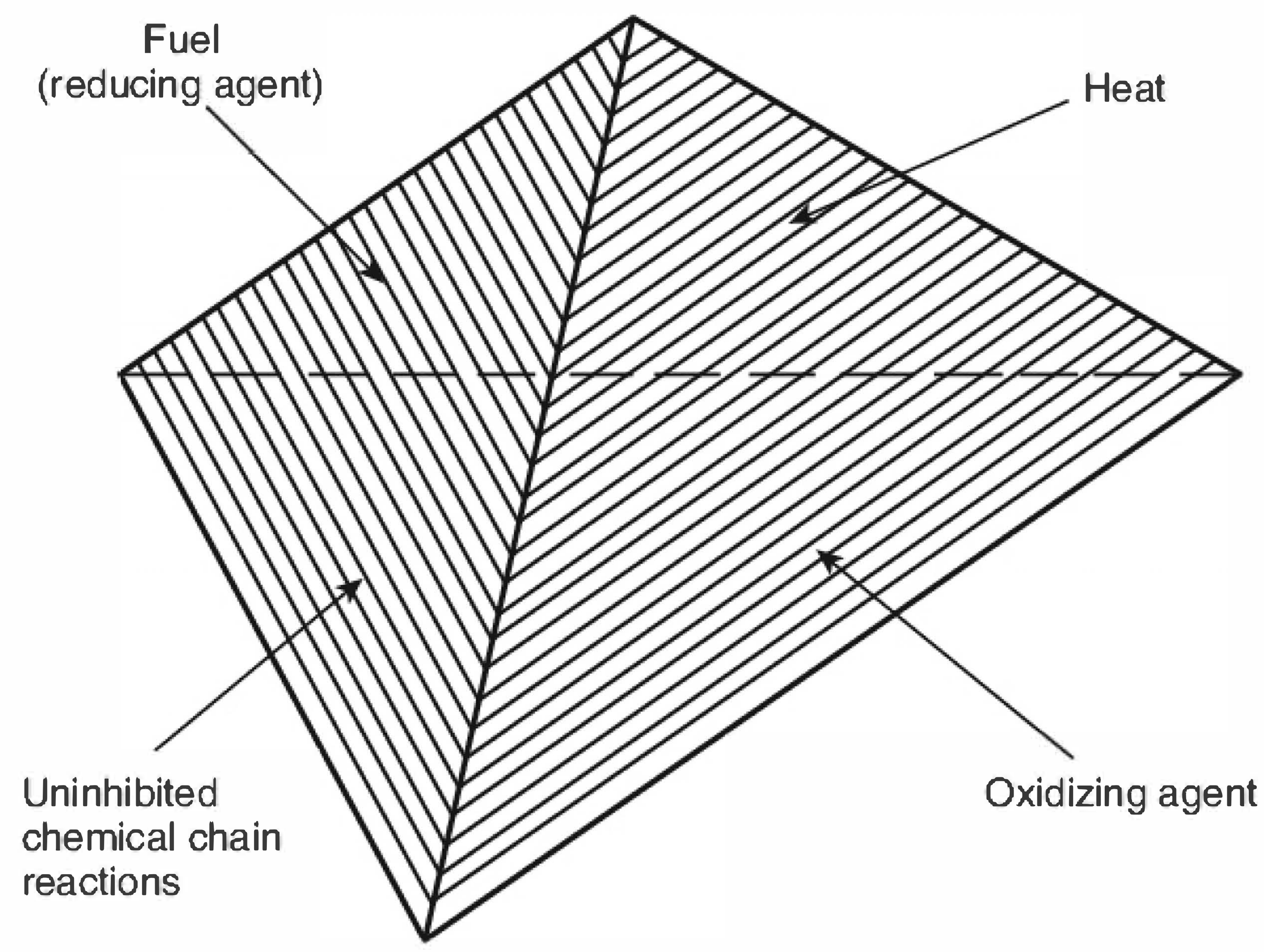

FIGURE 5.5 Fire Tetrahedron ([921:5.1.5]).

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 wood that is "on fire," a gap can be seen between the wood and the flames. The fuel gases being emitted from the wood mix with oxygen in the air, and the combustion takes place above the fuel surface area in a region of vapors created by heating the fuel surface. If the thermal exposure to the fuel is increased, the rate of pyrolysis (gaseous fuel generation) may increase.

5.5.1.4.3 Vaporization. Combustion of liquid fuels also takes place above the fuel surface in a region of vapors created by heating the fuel surface. The heat can come from the ambient conditions, from the presence of an ignition source, or from exposure to an existing fire. The application of heat causes vapors to be released into the atmosphere, where they can burn if in the proper mixture with an oxygen and if a competent ignition source is present.

5.5.1.4.4 Gaseous Fuels. Fuels that exist as a gas under atmospheric temperature and pressure do not require vaporization or pyrolysis before combustion can occur. Only the proper mixture with an oxidizer and an ignition source are needed.

5.5.1.4.5 Heat of Combustion. This material property is the total energy released as heat when a substance undergoes complete combustion. Heats of combustion typically range from 10 MJ/kg to 45 MJ/kg with hydrocarbon-based products having two to three times higher values than natural products.

5.5.2 Oxidizing Agent. In most fire situations, the oxidizing agent is the oxygen in the earth's atmosphere. Air in the earth's atmosphere is made up of approximately 21 percent oxygen and 78 percent nitrogen. In order for a fire to burn, fuel and sufficient oxygen must be combined. Fire can occur in the absence of atmospheric oxygen, when fuels are mixed with chemical oxidizers. Many chemical oxidizers contain readily released oxygen. Ammonium nitrate fertilizer (NH_4NO_3), potassium nitrate (KNO_3), and hydrogen peroxide (H_2O_2) are examples.

5.5.2.1 Every fuel–air mixture has an optimum ratio at which point the combustion will be most efficient. This ratio occurs at or near the mixture known by chemists as the stoichiometric ratio.

5.5.2.2 When the amount of air is in balance with the amount of fuel (i.e., after burning there is neither unused fuel nor unused air), the burning is referred to as stoichiometric. This condition rarely occurs in the fires that fire fighters respond to. Visible smoke is an indication of inefficient combustion.

5.5.3 Heat. The heat component of the tetrahedron represents thermal energy above the minimum level necessary to release fuel vapors and cause ignition. Heat is commonly defined in terms of heating rate (kW) intensity measured in kilowatts per meter squared (kW/m^2), or as the total heat energy received over time. In a fire, heat produces fuel vapors, causes ignition, and promotes fire growth and flame spread by maintaining a continuous cycle of fuel production and ignition. In the past, in the American fire service, heat is expressed in British thermal units (Btu), though this document will exclusively use SI units when relating to heat. A conversation for SI and U.S. customary units can be found in Section 1.4.

5.5.3.1 Heat Release Rate. Heat release rate (HRR) is the rate at which fire releases energy. It is the power output of the fire. HRR is measured in units of watts (W), kilowatts (kW), or megawatts (MW). The heat release rate of a fire is variable over time and is dependent on the fuel load characteristics, oxygen available (ventilation), and enclosure characteristics. The HRR of a fire inside a compartment or structure can influence interior temperatures, compartment pressure, the amount of smoke produced by the fire, structural stability, and the amount of water needed to control the fire. *(See Table 5.5.3.1.)*

5.5.3.2 Heat Flux. Heat flux is the measure of the rate of heat transfer to a surface, expressed in kilowatts per meter squared (kW/m^2). The higher the heat flux from a fire to surface, the faster the temperature of the surface will increase. The higher the heat flux exposure to protective equipment, the sooner it will fail. The higher the heat flux to bare skin the shorter the time to pain and injury.

Table 5.5.3.1 Representative Peak Release Rates (Unconfined Burning) [921:5.6.3.1]

Fuel	Mass		Peak HRR (kW)
	kg	lb	
Wastebasket, small	0.7–1.4	1.5–3	4–50
Trash bags, 42 L (11 gal) with mixed plastic and paper trash	2.5	7.5	140–350
Cotton mattress	12–13	26–29	40–970
TV sets	31–33	69–72	120 to over 1500
Plastic trash bags/paper trash	1.2–14	2.6–31	120–350
PVC waiting room chair, metal frame	15	34	270
Cotton easy chair	18–32	39–70	290–370
Gasoline or kerosene in 0.2 m^2 (2 ft^2) pool	19	42	400
Christmas trees, dry	6–20	13–44	3000–5000
Polyurethane mattress	3–14	7–31	810–2630
Polyurethane easy chair	12–28	27–61	1350–1990
Polyurethane sofa	51	113	3120
Wardrobe, wood construction	70–121	154–267	1900–6400

Sources: Values are from the following 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 ed., National Fire Protection Association.

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

NFPA 72.

5.5.3.3 Temperature. Temperature is a measure of heat, an indication of molecular motion in a gas, liquid, or solid, as measured by a thermometer or similar instrument. Increasing the HRR of a fire may not increase the temperature of the flames. *(See Figure 5.5.3.3.)*

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

5.6 Fire Chemistry.

5.6.1 General. Fire chemistry is the study of chemical processes that occur in fires, including changes of state, decomposition, and combustion.

5.6.2 Phase Changes and Thermal Decomposition. The response of fuels to heat is quite varied. Figure 5.6.2 illustrates the wide range of processes that can occur.

5.6.2.1 Phase changes most relevant in fire are melting and vaporization. In melting, the material changes from a solid to a liquid with no change in the chemical structure of the material (e.g., melting of candle wax). In vaporization, the material changes from a liquid to a vapor with no change in chemical structure of the material (e.g., evaporation of molten candle wax on the wick to form the vapor that burns in the candle flame). Phase changes are reversible events — that is, upon cooling, vapors will return to the liquid state and liquids will solidify.

5.6.2.2 Thermal decomposition involves irreversible changes in the chemical structure of a material due to the effects of heat (pyrolysis). Thermal decomposition of a solid or liquid most often results in the production of gases. Wood decomposes to create char and vapors, some of which are flammable. Under vigorous heating, flexible polyurethane decomposes to form a liquid and flammable gases or vapors. At more moderate heating conditions, flexible polyurethane decomposes to a char and flammable gases or vapors.

5.6.3 Combustion. The combustion reactions can be characterized by the fire tetrahedron, Figure 5.5, and may occur with the fuel and oxidizing agent already mixed (premixed burning) or with the fuel and oxidizing agent initially separate (diffusion burning). Structure fires would be an example of diffusion burning.

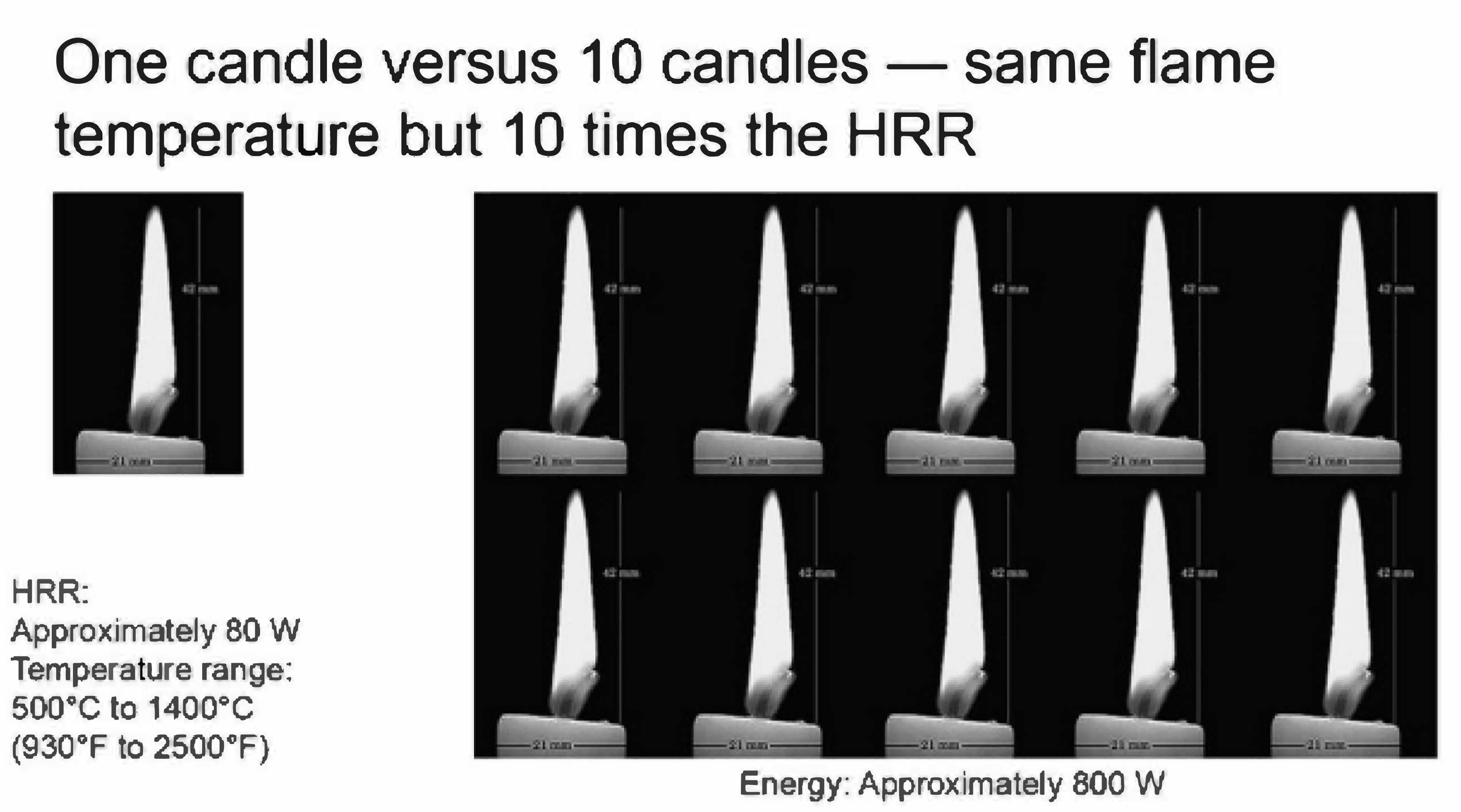

FIGURE 5.5.3.3 Heat Release Rate Versus Temperature Visualization.

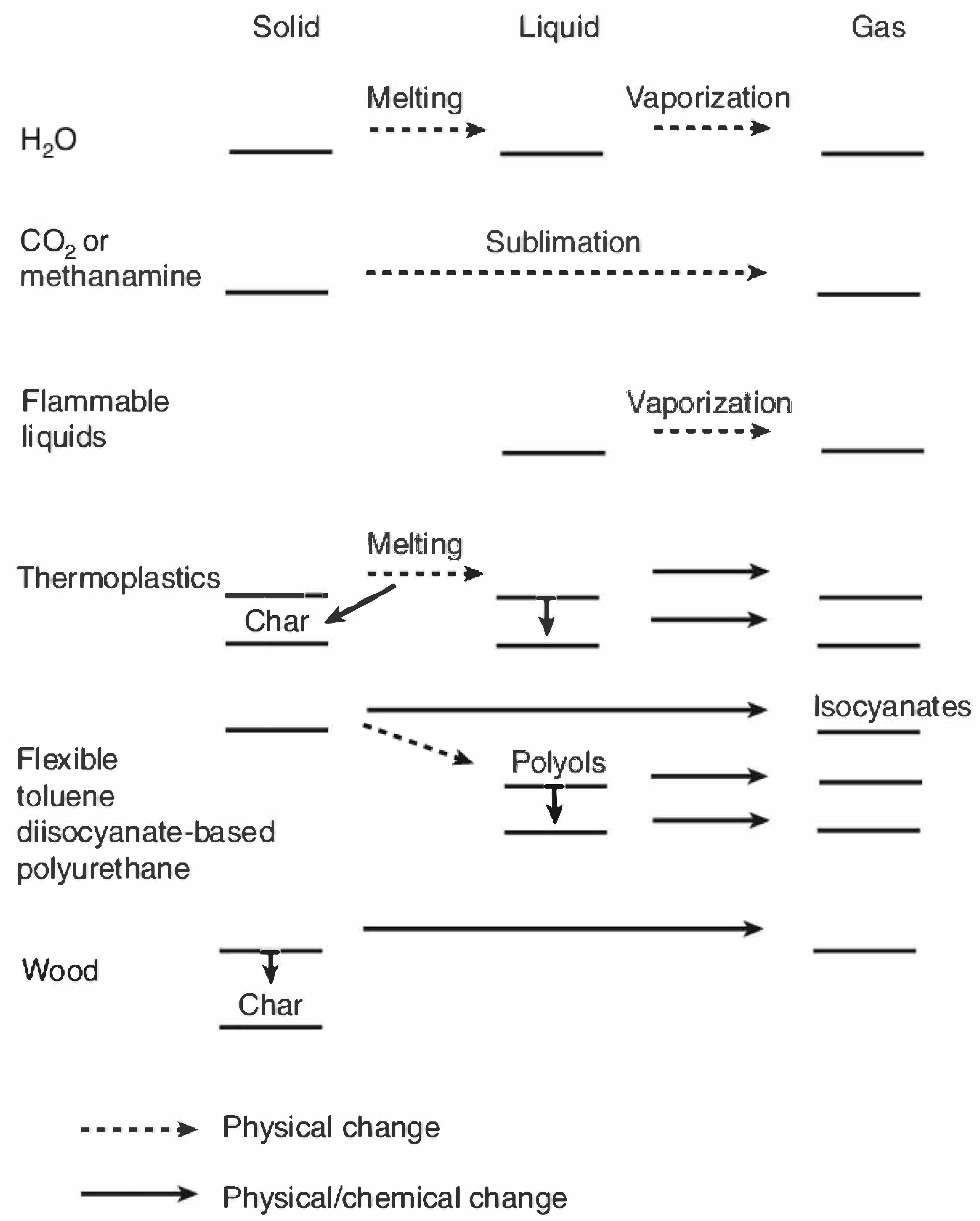

FIGURE 5.6.2 Phase Changes.

5.6.3.1 Premixed burning occurs when fuel vapors mix with air in the absence of an ignition source and the fuel–air mixture is subsequently ignited. Examples of premixed fuel and air include a natural gas release into the environment and evaporation of gasoline. Upon application of an ignition source to the fuel–air mixture, a premixed flame quickly propagates through the volume of fuel–air. Premixed flame spread can proceed as a deflagration (subsonic combustion) or as a detonation (supersonic combustion). Deflagration velocities normally range from cm/sec to m/sec, though velocities into the hundreds of m/sec are possible. Detonation velocities are normally in the thousands of m/sec. Premixed flame propagation in a confined volume is normally considered a smoke explosion.

5.6.3.2 In order for flammable gases and vapors of ignitable liquids to ignite, they must be mixed with a sufficient amount of oxidizer (typically atmospheric oxygen) to allow the combustion reaction to occur. The percentage of the mixture of gaseous fuel to air by volume must be within a specific range for combustion to occur. This is known as the flammable or explosive range of the fuel.

5.6.3.2.1 Flammable/Explosive Range. For fuels in gaseous form to be combustible they must be mixed with a sufficient amount of oxidizer, typically atmospheric oxygen. The mixture of gaseous fuel and air must be within a specific range for combustion to occur. This is known as the flammable or explosive range of the fuel. In this context, the words *flammable* or *explosive* are interchangeable.

5.6.3.2.2 Lower Explosive Limit (Lower Flammable Limit). The minimum percentage of fuel in air (by volume) in which combustion can occur is the lower explosive limit (LEL) of the material. In a mixture that is below its LEL, no combustion will occur. This is because below the LEL there are insufficient fuel molecules in the mixture. The mixture can be said to be "too lean."

5.6.3.2.3 Upper Explosive Limit (Upper Flammability Limit). There is also a maximum percentage of fuel in air (by volume) in which combustion can occur. This is called the upper explosive limit (UEL). This is because above the UEL combustion will not occur because there are insufficient oxygen molecules in the mixture. These mixtures can be said to be "too rich."

5.6.3.3 Diffusion flame burning is the ordinary sustained burning mode in most fires. Fuel vapors and oxidizer are separate, and combustion occurs in the region where they come together. A diffusion flame is typified by a candle flame in which the luminous flame zone exists where the air and the fuel vapors meet.

5.6.3.3.1 Diffusion flames can only occur for certain concentrations of the mixture components. The lowest oxygen concentration in nitrogen is termed the limiting oxygen index (LOI). For most fuel vapors, the LOI is in the range of 10 percent to 14 percent by volume at ordinary temperatures (Beyler 2002). Similarly, the fuel gas stream can be diluted with nitrogen or other inert gas to the extent where burning is no longer possible. For example, methane diluted with nitrogen to below 14 percent methane will not burn with air at normal temperatures.

5.6.3.3.2 Transitions from premixed burning to diffusion flame burning are common during the ignition of liquid and solid fuels. For instance, if an ignition source is applied to a pan of gasoline, the ignition source ignites gasoline vapors mixed with air above the pan. These vapors are quickly consumed and the burning of fuel vapors from the pan of gasoline occurs as a diffusion flame.

5.6.3.3.3 The amount of heat generated by a fire is dependent on the amount of oxygen consumed as part of the chemical reaction. On average, 13.1 MJ of heat is produced for every kg of oxygen consumed. The amount of energy generated per kg of oxygen consumed is independent of the heat of combustion of the fuel.

5.7 Products of Combustion.

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

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

5.7.3 Combustion products exist in all three states of matter: solid, liquid, and gas. Solid material makes up the ash and soot products that represent the visible "smoke." Many of the other products of incomplete combustion exist as vapors or as extremely small tarry droplets or aerosols. These vapors and droplets often condense on surfaces that are cooler than the smoke — for example, sticky carcinogenic residue on firefighting PPE.

5.7.4 Some fuels, such as alcohol or natural gas, burn very cleanly, while others, such as fuel oil, polyurethane foam, or styrene, will produce large amounts of sooty smoke even when the fire is fuel controlled. These sooty fuels require oxygen concentration above what is available in the air in order to burn cleanly.

5.7.5 Smoke may contain a collection of the solid, liquid, and gaseous products of incomplete combustion as well as unburned pyrolyzates (fuel).

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

5.7.7 The action of fire fighting can also have an effect on the color of the smoke being produced. The application of water can produce large volumes of condensing vapor that will appear white or gray when mixed with black smoke from the fire.

5.7.8 Smoke production rates are generally less in the early phase of a fire but increase greatly with the onset of flashover, if flashover occurs. White smoke from a fire compartment may be unburned pyrolyzate.

5.8 Fluid Flows.

5.8.1 General. Fluid flows can be composed of liquids, gases, or a combination of the two. Fluid flows generated by fires are mainly composed of heated gases. Fluids move as the result of differences in pressure.

5.8.2 Buoyant Flows. Buoyant flows occur when gases are heated by the fire. The gases local to the fire expand and become less dense than the cooler air surrounding the fire. As a result, the heated less dense gases float on the air.

5.8.3 Fire Plumes. The hot gases created by the fire rise above the fire source as a fire plume. The rising gases move with a faster velocity than the surrounding cooler, denser air. The higher velocity of the fire plume causes a local reduction in pressure. This pressure difference near the base of the plume results in the surrounding air being entrained into the fire and fire plume. As the hot gases rise through the surrounding cooler, denser air, additional air is mixed with the plume.

5.9 Heat Transfer.

5.9.1 The transfer of heat is a major factor in fires and has an effect on ignition, growth, spread, and extinction. Heat is always transferred from the higher temperature object to the lower temperature object. Heat transfer is measured in terms of energy flow per unit of time. It is important to distinguish between heat and temperature. Temperature is a measure that expresses the average of molecular activity of a material compared to a reference point. The energy that causes a change in the temperature of an object is referred to as sensible heat, while the transfer of energy that results in phase change is called latent heat. When heat energy is transferred to an object, without a phase change, the temperature increases. When heat is transferred away from an object, without a phase change, the temperature of the object decreases.

5.9.2 Conduction is heat transfer within solids or between contacting solids. Heat energy will be transferred into and through a solid, or contacting solids, from the higher to the lower temperature areas. Fire fighters often experience conductive heat transfer when wearing PPE during fire-fighting operations. As the PPE absorbs heat energy from the fire environment, it is transferred conductively through the various layers of material and to the fire fighter's body.

5.9.3 Convection is the transfer of heat energy by the movement of heated liquids or gases from the source of heat to a cooler part of the environment. During a fire, heat is transferred by convection to a solid when hot gases pass over cooler surfaces or when hot smoke mixes with atmospheric air. The rate of heat absorbed by the solid is a function of the temperature difference between the hot gas and the surface, the material properties of the surface being heated, and the velocity of the hot gas. The higher the velocity and turbulence of the gas, the greater the rate of convective heat transfer.

5.9.4 Radiation is a line of sight transfer of heat energy from a hot surface or gas to a cooler material by electromagnetic waves. Although flame is often the greatest source of radiant heat transfer during a compartment fire, the smoke and hot gases that collect at ceiling level is also a source of radiant heat and often contributes to the ignition of materials.

5.10 Solid Fuel Load.

5.10.1 The term *fuel load* is used to describe the amount of fuel present, usually within a compartment. Residential and office occupancies are considered to be "light hazard" when designing a sprinkler system, as opposed a warehouse or industrial occupancy. Even though considered a light hazard, a residential room could easily have 5 MW to 15 MW of potential peak HRR, provided sufficient oxygen/ventilation is available.

5.10.2 The potential HRR is determined by multiplying the mass of fuel by the heat of combustion of the fuels. Heats of combustion typically range from 10 MJ/kg to 45 MJ/kg. While the total fuel load for a compartment is a measure of the total heat available if all the fuel burns, it does not determine how fast the fire will develop once the fire starts. Fuel load can be used in conjunction with the size of vent openings to estimate the duration of fully developed burning in a compartment.

5.10.3 The term fuel load density is the potential combustion energy output per unit floor area [MJ/m^2] or the mass of fuel per unit floor area [kg/m^2]. Fuel load densities are most often associated with particular occupancies or used as a means to characterize the fire load characteristics of the room contents. The fuel load of a compartment is determined by multiplying the fuel load density by the compartment floor area.

Chapter 6 Fire Dynamics in Structures

6.1 Scope. This chapter addresses only the basic and fundamental knowledge of fire dynamics required to sufficiently understand the concepts presented in this guideline. This chapter is not intended to serve as a complete source of education.

6.2 Purpose. The purpose of this chapter is to provide fire dynamics information to help identify strategy and tactics.

6.3 Application. The content of this chapter first addresses fire dynamics within a compartment and is followed by information regarding fire dynamics in structures comprised of multiple compartments.

6.4 General.

6.4.1 Compartment Fires.

6.4.1.1 A *compartment fire* is a fire that occurs within an area enclosed by a floor, walls, and a ceiling. This is commonly referred to as a *contents fire* or a *room and contents* fire. The examination and understanding of the fire dynamics that occur in such a space is critical, as the fundamental science principles that govern compartment fires also govern all fire dynamics that occur within larger and more complex structures.

6.4.1.2 During fires within a compartment, the characteristics of the initial fuel package, as well as all other fuels present, will influence the rate of fire spread and growth within the space. Additionally, the material properties of the compartment linings and geometry of the space, as well as size of the ventilation opening, will also be influential.

6.4.2 Fire Progression in Ventilated vs. Unventilated Compartments. Figure 6.4.2 provides a visual comparison of two different progressions that a compartment fire is likely to follow. The first progression, shown with the solid line, represents a fire that is ignited in a compartment that has ventilation, such as an open door or window. The second progression, shown with the broken line, represents a fire that is ignited in an underventilated compartment with all doors and openings closed.

6.4.2.1 Fire in a Ventilated Compartment.

6.4.2.1.1 Position 1. During the development of an incipient fire, the rate of flame spread and heat release rate (HRR) is greatly dependent on the configuration and characteristics of the fuels involved.

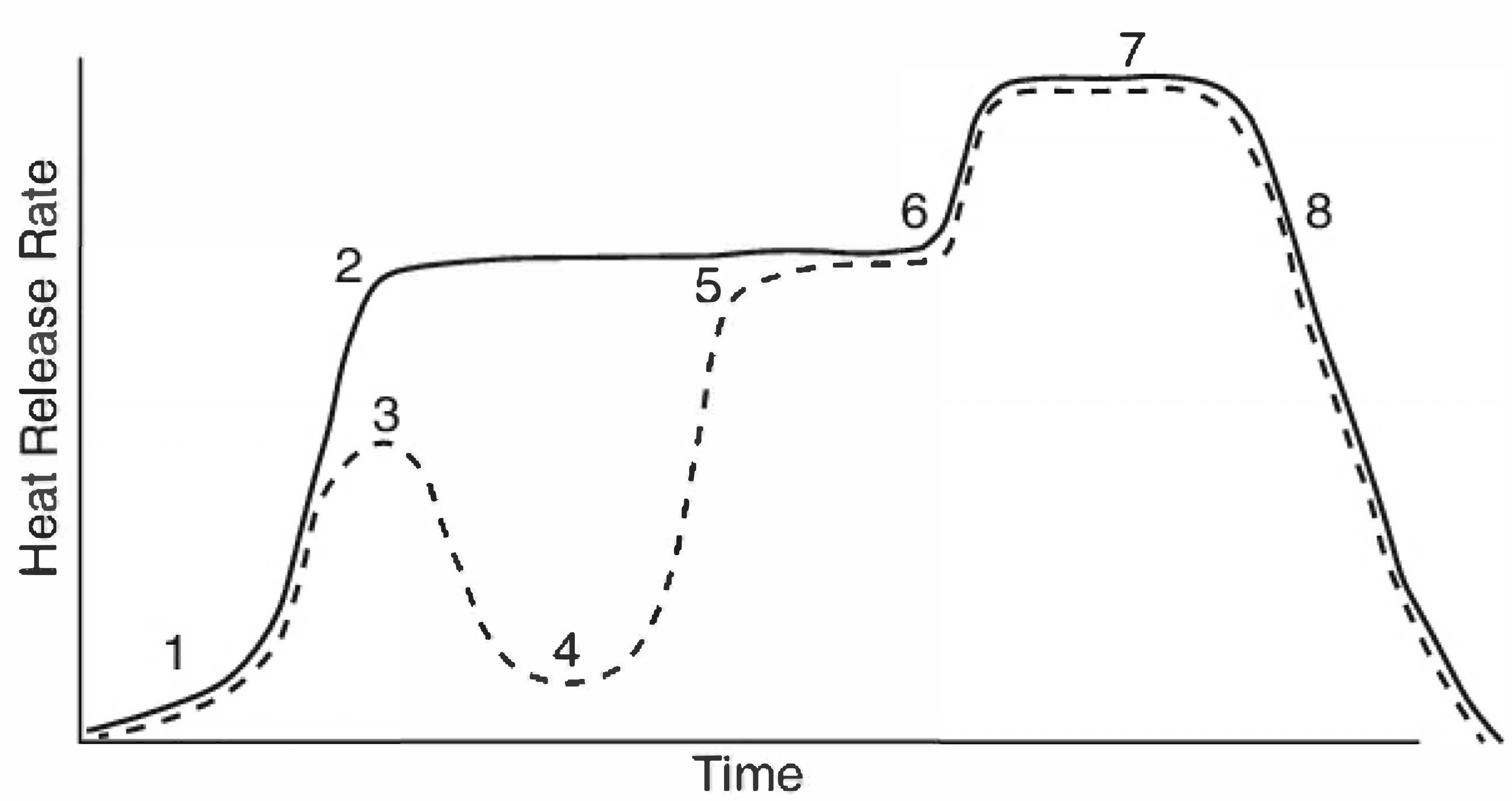

FIGURE 6.4.2 Fire Progression in Ventilated Versus Unventilated Compartments.

6.4.2.1.1.1 As radiant heat from the fire warms nearby fuels, it continues the progress of further pyrolysis allowing the flames to continue to spread and involve more fuel surfaces causing the fire's HRR to increase as the fire moves into the growth stage.

6.4.2.1.1.2 During these early stages of fire development there is often sufficient air to burn all of the materials being pyrolyzed, and it is only the fuel load within the compartment that limits the HRR. This fire is then said to be *fuel-limited*.

6.4.2.1.1.3 As the fire burns, the gaseous products of combustion move upwards due to differences in temperature, density, and pressure between the room-temperature air and the gases generated and heated by the fire, creating a *thermal/plume*.

6.4.2.1.1.4 When the plume reaches the ceiling, the flow is diverted horizontally under the ceiling as a ceiling jet and flows in all directions until the gases strike the walls of the compartment. As the horizontal spread is restricted, the gases turn downward and begin the creation of a layer of hot gases below the ceiling, as shown in Figure 6.4.2.1.1.4. During this stage, convection is the primary method of heat transfer taking place within the compartment. As hot gases flow over cooler surfaces, energy is transferred to these objects; the greater the temperature and velocity of these moving gases, the greater the rate of heat transfer. When the hot smoky layer reaches the top of the door opening it will flow out of the compartment, and a well-defined flow pattern will be established at the opening.

6.4.2.1.1.5 The outward flow is due to the higher pressure, relative to atmospheric pressure, created by the fire. Subsequently, a region of lower pressure is also created below the outflowing gases where fresh air is drawn into the fire compartment. The rate of air entrainment to the fire is influenced by the rate of outflowing gases. If outflow increases, air entrainment will also increase. The height at which the flow changes direction is known as the neutral plane.

6.4.2.1.1.6 The height at which the flow changes direction is known as the "neutral plane" *[See Figure 6.4.2.1.1.6(a), Figure 6.4.2.1.1.6(b), and Figure 6.4.2.1.1.6(c)]*. As the fire grows, the bottom of the smoke layer — the neutral plane — will continue to descend.

6.4.2.1.1.7 As the fire continues to grow, the ceiling layer gas temperature and the intensity of the radiation on the exposed combustible contents in the room increases. While both convective and radiant heat fluxes increase, radiation now becomes the dominant method of heat transfer. Flameover, which describes the condition where flames propagate through or across the ceiling layer only and do not involve the surfaces of target fuels, may be present. Flameover generally precedes flashover. The high radiant heat flux present causes the surface temperature of the combustible fuels within the compartment to rise, and pyrolysis gases are produced.

6.4.2.1.2 Position 2. When the hot gas layer temperature reaches approximately 590°C (1100°F), a heat flux from the hot gas layer of approximately 20 kW/m^2 at floor level is often present. This is sufficient to cause a rapid auto-ignition all of the combustible surfaces exposed to upper layer radiation. This phenomenon is known as flashover, and it is illustrated in Figure 6.4.2.1.2.

6.4.2.1.2.1 Flashover, which is a rapid transition of a growth phase fire to a fully developed fire, is a dangerous phenomenon and has claimed the lives of countless fire fighters. Time to flashover from ignition was as little as 3 to 5 minutes.

6.4.2.1.2.2 Flashover may occur multiple times in a structure as the fire progresses from one area to another with each event having a potential to impact other compartments.

6.4.2.1.2.3 In a fully developed fire the air flow into the compartment is not sufficient to burn all of the combustibles being pyrolyzed by the fire, and the fire will shift from *fuel-limited* to *ventilation-limited* where the HRR is limited by the amount of oxygen available *[see Figure 6.4.2.1.2.3]*. Although pyrolysis can continue throughout the compartment, flaming combustion will only occur where there is sufficient oxygen present. Depending on the momentum of the entraining air, flaming combustion may occur within the ventilation stream at various depths into the compartment.

6.4.2.1.3 Position 6. Fully developed fires are ventilation-limited. As the HRR of the fire is now directly proportional to the amount of air available to the fire, any further increase in ventilation will result in a further increase in the HRR. Increases in heat release rate can increase temperatures and amount of toxic gases in the structure. Additionally, structural stability

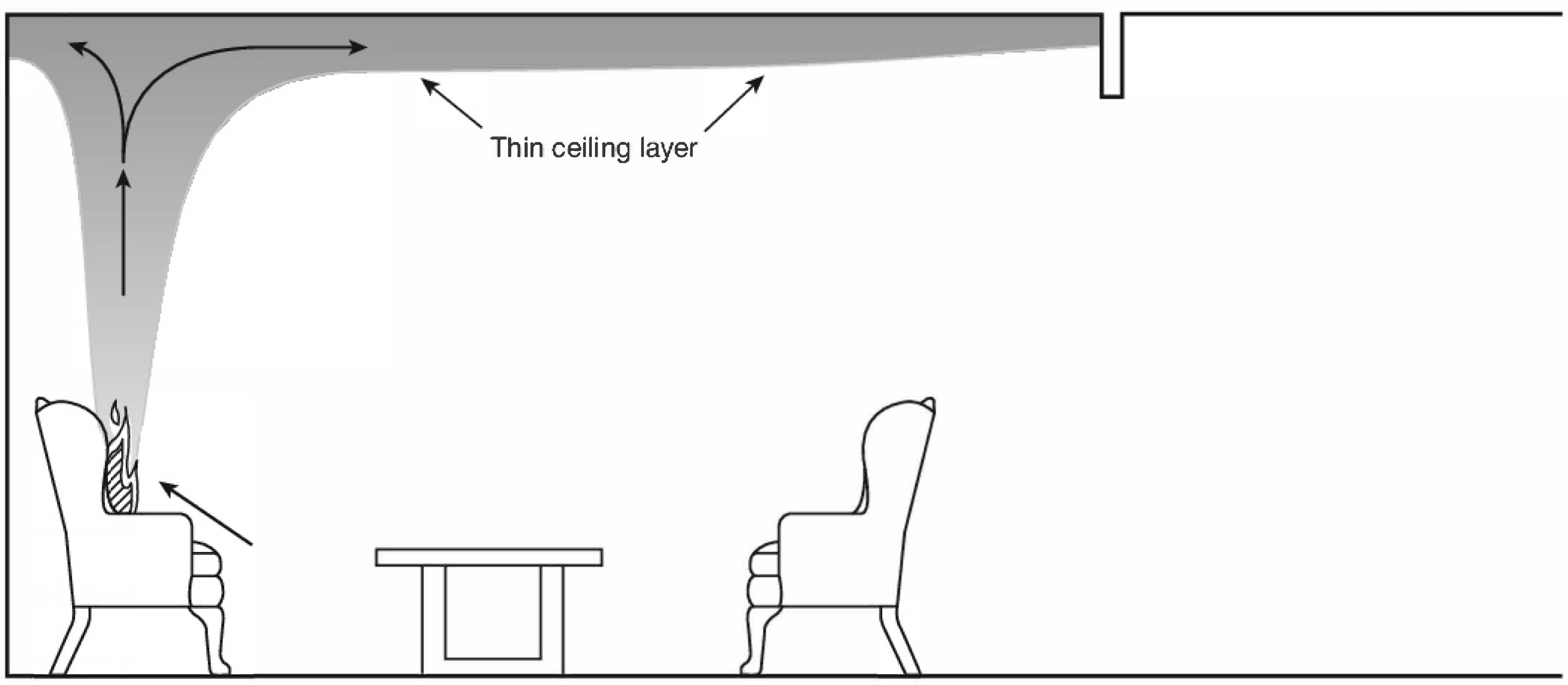

FIGURE 6.4.2.1.1.4 Early Compartment Fire Development.

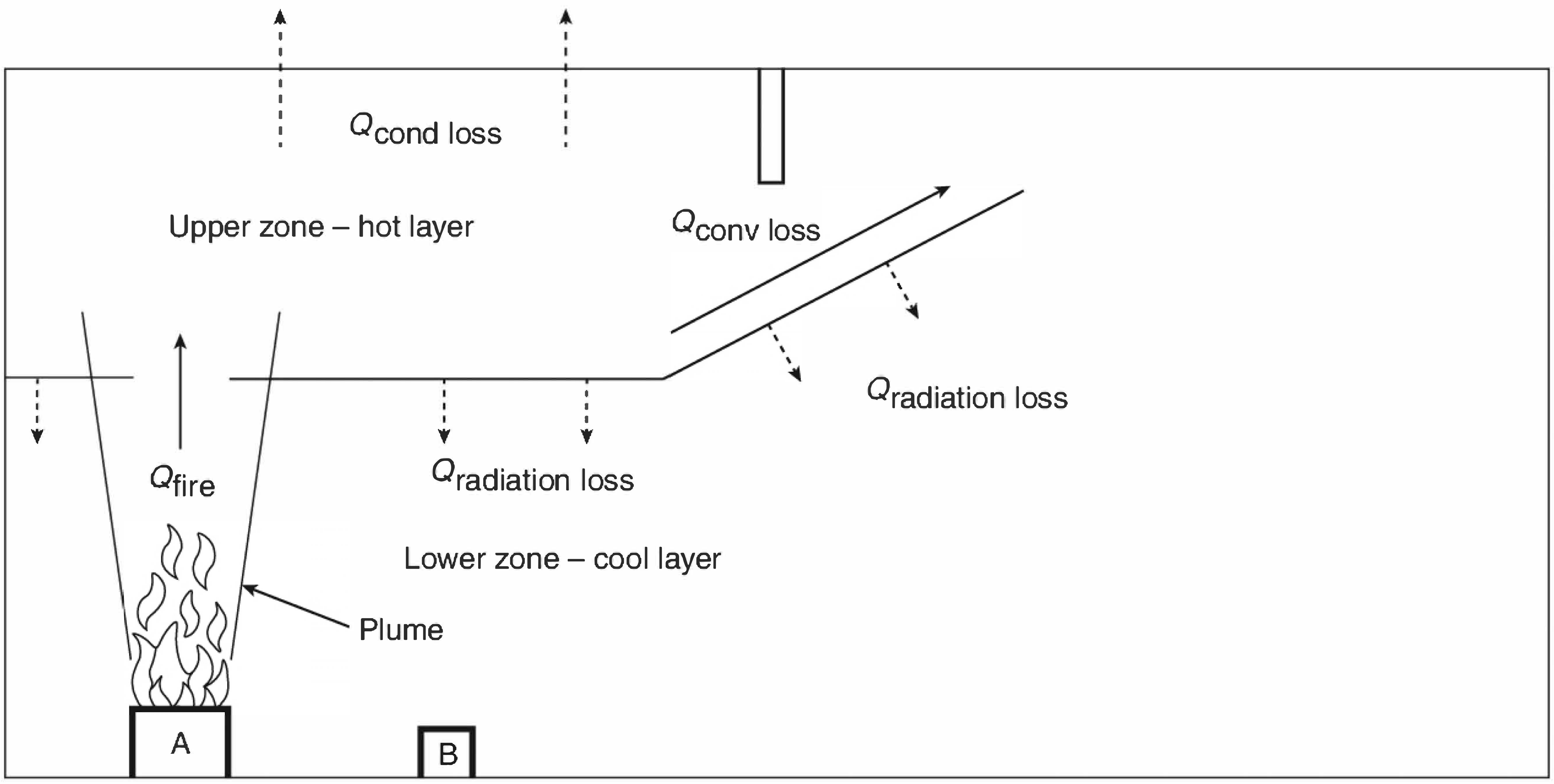

FIGURE 6.4.2.1.1.6(a) Neutral Plane — Compartment Fire Zones and Heat Transfer.

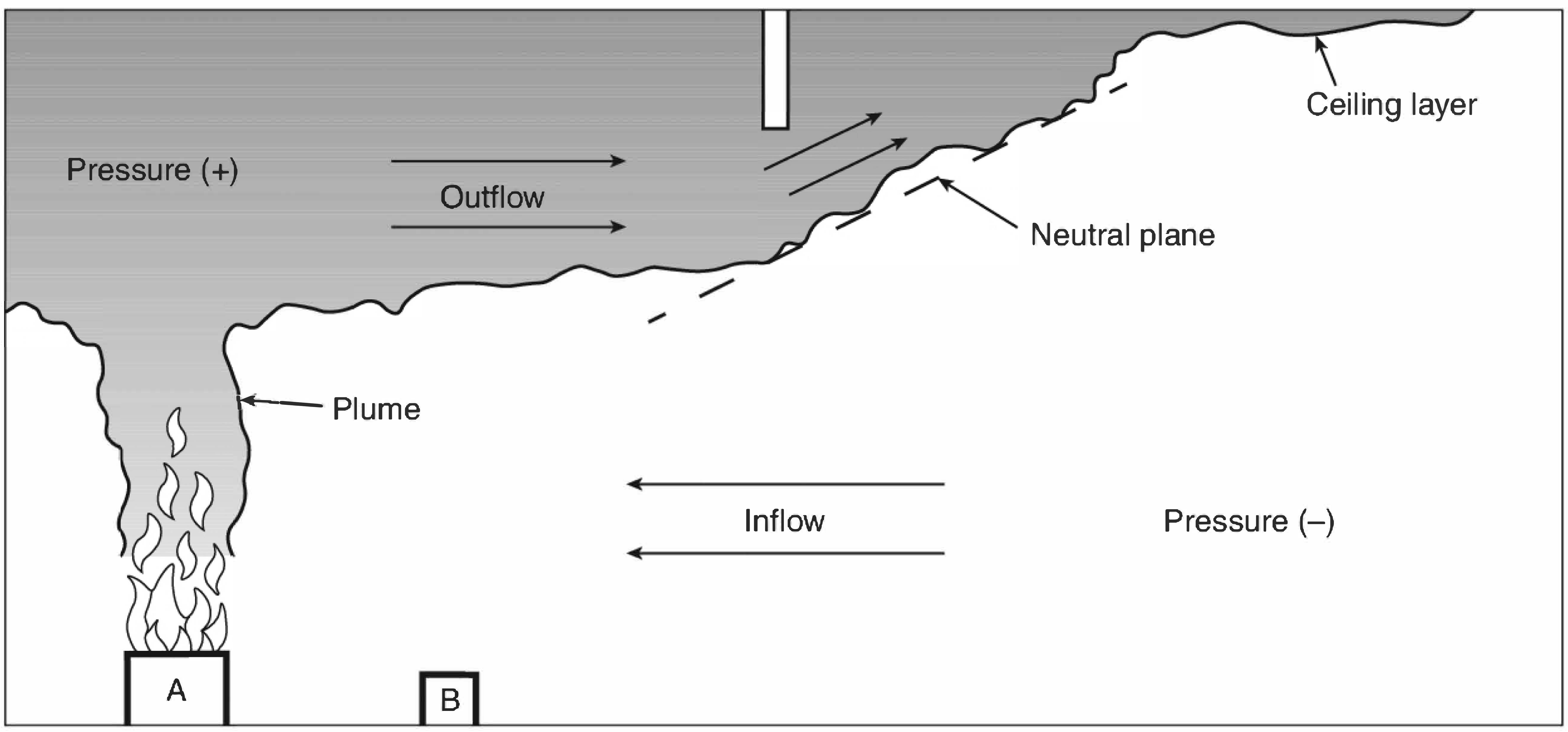

FIGURE 6.4.2.1.1.6(b) Neutral Plane — Compartment Fire Pressure and Airflow.

of the affected areas could be compromised at an increased rate, and the amount of cooling agent (water) required to control the energy production will also be increased.

6.4.2.1.4 Position 7. This position represents a fully developed fire that has increased its HRR due to additional ventilation from openings made. Any further increases in ventilation after this period will again cause further increased HRR if effective water suppression has not been achieved.

6.4.2.1.5 Position 8. A fire will enter into the decay stage with effective fire control, depletion of fuel load, or oxygen restriction.

6.4.2.2 Fire in an Unventilated Compartment.

6.4.2.2.1 Position 1. During the development of an incipient fire, the rate of flame spread and (HRR) is greatly dependent on the configuration and characteristics of the fuels involved.

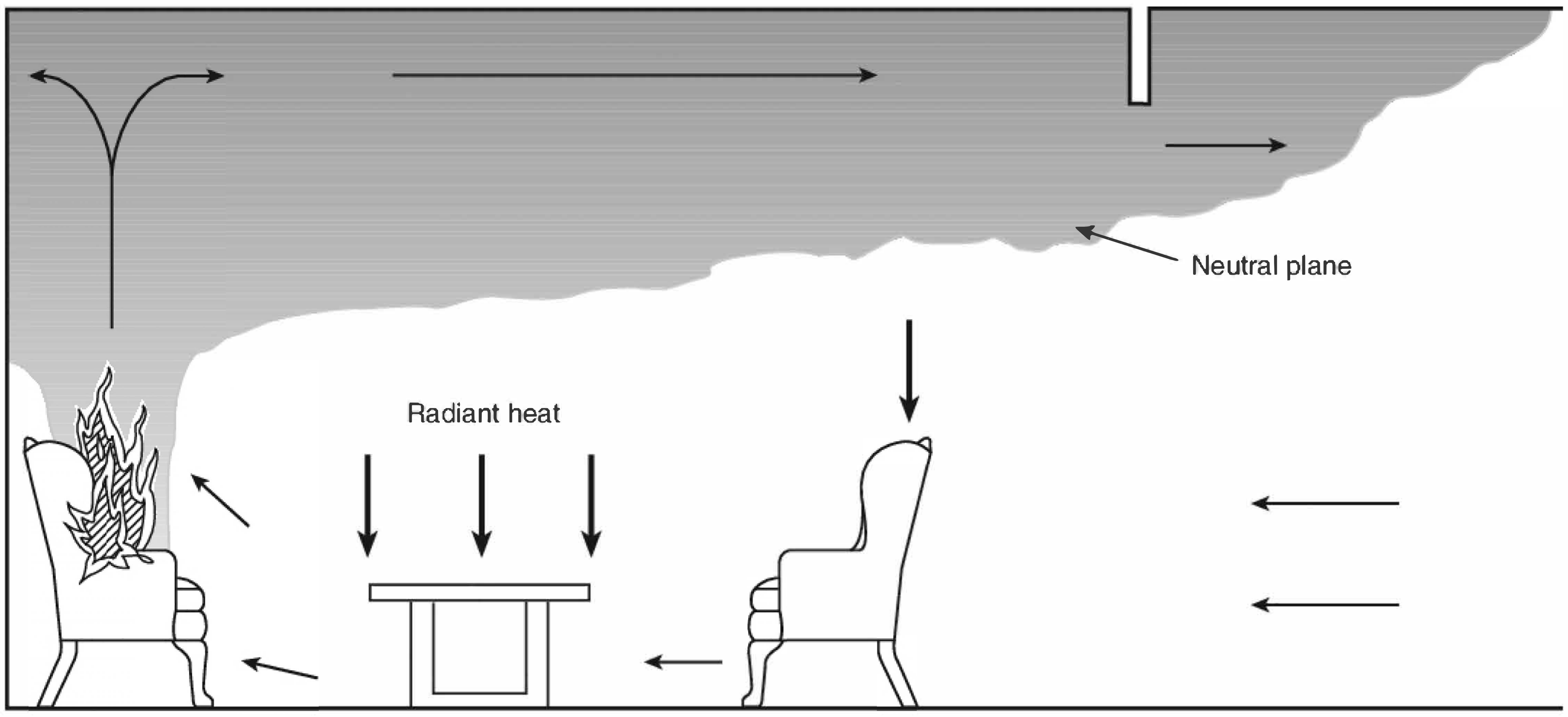

FIGURE 6.4.2.1.1.6(c) Neutral Plane — Upper Layer Development and Airflow.

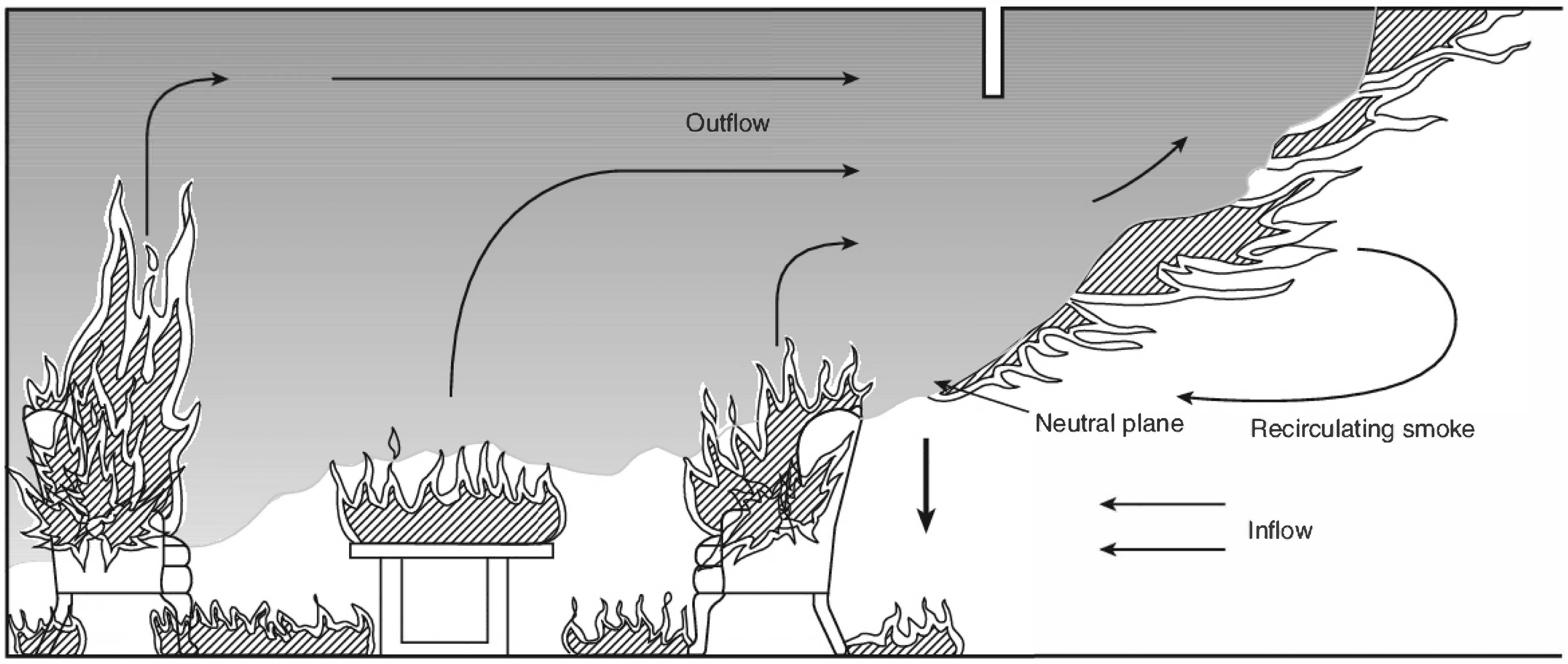

FIGURE 6.4.2.1.2 Flashover Conditions in Compartment Fire.

6.4.2.2.1.1 As radiant heat from the fire warms nearby fuels, it continues the progress of further pyrolysis, allowing the flames to continue to spread and involve more fuel surfaces, causing the fire's HRR to increase as the fire moves into the growth stage.

6.4.2.2.1.2 During these early stages of fire development there is often sufficient air to burn all of the materials being pyrolyzed, and it is only the fuel load within the compartment that limits the HRR. This fire is then said to be *fuel-limited*.

6.4.2.2.1.3 As the fire burns, the gaseous products of combustion move upwards due to differences in temperature, density, and pressure between the room-temperature air and the gases generated and heated by the fire, creating a fire plume.

6.4.2.2.1.4 When the plume reaches the ceiling, the flow is diverted horizontally under the ceiling as a ceiling jet and flows in all directions until the gases strike the walls of the compartment. As the horizontal spread is restricted, the gases turn downward and begin the creation of a layer of hot gases below the ceiling. During this stage, convection is the primary method of heat transfer taking place within the compartment. As hot gases flow over cooler surfaces, energy is transferred to these objects; the greater the temperature and velocity of these moving gases, the greater the rate of heat transfer.

6.4.2.2.1.5 During the growth stage in compartments with no openings, the increasing gas temperatures and their inhibited expansion can result in considerable pressure development.

6.4.2.2.2 Position 3. Without openings to the outside, such as a door or window, the available oxygen for the fire is limited. With limited ventilation, the burning process becomes less effective. When the hot gas layer, which has a reduced oxygen concentration relative to the room air, increases in depth down from the ceiling and continues to descend, it will interfere with combustion.

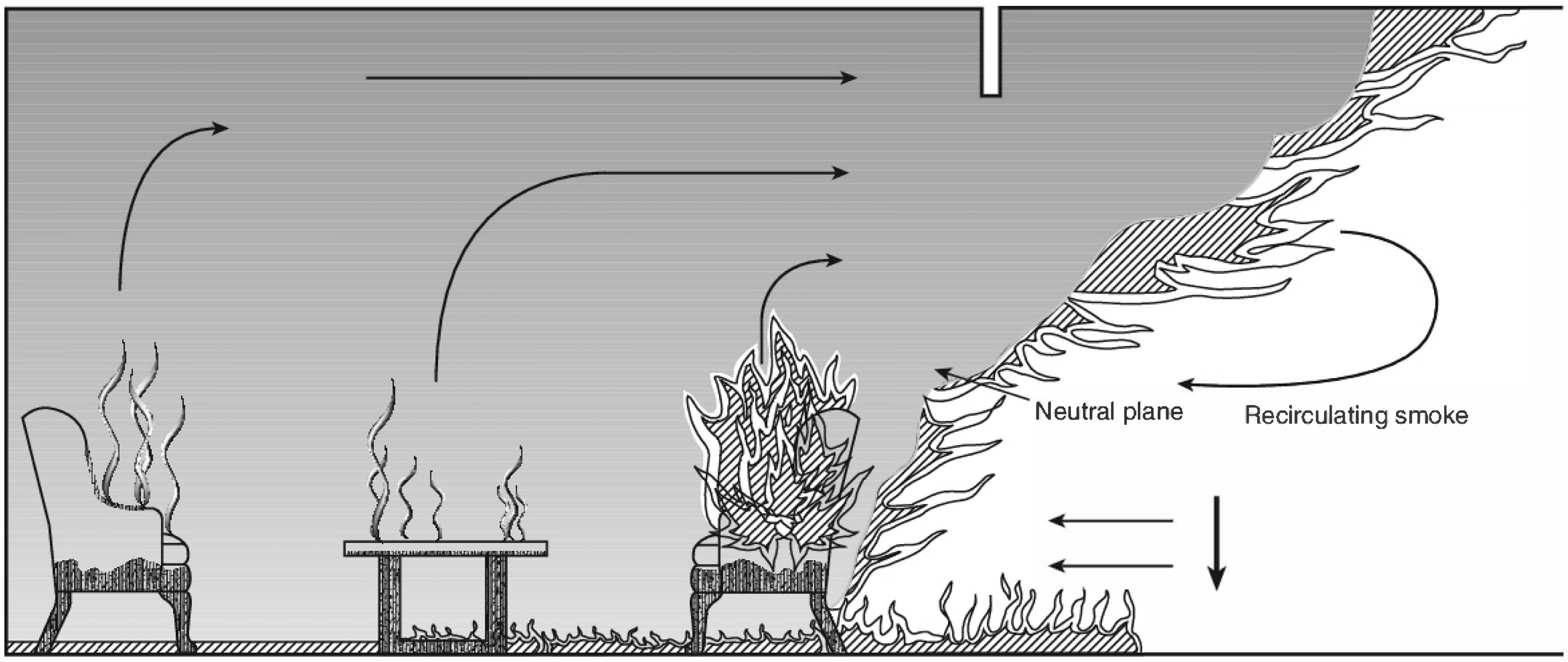

FIGURE 6.4.2.1.2.3 Flashover or Full Room Involvement in Compartment Fire.

6.4.2.2.2.1 As the fire compartment's oxygen concentration decreases below what is needed for combustion, the fire will go into *early decay.*

6.4.2.2.2.2 When in *early decay*, the HRR of the fire will decrease dramatically, causing gas temperatures within the fire area to decrease. This reduction of temperature will cause the hot gas layer to contract, and the affected fire area may transition from positive pressure, relative atmospheric pressure, to negative pressure.

6.4.2.2.2.3 If the fire compartment pressure becomes negative, smoke that was previously exiting through any leakage points or cracks within the compartment may stop, and air may then be drawn inwards.

6.4.2.2.3 Position 4. If the fire receives a fresh oxygen source at this point in development by opening a window, door, or otherwise providing ventilation, the fire's HRR will increase, returning the fire to the growth stage.

6.4.2.2.3.1 Because the room's ceiling and the upper portions of the wall were preheated as the fire was burning prior to entering early decay and the hot gas layer contains unburned fuel gases, the fire's growth rate within the compartment can recover quickly.

6.4.2.2.3.2 As the fire becomes re-established with oxygen, flashover and full development are now possible.

6.4.2.2.4 Position 5. When the hot gas layer temperature reaches approximately 590°C (1100°F), a heat flux from the hot gas layer of approximately 20 kW/m^2 at floor level is generally present. This is sufficient to cause a rapid auto-ignition all of the combustible surfaces exposed to upper layer radiation. This phenomenon, known as flashover, is illustrated in Figure 6.4.2.1.2.

6.4.2.2.4.1 Flashover can occur within seconds after providing ventilation to vent-limited (decay) fires.

6.4.2.2.4.2 Flashover may occur multiple times in a structure as the fire progresses from one area to another, with each event having a potential to impact other compartments.

6.4.2.2.4.3 In a fully developed fire the air flow into the compartment is not sufficient to burn all of the combustibles being pyrolyzed by the fire, and the fire will shift from fuel-limited to ventilation-limited where the heat release rate is limited by the amount of oxygen available *[see Figure 6.4.2.1.2.3].*

6.4.2.2.5 Position 6. Fully developed fires are ventilation-limited. As the HRR of the fire is now directly proportional to the amount of air available to the fire, any further increase in ventilation will result in a further increase in the HRR. Increases in heat release rate can increase temperatures and amount of toxic gases in the structure. Additionally, structural stability of the affected areas could be compromised at an increased rate, and the amount of cooling agent (water) required to control the energy production will also be increased.

6.4.2.2.6 Position 7. This position represents a fully developed fire that has increased its HRR due to additional ventilation from openings made. Any further increases in ventilation after this period will again cause further increased HRR if effective water suppression has not been achieved.

6.4.2.2.7 Position 8. A fire will enter into the decay stage with effective fire control, depletion of fuel load, or oxygen restriction.

6.5 Flow Path.

6.5.1 As a fire develops within a compartment that is interconnected to other spaces in the structure, fluid flows develop due to the pressure differentials created by the fire. This pressure differential is the result of the higher pressure created by the expansion of gasses when heated by the fire versus the lower-pressure spaces in the remainder of the structure. During most structure fires there will often be multiple flows between multiple compartments. *(See Figure 6.5.1.)*

6.5.2 As the fire gases move out of their original compartment, they will transfer thermal energy through conduction, convection, and radiation at a rate that is influenced by many factors, including, but not limited to, temperature and velocity.

6.5.3 The rate that fire gases flow is caused by pressure differences that might result from temperature differences, buoy-

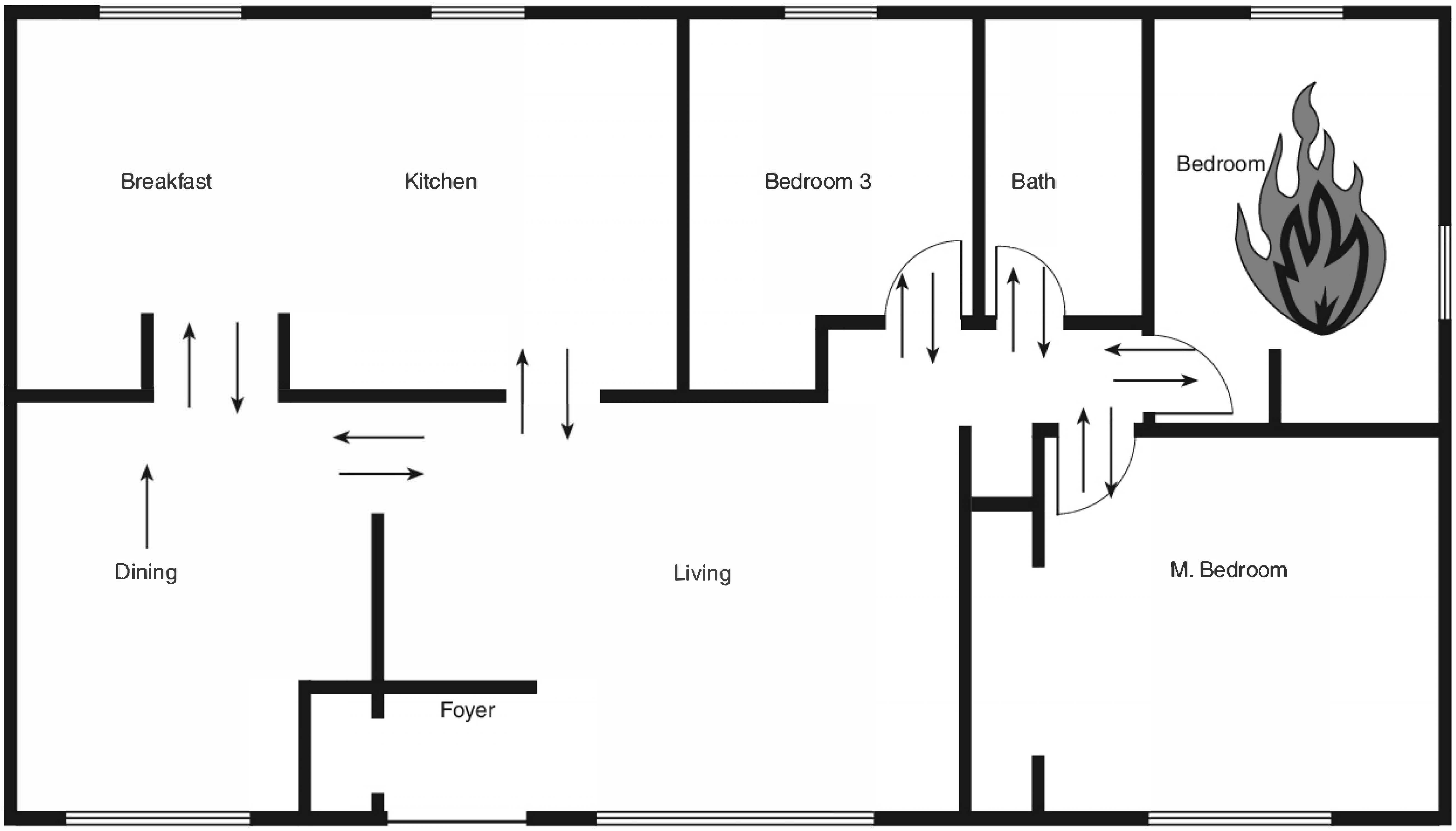

FIGURE 6.5.1 Multiple Flows Between Multiple Compartments.

ancy, expansion, wind impact, and HVAC systems. The greater the difference the faster the flows will travel. Any elevation changes within the structure, such as a staircase leading to another floor, will also impact the velocity of moving fire gases.

6.5.4 Flow path is the route followed by smoke, air, heat, or flame between the fire and the opening(s); typically, a window, door, or other leakage points. It must be composed of at least one intake vent, one exhaust vent, and a connecting volume between the vents. A single opening can be comprised of both the intake and exhaust vent. Based on varying building design and the available ventilation openings (e.g., doors, windows, staircases, etc.), there may be several different flow paths within a structure.

6.5.5 Hot gas flows have claimed the lives of many fire fighters and can be extremely dangerous when crews are positioned in the exhaust portion of the flow path, which is between the fire and the exhaust vent.

6.5.6 Exhaust portions of the flow path exist above the neutral plane and allow fire gases to exit the structure.

6.5.7 Intake portions of the flow path exist below the neutral plane and allow fresh air into the structure. The safest position from which to mount an interior fire control is to place fire fighters on the intake side of the flow path.

6.5.8 A bidirectional flow can often be seen at an opening positioned at the same level as the fire. A neutral plane will be present with fire gases flowing out and air flowing in at the same opening. *(See Figure 6.5.8.)*

6.5.9 A unidirectional flow can often be seen when two openings exist at different elevations allowing the whole inlet or exhaust openings to be positioned completely below or above the neutral plane. This commonly occurs at fires involving multilevel structures. *(See Figure 6.5.9.)*

6.5.10 The most dangerous place for fire fighters to be located is in the exhaust portion of the flow path. Exhaust portions of the flow path have had gas speeds recorded up to 20 mph (32.2 kph). These high velocities increase the rate of energy transfer exponentially to all objects in the flow path, including fire fighters. Modern fire fighter PPE can only protect fire fighters a few seconds in high-temperature and high-velocity flows.

6.5.11 Fire fighters on floors above an uncontrolled fire will be at increased risk of being caught in the exhaust portion of a flow path if any upper floor windows are open.

6.5.12 Vertical ventilation can create dangerous flows if fire fighters are located between an uncontrolled fire and the ventilation opening.

6.5.13* Dynamic Flow. *Dynamic flow* is a condition where unidirectional or bidirectional flow of smoke/air presents irregular stratification and shape or alternates in direction (i.e., pulsations).

6.5.13.1 A unidirectional or bidirectional flow of smoke/air that presents irregular stratification and shape or alternates in direction (i.e., pulsations) is identified as dynamic flow.

6.5.13.2 Dynamic flows may be caused by oscillations in the combustion cycle or as the result of being impacted by wind.

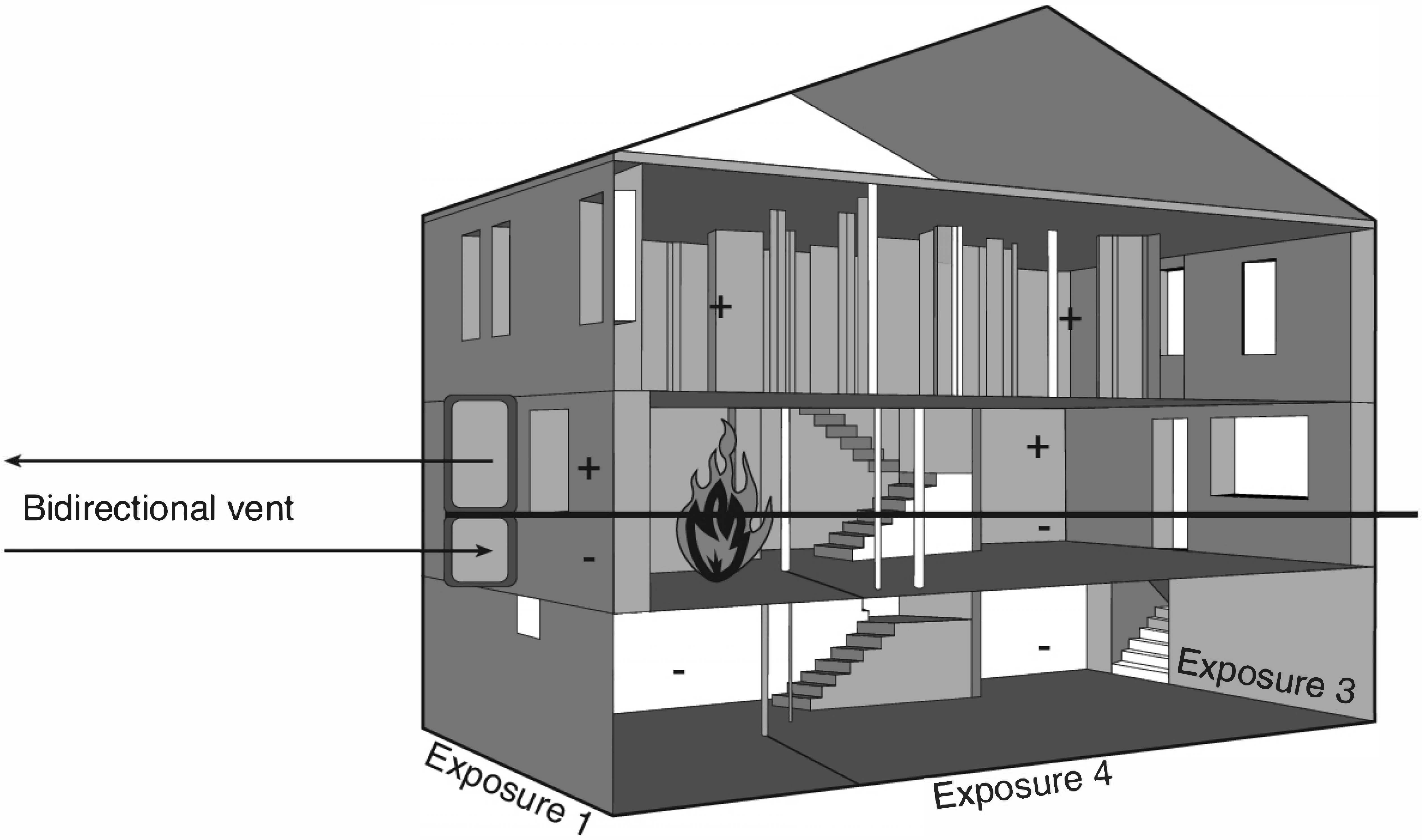

FIGURE 6.5.8 Bidirectional Flow Path.

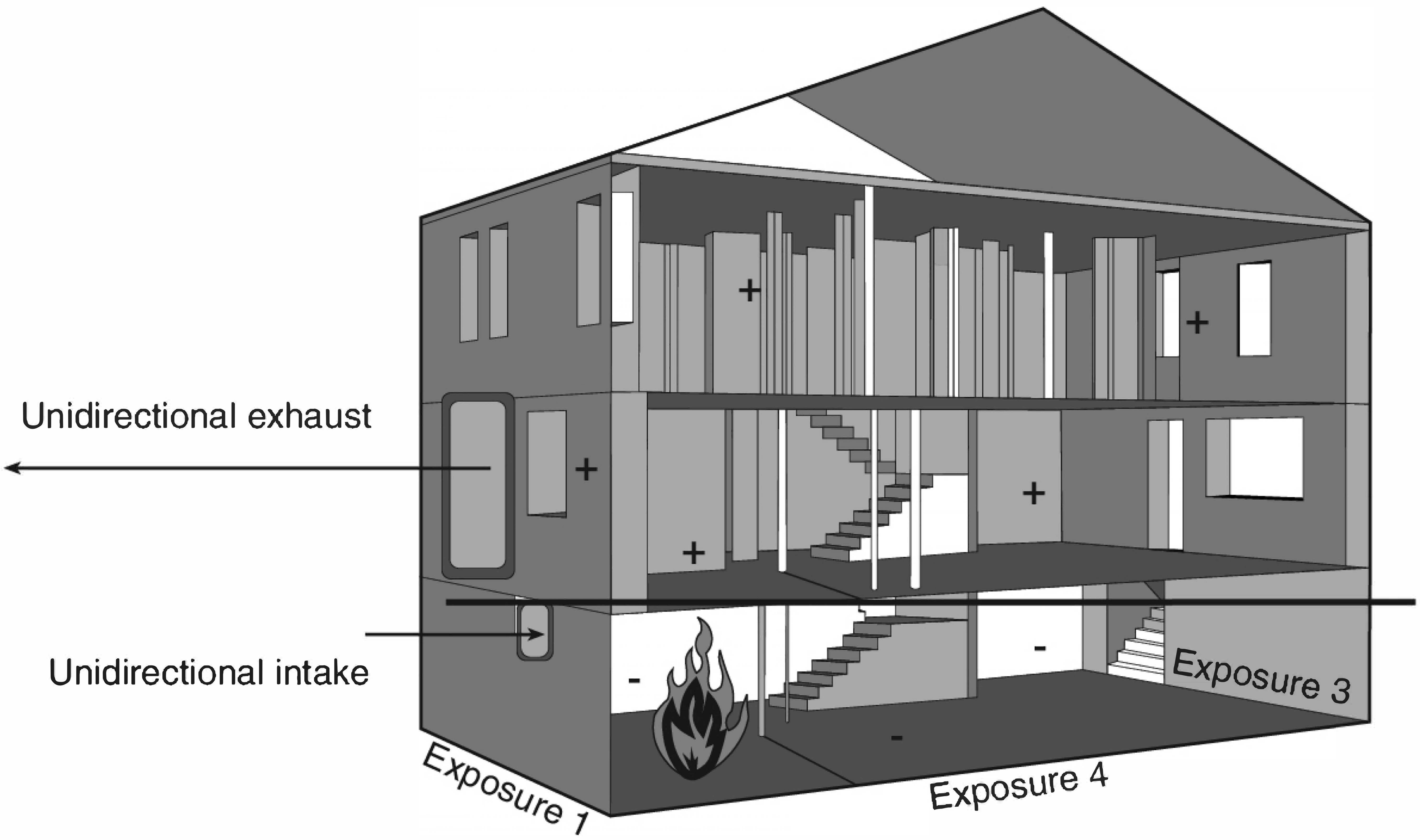

FIGURE 6.5.9 Unidirectional Flow Path.

6.6 Wind Influenced Fires.

6.6.1 Anything that increases the speed that the gases flow or changes their direction presents an increased risk to fire fighters who may be working on the exhaust portion of the flow path. This includes wind, which can create a unidirectional flow.

6.6.2 Flow behavior can change dramatically based on the speed and direction of the wind.

6.6.3 Wind speeds as low as 9 mph (14.5 kph) can have a significant impact on the flow behavior of the fire gases and increase the risk of fire extension and threat to human life.

6.7 Fire Dynamics in Attics.

6.7.1 Attic fires are influenced by a number of factors that are not typical of fire development in a normal building compartment.

6.7.2 High fuel loads can be present in attics due to the wood trusses and sheeting. These combustible surfaces can support high heat release rates. Because of high fuel loads, attic fire can often become ventilation-limited.

6.7.3 Attics are often constructed with built-in passive ventilation that utilizes the buoyancy of warmer air to rise up and out of the attic while drawing fresh air in from lower elevations. This ventilation can influence fire growth and spread.

6.7.4 When a fire has grown to the extent in which it has caused failure of a portion of the roof system and flames are visible from the exterior, the fire will likely be ventilation-limited. Additional ventilation will increase the HRR within the attic space. Even without the fire breaching the attic construction, the fire may still be ventilation-limited.

6.8 Fire Dynamics in Basements.

6.8.1 Basement fires are influenced by a number of factors that are not typical of fire development in normal (i.e., ground level) building compartments. High fuel loads are inherent in basements due to exposed wood floor joists and the potential for unfinished rooms. These combustible surfaces can produce high heat release rates.

6.8.2 An additional concern with basement fires is the unknown fuel loading that might exist due to storage. On occasion, the amount of storage may be in excess of the intended fuel loading for the compartment size.

6.8.3 Basement fires are likely ventilation-limited due to their positioning relative to the natural inlet points (i.e., windows, stairway opening).

6.8.4 Primary hazards associated with basement (i.e., below-grade) fires include the following:

(1) The likelihood of structural collapse. A collapse will represent a vertical vent for the fire and will result in an increase in fire intensity.
(2) Increased potential that fire fighters will be operating in the exhaust flow as they position themselves for a fire control. Flows at the top of the stairs can reach speeds of 20 mph (32.2 kph) and will present an extreme risk for any personnel positioned at the top of the stairs.

6.9 Backdraft.

6.9.1 Backdraft conditions may develop in instances where the closed compartment has a minimal amount of ventilation openings provided by small cracks around windows, doors, and structural features. As the fire develops, these smaller openings support the release of the expanding fire gases, minimizing the pressure rise within the compartment but not to the extent of complete ventilation. As the hot gas layer lowers in the compartment, it descends around the primary fuel package, further limiting ventilation and preventing the complete consumption of the fuel package. The unburned fuels now exist within an area that has insufficient oxygen to support flaming combustion but will still support smoldering combustion.

6.9.2 Elsewhere in this same fire compartment, or an immediately adjacent compartment, glowing embers or smaller volumes of flaming combustion may still exist. Any sudden action, either planned or unplanned, that introduces a new ventilation opening on the compartment will provide an avenue for the now hot, fuel-rich atmosphere to flow out and relatively cooler, oxygen-rich air to be drawn in the lower portions of the compartment. A mixed layer forms due to the shearing action between the outflowing hot gases and the cooler air flowing in. This mixed layer rides on the gravity current across the compartment. With a portion of the mixed current within its flammable range, it may ignite when it reaches flame or a glowing ember in the compartment. After ignition, a new flame will propagate back through the mixed gas area between the entering gravity current and the exiting compartment gases. The flame and its wake can be extremely unstable and generate a rapidly propagating turbulent flame. The resulting expanding flame within the compartment drives some of the accumulated fuel out of the opening and consumes the fuel that was initially forced out of the compartment ahead of the initial flame, forming a dramatic fireball. This entire process — the accumulation of unburned gaseous fuel, the propagation of an oxygen-rich gravity current creating a mixed region and carrying it to the ignition source, and the ignition and propagation of an eventually turbulent explosion — constitute a backdraft *(for reference see Defining the Difference Between Backdraft and Smoke Explosions)*.

6.10 Fire Gas Ignition/Smoke Explosions.

6.10.1 Conditions leading to a smoke explosion start like any other fire in a closed compartment with a minimal amount of ventilation openings provided by small cracks around windows, doors, and structural features (e.g., electrical outlets). Although the fire will start like any other fire, there is insufficient air for the fire to reach flashover or break the windows during its development to provide an unimpeded air supply. This results in fire development becoming limited by the available air supply within the compartment. Once most of the available oxygen in the compartment is consumed, flaming combustion will cease and the fire will transition to a smoldering state, releasing a large amount of carbon monoxide and excess gaseous fuel. As the fire continues to smolder, the compartment will reach a “quasi-steady” condition with the combustion products being generated by the smoldering fire leaking out of the compartment and being replaced by oxygen-rich air leaking back into the compartment below the level of the neutral plane.

6.10.2 Unlike backdraft conditions, which require the creation of a new ventilation opening to allow oxygen-rich air to mix with the fuel-rich gases within the compartment, a new ventilation opening is not required for a smoke explosion to occur. Instead, the fuel-rich gases within the compartment will mix with the available oxygen to create premixed conditions that require only a minimal amount of oxygen to elevate the mixture into its flammability range. There are a number of possible explanations for how the fire may reach this condition: perhaps the fire is located far from the openings and has a difficult flow path to reach the seat of the fire, the fire could be located inside a small compartment within a larger compartment thereby delaying air flow, or the fire could be located high in the compartment making it difficult for the cold oxygen-rich air to reach the seat of the fire.

6.10.3 Regardless of the reason(s), the fire remains in a smoldering state with the oxygen level slowly rising as the oxygen-rich air leaks into the compartment below the neutral plane to replace the mass of fuel-rich gases leaking out above the neutral plane. Under the right conditions, the fuel-to-air mixture in the vicinity of the smoldering source can become ignited, and a smoke explosion occurs as a deflagration moves quickly through the premixed flammable mixture. Pressures generated by a smoke explosion may be significant enough to cause structural damage and loss of life within or immediately adjacent to the compartment *(for reference see Defining the Difference Between Backdraft and Smoke Explosions).*

6.11 Fire Dynamics of Exterior Fires.

6.11.1 Exterior fires can present a significant hazard if not addressed with early fire control. The flaming combustion of siding, sheathing, and insulation materials on the exterior surfaces of a structure can extend vertically and transition into the structural elements themselves or the interior of the structure through natural openings such as windows, doors, and soffit vents.

6.11.2 With the recent addition of rigid foam board to exteriors of some buildings to increase the insulative performance, significantly faster flame spread has been observed. In addition to the hazard of direct flame exposure, the heated smoke and unburned pyrolyzates produced by the fire can follow natural intakes into the structure (i.e., soffits, overhangs, windows) where they collect in interior void spaces presenting further hazards. Many of these structural openings (e.g., soffits) are designed to provide an avenue for passive ventilation into the attic space, and this would not change in the event of a fire situation where hot smoke and fire gases would be drawn along that same pathway. *(For reference see UL FSRI Attic Fire Study.)*

6.11.3 Additional consideration should be given to commercial and high-rise structures that include facades with rain-screen-type cladding systems (or similar). These cladding systems are typically composed from multiple pieces assembled together amongst vertical and horizontal gaps to provide thermal transfer, passive ventilation, and moisture control within the structural components. These purpose-built gaps create hidden voids beneath the entire surface area of the facade and may provide avenues for fire and smoke spread within the structure.

6.12 Fire Spread to Nearby Buildings (Exposures). The spread of fire from outside a compartment or structure to a nearby structures can pose a potential risk to communities and fire services. This occurs when the exterior flame provides sufficient heat flux to a nearby structure's exterior materials for pyrolysis to occur. If pyrolysis gases are of an ignitable mixture, they can be ignited by piloted ignition or autoignition if a sufficient temperature is reached. The exposed structure's distance away from the flame and exterior materials will influence its risk of ignition.

Chapter 7 Building Construction and Structural Considerations

7.1 Scope. This chapter addresses information on building construction and structures and how they interact with fire.

7.2 Purpose. The purpose of this chapter is to provide building construction and structural performance information that may influence strategy and tactics for effective and safe firefighting.

7.3 Application. The intent of this chapter is for fire-fighting personnel to conduct a proper assessment of the effect of the fire on building materials and building construction.

7.4 General.

7.4.1 Compartmentation. Compartmentation is the ability to contain a fire to an area to limit the growth and spread of fire and smoke to other areas of a structure. Internal construction that provides limits to the amount of open spaces within a structure. The type of construction and the occupancy establishes the level of compartmentation and boundary properties such as how the floor, wall, and ceilings are finished along with the thermal properties of those finishes.

7.4.1.1* The compartment size in terms of its area and height, the open volume of rooms, and geometry, such as sloped ceilings within, all play a role in shaping the growth in the size of a fire and the progress of the burning regime(s) to be encountered within the volume.

7.4.1.2 Compartment size is a factor in determining fire spread within each type of construction.

7.4.2* Finishes. Finishes are non-load-bearing materials that provide for the surface layer of an interior or exterior structural component. Finishes can range from highly combustible to noncombustible materials. Construction finishes can have a high (thermally thick) or low (thermally thin) thermal mass, which can affect the ability of a compartment to absorb and hold heat energy. This can affect the fire growth rate.

7.4.3 Protective Features. Part of the structural evaluation and the ability to contain or limit fire spread of a fully developed fire is an assessment of the protective features within the structure. Both passive (e.g., fire code drywall, fire walls) and active (e.g., sprinklers, stairwell pressurization systems) methods, and the role they might play in fire control and protecting life, property, and environmental exposures both internal and external to the compartment fire should be considered.

7.4.4 Fire Protection Systems. Fire alarm and suppression systems are designed to provide early notification, prevent or limit fire growth, support intervention, and enhance occupant and fire fighter safety. Knowledge and understanding of these systems, in conjunction with pre-emergency planning and fire prevention activities, are important components of conducting effective structural fire-fighting operations.

7.4.4.1 Fire Alarm Systems. A fire alarm system is 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. Fire alarm systems are designed to provide notification of alarm, supervisory, and trouble conditions, alert occupants, summon aid, and initiate emergency control functions. *(See NFPA 72 for additional information.)*

7.4.4.2 Fire Command Center. The fire command center is 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. They are typically provided in high-rise or other complex buildings. This area can be used as the incident command post for fire control operations.

7.4.4.2.1 Emergency Voice Communication System. Emergency voice communication systems are for the protection of life by indicating the existence of an emergency situation and communicating information necessary to facilitate an appropriate response and action. The notification is often both audible and visual.

7.4.4.2.2 Fire Department Communication Systems. Fire department communication systems are usually found in high-rise buildings where normal fire department radio connectivity could be impacted. These systems typically consist of two-way telephone type systems and are used to connect the incident commander with fire response teams deployed in a structure. As an alternative to the dedicated fire communication system, a fire service radio signal enhancement system may be installed. One benefit of these systems is that fire fighters can use radios they regularly use and are familiar with.

7.4.4.3 Fire Suppression Systems.

7.4.4.3.1 Water-Based Systems. A water-based suppression system is an integrated network of piping with water under pressure that allows water to be discharged immediately when a sprinkler head operates. It typically consists of a water supply source(s), network of piping, and sprinkler heads. Sprinkler systems are designed to provide early fire control or extinguishment, helping to mitigate the hazards for occupants and fire fighters. The system is commonly activated by heat from a fire and discharges water over the fire area. *(See NFPA 13, 13R, and 13D for additional information.)*

7.4.4.3.2 Non-Water-Based Suppression Systems. There are a number of special extinguishing systems that may be found within buildings and structures. They are designed to protect specific hazards, enclosures, or areas within a building. The method of these systems is to suppress the fire through any combination of cooling, displacement of oxygen, and inhibiting the chemical chain reaction. *(See NFPA 12 for additional information.)*

7.4.4.3.3 Standpipe Systems. Standpipe systems are a series of fixed piping typically found in high-rise and larger buildings and storage areas. These systems connect a water supply to hose connections located within the building. They help eliminate the need for long hose lays and are designed for the purpose of manual fire-fighting operations by the fire department or trained building occupants. *(See NFPA 14 for additional information.)*

7.4.4.3.4 Fire Department Connections. Fire department connection is a method for the fire department to supply either a primary or a secondary water supply to standpipe systems or to supplement existing water supplies for fire sprinkler systems. Knowledge of the location and arrangement of fire department connections in advance of an emergency can facilitate more efficient and effective fire-fighting operations. The location can be visually identified on site by the appropriate signage or special lighting.

7.4.5 Building Utilities.

7.4.5.1 Electrical. Fire personnel must be aware of the electrical hazards at all structure fires. Electric hazards should be assumed during all phases, especially during aerial and ground ladder placements. Modern services allow for secondary electrical sources to activate once primary sources fail or are disconnected.

7.4.5.2 Fuel Gas. Gas (i.e., propane/natural gas) size-up at structure fires should assume the presence of gas for cooking or heating. If the fire is gas fed — that is, the gas piping or appliance was part of the ignition source and ultimately failed and is releasing gas into the fire — it is imperative to shut off gas supply before completely extinguishing. Water supply should be directed in a way that does not extinguish fire exiting from gas piping but to direct water stream to extinguish the surrounding areas.

7.4.6 Lightweight Construction. Lightweight construction can present special hazards including the early failure of structural components and collapse. (*For reference see NIOSH ALERT, Preventing Injuries and Deaths of Fire Fighters due to Truss System Failures.*)

7.5 Types of Construction. The five NFPA types of construction (fire resistive, noncombustible, heavy timber, ordinary, and wood frame) provide context for the assessment of fire propagation within that type. Therefore, type of construction is a primary building factor to evaluate.

7.5.1* Type I: Fire-Resistive Construction. These structures are classified as fire-resistive as all structural support members are protected with a fire-rated assembly. Typically, these structures protect a large number of occupants. Examples of Type I construction include high-rise buildings, healthcare facilities, and parking garages.

7.5.1.1 Type I Building Materials. Type I building materials are noncombustible materials. These materials can include steel, concrete, masonry, and glazings.

7.5.1.2 Components of Type I Construction.

7.5.1.2.1 Common fire protection features may include the following:

(1) Fire protection suppression systems, which include the following:
    (a) Dedicated wet pipe system, which is most common
    (b) Clean agent, CO_2, water mist for server room/electrical room applications, which are less common
(2) Common area interior finishes regulated for fire safety
(3) Common area furnishings regulated for fire safety
(4) No unprotected structural components (e.g., fire spray protections of beams, intumescent paint)
(5) Monitored fire alarm system with various detection elements

(6) Fire-rated separations, assemblies, doors
(7) Fire pump rooms
(8) Standpipes

7.5.1.2.2 Common life safety features may include the following:

(1) Travel distances
(2) Signage
(3) Smoke control and evacuation
(4) Emergency lighting
(5) Elevator recalls
(6) Stairwell pressurization control

7.5.1.2.3 Common Occupancies for Type I Construction.

7.5.1.2.3.1* High-Rise. Stack effect is the movement of air into and out of buildings, chimneys, flue gas stacks, or other containers, resulting from air buoyancy. Buoyancy occurs due to a difference in indoor-to-outdoor air density resulting from temperature and moisture differences. The buoyant force creates differential pressures that can have significant impact on smoke, air, heat and flame (SAHF) movement and control. Stack effect is usually associated with tall buildings due to the numerous leakage paths, shafts and ductwork that are compounded by operational practices and occupant behavior when opening and failing to close doors. Stack effect can be used to great advantage in clearing stairwells during high-rise operations and even more so in winter conditions.

7.5.1.2.3.2 Other Occupancies. Other common occupancies for Type I construction include the following:

(1) Hospitals
(2) Healthcare facilities
(3) Industrial facilities
(4) University facilities
(5) Newer commercial structures
(6) Parking garages

7.5.1.3 Green Construction Insulating Materials Considerations for Type I Buildings. (Reserved)

7.5.1.4 Vulnerabilities of Type I Buildings. Examples of Type I building vulnerabilities include the following:

(1) Elevators to get to fire floor (high-rise)
(2) Limited ladder truck access (high-rise)
(3) Fire could be remote from building entry
(4) Need controlled evacuation/movement of occupants
(5) Limited entrance and egress to fire floor
(6) Must rely on building fire protection and life safety features (command center, fire pump, sprinkler system, standpipes)
(7) Complex ventilation issues (heat, smoke control, stratification of smoke produced)
(8) Transport of personnel and equipment to upper floors (weight, fatigue)
(9) Delay in response to fire area
(10) Wind-driven
(11) Collapse zone should be considered (larger than other types of construction)

7.5.2 Type II: Noncombustible Construction. Type II is similar to Type I construction and can be considered to be noncombustible. Type II construction may contain protected structural assemblies; however, unlike Type I, they can contain unprotected assemblies. Type II construction can be Type IIA or Type IIB. Type IIA is required to protect structural assemblies with a 1-hour fire-resistance rating. The designer or builder may use a few strategies to achieve the rating, but the most common method is an assembly utilizing gypsum board. Type II may have occupancies including educational, assembly, business, and so forth.

7.5.2.1* Type II Building Materials. Type II building materials are noncombustible materials. These materials can include steel, concrete, masonry, and glazings. Type II B construction utilizes a noncombustible material to construct the structural components of a building. Examples would be metal-bar joist truss, steel I-beams, cold form steel, and so forth.

7.5.2.2 Components of Type II Construction.

7.5.2.2.1 Common fire protection features may include the following:

(1) Fire protection suppression systems
    (a) Dedicated wet pipe system, which is most common
    (b) Clean agent, CO_2, water mist for server room/electrical room applications, which are less common
(2) Common area interior finishes regulated for fire safety
(3) Common area furnishings regulated for fire safety
(4) Monitored fire alarm system with various detection elements
(5) Fire rated separations, assemblies, doors
(6) Fire pump rooms
(7) Standpipes

7.5.2.2.2 Common life safety features may include the following:

(1) Travel distances
(2) Signage
(3) Smoke control and evacuation
(4) Emergency lighting
(5) Elevator recalls
(6) Stairwell pressurization control

7.5.2.2.3 Common occupancies for Type II construction include the following:

(1) Strip malls
(2) Mercantile
(3) Educational
(4) Assembly
(5) Business
(6) Car dealerships

7.5.2.3 Green Construction and Insulating Materials Considerations for Type II Buildings. (Reserved)

7.5.2.4 Vulnerabilities of Type II Buildings. Types of Type IIB occupancies fire fighters will encounter include box stores, strip malls, car dealerships, and so forth. In some cases, these occupancies may be protected with active sprinkler protection, but in many occupancies there is no sprinkler protection leading to catastrophic collapse very early in the event. Fire fighters must use extreme caution in these structures because of the likelihood of early structural collapse due to the effect of heat on unprotected structural components. Examples of Type II building vulnerabilities include the following:

(1) Large open-area floor plans, achieved by utilizing lightweight truss construction
(2) Elevators to get to fire floor (e.g., elevated, but not full high-rise)
(3) Limited aerial fire apparatus access

(4) Fire remote from building entry
(5) Need controlled evacuation/movement of building occupants
(6) Limited entrance and egress to fire floor
(7) Must rely on building fire protection and life safety features (e.g., command center, fire pump, sprinkler system, standpipes)
(8) Complex ventilation issues (e.g., heat, smoke control, stratification of smoke produced)
(9) Transport of personnel and equipment to upper floors (e.g., weight, fatigue, dehydration)
(10) Delay in response to fire area
(11) High winds
(12) Collapse zone consideration

7.5.3* Type III: Ordinary Construction. Ordinary construction has a noncombustible exterior but the structural components are combustible. Most common Type III structures have a masonry exterior enclosing a wood frame. As with Type II, there are occupancies that are designated as Type IIIA and Type IIIB. Consistent with Type II, the Type IIIA has a 1-hour rating, and Type IIIB is not required to protect the combustible structural components.

7.5.3.1 Type III Building Materials. Type III building materials include noncombustible materials for exterior walls and can include combustible interior building elements. Exterior wall materials can include masonry and glazings. Interior building elements can include conventional or pre-engineered wood framing. Older structures can have solid-sawn wood construction.

7.5.3.2 Components of Type III Construction.

7.5.3.2.1 Common fire protection features may include the following:

(1) Sprinkler systems
(2) Fire alarm systems
(3) Higher rated separations (passive fire protection) in lieu of active fire protection such as sprinklers and fire alarm systems in alternative construction
(4) Common area interior finishes regulated for fire safety
(5) Common area furnishings regulated for fire safety
(6) Fire rated separations, assemblies, doors
(7) Fire pump rooms
(8) Standpipes

7.5.3.2.1.1 Fire protection construction requirements vary by local code for Type III construction.

7.5.3.2.2 Common life safety features may include the following:

(1) Travel distances
(2) Signage
(3) Emergency lighting
(4) Elevators

7.5.3.2.3 Common occupancies for Type III construction include the following:

(1) Residential
(2) Mercantile
(3) Mixed use
(4) Strip malls

7.5.3.3 Green Construction Considerations for Type III Buildings.

7.5.3.3.1 Insulating Materials. (Reserved)

7.5.3.3.2 Light-Weight Construction. (Reserved)

7.5.3.4 Vulnerabilities of Type III Buildings. Type III buildings may be protected with active sprinkler protection but in many occupancies there is no sprinkler protection, leading to catastrophic collapse very early in the event. Fire fighters must use extreme caution in these structures because of the likelihood of early structural collapse due to the effect of heat on unprotected structural components. Common vulnerabilities to Type III construction include the following:

(1) Open floor plans, achieved by utilizing lightweight truss construction
(2) Limited, unknown, or inconsistent building fire protection and life safety features
(3) Ventilation issues (heat, smoke control)
(4) Collapse zone consideration
(5) Fire spread to adjacent separated spaces within the building envelop through penetrations, unprotected openings, interstitial spaces, and so forth
(6) When present, fire sprinkler systems for residential occupancies might not provide coverage in concealed combustible spaces, such as attics

7.5.4 Type IV: Heavy Timber. Type IV Construction has historically been associated with older large industrial sites. Constructed using unprotected heavy timber structural members and wide open floor plans, these structures are associated with large fire events. These occupancies are commonly renovated into mixed-use residential and mercantile occupancies.

7.5.4.1* Type IV Building Materials. Type IV building materials include noncombustible materials for the exterior walls and interior building elements composed of solid or laminated wood without concealed spaces. Older structures can have solid-sawn wood construction.

7.5.4.2 Components of Type IV Construction.

7.5.4.2.1 Common fire protection features may include the following:

(1) Sprinkler systems
(2) Fire alarm systems
(3) Common area interior finishes regulated for fire safety
(4) Common area furnishings regulated for fire safety
(5) Fire rated separations, assemblies, doors
(6) Fire pump rooms
(7) Standpipes

7.5.4.2.1.1 Fire protection construction requirements vary by local code for Type IV construction.

7.5.4.2.2 Common life safety features may include the following:

(1) Travel distances may not comply due to older structures
(2) Signage
(3) Emergency lighting
(4) Elevators

7.5.4.2.3 Common occupancies for Type IV construction include the following:

(1) Mixed-use residential and mercantile occupancies
(2) Warehouse

7.5.4.3 Green Construction and Insulating Material Considerations for Type IV Buildings. (Reserved)

7.5.4.4 Vulnerabilities of Type IV Buildings. Due to the open floor plans, heavy fuel load, and combustible construction, Type IV buildings have been a challenge for many fire departments when involved with fire. Much of the current building stock was constructed over 100 years ago and is in various stages of occupancy. While constructed for industrial use, current structures are in use in a wide variety of occupancies, including residential as "loft" apartments or condos. Once a fire gains headway in these structures, it can be a long night. Common vulnerabilities for Type IV construction include the following:

(1) Outdated or unmaintained fire protection features
(2) Vacant structures, unmaintained
(3) Prone to vandalism and large fires
(4) Large open floorplans
(5) Prone to large long duration fire incidents due to heavy timber
(6) Concealed spaces, unknown compartmentation, and interstitial spaces in renovated Type IV buildings
(7) Collapse zones

7.5.5* Type V: Combustible Construction. The vast majority of Type V construction is residential construction. Type V may be classified as VA or VB. Type VA is required to carry a 1-hour fire-resistance rating.

7.5.5.1 Type V Building Materials. Type V building materials include structural elements, exterior walls, and interior walls composed of any materials, often combustible. These materials often include conventional wood, glue laminated wood, pre-engineered wood, and other lightweight systems. Older structures can have solid-sawn wood construction.

7.5.5.2 Components of Type V Construction.

7.5.5.2.1 Common fire protection features may include the following:

(1) Sprinkler systems
(2) Fire alarm systems
(3) No requirements for fire resistance of contents
(4) Fire rated separations, assemblies, doors
(5) Fire pump rooms
(6) Standpipes

7.5.5.2.1.1 Fire protection construction requirements vary by local code for Type V construction.

7.5.5.2.2 Common life safety features may include the following:

(1) Travel distances
(2) Signage
(3) Emergency lighting
(4) Elevators

7.5.5.2.3 Common occupancies for Type V construction include the following:

(1) Single-family and two-family dwellings
(2) Multi-family, business, or assisted living facilities

7.5.5.3 Green Construction and Insulating Material Considerations for Type V Buildings. (Reserved)

7.5.5.4 Vulnerabilities of Type V Buildings. Fire fighters can begin to assess the presence of Type V building construction based upon the occupancy of the structure. Even if the structure has a 1-hour rating, caution should be exercised due to the large amount of concealed spaces. These spaces may potentially conceal fire, unburnt fuel, and fire extension. Opening these spaces can have explosive results as the super-heated gases mix with the newly available oxygen. Common vulnerabilities for Type V construction include the following:

(1) No enforceable fire code in private residences
(2) Vacant/abandoned structures, unmaintained, prone to vandalism
(3) Fire growth can be rapid over non-rated contents
(4) Collapse zones
(5) Highest frequency of accidental fires within this construction type (cooking, smoking, etc.), which can lead to increased fire fighter injuries
(6) When present, fire sprinkler systems for residential occupancies might not provide coverage in concealed combustible spaces, such as attics

7.6 Special Structures or Occupancies. Some structures where fires will occur cannot be classified within the context of building type as defined by the building codes or present unique vulnerabilities due to life safety or internal process. Examples of these types of structures that might require special consideration and planning for fire-fighting activities include the following:

(1) Industrial settings
(2) Silos
(3) Underground buildings and occupancies; below grade
(4) Limited-access structures
(5) Theaters
(6) Churches
(7) Industrial facilities, such as power plants
(8) Special amusement buildings
(9) Piers and water-surrounded structures

7.7 Emerging Building Features. Emerging building features may inhibit fire-fighting operations due to the presence of a new feature (e.g., one that emits energy, increases a load, or creates an obstruction).

7.7.1 Photovoltaic. An often-used green initiative is photovoltaic (PV) solar panels to generate electrical power. A PV system typically includes the PV module (array) that generates electric direct current from the sun's energy, inverters that convert direct current to alternating current, and disconnects that isolate the PV module (array) from the building's electrical circuitry conduit. The system may include an electric storage device (batteries) to store the solar-generated electricity. Even if the PV system is disconnected, a PV module will always generate electricity when the sun shines. Therefore, the units will almost always contain energy and can present a significant electric shock hazard to fire fighters should a fire occur.

7.7.1.1 In addition to the shock hazard, a PV system poses other safety considerations. Structural collapse is a concern due to the added weight from the system, especially when structural elements experience fire conditions. The PV panels and system components can be combustible and add fuel to a fire, and the PV system can also provide an ignition source.

7.7.1.2 Solar power installations can obstruct access for fire-fighting activities, including vertical ventilation and stretching of hose lines, thereby reducing the effectiveness of suppression operations. Strong building code adoption and enforcement can address structural load requirements and proper installation of the PV system. Fire department standard operating procedures (SOPs) or standard operating guidelines (SOGs) should be in place to clarify response strategies and tactics. Identifying and preplanning such installations are also essential components of effective response.

7.7.1.3 The rapidly growing solar industry throughout North America and much of the world increases the potential for a fire department response to a building fire containing a photovoltaic system. These systems present safety hazards and tactical issues to the responding department.

7.7.1.4 The following are the three types of photovoltaic systems:

(1) Stand-alone. A stand-alone photovoltaic system is not connected to power grid. It may contain solar panels, batteries, combiner boxes, charge controls, and inverters.
(2) Grid interactive. A grid interactive photovoltaic system is connected to the grid and may contain solar panels, combiner boxes, charge controls, and inverters.
(3) Hybrid. A hybrid photovoltaic system is a grid interactive system containing batteries.

7.7.1.5 Photovoltaic systems present a variety of safety hazards, including the following, to fire fighters during and after fire control operations:

(1) Shock hazard due to direct contact with energized components of the system during fire control operations
(2) Shock hazard from water from fire control operations
(3) Shock hazard after fire control operations
(4) Collapse hazard due to weakening of structure members
(5) Tactical issues to fire fighters during fire control from photovoltaic systems connected to and located on buildings
(6) Vertical ventilation issues
(7) Hose stream application
(8) Overhaul issues
(9) Shielded fires

7.7.2 Energy Storage Systems. The following are examples of energy storage systems:

(1) Battery systems
(2) Hydrogen generators

7.7.3 Vegetative Roof. Another popular green initiative is a vegetative, or green, roof on a building to reduce the carbon footprint and improve insulation. Green roofs typically consist of a growth medium on top of a root barrier, drainage and water-retention layers, and a waterproof base. Foliage is planted in the growth medium. A green roof reduces building energy consumption, and the overall positive effect to the environment is unquestioned.

7.7.3.1 A properly designed and well-maintained green roof can actually reduce the threat of a roof fire, since a green roof system contains a large amount of aggregate material that is not combustible. However, a green roof can pose potential risks to the building itself or neighboring buildings if it is not designed and maintained properly. A vegetative roof can accumulate dead or dry plantings that provide a highly combustible fuel source that can cause a fire to spread within the building or to adjacent buildings.

7.7.3.2 Other risks include roof collapse if the underlying structure experiences the effects of fire, possibly enhanced by the saturation of the growth medium from fire streams or a malfunctioning drainage system. Additionally, green roofs may affect fire department access and hinder standard fire-fighting operations, including ventilation and deployment.

Chapter 8 Fire-Fighting Protective Clothing and Equipment Characteristics and Limitations

8.1 Scope. This chapter addresses protection characteristic and limitation of fire-fighting protective clothing and equipment when exposed to products of combustion.

8.2* Purpose. The purpose of this chapter is to provide information to fire-fighting personnel on the limitations during exposure to products of combustion of the equipment to make effective and safe fire-fighting decisions.

8.3 Application. The intent of this chapter is for fire-fighting personnel to have a good working knowledge of the limitations of fire-fighting gear and equipment used during interior fire-fighting operations on a structure fire.

8.4 Thermal Testing Requirements for Fire Fighter Protective Clothing and Equipment. The criteria for thermal limitation, time exposed, and test method is compiled from the most current edition of the applicable standard at the time of publication. The fire fighter should be aware of these minimum requirements and how their equipment is tested as it compares to their work environment. Additionally, standards are continually evolving, and gear and equipment can be used that is tested to different criteria or no criteria. *(See Table 8.4.)*

8.5 Fire-fighting Protective Clothing (NFPA 1971).

8.5.1 NFPA 1971 specifies the minimum design, performance, testing, and certification requirements for structural fire-fighting protective ensembles and ensemble elements that include garments (coats, trousers, and coveralls), helmets, gloves, footwear, and interface components (hoods).

8.5.2 The purpose of NFPA 1971 is to establish minimum levels of protection for fire-fighting personnel assigned to fire department operations including but not limited to structural fire fighting, proximity fire fighting, rescue, emergency medical, and other emergency first responder functions. To accomplish this, NFPA 1971 establishes the minimum requirements for structural fire fighting protective ensembles and ensemble elements designed to provide fire-fighting personnel limited protection from thermal, physical, environmental, and bloodborne pathogen hazards encountered during structural fire-fighting operations.

8.5.3 For the needs of NFPA 1700, only the thermal performance requirements and test methods for structural fire-fighting protective ensembles will be included in this summary.

Table 8.4 Thermal Testing Requirements for Fire Fighter Protective Clothing and Equipment

Fire-fighting Gear and Equipment (NFPA Reference Standard-Edition)	Thermal Limitations	Time Exposed	Standard Test Method
Helmet flaps (1971–2018)	500°F (260°C) 7.39 Btu/ft^2 (84 kW/m^2) Open flame	5 minutes Minimum TPP — 20 12 to 15 seconds	Heat and thermal shrinkage resistance — convective oven Thermal protective performance (TPP) test Flame resistance test — Bunsen burner
Face shield and goggle components (1971–2018)	Open flame	15 seconds	Flame resistance test — Bunsen burner
Helmet (1971–2018)	Open flame Open flame and 0.88 Btu/ft^2 (10 kW/m^2)	15 seconds 60 seconds followed by 15 seconds	Flame resistance — Bunsen burner Bunsen Burner and radiative source
Hood (1971–2018)	500°F (260°C) 7.39 Btu/ft^2 (84 kW/m^2) Open flame	5 minutes Minimum TPP — 20 12 to 15 seconds	Heat and thermal shrinkage resistance — convective oven Thermal protective performance (TPP) test Flame resistance test — Bunsen burner
Protective coat and trousers (1971–2018)	500°F (260°C) 7.39 Btu/ft^2 (84 kW/m^2) Open flame	5 minutes Minimum TPP — 35 12 to 15 seconds	Heat and thermal shrinkage resistance — convective oven Thermal protective performance (TPP) test Flame resistance test — Bunsen burner
Gloves (1971–2018)	500°F (260°C) Open flame	5 minutes 12 to 15 seconds	Heat and thermal shrinkage resistance — convective oven Flame resistance test — Bunsen burner
Boots (1971–2018)	500°F (260°C) Open flame	5 minutes 12 seconds	Heat and thermal shrinkage resistance — convective oven Flame resistance test — heptane fueled pan fire
Station/work uniform (1975–2019)	500°F (260°C) 510°F (265°C) Exists in ASTM D6413/D6413M	10 minutes — hot air circulating 10 seconds — flame resistance test 3 in. × 12 in. rectangle specimen 12 seconds	Heat and thermal shrinkage resistance — convective oven Thermal stability (sticking) — convective oven Direct flame — flame resistance of textiles (vertical test)
SCBA ensemble (1981–2019)	350°F (177°C) Oven test 500°F (260°C) Precondition at 1500°F–2102°F (815°C–1150°C) followed by open flame contact Open flame	15 minutes 5 minutes 5 minute oven test 10 seconds	Environmental test Oven test — complete SCBA Elevated temperature test — complete SCBA
SCBA facepiece (1981–2019)	Precondition at 203°F (95°C) followed by open flame contact Open flame 500°F (260°C) 1.32 Btu/ft^2 (15 kW/m^2)	15 minutes 10 seconds 5 minutes 5 minutes	Heat and flame test Elevated heat and flame resistance test Radiant heat test panel
Pass devices (1982–2018)	350°F (177°C) oven test 500°F (260°C) oven test Precondition at 203°F (95°C) oven test followed by 1500°F–2102°F (815°C–1150°C) Open flame	15 minutes 5 minutes 15 minutes 10 seconds	Heat and immersion resistance test High-temp functionality test Heat and flame resistance test
Thermal imagers (1801–2018)	203°F (95°C) Open flame 500°F (260°C)	15 minutes 10 seconds 5 minutes	Heat and flame test Heat resistance test

(continues)

Table 8.4 ***Continued***

Fire-fighting Gear and Equipment (NFPA Reference Standard-Edition)	Thermal Limitations	Time Exposed	Standard Test Method
Escape ropes (1983–2017)	752°F (400°C) 1112°F (600°C)	5 minutes 300 lb (136 kg) dead load 45 seconds 300 lb (136 kg) dead load	Elevated temperature rope test Elevated temperature rope test
Hose* (1961–2020)	500°F (260°C) 158°F (70°C) –4°F (–20°C)	5 minutes 96 hours 24 hours	UL-19 hot block test Oven aging test Cold bending and flexibility test
Nozzles (1964–2018)	135°F (57°C) and –25°F (–32°C)	24 hours	Hot conditioning then function test Cold conditioning then function test and rough-handling tests
Ladders (1931–2020)	At 300°F (149°C)	N/A	Pass all of the tests while maintaining 75% strength

*The NFPA Technical Committee is currently investigating changes to the thermal protection requirements for fire hose.

8.5.4 NFPA 1971 requires the structural fire-fighting protective ensemble components to pass dozens of tests. Depending on the component, three to five of the tests are to ensure that the thermal requirements of the standard are met. These tests include thermal protective performance (TPP), flame resistance, heat/thermal resistance, conductive heat resistance, radiative heat resistance, total heat loss, and thread melting. Each of the types of components, garments, helmets, gloves, and interface garments have different test methods and requirements. In this section, a brief summary of the key test methods, and pass/fail criteria will be provided. The purpose is to consolidate and list the test conditions for consideration with conditions that could be generated by a fire. For complete details on each test method, please refer to NFPA 1971.

8.5.4.1 Thermal Protective Performance (TPP) Test.

8.5.4.1.1 Protective garment elements, such as turnout coat and pants, are composed of an outer shell, moisture barrier, and thermal barrier. This composite system of materials should be tested for thermal insulation capabilities with the TPP test and should have an average TPP of not less than 35. Helmet ear covers, hoods, and other interfaces should have an average TPP of not less than 20.

8.5.4.1.2 The test uses an exposure heat flux of 7.39 Btu/ft^2 (84 kW/m^2). This heat flux is intended to be representative of the thermal energy present in a flashover. It should be noted that this is a harsh exposure and does not represent conditions in which fire fighters are intended to work. It measures the ability of the composite to provide a few seconds to escape from such an exposure. It should also be understood that although the heat flux used in this test is severe, this is a laboratory test and fire fighters can encounter conditions that are even more severe. Heat fluxes due to direct flame contact have been measured in the range of 5.28 Btu/ft^2 (60 kW/m^2) to 14.96 Btu/ft^2 (170 kW/m^2).

8.5.4.2 Flame Resistance Test.

8.5.4.2.1 Helmets, gloves, garment outer shells, moisture barriers, thermal barriers, collar linings, winter liners where provided, drag rescue devices (DRDs), trim, lettering, and other materials used in garment construction including, but not limited to, padding, reinforcement, interfacing, binding, hanger loops, emblems, and patches should be individually tested for resistance to flame. Basically the materials are exposed to the open, pre-mixed flame from a small laboratory burner (flame height approximately 2 in. (51 mm) and a flame temperature of approximately 2192°F ± 180°F (1200°C ± 100°C). The item to be tested is exposed to the flame for approximately 12 to 15 seconds. After that exposure, garment materials should not have a char length of more than 4 in. (100 mm), should not have an afterflame of more than 2.0 seconds, and should not melt or drip. Helmets have limits on the amount of distortion acceptable after exposure and are allowed up to 5 seconds for afterflame or glow. In one of the helmet flame resistance tests, the top of the helmet is exposed to a radiant heat flux of .88 Btu/ft^2 (10 kW/m^2) for 60 seconds before the flame is applied.

8.5.4.2.2 The flame resistance test for footwear is a different exposure. The footwear are exposed to the flame from a heptane fueled pan fire sized 12 in. × 18 in. (30.48 cm × 45.72 cm) for 12 seconds. The footwear should not have an afterflame of more than 5 seconds, should not melt or drip, and should not exhibit any burn-through in order to pass the test.

8.5.4.3 Heat and Thermal Shrinkage Resistance Test.

8.5.4.3.1 Helmets, gloves, interfaces and garment outer shells, moisture barriers, thermal barriers, collar linings, winter liners where provided, DRDs, trim, lettering, and other materials used in garment construction, including, but not limited to, padding, reinforcement, labels, interfacing, binding, hanger loops, emblems, or patches, but excluding elastic and hook and pile fasteners where these items are placed so that they will not directly contact the wearer's body, should be individually tested for resistance to heat not shrink more than 8 percent to 10 percent in any direction and should not melt, separate, or ignite.

8.5.4.3.2 Samples are placed inside of an oven and exposed to 260°C, +6/−0°C (500°F, +10/−0°F) for 5 minutes.

8.5.4.4 Conductive and Compressive Heat Resistance (CCHR) Test. The garment composite from the shoulder areas and the knee areas should be tested for resistance to heat transfer. Eight-inch squares of the garment composite layers should be conditioned for both “wet” and “dry” testing. Specimens should be tested using an exposure temperature of 536°F, +5/−0°F (280°C, +3/−0 °C). At time “zero” the sensor and specimen are placed in direct contact with the exposure surface and under the appropriate pressure, 2 psi (0.13 bar) for the shoulder or 8 psi (0.55 bar) for the knee. A determination should be made if the time to second degree burn is equal to or exceeds 25 seconds. Specimens showing a second degree burn time that is equal to or greater than 25 seconds are considered as having passing performance. Specimens that have a second degree burn time that is less than 25 seconds are considered as having failing performance.

8.5.4.5 Thread Melting Test. All sewing thread utilized in the construction of garments, DRDs, helmets, boots, and interface components (hoods and wristlets) should be tested for resistance to melting and should not melt at or below 500°F (260°C).

8.5.4.6 Conductive Heat Resistance Test. Gloves and footwear are required to pass versions on the conductive heat resistance test so that when the fire fighter is in contact with a hot surface with a temperature of 500°F, +10/−0°F (260°C, +6/−0°C), with pressure of 0.5 psi ± 0.05 psi (0.034 bar ± 0.003 bar) or 2 psi ± 0.2 psi (0.13 bar ± 001 bar), the heat transfer is slowed down so that a second-degree burn will not occur in less than 10 seconds and have a pain time of not less than 6 seconds. For footwear, the sole of the boot is placed on the hot plate for 20 minutes. During that period, temperature of the insole surface in contact with the foot should not exceed 111°F (44°C).

8.5.4.7 Radiant Heat Resistance Test.

8.5.4.7.1 The footwear is exposed to 0.88 Btu/ft^2 (10 kW/m^2) from a radiant panel for 30 seconds. During the test period, the upper surface in contact with the skin should not exceed 111°F (44°C).

8.5.4.7.2 Based on the tests that the PPE must pass, the gear is intended to survive temperatures of at least 500°F (260°C) for 5 minutes. However, this short overview shows that the structural ensemble is tested for protecting the fire fighters from short duration (seconds) exposures to flame and hot surfaces. Second degree burns to the skin can occur when the skin temperature reaches 135°F (57°C).

8.6 Station/Work Uniform (NFPA 1975).

8.6.1 Minimum thermal requirements (4 in. × 4 in. (100 mm × 100 mm) square sample) are as follows:

(1) 500°F (260°C) for 10 minutes — hot air circulating thermal resistance
(2) 510°F (265°C) — thermal stability
(3) 500°F (260°C) for 10 minutes — flame resistance test 3 in. × 12 in. (76 mm x 305 mm) rectangle specimen

8.6.2 Thermal stability test samples are placed between 4 in. × 4 in. (100 mm × 100 mm) glass plates and are placed in a convective oven at 510°F (265°C). Samples are removed and allowed to cool. Glass plates are lifted from the sample to test for any sticking of material to plates.

8.7 SCBA and SCBA Face Pieces (NFPA 1981). Equipment produced to previous edition of the standard (before 2013) were tested to a lower thermal exposure.

8.7.1 Heat and Flame Resistance Test. The SCBA facepiece is mounted on a headform and placed in a convection oven at 203°F (95°C) for 15 minutes, while breathing is simulated at a ventilation rate of 10.6 g/min (40 L/min). After the headform is removed from the oven, the breathing rate is increased to 27.2 g/min (103 L/min) and the mask is exposed to direct flame contact at a temperature of 1500°F to 2102°F (815°C to 1150°C) for 10 seconds. Immediately following the direct flame exposure, the SCBA and mannequin are dropped 5.9 in. (150 mm). During the test, no components of the SCBA may fail or separate from the assembly, no afterflame can be sustained longer than 2.2 seconds, and positive pressure must be maintained within the facepiece throughout the test. In addition, the lens cannot incur damage that obscures visual acuity below 20/100.

8.7.2 Elevated Heat and Flame Resistance Test. This test introduces the SCBA facepiece and breathing mannequin ensemble into a convection oven at 500°F (260°C) for 5 minutes prior to direct flame contact for 10 seconds and a vertical drop test. Any loss of positive pressure during the test results in a failure.

8.7.3 Lens Radiant Heat Test. SCBA facepieces, mounted on a headform, are exposed to a constant heat flux of 1.32 Btu/ft^2 (15 kW/m^2) for 5 minutes. After 5 minutes of exposure, the radiant source is removed and the headform is dropped 5.9 in. (150 mm). The facepiece is required to maintain a positive pressure air supply within certain limits for a total of 24 minutes. Any loss of positive pressure during the test results in a failure.

8.8 Integrated and Stand-alone PASS (NFPA 1982). Minimum thermal performance requirements necessitates both integrated and stand-alone PASS devices.

8.8.1 High Temperature Functionality Test. This test introduces the complete PASS device into a test convective oven at 500°F (260°C) for 5 minutes. Following the 5 minute exposure, the PASS device should be tested to ensure it functions as designed.

8.8.2 Heat and Flame Test. This test exposes the complete PASS device assembly to direct flame contact for 10 seconds. The flame temperature should be measured to insure the flame temperature falls within the range of 1500°F to 2101°F (815°C to 1150°C). The direct flame contact occurs immediately after the pass device assembly has been preconditioned at 203°F (95°C) for 15 minutes in a convection oven.

8.9 Thermal Imager — TIC (NFPA 1801). See 8.8.2, “Heat and Flame Test” (203°F (95°C) convective oven for 15 minutes followed by 10 second direct flame contact) and 8.7.2, “Elevated Heat and Flame Resistance Test” (convection oven at 500°F (260°C) for 5 minutes).

8.10 Elevated Temperature Rope Test (NFPA 1983). One of the ends of the rope is attached to a load cell and the other to a constant 300 lb (136 kg) load that is applied to the rope throughout the duration of the test (after an initial stabilization period — within 5 seconds). A thermocouple is attached to the rope at the location where the maximum temperature is expected. After the rope is passed into the furnace [held at ±41°F (±5°C) of set temperature], the exposure time begins when the thermocouple temperature increases by 10 percent. Failure is determined when the load cell reading [initially at 300 lb (136 kg)] drops to zero when the rope separates. One or more specimens failing this test results in a failing performance.

8.11 RIT Bag. While no standards exist for RIT kits, fire department personnel should have a working knowledge of the minimal thermal performance of RIT parts, including bag, escape rope, cylinder, hoses, regulator, spare facepiece, and related equipment. Examples of these items can be found throughout this chapter.

8.12 Flashlight. While no standards exist for fire service flashlights, fire department personnel should have a working knowledge of the minimum thermal limits of the flashlight shell, lens gasket, and electronics.

8.13 Nozzles (NFPA 1964). Minimum thermal testing requirements are as follows:

(1) The operational temperature range of the nozzles is tested. The nozzle should be capable of operation after storage in high temperatures of 135°F (57°C) and after storage in low temperatures, with a dry nozzle, of –25°F (–32°C) for 24 hours. After the exposure, the nozzle should be able to meet the operational control requirements and be free of any cracks or broken sections.
(2) There is another thermal test for nozzles with nonmetallic components, other than rubber gaskets where a nozzle connects to a hose line. They are subjected to the air-oven aging test. The air-oven aging test exposes the nozzles to 158°F (70°C) for 180 days and then allowed to cool at least 24 hours in air at 74°F (23°C) at 50 percent relative humidity. After the oven exposure and cool down, the nozzles must meet the rough usage requirements of this standard and be free of cracking or crazing.

8.14 Hose (NFPA 1961). Minimum thermal requirements are as follows:

(1)* 500°F (260°C) for 5 minutes UL-19 hot block test
(2) 158°F (70°C) for 96 hours oven test
(3) –4°F (–20°C) for 24 hours cold box test

8.15 Ladders (NFPA 1931). Minimal thermal requirements at 300°F (149°C) must retain 75 percent of the strength necessary to pass all test requirements.

Chapter 9 Strategic Considerations

9.1 Scope. This chapter addresses the sources of information that can be utilized to initiate strategic decisions.

9.2 Purpose. The purpose of this chapter is to provide key variables in the development and assessment of structural firefighting strategies.

9.3 Application. The intent of this chapter is for fire-fighting personnel to conduct initial and ongoing assessments to choose an initial strategy and evaluate the effectiveness of the current strategy.

9.4 Pre-Arrival Factors. Pre-arrival factors form the basis of the initial incident strategy and should be continually reevaluated during an incident.

9.4.1 Existing Reference Materials. Materials such as pre-incident plans and maps should be developed per NFPA 1620, providing information regarding the structure, its contents, and occupancy.

9.4.2 CAD Resources. This information may give the officer details on resources, amount, estimated on-scene time, arrival order, dispatched occupancy type, and pre-existing structural hazards.

9.4.3 Weather Conditions. Adverse conditions such as wind and precipitation should be considered.

9.4.4 Occupancy Status. The occupancy status includes specific factors associated with the occupancy as it concerns life safety, building types, and fire loads.

9.4.5 Time of Day. Effects on operations such as visibility, night-time operation, occupant status, and effects on response times may be considered.

9.5 Initial Arrival Factors.

9.5.1 The initial fire control strategy should be assessed through evaluation of overall conditions upon arrival.

9.5.2 Initial arrival factors should include considerations of the following:

(1) Bystander/witness statements
(2) Access concerns on the property
(3) Building height, size, and stability
(4) Occupancy type
(5) Construction type
(6) Wind direction relative to the building location and configuration
(7) Fire location, size, extent
(8) Civilian and fire fighter life safety
(9) Suspected direction of fire and smoke travel within the structure (flow path)
(10) Smoke and fire exposures exterior to the structure
(11) Presence and status of fixed fire protection systems
(12) Fire fighter safety building marking systems
(13) Resources available

9.5.3 Upon arrival at an incident, fire fighters and officers will need to take into account all the pre-arrival factors and then combine those with the on-scene factors. These on-scene factors are the observations and knowledge of the incident scene that help assist in determining the incident strategy. Arriving fire fighters and officers should identify the most significant incident factors.

9.6 360-Degree Survey.

9.6.1 A visual assessment of all four sides of the structure looking at smoke conditions, fire conditions, openings, and personnel hazards is essential to assessing the fire dynamics occurring within the building to the extent practicable.

9.6.2 Information obtained during the 360-degree survey should challenge and verify the initial arriving A-side size-up. This may involve a change in strategy from offensive to defensive or from defensive to offensive. Changing conditions should initiate a reassessment of strategy decision.

9.6.3 The use of a 360-degree survey of a structure fire is extremely important concerning the possible location of occupants, fire dynamics, and crew safetyinformation. The exterior survey should provide essential data to develop an incident action plan.

9.6.4 A 360-degree survey should be focused on the protection of all occupants in conjunction with controlling the fire and maintaining the tenability of the likely avenues of exit from the building by occupants.

9.6.5 Considerations should include the following:

(1) Number of stories A and C sides
(2) Verify basement type (finished or unfinished) and consider the following factors:
    (a) Type of windows
    (b) Likelihood of occupancy
(3) Presence of occupant escape systems
(4) Utilities, including the following:
    (a) Electrical drops
    (b) Fuel gas tanks
    (c) Natural gas service (location of shutoff)
(5) Pre-existing structural hazards
(6) Hazardous grade changes
(7) Roof type and construction
(8) Presence of fire protection features (hydrants, FDC, fire pump, etc.)

9.6.6 If available and appropriate, a thermal imager (TI) is a valuable tool and should be used during the initial 360-degree size-up to assist in determining fire location and extension.

9.7 Assessment of Fire Dynamics to Determine Strategy. Factors observed from the exterior of the structure should be used for the determination of interior conditions.

9.7.1 Smoke and Fire Conditions. Specific evaluation of smoke, air, flame, and heat conditions issuing from an opening can be made by observing volume, speed/velocity, optical density, and color. Fires that have become ventilation-limited may present with little to no smoke showing from the exterior when initial companies arrive on scene. Members on scene should continually evaluate smoke production and characteristics throughout the course of the incident and make tactical adjustments as needed based on changing or deteriorating conditions. Smoke and fire conditions can assist in locating the source of the fire.

9.7.2 Fuel Load. An increased fuel load in a structure may cause higher heat release rates and longer burn times. Fuel packages may be arranged closer to structural elements, resulting in larger threat of structural involvement in the fire. Comparison should be made of the fuel load vs. the available water application.

9.7.3 Openings. Openings can include windows, doors, garage/roll-up doors, skylights, gable/ridge vents, and any other similar opening designed into the building. Fire conditions can further create additional openings as a result of burned-through sections of the roof or walls or the breaching of windows and doors by a developing fire. Openings may be exhausting smoke and/or fire conditions to the exterior, may be serving as air inlets for exhaust openings in other portions of the building, or may be doing both as the pressure inside the building naturally seeks equilibrium due to the developing fire.

9.7.4 Assessing Flow Path. The flow path is the route by which the flow of gases, including air and fire gases, move from high pressure to low pressure. Initial arriving companies need to evaluate all existing openings in the building to develop an accurate ventilation profile for the early stages of the incident prior to determination of strategy. Flow path assessment should include an evaluation of the neutral plane relative to the size and physical position of the opening in relation to the fire location. Another consideration should include the direction of flow within each opening. Opening of doors and windows for the purposes of fire fighter entry can affect the flow path and should be considered. Some things to consider when assessing the flow path are the type of flow (i.e., unidirectional, bidirectional, or dynamic) and the characteristics of the flow (i.e., height within the boundaries of a compartment or at an opening, the degree of turbulence and its direction, velocity, and shape).

9.7.5 Weather Conditions. The impact of wind on a fire should be considered. Wind speeds of 10 mph or greater may cause a high pressure in one area of the building and lower pressures in others. This pressure difference can affect the ventilation profile. Consideration should be given to temperature and its influence on stack effect.

9.7.6 Accessibility of the Structure. Initial arriving units should determine accessibility to the structure and its surroundings. Consideration should be given to the ability to position apparatus to allow for the use of tools and equipment effectively. Consideration should be given to the ability of crews to access the structure via foot and ground ladders.

9.7.7 Fire Progression. Based upon the 360-degree survey, identify the fire's suspected direction of travel or potential directions of travel. Consider dynamic events such as changes in ventilation and application of cooling, which may affect the path of travel. What is the current perimeter of the fire, and where is it spreading?

9.7.8 Fire Control Positioning. Determining the size and location of the fire assists in determining the safest and most effective fire control positions for fire suppression personnel. Fire control positions should be established to prevent crews from operating above the main body of fire, or on the existing (or potential) exhaust side of the flow path. The following questions should be considered:

(1) What floor is the fire located on?
(2) Where might potentially viable occupants be located?
(3) What area of the floor plan is the fire located on?
(4) Is there direct and timely access to the fire given its location?

9.8 Risk Management Plan. Every department should have a risk management plan in writing. The combined processes of understanding of risk management, pre-arrival factors, and on-scene factors will drive the decision of the initial declaration of strategy by the first arriving unit. The constant evaluation of the incident and all factors could possible change the strategy of the incident depending on the changes. *(See NFPA 1500.)*

9.9 Identification of Strategy.

9.9.1 The incident commander (IC) should consider the entirety of the available information when making a decision with respect to strategy. The IC should continually re-assess the strategy decision based upon changing conditions.

9.9.2 Crew accessibility to the fire is a key component in determination of strategy. Selection of the appropriate operational strategy for the incident is based on the efficiency with which crews can perform their tactical responsibilities from safe and protected fire control positions.

9.9.3 The initial IC should assess accessibility and fire control positioning. Consideration should be given to the ability to position apparatus to support the efficient use of tools and equipment and the ability of crews to access the structure via the most direct route to the fire location. Considerations may include the following:

(1) Existence of barriers impeding the positioning of apparatus (fences, grade changes)
(2) Existing barricades or security features on the structure to delay fire fighter access
(3) Status of entrance and egress points on the structure and their integrity and operational ability under present and potential fire conditions

9.10 Strategic Decision.

9.10.1 Once a thorough size-up has been performed, the IC must take all size-up considerations to formulate an appropriate strategic decision, whether offensive or defensive.

9.10.2 Life safety is the greatest consideration when determining the overall incident strategy.

9.10.3 The decision for implementing the offensive strategy is predicated on the ability of the IC to consider the most effective fire control positions.

9.10.4 The decision for implementing the defensive strategy is predicated on the incident's hazards outweighing the ability to safely operate inside the structure.

9.10.4.1 When the defensive strategy is selected, all control operations should occur in positions outside of the exclusion zone.

9.11 Strategy Implementation.

9.11.1 The IC should make the strategy known via verbal or radio communications through the chain of command so that all on-scene personnel are aware.

9.11.2 Whenever there is a change of strategy, the IC should make the new strategy known via verbal or radio communications through the chain of command so that all on-scene personnel are aware.

Chapter 10 Tactical Considerations for Fire Control and Extinguishment.

10.1 Scope. This chapter addresses the tactical considerations for coordinated fire control and extinguishment operations.

10.2 Purpose. The purpose of this chapter is to provide guidance on fire control and extinguishment options for tactical consideration.

10.3 Application. The intent of this chapter is for fire-fighting personnel to apply science-based tactical considerations for fire control and extinguishment.

10.4 General.

10.4.1 The primary mission on the fireground is life safety; therefore, fire control, search, and ventilation/nonventilation become primary tactical objectives. How, where, and with how many fire fighters each department operates on the fireground should be based on an ongoing (exterior and interior) size-up. Since the fireground is not black and white, there is no single tactic that is ideal for all fires. Coordinated actions are identified in this chapter and Chapter 12.

10.4.2 On the fireground, coordination means that all of the crews operating on the fireground are working together. It means that timing is precise, movements are well choreographed, and communications are clear and concise. Specifically, fire control, search and rescue, and ventilation/nonventilation crews should all operate as one. Coordinated fireground operations enhance life safety, incident stabilization, and property conservation.

10.4.3 Conditions, staffing, and resources should drive fireground tactics and tasks. While the majority of this chapter focuses on fire control and ventilation (water and air), that is not because search and rescue is being minimized, it is only because this document is driven by empirical data, and the fire service has yet to truly dissect the tactic and tasks of search and rescue. Search and rescue is, and always will be, of utmost importance to the fire service and to unprotected occupants. Although we do not yet have empirical data on search, the fire service does have data points on occupant survivability. We now know that, apart from fire department operations, three things impact the survivability of a given space in the structure: the proximity to the fire, the elevation in the space, and whether or not the room/volume is isolated from the fire.

10.4.4 An occupant located in a room during a search with a closed door between them and the fire has a much higher likelihood of survivability than an occupant with an open bedroom door. If the door is open, and/or smoke and heat are communicating between two spaces, the proximity to the fire compartment increases the exposure to toxic gases and thermal injuries. A closed door gives the highest chance of occupant survival, although places further from the compartment of origin and low in the space increase the occupant(s) chance of survival. Places closest to the fire and high in the space have the least chance of survival.

10.4.5 Removing any potential victims from the hazardous atmosphere as soon as possible after arrival is essential to minimizing their exposure, thereby increasing their chance of survival. As the exposure dose is a function of the time an individual is exposed to the hazard (i.e., thermal exposure and/or toxic gases), the earlier into an incident the occupant is removed from the atmosphere, the lower dose he/she is likely to have been exposed to and the greater the chances for survival. Finding them is the first step to removing them, and therefore searches need to start as soon as possible.

10.4.6 While this chapter does not focus on search, it is still essential to our operations and therefore is defined and mentioned here. Primary search is the fast, yet thorough, search for life and fire. At residential fires, fire control and ventilation are there to support the primary search. A primary search needs to be conducted in all involved and exposed buildings that can be entered. As more research is conducted, and more data made available to the fire service, this chapter will continue to evolve to help improve efficiency and effectiveness on the fireground.

10.4.7 Fire control and extinguishment tactics are the art and science of fire fighting. Fire-fighting tactics presented in this section are intended to provide guidance to fire fighters on how to implement the incident commander's strategic objectives through tactical actions, without restriction to chosen methods or techniques.

10.4.8 Tactical options provided herein only address those tactics associated with water and air. They are intended as templates for action(s) to be ordered and organized when positioning and moving fire fighters in response to life safety, fire control, or property conservation priorities.

10.4.9 The intent of these templates is not to restrict innovation or prevent the addition of newly discovered tactics, whether derived through evidence from empirical research or fire community best practices. Rather, the guidance provided rests on the understanding that tactics will evolve as discovery is made and should be revised within the template so that innovation can be shared and quickly disseminated to the practitioner.

10.4.10 Tactical options are presented in an order that moves from the outside to the inside of a structure (in terms of water use) and from simple to more complex ventilation (in terms of air). The ordering is not restrictive but rather intended to assist new recruits, fire fighters, company officers, and chief officers in enhancing their understanding of fire control and extinguishment tactics and in advancing their abilities in coordinated operational practices.

10.4.11 Coordination of operational practices requires clear, direct communication between command and companies or crews assigned to fire control, ventilation, and other tactical (e.g., search, rescue) functions that are or will be taking place inside a structure. Coordination in this sense is the act of working together and implies a tactical plan that is matched to the incident risks and the available resources to manage those risks.

10.4.12 A tactical plan prioritizes the consideration to control or neutralize any dangers. When multiple high-priority tasks must be accomplished *sequentially*, fire control should be the first priority. Rescue of trapped occupants is the first strategic priority but not necessarily the first tactical priority.

10.4.13 More people are saved by a well-placed and advanced hose line than by any other tactic. Controlling the fire reduces the exposure hazards to the victim and facilitates a more effective primary search. In the absence of confirmed viable occupants, it is vital to find, control, and extinguish the fire as quickly as possible.

10.4.14 When high-priority tasks can be accomplished *simultaneously*, it is important to support and protect the rescue or search operations using hose line(s) and flow path management. Ignoring the fire during search and/or rescue operations is a recipe for disaster. If the fire is extinguished early enough, there will be less smoke, heat, flame, and potential for rapid fire development and its associated dangers. Regardless of the assigned priorities of on-scene crews, a fire control crew should not overlook the needs of a trapped occupant, and a rescue or search crew should not disregard the risks presented by active fire.

10.4.15 Coordination therefore becomes a tactical decision as to whether the need is to apply tactical actions sequentially due to insufficient resources or to undertake tactical actions simultaneously because resources are sufficient for that level of incident action plan. Specifically, fireground tactics are formed when equipment, techniques, and positioning are combined and deployed to complete a strategic objective.

10.5 Water.

10.5.1 General. Water is the most widely used fire extinguishing agent due to it being effective (absorbs heat energy), environmentally friendly, nontoxic, inexpensive, and, in many cases, readily available. Therefore, it is important to understand the most effective ways to use hose streams in order to optimize the effectiveness.

10.5.2 Exposure Control.

10.5.2.1 Tactical Objective. The main objective is to control fire extension and limit fire growth to the building of origin.

10.5.2.2 How It Works. Water reduces the impact of radiant heat or direct flame contact on exposed surfaces.

10.5.2.3 Tactical Considerations.

10.5.2.3.1 Surface wetting utilizes water streams to limit exposure of radiant heat transfer to the following:

(1) Building of origin
(2) Other building(s) or adjacent combustibles

10.5.2.3.2 A water curtain is not effective on radiant heat transfer as direct application.

10.5.2.4 Preferred Technique. Direct water application to exposed surfaces using straight or solid stream or large droplet fog is the preferred technique.

10.5.2.5 Alternative Technique. The following are alternative techniques for exposure control:

(1) Foam application to exposure
(2) Direct/indirect application to source fire

10.5.2.6 Safety Consideration. The following are safety considerations for exposure control:

(1) Collapse zones
(2) Radiant heat

10.5.3 Exterior Control — Transitional Attack.

10.5.3.1 Tactical Objective. The objective is to improve occupant tenability and interior conditions for fire control.

10.5.3.2 How It Works. The following are examples of successful outcomes of exterior control-transitional fire control:

(1) Compartment linings and burning fuel surfaces are cooled, interfering with pyrolysis, which halts flaming combustion and in turn reduces the heat release rate.
(2) Reducing surface temperature of unignited fuels stops pyrolysis.
(3) The flame is displaced from the surface of burning fuels.
(4) Steam production absorbs energy from the environment to cool smoke.

10.5.3.3 Tactical Considerations. The following are tactical considerations:

(1) Coordinated to support other fire operations (e.g., fire control/rescue)
(2) Performed from an exterior position
(3) Optimal through a ventilation opening to the fire room
(4) Flow path not disrupted
(5) Flow rate appropriate with heat release rate and area of involvement; balanced to avoid excessive water damage

(6) Rapid interior control following/concurrent with exterior control crucial to limit regrowth and maintain tenability
(7) Limited on-scene resources, large fire volume, delayed entry time/access for direct fire control may require multiple or longer applications; more time equals more water

10.5.3.4 Preferred Technique. The preferred technique is a *stationary* straight or solid stream hand line through the bottom third of an opening, at a steep angle, deflected off the ceiling in the fire room, with care taken to not disrupt the flow path.

10.5.3.5 Alternative Technique. The following are alternative techniques:

(1) Master stream devices/appliances
(2) Water application to eaves for attic fire control
(3) Floor below nozzle or rotary nozzle from above for high-rise structures

10.5.3.6 Safety Considerations. The following are safety considerations:

(1) Improper nozzle application may disrupt flow path and can injure or kill occupants and/or interior fire fighters.
(2) Change of flow path may also result in rapid fire growth to other uninvolved areas.

10.5.4 Interior Advancement.

10.5.4.1 Tactical Objective. The primary tactical objective is to cool and control smoke temperature, flammability, and radiation to increase safety during interior progression to the seat of the fire and until effective water is applied to the source fire.

10.5.4.2 How It Works.

10.5.4.2.1 Straight Stream/Solid Bore Application. The following are examples of successful outcomes using straight stream/solid bore application:

(1) Water is used to cool hot compartment surfaces, which allow those surfaces then to have the ability to absorb more thermal energy from the hot smoke layer.
(2) Water deflection off the ceiling cools the hot gases as droplets travel through the hot layer.
(3) Steam created from cooling both the ceiling area and hot gases will further absorb thermal energy as the steam is heated to equalize with the hot layer.

10.5.4.2.2 Fog Stream Application. The following are examples of successful outcomes using fog stream application:

(1) Water droplets applied to the smoke volume convert to steam cooling the smoke.
(2) Steam conversion reduces temperature causing contraction and dilution of smoke, resulting in reduced flammability and radiation.

10.5.4.3 Tactical Considerations. The following are tactical considerations:

(1) These are not extinguishment techniques but a means of safer interior progression to the seat of the fire.
(2) Factors that affect these techniques include fire intensity, room size and configuration, location, ventilation profile, and distance to the source fire.
(3) Effectiveness of the water application technique and reapplication should be continuously assessed while advancing.
(4) Water must be applied to the source fire as soon as possible with consideration given to safe positioning.
(5) Optimal position, nozzle pattern, and technique should be evaluated to maximize or minimize air entrainment/movement based on ventilation conditions and flow path.
(6) Ventilation should be coordinated until water is applied to the main body of fire.
(7) Limiting ventilation with door control will increase the effectiveness of smoke cooling techniques and should be considered.
(8) If the intent is to move smoke ahead of the advancing crew, a large and sufficient vent opposite the advancing crew is required.
    (a) The hose stream can then be moved rapidly and consistently in an O, T, Z, or ∩ pattern to maximize air movement.
    (b) Utilize a reach and penetration of the stream to wet all surfaces forward of the operating position.
    (c) A "flow and move" technique is most effective in dwellings with a known fire location, or if a "shut down and move" technique is utilized, reapplication of water as needed to control heat rebound of fire is necessary.

10.5.4.4 Preferred Technique. A straight stream/smooth bore application is preferred with the following techniques to consider:

(1) Utilize a reach of the stream to wet ceiling surfaces forward of the crew position.
(2) A straight stream pattern should be flowed and swept across the ceiling area.
(3) New ceiling areas should be swept and cooled while advancing towards the fire area.
(4) The frequency and extent of the water application is influenced by fire intensity, smoke temperatures, room size and configuration, location, and distance to the source fire.

10.5.4.5 Alternative Technique. A fog stream application is an alternative with the following techniques to consider:

(1) Water mist or fog stream is directed into the smoke layer in short or long pulses (with a sweeping motion).
(2) Nozzle, cone angle, pulse duration, and flow rate are important in achieving an optimal droplet size of 0.12 in. (0.3 mm); this ensures effective cooling and contraction of the smoke and lessens the disruption of the thermal balance.
(3) Avoid contact with hot surfaces to prevent excess wet steam and disruption of thermal balance.
(4) Reapplication is necessary during advance.
(5) Water application should quickly transition to extinguishment on the source fire.

10.5.4.6 Safety Considerations. The following are safety considerations:

(1) Fire fighters should avoid advancing under a superheated thermal layer without cooling as they advance.
(2) Hose stream air entrainment should be limited when no vent is available opposite the fire.
(3) Continuous monitoring of cooling effectiveness against fire conditions with a thermal imager should be maintained while advancing to the source fire.
(4) PPE can be quickly compromised during interior advancement within a convective flow.

(5) Wind speed and direction in relation to intended flow path should be checked prior to and during cooling operations.

10.5.5 Interior Fire Control.

10.5.5.1 Tactical Objective. The primary tactical objective is fire control and extinguishment.

10.5.5.2 How It Works. The following are examples of successful outcomes of interior direct fire control:

(1) Water cools burning fuel surfaces interfering with pyrolysis, which halts flaming combustion and in turn reduces the heat release rate.
(2) The flame is displaced from the surface of burning fuels.
(3) Reducing surface temperature of unignited fuels stops pyrolysis.
(4) Secondary steam production absorbs energy from the environment to cool smoke.

10.5.5.3 Tactical Considerations. The following are tactical considerations:

(1) Direct fire control should be conducted as soon as the fire seat is located and can be reached with a water stream.
(2) Direct water application should be performed from an interior or exterior position to the fire room.
(3) The flow rate should be appropriate with the heat release rate and area of involvement and balanced to avoid excessive steam generation and water damage.
(4) The ideal position is the air intake side of the flow path with flow path control.
(5) Optimal position, nozzle pattern, and technique should be evaluated to maximize or minimize air entrainment/movement based on ventilation conditions and flow path.
(6) Advance should be matched to interior conditions.
(7) Smoke or surface cooling prior to direct attack may be appropriate.

10.5.5.4 Preferred Technique. The following are preferred techniques:

(1) Straight or solid stream, applied in an unbroken pattern directly to burning fuels, where compartment/room is unvented opposite the attack line
(2) O, T, Z, or ∩ pattern applied from furthest distance if compartment/room has vent opposite attack line

10.5.5.5 Alternative Technique. The following are techniques for direct fire control:

(1) An indirect attack.
(2) Switching to a fog pattern may improve coverage and reduce water damage.

10.5.5.6 Safety Considerations. The following are safety considerations:

(1) Avoid position between the seat of the fire and the exhaust outlet.
(2) Apply reach and penetration of the stream to provide standoff distance from the effects of fire.
(3) Wind speed and direction are in relation to the intended flow path.

10.5.6 Interior Indirect Attack.

10.5.6.1 Tactical Objective. The primary tactical objective is fire suppression to improve tenability for follow-up fire control and overhaul.

10.5.6.2 How It Works. Water is applied to compartment linings, burning fuel, and the smoke layer to produce the maximum volume of steam. Steam production reduces temperature, dilutes smoke, and displaces oxygen.

10.5.6.3 Tactical Considerations. The following are tactical considerations:

(1) Application is made from outside the fire compartment/room that remains under-ventilated.
(2) Smoke or surface cooling may be appropriate to gain access to the fire room prior to indirect attack.
(3) Indirect water application can be utilized for shielded fires.
(4) The flow rate should be appropriate with heat release rate and area of involvement and balanced to avoid excessive water damage.
(5) Advance should be matched to interior conditions.
(6) This technique is not intended for use in occupied spaces.

10.5.6.4 Preferred Technique. The following are preferred techniques for interior indirect attack fire control:

(1) Water is applied from the exterior of the compartment/room utilizing a fog stream.
(2) A narrow fog is applied to compartment linings, burning fuel, and the smoke layer to quickly produce the maximum volume of steam.
(3) The compartment/room is isolated to ensure maximum effectiveness of steam production.

10.5.6.5 Alternative Technique. The following are alternative techniques for interior indirect attack fire control:

(1) Broken straight or solid stream
(2) Rotary nozzle
(3) Fog- or mist-producing piercing nozzle
(4) Fire extinguisher

10.5.6.6 Safety Considerations. The following are safety considerations:

(1) Fog application from a position exposed to resultant outflow of heated smoke and steam can be dangerous.
(2) Steam production may reduce tenability in adjoining spaces.

10.6 Air.

10.6.1 General. Decisions about when and where ventilation is needed and the method(s) employed is to be guided by an understanding that, in the absence of effective water being applied on the fire, air increases the HRR and potential for rapid fire development. With this understanding of the impact of air on fire growth and the requirement for coordinated water, the tactical options are for either nonventilation or ventilation.

10.6.2 Nonventilation.

10.6.2.1 Tactical Objective. The primary tactical objective is limiting combustion air to the fire to hold fire growth in preparation for interior operations.

10.6.2.2 How It Works. Fire growth is dependent on oxygen. By limiting the oxygen supplied to the fire, growth and heat release rate are reduced.

10.6.2.3 Tactical Considerations. The following are tactical considerations:

(1) Life-fire-layout sweep to assess survivability profile in the fire compartment/room.
(2) Assess ability to close or restrict openings.
(3) Utilize to create survivable areas in other parts of the structure.
(4) Height of interface layer lowers and reduces tenability.
(5) Thermal imaging to source fire and monitor changing conditions.
(6) Plan for exposure control.

10.6.2.4 Preferred Technique. The following are preferred techniques for nonventilation fire control:

(1) Close or restrict building ventilation openings.
(2) Manage the flow path by control of the air inlet(s) and/or the smoke outlet(s).

10.6.2.5 Alternative Technique. An alternative technique is to employ ventilation control devices or a portable door or smoke curtain.

10.6.2.6 Safety Considerations. The following are safety considerations:

(1) Interior fire control crew must be consulted prior to any tactical ventilation.
(2) Anticipate rapid fire development if ventilation is increased absent the application of water for both planned and unplanned ventilation.
(3) Wind speed and direction is in relation to position and potential flow path.

10.6.3 Horizontal Ventilation.

10.6.3.1 Tactical Objective. The primary tactical objective is to improve interior tenability by releasing smoke and heat during the fire control and to support search, extinguishment, overhaul, and post-fire ventilation.

10.6.3.2 How It Works. Buoyant smoke is replaced by denser fresh air due to the gravity current and/or air pressure differentials.

10.6.3.3 Tactical Considerations. The following are tactical considerations for horizontal ventilation:

(1) Coordinated inlet and outlet openings concurrent with effective application of water
(2) Survivability profile in the fire room
(3) Smoke or surface cooling prior to fire control may be appropriate
(4) Purposeful management of the flow path considering wind direction
(5) Thermal imaging to source fire and monitor changing conditions.
(6) Plan for exposure control

10.6.3.4 Preferred Technique. The following are preferred techniques for horizontal ventilation:

(1) Door control and limited ventilation may be used until effective water is on the fire.
(2) Ventilation outlet is established in the fire compartment.
(3) Opening the entry door as an additional inlet, while considering flow path impacts.
(4) Inlet and outlet on opposite sides of the structure or compartment.
(5) Vent openings chosen to take into account wind speed and direction and potential flow path.

10.6.3.5 Alternative Technique. Vertical ventilation is an alternative technique for horizontal ventilation.

10.6.3.6 Safety Considerations. The following are safety considerations for horizontal ventilation:

(1) Failure to coordinate ventilation with effective water application will increase heat release rate.
(2) Rapid fire development should be anticipated if ventilation is increased absent the application of water for both planned and unplanned ventilation.
(3) Consider opposing wind, wind speed, and impact on the direction of the flow path.

10.6.4 Vertical Ventilation.

10.6.4.1 Tactical Objectives. To improve interior tenability by releasing smoke and heat during fire attack and to support search, extinguishment, overhaul, defensive trenching operations, and post-fire ventilation.

10.6.4.2 How It Works. The following are examples of successful outcomes of vertical ventilation:

(1) Buoyant smoke is replaced by denser fresh air due to the gravity current and/or air pressure differentials.
(2) Buoyant smoke is exhausted from an opening located above the level of fire utilizing the stack effect, and denser fresh air is entrained via a horizontal inlet(s) due to the gravity current and/or air pressure differentials.

10.6.4.3 Tactical Considerations. The following are tactical considerations for vertical ventilation:

(1) Coordinated inlet and outlet openings concurrent with effective application of water.
(2) Survivability profile in the fire room/compartment.
(3) Inability to horizontally ventilate.
(4) Smoke cooling prior to fire control or indirect attack may be appropriate.
(5) Purposeful management of the flow path considering wind, wind speed, and direction.
(6) Raising of interface layer height and visibility will be temporary if fire is not controlled.
(7) Thermal imaging to source fire and monitor changing conditions.
(8) Plan for exposure control.
(9) Delays due to staffing, assembly time, or equipment.
(10) A 4 ft × 4 ft (1.22 m × 1.22 m) hole is rarely sufficient for effective ventilation.

10.6.4.4 Preferred Technique. The following are preferred techniques for vertical ventilation:

(1) Door control and limited inlet ventilation until vertical outlet is established.
(2) Inlet opening is on the windward side and outlet is above or close to the source fire.
(3) Establish outlet openings followed by inlet openings coordinated with fire control.

10.6.4.5 Alternative Technique. Alternative techniques for vertical ventilation should be considered to minimize risk.

10.6.4.6 Safety Considerations. The following are safety considerations for vertical ventilation:

(1) Failure to coordinate ventilation with effective water application will increase heat release rate.
(2) Rapid fire growth should be anticipated if ventilation is increased absent the application of water for both planned and unplanned ventilation.
(3) Consider wind speed and direction.
(4) Working at heights increases risks for falls from or through a roof.
(5) Working position, means of egress, and structural performance must be continually assessed.

10.6.5 Positive Pressure Attack (PPA).

10.6.5.1 Tactical Objectives. The primary objective is to improve interior tenability conditions for advancing crews and trapped occupants. Additional objectives include purposeful direction of the flow path, extinguishment, and property conservation.

10.6.5.2 How It Works. Fans are used to create a pressure differential influencing the flow of smoke, air, heat, and flame from the inlet to the exhaust.

10.6.5.3 Tactical Considerations. The following are tactical considerations for positive pressure attack:

(1) Staff controlling operation of the fan should have a radio to coordinate operations (e.g., change speed, angle) if adverse conditions develop.
(2) Staff controlling exhaust should have a radio to coordinate operations if adverse conditions develop.
(3) Bringing a line to the exhaust(s) for protection should be considered.
(4) Fan activation should be communicated and the structure for negative effects should be continuously monitored.
(5) Transitional attack may be utilized, if possible, prior to fan activation.
(6) Fire growth due to ventilation must be reduced by applying water on the fire during fan operation.
(7) PPA in domestic floor plans with many rooms and closed doors (compartmented) is more effective.
(8) PPA will not be effective on a fire located in an open floor concept plan or any floor plan with high ceilings.
(9) Source fire must be near or adjacent to an exterior outlet.
(10) It should be understood that the inlet is the opening to the fire compartment, and not necessarily the exterior door.
(11) During PPA, creating additional openings not in the fire room will create additional flow paths, making PPA ineffective with the potential to draw the fire into all flow paths
(12) An exhaust larger than the inlet must be provided in the fire room to allow for effective PPA.
(13) PPA should be coordinated with exhaust.
(14) During PPA, an ongoing assessment of inlet and exhaust flow is imperative to understanding whether or not a fan flow path has been established and if conditions are improving/effective.
(15) The setback of the fan or development of a cone of air is not as important as the exhaust size.
(16) The application of water, as quickly as possible, whether from the interior or exterior prior to initiating PPA will increase the likelihood of a successful outcome
(17) PPA is not a replacement for using the reach of your hose stream.
(18) During PPA, extension into void spaces when using PPA is directly related to the exhaust capabilities of the void space.
(19) PPA does not negatively affect the survivability of occupants behind a closed door.

10.6.5.4 Preferred Technique. Exhaust ventilation should be established prior to mechanical ventilation at the inlet. The exhaust should be larger than the inlet. Interior advancement techniques can be used as appropriate, followed up by timely fire control.

10.6.5.5 Alternative Technique. Positive pressure ventilation or positive pressure isolation might be used as an alternative technique to PPA.

10.6.5.6 Safety Considerations. The attack team should coordinate and communicate with the IC and fan and exhaust control personnel. The assessment of inlet and exhaust must be continuous for adverse conditions. Rapid fire growth should be anticipated if ventilation is increased absent the application of water for both planned and unplanned ventilation. Consideration should be given to wind speed and direction.

10.6.6 Positive Pressure Ventilation (PPV).

10.6.6.1 Tactical Objective. Tactical objectives are as follows:

(1) Remove smoke from the non-fire area to improve tenability
(2) Secure egress path to assist search and rescue or the approach to fire area
(3) Remove smoke from fire room post-fire
(4) Purposeful management of the flow path

10.6.6.2 How It Works. The fan is used to create a pressure differential influencing the flow of air and smoke from the inlet to the exhaust.

10.6.6.3 Tactical Considerations. The following are tactical considerations for positive pressure ventilation:

(1) Communicate fan activation and continuously monitor the structure for negative effects.
(2) Hose line(s) should be in place for potential growth or extension of fire.
(3) When PPV is used post fire control, in single-story residential structures, the more openings made in the structure during PPV, the more efficient it is at ventilating the structure.
(4) When PPV is used post fire control, it is important to assess for extension.
(5) When PPV is used post fire control, starting or turning in the fan immediately after fire control will provide the most benefit.
(6) Interior CO concentration levels should be monitored for gas-powered fans when clearing smoke post fire.

10.6.6.4 Preferred Technique. Outlet ventilation should be established prior to mechanical ventilation at the inlet. Multiple exhaust openings should be created wherever possible to increase efficiency.

10.6.6.5 Alternative Technique. Hydraulic ventilation should be considered an alternate technique for positive pressure ventilation.

10.6.6.6 Safety Considerations. The attack team coordinates and communicates with the IC and fan and exhaust control personnel. Rapid fire development should be anticipated if ventilation is increased absent the application of water for both planned and unplanned ventilation. Consideration should be given to wind speed and direction.

10.6.7 Positive Pressure Isolation (PPI).

10.6.7.1 Tactical Objective. The primary objective is to create a positive pressure in the non-fire area greater than the pressure in the fire area to limit fire and smoke propagation.

10.6.7.2 How It Works. Mechanical fans or systems are used to increase the pressure in an adjoining room or compartment to contain smoke to the fire room or compartment. Protected areas have a mechanical fan at the inlet with limited or no exhaust openings.

10.6.7.3 Tactical Considerations. PPI is contra-indicated in compartments impacted by fire extension from the compartment of origin. Fan activation should be communicated and the structure should be continuously monitored for fire/smoke propagation. As long as a flow path through the seat of fire is not created there is no fire growth. Pressurize areas of the structure that are isolated from the fire compartment. Anticipate rapid fire growth if ventilation is increased absent the application of water for both planned and unplanned ventilation.

10.6.7.4 Preferred Technique. All inlet and exhaust openings should be controlled to maintain desired pressure differential and isolate the fire.

10.6.7.5 Alternative Technique. Nonventilation might be a viable alternative.

10.6.7.6 Safety Considerations. Progress reports should be given to the IC and should be coordinated with fan control personnel. Consideration should be given to wind speed and direction. Rapid fire development is possible if the fire has extended to concealed spaces.

10.6.8 Hydraulic Ventilation.

10.6.8.1 Tactical Objective. The primary tactical objective is to improve interior tenability conditions during primary/secondary search, overhaul, and property conservation through purposeful direction of the flow path.

10.6.8.2 How It Works. The following are examples of successful outcomes of hydraulic ventilation:

(1) A hose stream is employed at an opening, creating a pressure differential, entraining smoke, and discharging it from the compartment/room.
(2) This action results in a net negative pressure in the compartment/room, drawing in replacement air from other openings.

10.6.8.3 Tactical Considerations. The following are tactical considerations for hydraulic ventilation:

(1) Check if ventilation can be done safely post-fire utilizing the fire control hose line.
(2) Evaluate optimal position, nozzle pattern, and technique to maximize air entrainment/movement.
(3) Observe the movement of smoke and adjust position for best ventilation effect.
(4) Check surroundings for rekindling or adverse effects.
(5) Check for exterior consequences of stream application.

10.6.8.4 Preferred Technique. The hoseline should be open on a straight stream and move to fog selection within the opening to prevent turbulence. The opening should be approached from a low position. Nozzle placement should create a water pattern that fills the window opening.

10.6.8.5 Alternative Technique. An alternative technique is a straight stream or straight bore nozzle pattern with positioning furthest from the opening as possible with a rapid consistent O, T, Z, or ∩ pattern to maximize air movement.

10.6.8.6 Safety Considerations. Personnel should stay low on approach to the intended vent location and ensure hose stream operation does not create other hazards downstream (e.g., energized electrical, structural damage, or compromise other control operations). The operation should be monitored for fire rekindle. Consideration should be given to wind speed and direction.

10.6.9 Negative Pressure Ventilation.

10.6.9.1 Tactical Objective. The tactical objective is to create a negative pressure at an established ventilation opening post-fire to exhaust smoke.

10.6.9.2 How It Works. A mechanical fan (i.e., ejector) is used to create a negative pressure at an outlet to pull smoke from a structure.

10.6.9.3 Tactical Considerations. The following are tactical considerations for negative pressure ventilation:

(1) Smoke ejectors are most effective when working with natural air flow and not against a prevailing wind.
(2) Ventilation efficiency is greatly reduced if air is allowed to recirculate around the ejector or by opening windows or doors near the ejector.
(3) Man-hole or spiral duct adapters can enable more effective and efficient smoke extraction delivery to hard-to-reach spaces, both above and below grade.
(4) Power supply and electrical cords are required.
(5) Ventilation is ineffective in high ceiling areas

10.6.9.4 Preferred Technique. The ejector is placed on the leeward side of structure with the perimeter of the fan sealed to the ventilation opening with a tarp or commercial adapter while ensuring the ejector inlet and outlet are not obstructed.

10.6.9.5 Alternative Technique. Positive pressure ventilation might be considered as an alternative technique.

10.6.9.6 Safety Considerations. The following are safety considerations:

(1) Ensure ejector fan is intrinsically safe.
(2) Ensure electrical cords are protected from environmental conditions.
(3) Do not move operating fans.

Chapter 11 Exposure and Hygiene Considerations

11.1 Scope. This chapter provides the fundamental linkage between fire dynamics research and the need for implementing health hygiene policies for the fire service.

11.2 Purpose. The purpose of this chapter is to provide science-based information to fire-fighting personnel regarding procedures to minimize the exposure and health risks of fire-fighting.

11.3 Application. The intent of this chapter is to apply the principles of science-based research to minimize fire fighters' risk on the fireground and reduce secondary impacts before and after the incident.

11.4 General. Cancer is one of the leading causes of line-of-duty deaths among fire fighters today. Fire-fighting duties significantly increase an individual's risks for contracting several types of cancers. Cancer rates for fire fighters have risen dramatically in correlation with the increase in toxicity of smoke. Smoke from a fire always contains contaminants, which are harmful to health when these toxins enter the body via mouth, respiratory tract, mucous tissue, or skin. During working fire responses ("hot smoke"), these contaminants occur in high concentrations as gases, which are easily absorbed. During overhaul operations or other lower heat conditions ("cold smoke"), contaminants may be bonded to soot, run off water, or ash. Additional hazards at the fireground may be caused by hazardous materials, such as asbestos or flame-retardant materials found in the products of combustion.

11.4.1 Prior to complete fire suppression, combustion products are released as smoke. Initially many of these substances are mobile. The toxic and/or caustic gases and vapors that occur in high concentrations during this phase, such as carbon monoxide (CO), carbon dioxide (CO_2), hydrogen chloride (HCl, hydrochloric acid when condensed), acrolein, and hydrogen cyanide (HCN, prussic acid when condensed), constitute a potential hazard for operating members and civilians. The smoke plume must be considered when the incident commander designates the hot zone at an operation.

11.4.2 Once the fire has been extinguished and the burnt materials have cooled down to ambient temperature, hazardous organic substances, in particular soot particles, are still present. Operating personnel continue to have the potential for contamination, and members continue to utilize the appropriate level of personal protective equipment (PPE), including respiratory protection. Care must be taken not to transport contaminants outside the hot zone.

11.4.3 There are three primary ways in which airborne harmful substances produced by fires can make their way into the body: via inhalation, via skin absorption, and via the mouth (orally). Fire fighters should be aware of good hygiene practices to minimize their exposure to harmful substances both on scene and post-incident. Ensuring fire fighters have the proper tools, processes, and knowledge is essential in minimizing exposure to harmful substances involved with structural fire-fighting.

11.4.4 Fire fighters can protect themselves to a great extent by limiting exposure and conducting fireground decontamination. During and after extinguishing the fire, respiratory protection should be worn when contaminants are present. To further limit exposures, the incident commander (IC) should establish zones on the fireground similar to those commonly accepted at the scene of a haz-mat release (hot, warm, cold). Operating apparatus should, if possible, be positioned outside the hot zone, and effort should be made to limit entry of smoke into the crew compartment by closing cab windows and additional openings. Structural fire-fighting gear will continue to off gas after the fire fighter leaves the hot zone. PPE should be removed prior to removing the facepiece (as dictated by best practices).

11.4.5 A critical on-scene tactical consideration is setting up decontamination and rehabilitation areas. Gross on-scene decontamination of PPE and fire-fighting equipment should be undertaken in the warm zone prior to PPE or equipment being removed to the cold zone and placed back on the fire apparatus. If necessary, contaminated PPE and equipment should be bagged and transported back to the station outside the crew compartment. In the cold zone adjacent to the rehabilitation areas, rehabilitation should be set up where drinking and eating is permissible.

11.4.6 Upon return to the fire station, personnel who were exposed to smoke and contaminants in the hot zone should shower immediately. Clothing should be laundered at the station and not transported in a private vehicle to a member's home. Contaminated equipment should be thoroughly cleaned before being placed back into service

11.5 On Scene. The fireground size up conducted by the IC must take smoke production and associated contaminants' potential impact on operating members, equipment, civilians, and the environment into account. Special consideration may be given under certain circumstances when known hazardous materials are burning to let the fire continue to burn under controlled conditions.

11.5.1 During and after extinguishing the fire, respiratory protection should be worn when contaminants are present. Lack of visible contaminants does not mean that the environment is free from contaminants; therefore, strict compliance with respiratory protection must be enforced. The IC should establish zones on the fireground similar to those commonly accepted at the scene of a hazardous materials release. A hot, warm, and cold zone should be designated, and appropriate levels of PPE should be required in the designated zones. The contamination zones are to be set as follows: hot zones for contaminated areas; warm zones to designate where gross on-scene decontamination takes place, decontaminated PPE is doffed, and contaminated equipment is stored; and cold zones for debriefings and rehabilitation. The incident commander should take into account the travel of the smoke plume when designating the perimeter of the hot zone.

11.5.2 The IC should limit the amount of operating personnel assigned to the hot zone. The fireground must always be secured and cordoned off during fire operations, removing non-essential personnel, civilians, apparatus, and equipment from the hot zone where contamination may occur. The incident commander should provide for timely relief of members operating in the hot zone to limit individual exposure to the lowest possible limits. Crews should be rotated when possible to reduce exposure and thermal risks to fire fighters. Chemicals found on the fireground pose an immediate threat to the respiratory tract if self-contained breathing apparatus (SCBA) is not worn and there is a latent threat through cutaneous exposure. Time influences the levels of airborne chemicals post knock-down; if crews are able to exit the structure as soon as reasonably possible and allow for the chemicals to dissipate naturally, their exposure will be reduced. Timely replacement of crews working in the fire structure and allowing them to rehabilitate can also reduce the exposure times of individual crews.

11.5.3 Fire engine cabs should be kept shut during operations and aired out briefly when operations have ended. After the fire has been extinguished, involved and contaminated rooms should be ventilated for a sufficient time prior to entry without respiratory protection for investigation purposes. Known carcinogens and hazardous chemicals can attach themselves to PPE and exposed skin. Proper use of PPE, including SCBA, is important and can minimize the smoke exposure risks to fire fighters. Members, apparatus, and equipment in the hot zone should be decontaminated. PPE that has been contaminated should be removed while using respiratory protection and placed in an area remote from operating personnel. This procedure will limit the exposure of operating personnel to the off gassing of contaminants from the PPE. Contaminated gear should not be removed from the warm zone unless decontaminated or bagged. Personnel working with equipment contaminated during a structure fire should use nitrile or latex emergency medical services (EMS) gloves and particulate filtering facepiece (N95 minimum) during the cleaning process.

11.5.4 Upon doffing of PPE, gear should be allowed to "air out" and off-gas volatile compounds released in the open air, upwind from the fire and away from personnel who are working on the incident and in decontamination or rehabilitation. Prior to transport of contaminated gear, it should be encapsulated utilizing an airtight container. The container should be of sufficient size and strength to contain all contaminated gear, including turnouts, helmet, mask, gloves, and boots. The contaminated gear should be placed outside of the passenger compartment. Gear should be transported in a similar manner to a facility with a specialized PPE washer (i.e., extractor) or to an independent service provider (ISP). The fire department should attempt to complete as much of the decontamination process on scene as possible to reduce exposures in the fire station. When possible, departments should hold responding companies out of service until the decontamination process is complete.

11.5.5 Gross on-scene decontamination of PPE and fire-fighting equipment should be undertaken on the fireground prior to PPE or equipment being placed back on the fire apparatus. The criterion for successful pre-cleaning is the removal of all visible traces of soot. PPE with traces of soot should be kept outside the crew compartment or transported separately. The pre-cleaned equipment should also be transported separately and only placed back into service when final decontamination is complete.

11.5.6 Gross on-scene decontamination of personnel should occur as soon as possible after the operating member exits the hot zone. After the fire, fire fighters who operated in the hot zone should immediately remove soot from the head and neck using skin cleansing wipes or soap and water washing if available. Wipes should be used during air cylinder changes and in rehabilitation areas between operational periods whenever possible. Gross on-scene decontamination should also be used prior to entering the rehabilitation area and consumption of fluids and/or food. Drinking and eating is permissible outside the area where smoke and contamination can occur after operating personnel have removed contaminated gear, conducted a gross on-scene decontamination, and thoroughly washed hands and faces. Washing can be considered as adequate when there are no visible traces of soot afterwards.

11.6 Post-Incident. On returning to quarters, fire fighters should ensure gear is cleaned in accordance with Chapter 7 of NFPA 1851 immediately after the fire has been extinguished and fire-fighting operations have concluded. Contaminated equipment should be initially cleaned on scene prior to being stored on the fire apparatus. Contaminated apparatus should be cleaned prior to leaving the scene.

11.6.1 No equipment, including SCBA, should be stored in the passenger compartment prior to decontamination. Crews should provide detailed cleaning of all contaminated tools, equipment, and apparatus while utilizing particulate filtering facepiece (N95 minimum) and nitrile or latex EMS gloves during the station decontamination process. Personnel should not enter clean areas of the station until they have completed the entire decontamination process.

11.6.2 With proper use of PPE at structure fires, most contaminants will likely remain outside the epidermis; however, a wash down on scene and a shower at quarters could reduce further exposure. After equipment has been decontaminated, fire fighters should shower as soon as possible to decontaminate their person. Care should be used to clean finger nails and other areas prone to absorption.

11.6.3 Personnel should utilize fresh uniforms when entering the clean areas of the fire station. After showering and changing to a clean uniform, any tools should be removed from turnouts and laundered in an extractor or repackaged for transport to a designated cleaning station or ISP. Departments should maintain documentation of gross exposures or contaminations in fire-fighter records.

11.7 Suppression Specific Concerns. Interior operations during live fire response typically expose fire fighters to the highest thermal conditions (heat flux and ambient temperatures) and highest concentration of fireground chemicals. As a result, the environmental risk is typically considered maximum for this group of fire fighters. Fire fighters working on the interior of the structure are most likely to be wearing a full complement of fire-fighting PPE. This reduces the risk for contamination and burn injuries but increases the physiological and thermal strain of the operations. PPE also increases the restrictions on movement and range of motion, increasing risk for slips, trips, and falls; overexertion; and other biomechanics-related injuries.

11.8 Incident Commander and Driver/Operator Specific Concerns. Exterior operations of incident command, engineer, and safety officers are often conducted with a reduced set of PPE due to the perceived reduced risk. As a result, breathing protection is often not worn. Skin exposures potential due to the lack of PPE or incomplete closure of PPE (even not wearing a hood) are increased. Significant exposures are still possible on the exterior of the structure due to incomplete lift of the smoke plume, diesel exhaust from operating apparatus (a known carcinogen), and radiant heat from exterior plumes and exposure to sun.

11.9 Overhaul Specific Concerns. After extinguishing the main body of fire, the IC should be aware that potential chemical exposure will remain elevated due to the continued chemical breakdown and off gassing of structural elements and furnishings. Many of these contaminants will be present in hazardous levels even when the environment appears free of visible smoke. Strict use of all PPE must continue in the post-control phase of operations in the hot zone. The number of operating members in the hot zone should be kept to the necessary minimum to limit exposure. Non-deployed members should be stationed in the cold zone to limit chemical exposure.

11.9.1 Overhaul operations are often viewed as reduced risk due to the lack of working fire conditions and the apparent heat and smoke production. Despite the apparent reduction in risk during overhaul, full PPE should be worn throughout operations. Significant physical exertion is required during overhaul operations, increasing metabolic heat generation inside the PPE. As a result, high core and skin temperatures have been measured during overhaul operations.

11.9.2 Ventilation is an important step to ensure that the environment becomes more tenable and ambient temperatures are reduced for the crews operating on the fireground. Studies have evaluated ventilation techniques related to the levels of toxicants, showing a reduction of airborne levels. However, toxicant levels rapidly increased when ventilation was discontinued. Care should be taken while using gas-powered fans that may increase carbon monoxide (CO) levels within the structure.

11.9.3 Discerning and quantifying the gasses and particulates present not only indicates when it is safe to doff SCBA, it provides the information that dictates proper decontamination and post-fire medical monitoring. The ability to monitor the air for particulates and harmful toxicants provides the best information to fireground personnel. However, current technology is limited. A four-gas or six-gas meter may not be adequate to effectively analyze the fireground, particularly for gasses other than those directly measured by the meter itself. A simple CO detector, or any other detection device by itself, cannot be relied upon to make this determination.

11.10 Apparatus. Operating apparatus should be positioned outside the hot zone in an effort to limit contamination whenever possible. Closing cab windows and additional openings will limit contamination of the crew cab. The exposure of operating apparatus and equipment to smoke and contaminants should be avoided wherever possible. Operating apparatus and equipment that has been severely contaminated with smoke and contaminants should receive a gross on-scene decontamination prior to leaving the scene.

11.10.1 Dust found inside apparatus has been found to be significantly contaminated. Apparatus windows left open during a working fire can result in smoke transport through the cab, which can deposit on surfaces. Wearing contaminated turnouts back to the fire station will transfer contaminants to apparatus seats, resulting in exposure to the next member who sits there due to cross-contamination. Storing and transporting contaminated PPE within the apparatus cab, particularly with closed windows, can lead to an increase in the concentration of compounds off-gassing from PPE. Decontamination, particularly of soft surfaces, of the cab is challenging.

11.10.2 Diesel exhaust is a known carcinogen. Where possible, apparatus should be placed so that the exhaust will not be upwind from operational personnel. In particular, engineers and command personnel without respiratory protection should not operate downwind from apparatus where feasible. Newer apparatus have improved emission controls, which has reduced their particulate contamination. However, this does not mean that it has removed all gasses of concern.

11.11 Support Personnel. PPE worn by support personnel should be appropriate for the services provided. Non-fire-service personnel often support air bottle changes and may assist with decontamination and rehabilitation. Nitrile or latex EMS gloves and potentially airway protection should be provided to reduce risk to these individuals.

11.12 Operational Hygiene at the Fire Station. Science-based research has characterized the significant level of contamination that is occurring on the fireground. Appropriate measures must be taken during the pre-control as well as the post-control phases of the fire control operations to limit exposure and decontaminate appropriately. Fireground exposure poses an ongoing health risk to civilians and fire-fighting personnel. Operating apparatus and equipment must be thoroughly decontaminated after every operation.

11.12.1 PPE should be laundered in an industrial extractor after exposed to smoke and contaminants on the fireground. Members who operated in the hot zone should be considered contaminated, and the IC should ensure that proper decontamination measures are taken. Boots must be thoroughly cleaned, and dirt and soot must be washed off (including the soles) using an appropriate cleaning solution.

11.12.2 Body areas contaminated with soot should be pre-cleaned with cold water and soap in an attempt to minimize the penetration of contaminants through open pores and allow the soot to be more easily removed. Thorough body washing with hot water should begin once all visible traces of soot have been removed. Cleaning with organic solvents or substances containing grease should also be avoided as pollutants can dissolve in these products and penetrate into the skin. Final cleaning can be regarded as successful if there are no visible traces of soot after washing with conventional body cleansing products. Only skin care products should be used after a thorough body washing.

11.12.3 Clothing that is worn during fire operations must be kept separate at the fire station and properly laundered. Care should be given not to cross-contaminate bedding and personal clothing during the laundering process. Fire fighters and support personnel should not leave the fire station in work clothing that has been contaminated with smoke.

11.13 Fireground Tactical Consideration — Gross On-Scene Decontamination.

11.13.1 Strategic Objective. Gross on-scene contamination is the systematic removal of the byproducts of the fireground from tools, equipment, and PPE. Fire fighters should make efforts to remove all byproducts from their equipment in an effort to promote a healthier environment, including reducing exposure to potential carcinogens and keeping tools and equipment serviceable.

11.13.2 How it Works.

11.13.2.1 Wet Decontamination. Water should be used with soap and/or physical brushing to remove contaminants that have been deposited onto the fire fighters' PPE, tools, and equipment while still on scene. The following are considerations for wet decontamination:

(1) Depending on the situation, gross decontamination may be performed prior to fire fighters doffing PPE or after it has been removed. Considerations must include environ-

mental conditions and potential for contaminating exposed skin through splash or dermal contamination.

(2) Members should brush large debris first and then spray each other with water to remove loose particulates from turnouts and equipment.

(3) Some products of combustion result in a “sticky” deposit on the gear, requiring detergents or other surfactants to remove.

(4) Wet decontamination techniques may temporarily place PPE out of service, and a second set of turnout gear fit to the fire fighter should be put in service where possible.

11.13.2.2 Dry Decontamination. Techniques that do not wet the PPE may be employed depending on the level of contamination, environmental conditions (particularly cold conditions), and materials available on scene. Dry brushing and air-based brushing methods have been proposed as means to remove the toxic products of combustions from the fire fighters. The following are considerations for dry decontamination:

(1) If wet decontamination is not an option, dry decontamination should be performed prior to the fire fighter doffing PPE unless there is a medical condition needing immediate attention or other emergency such as running out of air. Specifically, consider the impact of environmental conditions as well as the potential for the breathing of airborne contaminants and cross-contamination of exposed skin.

(2) When feasible, personnel should allow PPE to off-gas as described in 11.5.4 prior to bagging their gear for the return to the station.

(3) All fire fighters engaged in suppression activities, overhaul, or exposure to smoke should exchange their contaminated hoods and gloves after exiting the immediately dangerous to life and health (IDLH) environment.

11.13.3 Application.

11.13.3.1 Mitigation of Contaminated PPE.

11.13.3.1.1 Upon exiting the hot zone, no PPE should be removed, including the SCBA facepiece.

11.13.3.1.2 To reduce exposure to airborne particulates and gasses from off-gassing PPE, the SCBA facepiece should remain in place while doffing remaining PPE components.

11.13.3.1.3 If directly returning to the hot zone after an air cylinder change, the following should take place:

(1) Dry brush debris from helmet, facepiece, and SCBA prior to change-out.

(2) If available, fire fighters engaged in suppression activities or overhaul or who are otherwise exposed to smoke can further reduce contamination by exchanging their contaminated hood for a clean one when they exit the IDLH. Replacement hoods should be readily available on scene.

(3) Personnel performing mitigation should wear gloves, eye protection, and suitable PPE for the suspected contaminants.

11.13.3.1.4 Prior to removing fire-fighting ensembles worn in the hot zone, an appropriate gross decontamination procedure should be performed to remove potentially harmful contaminants.

11.13.3.1.4.1 If wet decontamination procedures are employed, members should brush large debris first and then spray each other with water to remove loose particulates from turnouts and equipment. Utilizing the pump operator for decontamination should not be allowed due to the lack of respiratory protection. A designated gross decontamination line may be deployed, preferably distant from the pump panel to eliminate overspray and unwanted exposure of the pump operator. Measures should be taken to position the decontamination area upwind of the incident scene in an effort to not expose personnel to more contaminants from smoke. The following should be considered for wet decontamination:

(1) Wet mitigation should begin using a fine mist from a decontamination hose line to rinse debris from the helmet, facepiece, SCBA, bunker gear, gloves, and boots.

(2) Initial decontamination of all PPE can be completed with a 1-in. hose line utilizing a 10 to 40 gpm (25.4 mm hose line utilizing 37.8 to 151.4 L/m) nozzle or a garden hose.

(3) Personnel performing mitigation should wear gloves, eye protection, and suitable PPE for the suspected contaminants.

(4) Personnel may require tents or buses to provide privacy and protect against extreme environmental exposure.

(5) Tyvek suits should be made available for members as necessary.

11.13.3.1.4.2 During cold weather operations, dry brushing should be conducted to remove the products of combustions from the fire fighters prior to removing respiratory protection and doffing SCBA facepieces. Contaminated PPE that is dry brushed should be allowed to off-gas in an open area away from any fire fighting, decontamination, or rehabilitation activities and away from locations where additional contamination may be experienced. Air-based decontamination methods have been proposed and are currently being studied in place of dry brushing techniques. Data on effectiveness and risks/benefits should be available shortly.

11.13.3.1.5 Certain parts of the PPE ensemble cannot be effectively deconned on scene due to their typically porous nature (e.g., hoods and gloves). These parts of the ensemble should be switched out on the scene until they can be properly cleaned in accordance with NFPA 1851.

11.13.3.1.6 After gross decontamination and before eating or drinking, a personal hand washing station, including hand soap and towels, should be set up. In lieu of soap and water, disposable wipes should be utilized for hands, face, and neck. Personnel should wash their hands before rehabilitation, at the end of suppression activities including overhaul, and before returning to the living quarters. The hand wash station or wipes should be available at the entry point to rehabilitation.

11.13.3.2 Containment of Contaminated PPE.

11.13.3.2.1 When released from the incident, fire fighters should place their contaminated turnouts in large, encapsulating leak-proof bags or totes for transport back to the station. Wearing contaminated turnouts back to the fire station will transfer contaminants to apparatus seats, resulting in exposure to the next member who sits there due to cross-contamination.

11.13.3.2.2 To protect hands from dermal absorption of contaminants while packaging turnouts, a minimum of nitrile or latex EMS gloves should be worn. Personnel should shower upon returning to quarters, or as soon as practical.

11.13.3.2.3 Contaminated turnouts, including hood, gloves, boots, and helmets, should be cleaned in accordance with

NFPA 1851 or they should be sent out to a designated station or an ISP for cleaning.

11.13.3.2.4 When cleaning contaminated equipment, appropriate PPE [gloves, splash gown, and particulate filtering facepiece (N95 minimum) if equipment is dry and particles could become airborne] should always be worn to protect against exposures from contaminated equipment.

11.14 Fireground Tactical Consideration — Rehabilitation. Rehabilitation is an intervention to mitigate against the physical, physiological, and emotional stress of fire fighting — in order to sustain a member's energy, improve performance, and decrease likelihood of on-scene injury or death. *(See NFPA 1584.)*

11.14.1 Strategic Objectives. Objectives for rehabilitation are to provide a refuge area where personnel who have been engaged in emergency incident activities can be properly rested, cooled, rehydrated, nourished, and medically and psychologically evaluated to help prevent incident-related illness and/or injury, and to prepare them physically and mentally to be able to continue to perform operational tasks as an incident dictates. Rehabilitation provides a controlled means for on-scene personal hygiene activities to be conducted, monitored, and verified.

11.14.2 How it Works. On-scene rehabilitation operations could consider location and services to be provided.

11.14.2.1 The rehabilitation setup should be located in the cold zone and the following should be considered when determining the rehabilitation setup location:

(1) Protected from dangerous environmental elements
  (a) Smoke, particulate, and radiant heat from the fire
  (b) Exhaust fumes
  (c) Environmental heat, cold, wind, precipitation, and noise
(2) Far enough away from the scene that members may safely remove PPE
(3) Located near emergency medical services (EMS)

11.14.2.2 Services provided by rehabilitation should include the following:

(1) Relief from incident and environmental conditions
(2) Personal hygiene
(3) Rest and recovery
(4) Rehydration
(5) Nourishment
(6) Medical monitoring

11.14.2.3 Rehabilitation should operate within the established accountability system. Fire fighters should be tracked as they enter and leave the rehabilitation sector, and their vitals, fluid intake, and what was eaten should be recorded.

11.14.3 Application.

11.14.3.1 Relief from incident and environmental conditions should be provided for the following considerations:

(1) When ambient temperature is elevated, shaded areas should be provided at a minimum. For extreme temperatures and high humidity, active cooling may include moving to an air-conditioned area, using misting systems/fans or wet towels, or submersion of extremities in water.
(2) When ambient temperatures are low, areas protected from precipitation or overspray from hose streams should be provided. Dry, warm clothing and hot beverages may need to be provided. During extreme cold conditions, structures (temporary or permanent) or large, heated vehicles may be required to provide protection from the elements and personnel warming.

11.14.3.2 Hygiene practices should be implemented directly into the rehab process for the following considerations:

(1) Skin must be decontaminated so that contamination isn't further distributed through the following:
  (a) Eating
  (b) Touching other body parts
  (c) Exposing members of the rehab team
(2) Turnout coats, pants, helmets, hoods, and SCBA should be removed to allow the following:
  (a) Distance from PPE that may be potentially off-gassing chemicals absorbed during the fire event
  (b) Cooling of the fire fighter through sweat evaporation from the skin

11.14.3.3 Rest and recovery provided by rehabilitation includes providing an environmentally comfortable area to sit down. Typical work/rest ratios recommended for rehabilitation include the following:

(1) 10-minute self-rehabilitation after working for 30 minutes on an SCBA cylinder or 20 minutes of intense work
(2) Formal 20-minute rehabilitation after two 30-minute SCBA cylinders or one 45-minute or 60-minute cylinder or 40 minutes of work without SCBA

11.14.3.3.1 Recent studies have shown a significant reduction in typical fire fighters' physical capabilities while working through a second 30-minute bottle or the second half of the first 60-minute bottle.

11.14.3.3.2 This same study found that one-third of the fire fighters were unable to complete a second bout of activity. This effect was elevated in fire fighters who were less fit and had a larger body size.

11.14.3.3.3 Significant thermal and cardiovascular strain may be experienced during outside ventilation operations that may not result in significant consumption of air. This effect can be further exacerbated by elevated ambient temperatures and direct sun exposure. Yet, the fire fighter may not have worked through SCBA.

11.14.3.3.4 Exposures on the fireground may be significant for exterior operations (command officers, engineers), yet prompts for rehab may not come from SCBA usage.

11.14.3.4 Replenishing lost fluids and expended fuels is critical and should include consideration of the following:

(1) Rehydration should be actively provided since a large portion of the human body is water. At a minimum, it is recommended that water be consumed during air bottle changes and during rehabilitation. Additional water should be consumed after the incident. Sports drinks with electrolytes may be desirable during prolonged incidents and are typically recommended after water. Carbonated and energy drinks should be avoided.
(2) Very cold incidents may necessitate hot beverages.
(3) Excessive fat and empty calories should be avoided.

11.14.3.5 Rehabilitation staffers should continually monitor personnel for signs of exhaustion, stress, and/or physical injury. Vital signs should be recorded upon entry, every 10 minutes and before exit from rehabilitation.

Chapter 12 Fire Specific Tactical Considerations

12.1 Scope. This chapter addresses the information, factors, and observations needed to develop the initial and ongoing operational strategy required for fire control for special circumstances.

12.2 Purpose. The purpose of this chapter is to provide options on science-based tactical considerations for fire control and extinguishment for special circumstances.

12.3 Application. The intent of this chapter is for fire-fighting personnel to apply tactical considerations for fire control and extinguishment for special circumstances.

12.4 Introduction. This chapter provides specific tactical considerations based on the building construction information combined with building design features and occupancy types. This list is not exclusive and will likely evolve over time.

12.5 One- and Two-Family Dwellings and Townhomes. More fires occur in these structures than any other occupancy type. The types of construction vary extensively, but the key commonality is that they are usually occupied by a single family.

12.5.1 These fires can generally be controlled by one or two properly operated handlines. Depending upon the situation, the fire control could be initiated by an interior or exterior water application.

12.5.2 Using the reach of the stream, the initial water application should be made as close to the fire as possible, including at the level and side of the building where fire is encountered.

12.5.3 The incident commander should consider the extent and location of fire involvement prior to the commencement of a primary search.

12.5.4 Generally, vertical travel of heat and smoke occurs in interior stairwells in multistory residences. This can create rescue and egress challenges, especially when upper floor windows are opened or compromised.

12.5.5 Exterior fire communication can occur through interior ceiling openings, and auto exposure through eaves and soffit vents can result in fire spread to the attic.

12.5.6 Non-code-compliant renovations may lead to basement occupants being trapped in this area of the structure.

12.5.7 Townhomes are a type of single-family dwelling that is structurally independent from adjacent single-family dwellings and separated by a common fire-resistive-rated wall assembly. As long as the wall integrity is maintained, the fire-specific considerations applicable to the single-family dwelling are applicable to the townhouse. Consideration should be given to confirming the integrity of the fire-resistive-rated wall assembly and extension has not occurred to adjacent townhouse units.

12.6 Concealed Space Fires. These fires involve balloon frame construction, void spaces, attics, knee walls, and other concealed spaces within a structure. Concealed fires present many hazards and are challenging to safely extinguish.

12.6.1 A search for fire shall be conducted with the protection of a charged hose line. The structure should be assessed from both the interior and exterior simultaneously to ensure rapid detection of signs of concealed space fires. Ventilation should be controlled during the search for fire.

12.6.2 Thermal imagers should be used from the interior and exterior of the structure to assess for temperature in concealed spaces.

12.6.3 Void fires in combustible buildings may consume structural support members and lead to collapse.

12.6.4 The utilization of penetrating nozzles should be considered for water application in a safe manner.

12.6.5 Complete overhaul to expose hidden spaces where fire may have traveled is essential to the prevention of fire spread.

12.7 Garage. Most garages contain a significant fuel load and fire control hazards due to vehicles, powered equipment, ignitable liquids, and various fuels. Detached garage roofs may be of inferior construction, including lightweight truss. Storage in and suspended from the overhead supports is common and will add to a collapse hazard.

12.7.1 Due to the storage of flammable compressed gases, the potential for a flash fire and boiling liquid expanding vapor explosion (BLEVE) in these spaces is relatively high.

12.7.2 The height of a garage may accommodate a hydraulic lift that may have a vehicle in a raised position. Failure of a hydraulic line could cause the lift to fail.

12.7.3 Overhead garage doors can open or close during a fire and have the potential to collapse or trap fire fighters.

12.7.4 It may be preferable to have a handline that flows more than 150 gpm to knock down and extinguish fires in these spaces from a relative area of safety. The utilization of exterior streams through as small an opening as possible, having a charged line flowing into an open vent as soon as possible, or the use of a piercing nozzle should be considered.

12.7.5 Consideration should be given to applying exterior water streams to attached garages, in particular in avoiding fire propagation into the main structure. Fire fighter safety and fire control, in most cases, is enhanced by an exterior stream application.

12.7.6 Crews should consider alternative access modes before opening, cutting, or removing overhead doors. If an overhead door is the best access, small openings can be cut in the door and fire streams can be applied through these openings to manage the ventilation of the compartment while extinguishing the fire. Thermal imagers and penetrating (i.e., piercing) nozzles can be effective in suppression operations.

12.7.7 Adjacent or attached structures should be assessed to identify any fire extension. Interior doors should be closed to confine the fire and slow extension into the living space when possible.

12.7.8 An interior charged hoseline should also be placed at potential fire spread openings in order to confine the fire.

12.7.9 Vertical ventilation should not be utilized due to the potential for early collapse. Incident commanders should thoroughly consider the risks and benefits before assigning crews to perform roof operations such as vertical ventilation.

12.7.10 Positive pressure ventilation should be considered in the living space to create a pressure differential, thereby inhibiting fire spread.

12.8 Manufactured and Modular Dwellings. Manufactured and modular dwellings are built off-site, may not have the same fire resistance as site-built structures, and may propagate fire rapidly due to the geometry of the building. These buildings may be susceptible to early failure due to numerous lightweight building construction materials.

12.8.1 Due to the building construction, fire conditions may result in considerable destruction of the floor, resulting in fire-fighters falling through the floor.

12.8.2 In a ventilation limited condition, an earlier flashover condition should be anticipated.

12.8.3 The utilization of exterior stream placement is a tactic that should be considered as all of the compartments in the structure are generally accessible from the exterior.

12.8.4 Vertical ventilation is not a recommended tactic due to the potential for early collapse.

12.9* Large Estate Dwellings. Building construction trends continue to evolve, producing larger and more open floor plans in residential structures that commonly include lightweight construction and engineered elements. It is not uncommon to encounter residential structures with square footage similar to commercial buildings. Large estate dwellings are structures that exceed 3000 ft^2, have open floor plan designs, and use lightweight construction and engineered structural elements, which creates the potential for large area fires and early collapse, necessitating adjustments to fire tactics as recommended by Section 12.9.

12.9.1 Operating units should make every effort in their size-up to identify the fire area and building construction features.

12.9.2 Due to the large open floor plan and fuel load it is recommended to control these fires with high-volume fire flows, utilizing the reach of the stream and the cooling ability of the increased flows.

12.9.3 Doorway curtains can be utilized to slow fire extension in these open spaces.

12.9.4 Incident commanders should consider the need for additional resources to complete primary and secondary searches of these structures in a reasonable amount of time.

12.9.5 Large windows present a significant inadvertent ventilation risk. The failure of such windows can result in rapid ventilation of the fire, which can cause rapidly deteriorating conditions and extreme fire conditions.

12.9.6 Large objects, such as light fixtures, artwork, and other decorations suspended in open areas, can pose an additional hazard to fire fighters.

12.9.7 Large open areas include long spans typically using lightweight truss construction. These structural characteristics can lead to early structural failure, primarily roof and floor collapse. Incident commanders should thoroughly consider the risks and benefits before assigning crews to perform roof operations such as vertical ventilation.

12.9.8 Multiple large open stairwells, the presence of elevators shafts, and large open floor plans can facilitate rapid spread of fire.

12.9.9 These structures often present numerous obstacles regarding access to the structure. Lengthy setbacks from public access, gates, and other impediments can complicate apparatus placement and result in long hose lays for supply and fire control lines.

12.10 Buildings Converted to Residential or Multiple Dwellings. These are buildings that have been converted from single-family residences, warehouses, retail, and all other types of occupancies for use by multiple families within the same structure. These living units may be located above or adjacent to commercial occupancies.

12.10.1 Many of these conversions have been completed without code compliance. This can result in delayed detection, limited egress paths, maze-like conditions with limited access for fire-fighting operations, increased fire load, rapid fire propagation, and unpredictable fire travel.

12.10.2 Living units may be found at all levels including the basement and the attic, resulting in extremely limited access for fire operations.

12.10.3 The structure may be overcrowded and the number of residents may far exceed the original anticipated occupancy load.

12.10.4 Due to the difficulty in conducting rescues and evacuations, it is essential to limit fire spread with a coordinated fire control as soon as practical.

12.10.5 Additional resources may be needed due to the challenges presented by potential multiple rescues and fire control within a converted structure.

12.11 Multifamily Dwellings. Multifamily dwellings include row houses and garden apartments.

12.11.1 Initial considerations to multifamily dwelling fires include the elements listed in 12.11.1.1 through 12.11.1.5.

12.11.1.1 Size-up. The first arriving water source should prioritize master streams to reset the fire with a deck gun or a monitor if possible. If a confirmed fire is reported from the first arriving resources, additional resources should be requested immediately. Placement of apparatus becomes paramount in many cases due to setbacks, parking lots, and a multitude of access issues.

12.11.1.2 Rescue. The residents in greatest danger should be an immediate priority. It must be understood if large numbers of residents require immediate rescue, resources become critical. Delayed extinguishment of the fire is often the result.

12.11.1.3 Evacuation. The difference between rescue and evacuation must be clear. The evacuation of residents is those that are not in immediate danger. Evacuation of residents not in the immediate fire area may not be an initial priority. Sheltering residents in place may be the most practical method of protection until fire control is complete and additional resources are on scene.

12.11.1.4 Water Supply. Apparatus placement should be considered due to the possible need of several water sources and the distance required to reach the fire.

12.11.1.5 Laddering. Active fires in these structures will often increase the demand of ground ladders. Incident commanders should proactively consider early placement of ground ladders.

12.11.2 Using the reach of the stream, the initial water application should be made as close to the fire as possible, including at the level and side of the building where fire is encountered.

12.11.3 The incident commander should consider the extent and location of fire involvement prior to the commencement of interior fire control and primary search.

12.11.4 Generally, vertical travel of heat and smoke occurs in interior stairwells in multistory residences. This can create rescue and egress challenges, especially when upper-floor windows are opened or compromised.

12.11.5 Exterior fire communication can occur through interior ceiling openings, and auto exposure through eaves and soffit vents can result in fire spread to the attic.

12.11.6 Non-code-compliant renovations may lead to basement occupants being trapped in this area of the structure.

12.11.7 Common attic areas can facilitate horizontal fire spread.

12.12 Multi-Unit Residential Buildings. These are buildings that were designed and constructed for multi-family occupancy.

12.12.1 Lightweight construction is routinely found in this type of building, and early collapse should be anticipated.

12.12.2 Exposure protection should be an early tactical priority.

12.12.3 Large and common attics and other concealed spaces may exist that permit undetected rapid fire propagation. Early use of thermal imagers and opening of spaces to detect fire spread is critical.

12.12.4 Protection of exit pathways should be a tactical priority.

12.12.5 The layout of the building and the number of occupants may present significant rescue challenges.

12.12.6 The incident action plan (IAP) should include consideration of flow path management that facilitates evacuation of occupants.

12.13 Abandoned and Vacant Structures. Abandoned or vacant structures are buildings that are no longer in use, and in many cases are in an unknown state of condition or compromise, which could result in weakened structural components, holes in floors, and structural deficiencies. The following should be considered when controlling fires in these structures:

(1) Exterior fire control should be considered prior to entry.
(2) Early collapse should be anticipated.
(3) Gutted, deteriorated, and modified interiors can result in unpredictable and increased fire activity. These conditions may impede normal fire-fighting operations.
(4) Occupancy by squatters and transients should be considered. As such, an evaluation of occupant survivability and rescue potential should be made.

12.14 Large-Space Buildings. Large-space buildings are structures with large, non-compartmentalized spaces, such as churches, skating rinks, bowling alleys, gymnasiums, concert halls, and so forth. They generally have atypical construction features.

12.14.1 A fire of any significance in a large structure of this type will challenge the resources of many departments.

12.14.2 Large noncompartmented areas with their fuel load and available air can lead to a well-developed fire.

12.14.3 Large open areas require long spans typically using truss construction. These structural characteristics can lead to early structural failure and roof and floor collapse.

12.14.4 Fire control may require multiple large flow streams.

12.14.5 These structures may have unique roof characteristics that can be hazardous for vertical ventilation operations.

12.14.6 Controlling the advancement of fire fighters into this structure is vital as there is increased potential of fire fighters becoming disoriented and so that command can determine their location. Special tactics and equipment, such as search ropes, should be considered.

12.14.7 Air management and accountability should be a critical consideration.

12.15 Warehouses. Warehouse and storage fires are complex incidents that expose fire fighters to many challenges and hazards. The complexity of these incidents is a function of a number of factors and can require significant resources to mitigate. Fires in these occupancies can involve large open areas and high fuel loads.

12.15.1 Key risk factors for warehouse fires include the following:

(1) Construction features including construction type, total building size, details of fire-rated enclosures, and the presence of large open fire areas
(2) The types and hazard level of material stored
(3) Details on the storage configurations such as height and type (e.g., rack storage, floor storage)
(4) Presence, type, and suitability of fire protection and detection systems
(5) Any available methods to facilitate ventilation such as roof vents, smoke control, and exhaust systems
(6) Available water supply sources and adequacy
(7) Equipment and machines related to material handling

12.15.2 Preplanning of warehouse and storage occupancies is a critical aspect of enabling an effective fire response.

12.15.3 High fuel loads, large open areas, and complex floor layouts can make size-up and determining the exact location of the fire difficult. These factors can require additional staffing to properly execute engine company, ladder company, and rapid-intervention team activities.

12.15.4 Large open areas with complex and confusing floor plans can facilitate fire fighter disorientation and hamper search operations and hose movement. If automatic-closing fire doors are present, they should be monitored so that they do not impact the emergency egress of fire crews. Good communication, controlled movements, and fire fighter accountability should be a focus of incident command.

12.15.5 High fuel loads and long structural spans can facilitate structural collapse. Structural conditions should be continually evaluated.

12.15.6 Localized collapse of storage racks and storage piles are a safety hazard to fire-fighting personnel.

12.15.7 Fire sprinkler systems may control, confine, or suppress fires, greatly reducing damage, helping to maintain structural stability, and providing time for the establishment of manual fire-fighting operations. Sprinkler control valves and associated water supplies should be verified to be in service, and systems should not be shut down until incident command determines it is appropriate to do so. Manual fire-fighting efforts should be supplemental to the efforts of the fire sprinkler system and typically are used for final extinguishment and overhaul.

12.15.8 Warehouse and storage occupancies can result in high fire flow demands. Potential sources of water include public hydrants, water supply shuttles (tanker/tender), and large diameter hose lays. If available, private water supplies are also an option; however, these systems are typically sized to supply fire sprinkler system demands so caution should be used when accessing these supplies so the effectiveness of the sprinkler systems is not impacted. Likewise, interior standpipe systems typically draw water from the sprinkler system. Utilization of these standpipe systems could hamper the effectiveness of the sprinkler system.

12.15.9 When the warehouse or storage facility is equipped with a fire sprinkler system, the first or second arriving engine should feed the fire department connection (FDC).

12.15.10 If the warehouse or storage building has multiple fire divisions, fire doors can be closed around the fire area to reduce the potential for the spread of fire and related fire gases and smoke.

12.15.11 Uninvolved fire-rated areas adjacent to the fire can be used as forward staging areas for staffing and equipment.

12.15.12 Consideration for use of handlines should include the following:

(1) Due to the high fuel loads and large areas involved, larger volume hand lines [≥2½ in. (≥63.5 mm)] that can reach the base of the fire should be considered.
(2) The large areas and complicated storage layouts can make the use of traditional pre-connected lines ineffective. In these cases consideration should be given to the use of portable monitors or gated wyes and hose/high-rise packs.

12.15.13 For large fires where the fire has vented through the roof, defensive operations are recommended. If defensive operations are initiated, personnel should be evacuated from within the interior and the roof areas and appropriate collapse zones established and enforced. Aerial water streams and ground-level monitors can be used to help control the spread of fire and for protection of exposures.

12.15.14 Rooftop ventilation operations, especially involving fires with high fuel load materials and when roof supports include lightweight construction and/or unprotected steel members, can be hazardous with structural collapse a significant concern. This is especially true for buildings not equipped with fire sprinkler systems. Use of existing ventilation facilities including skylights, melt out vents, and smoke control systems can be effective. Positive pressure ventilation may not be practical due to the large volume areas involved with warehouse and storage occupancies.

12.15.15 Products of combustion from the materials stored can contain hazardous or toxic components. Appropriate PPE and SCBA should be utilized at all times, and environmental monitoring of air and effluent water should be considered.

12.15.16 Controlling the advancement of fire fighters into this structure is vital as there is increased potential of fire fighters becoming disoriented and for command to determine their location.

12.15.17 Air management and accountability should be a critical consideration.

12.16 Variable Grade (Hillside) Building. These are buildings that have access to grade at various levels. As an example, the front of the structure may appear to be a single-story building from the front but from the rear may appear to be a two or-more-story structure. These structures create challenges involving accessibility, flow paths, stream application, and fire fighter safety, as well as the potential for rapid changes in fire conditions. Uncontrolled ventilation on any grade level can rapidly change the flow path on stairwells and hallways.

12.16.1 Early identification of a variable-grade building, including floor designations, operating areas, and unit assignments, should be clearly communicated and understood by all operating units and incident command.

12.16.2 Entering the structure above the fire creates the potential of being within the exhaust flow path.

12.16.3 If practical, entry should be made at or below the level of the fire.

12.16.4 Ventilation, tightly coordinated with fire control involving water streams, to control flow paths is essential in these occupancies. The potential impact of unintended ventilation creates a significant exposure to fire fighters and should be recognized.

12.16.5 Interior stairwells have the potential for vertical flow paths.

12.16.6 The different elevations create significant access challenges and create issues in the application of both interior and exterior fire streams.

12.17 Hospital/Health Institution. These fires normally involve buildings of noncombustible construction that are fully or partially sprinklered. Fire control is usually a lesser concern in fully sprinklered structures but is a critical concern in partially or nonsprinklered facilities with combustible construction. The movement and control of smoke (smoke management), conducting interior horizontal evacuation to safe area, and the control of medical gas systems are key tasks that must be considered.

12.17.1 When the hospital or health institution is equipped with a fire sprinkler and/or standpipe system, the first- or second-arriving engine should feed the fire department connection (FDC).

12.17.2 If the building is of combustible construction or not fully sprinklered, applying water to the fire area as quickly as practical from the interior or exterior is a critical task. Emphasis must be given to getting the first stream on the fire.

12.17.3 It is essential to have a smoke control plan to manage the smoke within the noninvolved fire areas to minimize the exposure to occupants.

12.17.4 The medical gases supply to the fire area should be isolated or terminated as soon as practical.

12.17.5 Sheltering in place is an option for patients based on fire conditions, building characteristics, and available response resources.

12.18 High-Rise. Fires in high-rise buildings require preplans, significant resources, and comprehensive SOPs/SOGs. Tasks that are normally considered routine for most fire departments, such as locating and controlling the fire, evacuating occupants, and performing ventilation, are more complex in high rises.

12.18.1 Access to floor levels that are beyond the reach of aerial apparatus are generally limited to the interior stairways. The use of elevators during fire operations should be designed for fire service operations and closely monitored with safety precautions.

12.18.2 Occupants may be exposed to the products of combustion while they are evacuating or unable to descend past a fire on a lower floor. Exits may be limited, which is further complicated by the simultaneous use for egress and for fire-fighting operations.

12.18.3 The ability to contain and control the fire is increasingly dependent on the construction of the building and the ability of sprinkler and/or standpipe systems to deliver water to the fire area.

12.18.4 Ventilation can be much more complicated and critical in highrises than in other types of structures. Vertical ventilation is often limited to stairways or elevator shafts, both of which may also have to be used to evacuate occupants. Horizontal ventilation, by breaking out windows, presents the risk of falling glass to those outside the building. Stack effect in the building can cause smoke movement in an upward (i.e., positive) or downward (i.e., negative) direction in vertical shafts. Accumulations of smoke remote from the fire areas can be found at the upper and lower floors of the building.

12.18.5 Reflex time, or the amount of time it takes to react and take action, is usually much higher in high-rise buildings than in non-high-rise buildings. It often takes longer to travel from the ground floor to the fire floor than it takes to respond from the fire station to the building. Fire fighters may have to climb dozens of floors before they can even reach the fire floor.

12.18.6 Communications, command, and control can be very difficult in a high-rise fire. Radio transmissions through a building's concrete and steel infrastructure may be compromised. The size and complexity of these buildings require large forces of fire fighters and well-coordinated operations in a very complex tactical environment. The establishment of an operations post and staging area on the floor below the fire can enhance communications, command, and control. Effective coordination and control of strategy and tactics are essential.

12.19 Basement. Basement or belowgrade fires can be extremely difficult to control and extinguish once they are past the incipient stage. Access and ventilation opportunities are limited, floor plans are not standard, and fuel loads can be extraordinary and unpredictable. Fire fighters are injured and killed at these fires when the floor beneath them collapses or they are caught in the exhaust portion of the flow path of the fire.

12.19.1 A thermal imager can be utilized on the exterior to assess the thermal conditions at windows, vents, and doorways to assess the potential for a fire within the basement. It should be noted that thermal imagers cannot see through walls or barriers, only the thermal conditions at the material's surface.

12.19.2 Smoke showing from chimney or vent pipes may indicate a basement fire.

12.19.3 Observing the position of the neutral plane at the first-floor entryway door of a building might indicate a basement fire. An observable indication of a basement fire can be smoke filling an entire first floor door opening of a structure without the presence of a neutral plane. Such observations may also indicate a fire located on the first floor, which is ventilated elsewhere providing fresh air to the fire. Additional openings on the first-floor might also affect the level of the neutral plane at the front door. Basement fires are more likely to be ventilation-limited upon fire department arrival, and control of the flow path on the first floor through managing openings is critical

12.19.4 A thermal imager may be used to assess the temperature of the interior basement door and to look for heat sources around ground-floor penetrations such as near heating registers and pipe penetrations. A thermal imager should not be used to assess the structural stability of the floor from above. Additionally, the use of a thermal imager on the ground floor surface is not a conclusive way to assess elevated temperatures in the basement area. The images in Figure 12.19.4 illustrate the thermal imaging view and temperatures just prior to collapse of the first floor in a basement fire research experiment.

12.19.5 During a suspected basement fire, the risk analysis should consider the fire fighter safety issues prior to placing personnel above the basement level.

12.19.6 When initiating the fire control, when possible, firefighters should control the basement fire from an exterior opening on the same level as the fire. If this is not possible, use of special nozzles or appliances may be used to flow water into the basement from the safest positions as possible including through exterior basement window openings, door openings, vent holes, or holes cut above the fire. The application of a water spray pattern that cools the hot gases is the most effective way to control a basement fire. There are many nozzles or application devices that provide an effective spray pattern such as spray nozzles, penetrating nozzles, and distributor nozzles.

12.19.7 Any potential ventilation operations including opening of doors to the basement or breakage of windows should be performed in a controlled manner once an incident action plan is established and at the direction of the incident commander. Controlling flow path through ventilation management is essential in conducting rescue operations and limiting fire spread. Positive pressure ventilation should be used with caution due to its effect on flow path and fire spread due to the limited exhaust vent sizes.

12.20 Strip Malls. The complexes are generally multiple retail establishments and are located adjacent to each other in a line. The separate retail businesses are separated by dividing walls and may have a common attic space and roof.

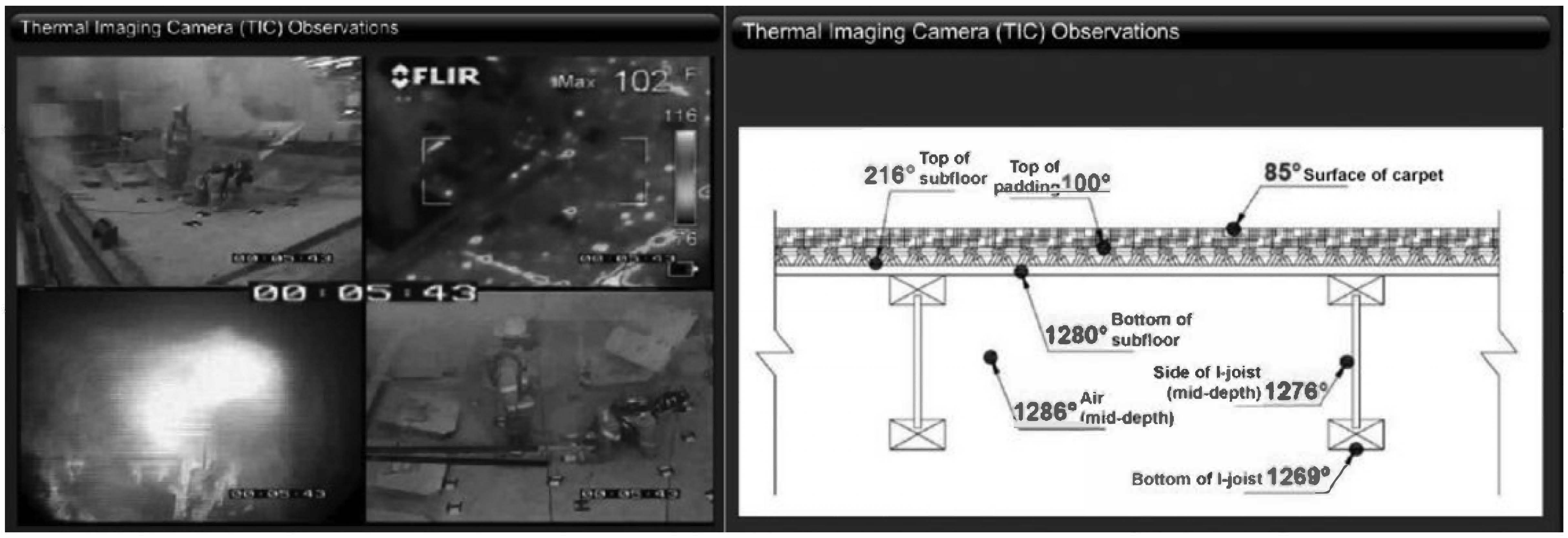

FIGURE 12.19.4 Exterior Thermal Imaging. *(Courtesy of UL Firefighter Safety Research Institute.)*

12.20.1 The existence of a common attic space (i.e., cockloft) may lead to rapid horizontal fire propagation. Generally, any visible fire on the ground floor will be in a wider area with the cockloft.

12.20.2 The examination of void space above ceilings in the adjacent occupancies should be considered.

12.20.3 In many cases, hydrants may not be close to the fire occupancy. This may require long hose lays.

12.20.4 These structures usually have no windows, only doors, in the rear. The rear doors should be forced open early in the incident to create a ventilation flow path and to provide a means of egress for occupants. Door control should be implemented so that ventilation may be coordinated with water application.

12.20.5 These buildings usually have a considerable roof load due to multiple HVAC units as well as other equipment. The additional load increases the possibility of early roof collapse.

12.21 Buildings Under Construction/Demolition. These buildings present particular challenges involving fire control. Building structural elements may be exposed to fire and propagation, which could result in early collapse. Fire systems such as sprinkler and alarm systems may not be operational.

12.21.1 Rapid fire propagation should be anticipated. Significant wind conditions could lead to a wind-driven fire. The call for additional resources should be considered early within the incident.

12.21.2 Large fire flows including master stream appliances should be deployed for fire spread and control.

12.21.3 Access to these structures is often limited.

12.21.4 Fire protection features such as separation doors, wall board protection, sprinklers, and stand pipes may not be operable.

12.22 Photovoltaic Systems.

12.22.1 General. As a result of the significant increased use of PV systems on residential and commercial structures, fire fighters and fire safety officials have raised concerns about the potential risks when PV systems may be part of the fire hazard or impact fire department operations. To help address these concerns, UL conducted fire and electrical performance experiments to identify and quantify the electrical shock hazard that may be present to fire fighters during the suppression, ventilation, and overhaul activities associated with a fire involving the PV equipment.

12.22.2 Fireground Considerations.

12.22.2.1 The electric shock hazard due to application of water is dependent on voltage, water conductivity, distance, and spray pattern. A slight adjustment from a solid stream toward a fog pattern (i.e., a 10-degree cone angle) reduced measured current below perception level. Salt water should not be used on live electrical equipment. A 20 ft (6.1 m) distance had been determined to reduce potential shock hazard from a 0.95 Btu/sec (1000 Vdc) source to a level below 0.002 W/volt (2 mA), which is considered safe. It should be noted that pooled water or foam may become energized due to damage in the PV system.

12.22.2.2 Outdoor weather-exposure-rated electrical enclosures are not resistant to water penetration by fire hose streams. A typical enclosure will collect water and present an electrical hazard.

12.22.2.3 Fire fighter's gloves and boots afford limited protection against electrical shock provided the insulating surface is intact and dry. They should not be considered equivalent to electrical PPE.

12.22.2.4 Turning off an array is not as simple as opening a disconnect switch. Depending on the individual system, there may be multiple circuits wired together to a common point such as a combiner box. All circuits supplying power to this point must be interrupted to partially de-energize the system. While the array is illuminated, parts of the system will remain energized. Unlike a typical electrical or gas utility, on a PV array there is no single point of disconnect.

12.22.2.5 Tarps offer varying degrees of effectiveness to interrupt the generation of power from a PV array, independent of cost. Heavy, densely woven fabric and dark plastic films reduce the power from PV to near zero. As a general guide, if light can be seen through a tarp, it should not be used. Caution should be exercised during the deployment of tarps on damaged equipment as a wet tarp may become energized and conduct hazardous current if it contacts live equipment. Also, firefighting foam should not be relied upon to block light.

12.22.2.6 When illuminated by artificial light sources such as fire department light trucks or an exposure fire, PV systems can produce electrical power sufficient to cause a lock-on hazard. Severely damaged PV arrays can produce hazardous conditions ranging from perception to electrocution. Damage to the array may result in the creation of new and unexpected circuit paths. These paths may include both array components (e.g., module frame, mounting racks, conduits, and so forth) and building components (e.g., metal roofs, flashings and gutters). Care must be exercised during all operations, both interior and exterior. Contacting a local professional PV installation company should be considered to mitigate potential hazards.

12.22.2.7 Damage to modules from tools may result in both electrical and fire hazards. The hazard may occur at the point of damage or at other locations depending on the electrical path. Metal roofs present unique challenges in that the surface is conductive, unlike other types such as shingle, ballasted, or single ply.

12.22.2.8 Severing of conductors in both metal and plastic conduit results in electrical and fire hazards. Care must be exercised during ventilation and overhaul.

12.22.2.9 Responding personnel must stay away from the roofline in the event of modules or sections of an array sliding off the roof.

12.22.2.10 Fires under an array but above the roof may breach roofing materials and decking allowing fire to propagate into the attic space.

12.23 Attic. Fast-moving fires with limited access are characteristics of attic fires. A critical aspect of these types of fires are structural collapse.

12.23.1 Many attic fires originate on the exterior of the structure from an adjacent structure fire, garage fire, motor vehicle fire, trash fire, porch or deck fire, mulch or vegetation fire, or wildland fire.

12.23.2 Use of plastics or combustibles such as vinyl siding in exterior wall assemblies can facilitate rapid fire spread into the attic space.

12.23.3 Exterior fires can transition to attic fires either directly via eave/soffit and wall vents or indirectly by burning through eaves/soffits, exterior walls and/or windows, and plumbing or electrical penetrations.

12.23.4 Rapid application of water from the exterior can inhibit exterior fire spread into the attic.

12.23.5 It should be recognized that residential occupancies equipped with fire sprinkler systems typically do not extend the protection to the attic area.

12.23.6 Continuous plastic ridge vents can melt and collapse on the opening of a peaked roof, creating an effective seal. Once the ridge vent seals, the eaves act as both the inlet and exhaust of air for the fire. The resultant restrictions in airflow can lead to a ventilation-limited fire with the extent of the fire potentially hidden during size-up. Smoke pulsing from the eaves can be an indicator that the ridge vent has melted, creating a seal.

12.23.7 Attic fires are typically ventilation-limited due to limited natural ventilation openings. Controlled openings created below the neutral plane (such as through the ceiling below the attic space) will not cause immediate growth and can provide access for suppression operations

12.23.8 For ventilation-limited fires, effective methods for the application of fire suppression water include a small hole in the ceiling and water from below, water introduced into the attic through the gable ends, and water applied to the underside of the roof by way of the eaves. While these methods are far less effective for well-vented attics, they are still preferable to flowing aerial streams directed into roof openings.

12.23.9 Wetting interior sheathing as part of offensive or defensive operations slows fire spread and reduces the potential for rapid fire growth, facilitating ventilation and access to the attic.

12.23.10 Vertical ventilation should be closely timed or limited until fire suppression water is available. In the absence of fire suppression water, vertical ventilation can result in uncontrollable fire growth, fire blow back into the occupied space, and potentially smoke explosions.

12.23.11 When fire in the attic space burns through the sheathing or out of the gable ends, the fire may become well-ventilated. In these cases, crews should be repositioned from the interior and transitioned to exterior operations. Traditional "top down" use of aerial devices and master streams through these openings fail to apply water to the underside of the roof deck or onto any burning material or contents that are not directly beneath or in the immediate vicinity of the hole. As an alternative, consider using aerial devices or portable ladders and handlines to open up the eaves and flow water into the attic from the "bottom up." This approach may result in controlling the fire enough to permit fire-fighting crews to transition back inside the structure to complete searches, suppression, and overhaul.

12.23.12 Attic construction affects hose stream penetration. The most effective water application takes into consideration the construction within the attic, using the natural channels created by the rafters or trusses to direct the water onto the vast majority of the surfaces.

12.23.13 Potential for structural collapse should be continually evaluated. Modern lightweight attic construction can collapse rapidly when exposed to fire conditions. If collapse becomes a concern, fire fighters should not be placed in the collapse zone. When transitioning to the interior after large amounts of water were flowed into the attic, it should be recognized that insulation will hold water and allow the ceiling to collapse in sections A defensive strategy should be strongly considered when the use of an offensive strategy would result in fire fighters performing fire-fighting operations under or above trusses that are compromised by fire or fire operations. If lightweight truss construction is exposed to fire and no rescue operations are required, a defensive strategy is highly recommended, as early collapse is likely.

12.23.14 Knee wall construction creates interconnected concealed spaces where the wooden structural members provide a relatively large surface area of exposed fuel along with air flow conducive to spreading fire. Knee walls in a finished attic create the potential for ventilation-limited fires with large amounts of fuel heated to near its ignition point in the spaces that surround interior operating crews. Subsequent ventilation at the roof or by breaching the knee wall from the interior provides the flow path to rapidly grow the fire to flashover. When the barrier between the concealed spaces and the occupied space fails or is breached, interior operating crews may become trapped between the newly created flow path and their means of egress. Even though there is a delay between making the breach and the change in conditions, once initiated, the transition to untenable conditions in the area of operation occur very rapidly.

12.23.15 The application of water should be applied on a knee wall fire at the source and toward the direction of spread before committing to the attic. Applying water utilizing the same path the fire took to enter the concealed space may be the most effective method at slowing fire growth, applying water through an exterior soffit or with the utilization of a piercing nozzle. Water application to the knee wall will not be effective until the source below it is controlled with direct water application. Consideration should be given to opening the floor below the knee wall.

12.23.16 The most effective approach for interior operations on knee wall fires is to control the source fire, cool the gasses prior to making large breaches in the barrier, and then aggressively open the knee walls to complete extinguishment, focusing on wetting the underside of the roof decking. The use of thermal imagers and penetrating (piercing) nozzles can be effective tools in suppression operations.

Chapter 13 Implementing NFPA 1700

13.1 Scope. This chapter addresses the implementation of NFPA 1700 within fire-fighting organizations.

13.2 Purpose. The purpose of this chapter is to provide assistance to AHJs in facilitating the implementation of science-based fire dynamics principles.

13.3 Application. The intent of this chapter is to apply the principles of science-based fire dynamics into an AHJ's cultural practice.

13.4 General. Implementation of new strategies, tactics, and tasks can be challenging for fire departments. Organizational bureaucracy, traditions, and department culture play a role in how new research findings are incorporated in department policies, procedures, and guidelines. Actual implementation of these changes to policies, procedures, and guidelines can be an additional challenge for an organization and requires long-term assessment and monitoring.

13.4.1* Organizational leaders and early adopters should be instructed on the value of incorporating science-based research within structure fire-fighting strategies and tactics.

13.4.2 A meeting should be held with stakeholders so they can provide input on the implementation plan. Stakeholders may include representatives from labor unions, volunteer associations, relevant instructor groups, and automatic and mutual aid departments. Involving a cross-section of operational personnel in this stakeholder meeting, across ranks and assignments, can help set the foundation for wide cultural acceptance in the organization.

13.4.3 The AHJ should establish an implementation work group consisting of individuals interested in change, subject matter experts, and those possessing the skills and abilities to navigate political and organizational cultural concerns. The work group should develop an implementation plan consisting of appropriate message delivery model(s).

13.4.4 Applicable research studies and training materials should be identified. Research studies and training resources from the UL Firefighter Safety Research Institute, National Institute of Standards and Technology, International Association of Fire Fighters, International Society of Fire Service Instructors, International Association of Fire Chiefs, and the Illinois Fire Safety Institute may be utilized.

13.4.5 Subject matter experts should be assigned to write policy, procedures, and guidelines. A multidisciplinary group (i.e., fire behavior specialists, hose and nozzle experts, recruit training cadre members, training officers, ventilation and forcible entry experts) should be assigned to write the policy. The policy writing may occur concurrently as the training materials are developed.

13.4.6 Consideration should be given to delivering the training prior to releasing official policy, procedures, and guidelines to allow personnel access to the information to understand the value and importance of science-based fire fighting and to develop the knowledge and skills to support such documents and fireground operations.

13.4.7 Science-based tactical considerations should be incorporated into all aspects of fireground operations, and existing training, policies, procedures, and guidelines should be updated. Forcible entry, rapid intervention, ventilation, search and rescue, and other related functions are inherently connected with structural fire-fighting operations. Policies, procedures, guidelines, and training content supporting these operations should be updated as new strategies and tactics are developed.

13.4.8 Training materials supporting the policy, procedures, and guidelines should be designed. Use of existing training materials developed by science-based research organizations devoted to fire service advancement should be considered. Departments can also develop their own customized message to address specific concerns of their organizations. A recognition of the potential challenges of cultural change in the fire service should also be included in the training, along with strategies to overcome them and evolve the organization.

13.4.9 The best method of knowledge-based training delivery should be identified. A preferred training delivery model may be different for each department. The training delivery model a department uses is dependent on the size, available training resources, time, and geography. Some departments may benefit from making some or all of the knowledge-based content available online and require access by each individual fire fighter. Other departments may only be able to deliver the training using instructor-led trainings. Additionally, a blended approach including both training models may serve to be beneficial.

13.4.10* Hands-on training should be provided to support the new policies, procedures, and guidelines. Training should focus on individual, company, and multi-company skills and tasks. Skills should progress from basic concept application to live-fire, multi-company drills.

13.4.11 The efficacy of the implementation model should be determined. After policies, procedures, and guidelines have been published and all forms of training delivered, assessment methods to determine the efficacy of the implementation model should be delivered. Requiring company officers and chiefs to report how new tactics were, or were not, used during structure fires should be considered.

13.4.12 Training should be revised and adjusted as required. Following the evaluation of operational behaviors on emergency incidents, training should be reviewed and adjusted where knowledge and skill gaps are identified.

Annex A Explanatory Material

Annex A is not a part of the recommendations of this NFPA document but is included for informational purposes only. This annex contains explanatory material, numbered to correspond with the applicable text paragraphs.

A.3.2.1 Approved. The National Fire Protection Association does not approve, inspect, or certify any installations, procedures, equipment, or materials; nor does it approve or evaluate testing laboratories. In determining the acceptability of installations, procedures, equipment, or materials, the authority having jurisdiction may base acceptance on compliance with NFPA or other appropriate standards. In the absence of such standards, said authority may require evidence of proper installation, procedure, or use. The authority having jurisdiction may also refer to the listings or labeling practices of an organization that is concerned with product evaluations and is thus in a position to determine compliance with appropriate standards for the current production of listed items.

A.3.2.2 Authority Having Jurisdiction (AHJ). The phrase "authority having jurisdiction," or its acronym AHJ, is used in NFPA documents in a broad manner, since jurisdictions and approval agencies vary, as do their responsibilities. Where public safety is primary, the authority having jurisdiction may be a federal, state, local, or other regional department or individual such as a fire chief; fire marshal; chief of a fire prevention bureau, labor department, or health department; building official; electrical inspector; or others having statutory authority. For insurance purposes, an insurance inspection department, rating bureau, or other insurance company representative may be the authority having jurisdiction. In many circumstances, the property owner or his or her designated agent assumes the role of the authority having jurisdiction; at government installations, the commanding officer or departmental official may be the authority having jurisdiction.

A.3.2.5 Listed. The means for identifying listed equipment may vary for each organization concerned with product evaluation; some organizations do not recognize equipment as listed unless it is also labeled. The authority having jurisdiction should utilize the system employed by the listing organization to identify a listed product.

A.3.3.35 Decontamination. Decontamination is sometimes abbreviated as "decon."

A.3.3.51 Energy Storage System (ESS). ESS(s) can include but is not limited to batteries, capacitors, and kinetic energy devices (e.g., fly wheels and compressed air). These systems can have ac or dc output for utilization and can include inverters and converters to change stored energy into electrical energy.

A.3.3.85 Flow Path. The following list details the types of flows in a flow path, how they are generated, and related characteristics:

(1) The flow is caused by pressure differences that result from temperature differences, buoyancy, expansion, wind impact, and HVAC systems.
(2) Flow characteristics include stratification within the boundaries of a compartment or at an opening, the degree of turbulence and its direction, velocity, and shape. These characteristics can often be identified by evaluating the smoke/air flows.
(3) At openings or within rooms, hallways, stairways, and shafts, the smoke/air flows may be classified as unidirectional, bidirectional, or dynamic.
(4) Multiple flow paths are possible within a structure fire, and there may be multiple combinations of inlets and/or outlets.
(5) Flow paths can be altered by fire fighting tactics.

A.3.3.99.3 Hot Zone. For a structure fire, the structure is part of the hot zone, regardless of what can be seen from the outside.

A.3.3.121 Incident Action Plan. It can include the identification of operational resources and assignments. It can also include attachments that provide direction and important information for management of the incident during one or more operational periods.

A.3.3.131 Latent Heat. When heat is added to a liquid fuel and it vaporizes into a gas phase fuel, the temperature of the liquid does not increase because we can add heat to a substance during its phase change and not see any rise in temperature; this is called "latent" or hidden heat.

A.3.3.134 Lightweight Construction. Lightweight construction can include, but is not limited to, the following:

(1) Lightweight wood structural members such as engineered-type trusses, laminated beams, oriented strand board (OSB), or other such products that are attached with lightweight nail plates or glued and pressed in place
(2) Lightweight metal structural members of light gauge metal in the form of bar trusses and other such materials

A.3.3.169 Rapid Fire Development. Rapid fire developments are subdivided into the two main categories of phenomena of flashover and smoke ignition.

A.3.3.188 Smoke Ignition. Smoke ignition is then further subdivided into three separate developments: smoke explosion, backdraft, and flash fire (propagating flame fronts including rollovers).

A.3.3.248 Watt (W). A watt is defined as one joule per second, a kilowatt is 1000 watts, and a megawatt is 1,000,000 watts.

A.4.8 Many governmental fire fighter training organizations and fire departments have incorporated fire dynamics and evidence-based practices into their training documents and/or their standard operational procedures or guidelines. The following is a list of those organizations and fire departments, but it is not all-inclusive:

(1) In the United States, examples of fire departments that have incorporated fire dynamics and evidence-based practices include the following:
    (a) Boston (MA) Fire Department
    (b) Chicago (IL) Fire Department
    (c) Cleveland (OH) Division of Fire

(d) Columbus (OH) Division of Fire
(e) Eau Claire (WI) Fire Department
(f) Fairfax County (VA) Fire and Rescue Department
(g) Fire Department City of New York (FDNY)
(h) Fort Worth (TX) Fire Department
(i) Hanover (VA) Fire EMS Department
(j) Houston (TX) Fire Department
(k) Laramie (WY) County Fire District #2
(l) Las Cruces (NM) Fire Department
(m) Los Angeles (CA) County Fire Department (LACoFD)
(n) Mesa (AZ) Fire and Medical Department
(o) Oklahoma City (OK) Fire Department
(p) Prince George's County (VA) Fire/Emergency Medical Services Department
(q) St. Petersburg (FL) Fire and Rescue
(r) San Jose (CA) Fire Department
(s) Tucson (AZ) Fire Department

(2) In Canada, many of the provincial organizations responsible for fire fighter training that have incorporated fire-dynamics-based fire tactics into their curriculums include the following:
(a) Justice Institute of British Columbia Fire and Safety
(b) Newfoundland Fire School
(c) Nova Scotia Fire School
(d) Ontario Fire College
(e) Ontario Association of Fire Training Officers
(f) IPIQ – Institut de protection contre les incendies du Québec
(g) Manitoba Emergency Services College

(3) Examples of Canadian fire departments that have incorporated fire dynamics and evidence-based practices include the following:
(a) District of North Vancouver Fire and Rescue Services
(b) Ottawa Fire Services
(c) Oakville Fire Department
(d) Hamilton Fire Department
(e) Calgary Fire Department
(f) Winnipeg Fire Paramedic Service
(g) Service d'Incendie de Montréal
(h) Halifax Regional Fire and Emergency
(i) Saint John Fire Department

(4) European fire departments that have implemented a fire dynamics training program include the following:
(a) Belgium: Brussels, Antwerp
(b) Croatia: Federal fire academy
(c) Finland: Federal fire academy
(d) France: Paris
(e) Germany: All 102 career departments especially the "big five": Berlin, Hamburg, Munich, Cologne, Frankfurt; all 20 state fire academies (main target group: volunteer fire departments all over the country)
(f) Greece: Thessaloniki
(g) Great Britain: Federal fire academy, some regional fire academies, London, Liverpool (Merseyside), and Birmingham
(h) Netherlands: Amsterdam, the Hague, and the national and regional fire academies
(i) Poland: Federal fire academy
(j) Sweden: The two federal academies: Stockholm and Gothenburg
(k) Spain: Madrid
(l) Switzerland: Both federal fire academies

A.6.5.13 Winds blowing into a closed fire compartment can lead to a high-pressure zone in the compartment. Under normal wind conditions, a room with only one opening will display a bidirectional air track. This will be either fuel-controlled (i.e., smooth flow) or ventilation-controlled (i.e., turbulent flow). In a wind-impacted scenario resulting from high winds, the opening can aggressively alternate from a total inlet to a total exhaust outlet with a range of unique vent profiles. Alternatively, a steady-state unidirectional flow path may also present a unique vent profile.

Smoke seen pulsing out of openings is a result of variations in pressure due to limited oxygen supply and indicates a ventilation-controlled fire. As the oxygen level decreases, so does the intensity of the combustion process. This condition, in turn, decreases the temperature and consequently the volume of hot smoke. This condition causes air to be drawn in, increasing the fire intensity and internal pressure until the air is consumed and the cycle starts over again. Audible indicators such as whistling noises may also help one to recognize the presence of pulsations. The whistling noises result from smoke being pushed in and out of the compartment through small gaps or openings, due to pressure variations. It should be noted that it might be difficult to notice this audible indicator above the background noise.

In some cases, pulsations can develop into a situation where the sudden opening of the compartment could lead to backdraft. Extreme caution should be exercised before creating any opening in these conditions. It is important for fire fighters to cool the smoke and surfaces while undertaking door control before tactical venting operations begin.

A.7.4.1.1 Traditional post-WWII home construction was typically one story in height with an area of 90 m^2 (1000 ft^2), consisting of many small volume rooms with 2.4 m^2 (8 ft^2) ceilings. Fires within these small homes tended to become ventilation controlled fairly quickly as the available oxygen was consumed by the fire. In contrast, modern homes have areas that run from 230 m^2 to 420 m^2 (2500 ft^2 to 4500 ft^2) with open concept floor plans, great rooms, or foyers with two-story high ceilings. The same fire within a larger volume will tend to grow in scale and be sustained given the available oxygen and the ability of buoyant smoke to spread, mix with air, and be collected in the upper regions of the great room due to the sloped (angled) ceiling well above the fire. Like the smaller volume home, the larger fire will eventually become ventilation controlled. The difference between the two scenarios is the lack of protective compartmentation, degree of fire development, and ultimate danger to occupants and responders due to rapid fire progress upon the reintroduction of air.

A.7.4.2 Once finishes have absorbed the heat energy, they will tend to hold it and this will make it difficult to cool the smoke. Metal claddings have a low thermal mass and an inability to absorb heat but transfers that heat quickly through conduction to other potential combustibles.

Well-insulated linings will hold the heat energy in the fire compartment and this may accelerate fire growth. Combustible linings will produce pyrolysis gases as they are heated to about 572°F to 752°F (300°C to 400°C) and this will contribute to fuel accumulating in the upper region of the fire room or compartment.

A.7.5.1 The fire-resistance rating is based upon assembly testing utilizing ASTM E119, *Standard Test Methods for Fire Tests of Building Construction and Materials.* A Type I structure will have a minimum of a 3-hour fire-resistance rating. The goal is to compartmentalize and protect the structural integrity of the building permitting interior fire-fighting operations and the evacuation of occupants. An ASTM E119 fire-resistance rating does not necessarily mean an assembly will protect the structure for the designated rating consistently. It is a testing system that utilizes the same testing formulas and stresses to compare dissimilar materials with the results reported in an hourly rating. Fire service members should be aware of the levels of ratings and expectant performances. This is beyond the scope of this document but an important consideration.

A.7.5.1.2.3.1 Stack effect is the movement of air into and out of buildings, chimneys, flue gas stacks, or other containers, resulting from air buoyancy. Buoyancy occurs due to a difference in indoor-to-outdoor air density resulting from temperature and moisture differences. The buoyant force creates differential pressures that can have significant impact on SAHF movement and control. Stack effect is usually associated with tall buildings due to the numerous leakage paths, shafts, and ductwork that are compounded by operational practices and occupant behavior when opening and failing to close doors. Stack effect can be used to great advantage in clearing stairwells during high-rise operations and even more so in winter conditions.

It should be noted that stack effects in winter are significant even in a one- or two-story house and very significant in tall buildings. Reverse stack effects are another possibility in warm climates within air-conditioned buildings, where smoke flow can be reversed and flows down a shaft can confuse the observer as to the actual fire location.

Extremely low ambient temperatures, for example, can cause rapid cooling of discharged smoke. The cooler smoke will have decreased buoyancy, and entrained water will condense and cause larger particles normally lofted in the smoke plume to be precipitated out to produce a dense white smoke. When combined with "low atmospheric pressure," an inversion layer can form that will prevent the smoke from rising.

The lack of buoyancy in the smoke may suggest to the observer that the fire intensity is not that great when in fact it may be quite severe.

A.7.5.2.1 While these structural components are noncombustible, they tend to fail very early in a fire when exposed to elevated heat. Steel will elongate and deform when exposed to temperatures of 1000 °F (538°C). The endurance of the steel depends on the mass of the steel. The smaller the structural element the less time until structural compromise. Many of the steel structural components in Type IIB are lightweight and will fail early in an event.

A.7.5.3 The United States fire service has a long history of battling fires in this type of construction. More fire fighters have lost their lives in battling residential fires in Type III construction than other forms of construction. Fire fighters should not develop a level of complacency because they encounter a noncombustible exterior. This may assist in reducing the risk of the fire propagating to the exposure, but the common concealed spaces and combustible structural components combine to make this a very dangerous occupancy to do business.

Fire fighters may encounter Type III construction in a wide variety of occupancies, but common occupancies include residential, mercantile, and mixed use. Quick knock down, occupant rescue, and opening void spaces are high priorities in Type III construction.

A.7.5.4.1 Modern Type IV structures utilize a more modern approach to heavy timber. Due to environmental concerns and supply challenges within the timber industry, many Type IV structures are using Glulam or laminated lumber in place of heavy timber. These products are created using pieces of dimensional lumber glued and compressed together to form one solid structural component. The resulting product is designed to carry and distribute an impressive load. The debate is how these structural members perform under fire conditions. Incident commanders should understand the type of construction within the Type IV construction when the structure is involved with fire.

Another form of construction that may fall under the Type IV construction category that is gaining interest is cross laminated timber (CLT). CLT is simply the use of layering of structural lumber boards stacked crosswise (typically at 90 degrees) and glued together on their wide faces and, sometimes, on the narrow faces as well. Manufacturers will layer dimensional lumber, which can consist of 2 × 4, 2 × 6, 2 × 8, and so forth. They will initially set a layer of lumber horizontally, then vertically, then horizontally, and so on until reaching the desired thickness. This thickness may be seven to 11 layers or greater. Manufacturers then calculate the inherent fire-resistance rating based on the established char rate for the used species. Completed products resemble a large block, and they are placed as a wall, floor, or ceiling. The result is similar to modular construction. The CLT slabs are mechanically connected and reinforced with adhesives. This is a rapidly developing market, and fire service members should monitor proposed construction projects in their jurisdictions to understand the buildings in their response districts.

At this time, CLT structures have been proposed for use in high-rise structures, but research is ongoing. Fire services members should be aware of the positives and negatives of this type of construction and remain alert for updated research as it becomes available.

A.7.5.5 By far the majority of fires encountered by the U.S. Fire Service occur in Type VB construction. Single- and two-family structures are prime examples of Type VB. It would be easy to classify most single-family structures as Type VB and lump the various structural components into one category, but it is not that simple.

A.8.2 There are many other limitations that are important to fire fighters such as mechanical, electrical, reliability, and aging testing.

A.8.14(1) The sample is to be sealed at one end, filled with tap water, sealed at the other end, and conditioned for 24 hours in a room maintained at 73°F (23°C). The steel block is to be heated for at least 16 hours in an oven maintained at 500°F (260°C), removed from the oven, and within 5 seconds placed so that the longitudinal axis of the steel block is perpendicular to the longitudinal axis of the sample. The contact area is to be the midpoint of the 2½ in. (63.5 mm) wide side of the steel block and the midpoint of the sample. A metal knife edge is to be used as a support near one end of the steel block to balance the steel block and obtain maximum force on the hose. After 60 seconds, the steel block is to be removed. After the hose has cooled, it is to be laid straight and subjected to the hydrostatic strength test.

A.9.7.3 Consideration should also be given to HVAC status in the building and factors such as air movement via the stack effect in high-rise structures. When evaluating exterior openings, a number of observations can be made. Influences such as fire location relative to the opening, stage of fire development, compartmentation inside the building, wind conditions on the exterior, and the length of time that an opening has been open or closed will all play a part into the conditions at an opening.

During the initial survey, fire companies may take specific action to close doors or windows that were already open in order to limit fire growth and control flow paths, or to open windows or doors for entry, water application, or coordinated ventilation related to fire control. When assessing the overall ventilation profile, consideration should be paid to the fact that fire burns in proportion to the oxygen in which it receives, and limiting ventilation prior to the application of water is typically an effective method to impede fire growth. When fire fighters and fire officers choose to limit ventilation by closing doors, or by controlling doors in a mostly closed position after forcing entry, a brief sweep or check for victims in the immediate area is necessary prior to closure. Doors may have been left open by fleeing occupants, opened by earlier-arriving responders such as police officers, or breached/burned-through by heat and fire conditions.

When evaluating the ventilation profile, strategic considerations include assessing the stage and progression of the fire in different areas of the building based on observed conditions at openings both visually and with the thermal imager. In the event that an offensive strategy is selected, any interior fire attack should be made on the inlet portion of the flow path if possible, with the airflow and/or wind at the back of the advancing fire crew. Continuous evaluation and management of the ventilation profile is particularly important in the offensive strategy, as window openings may be created to facilitate coordinated fire attack, and entry doors may be purposely controlled through partial closure or by flow-path control devices (i.e., curtains). Every building has its own individual ventilation profile.

A.9.7.4 Evaluation of the height and turbulence of any existing neutral plane is a critical factor in sizing up an opening. As a room progresses to flashover, the level of the neutral plane in the opening will lower, and the turbulence of the inlet flow at the boundary layer will increase. In the absence of a defined horizontal neutral plane, an opening in a fire building is likely functioning exclusively as an inlet or an outlet. Dynamic smoke and fire presentation at an opening, or a puffing or pulsation-type appearance, may indicate wind-impacted conditions. The incident commander may initiate tactics such as closing outside openings while performing his or her assessment of fire conditions.

A.12.9 2013 U.S. Census data indicates that the average dwelling size is approximately 2600 ft^2, and NFPA 1710 utilizes a two-story 2000 ft^2 house for initial deployment staffing considerations. Large estate dwellings over 3000 ft^2 can present significant challenges relative to ventilation and fire suppression and require additional resources.

A.13.4.1 Organizations incorporating science-based research might benefit from an understanding and use of the diffusion of innovation (DOI) theory.

The DOI theory, developed by E.M. Rogers in 1962, is one of the oldest social science theories. It originated in communication to explain how, over time, an idea or product gains momentum and diffuses (or spreads) through a specific population or social system. The end result of this diffusion is that people, as part of a social system, adopt a new idea, behavior, or product. Adoption means that a person does something differently than what they had previously (e.g., purchase or use a new product, acquire and perform a new behavior). The key to adoption is that the person must perceive the idea, behavior, or product as new or innovative. It is through this that diffusion is possible.

Adoption of a new idea, behavior, or product (i.e., “innovation”) does not happen simultaneously in a social system; rather it is a process whereby some people are more apt to adopt the innovation than others. Researchers have found that people who adopt an innovation early have different characteristics than people who adopt an innovation later. When promoting an innovation to a target population, it is important to understand the characteristics of the target population that will help or hinder adoption of the innovation. There are five established adopter categories, as shown in Figure A.13.4.1, and while the majority of the general population tends to fall in the middle categories, it is still necessary to understand the characteristics of the target population. When promoting an innovation, there are different strategies used to appeal to the different adopter categories:

(1) *Innovators*. These are people who want to be the first to try the innovation. They are venturesome and interested in new ideas. These people are very willing to take risks, and are often the first to develop new ideas. Very little, if anything, needs to be done to appeal to this population.
(2) *Early Adopters*. These are people who represent opinion leaders. They enjoy leadership roles, and embrace change opportunities. They are already aware of the need to change and so are very comfortable adopting new ideas. Strategies to appeal to this population include how-to manuals and information sheets on implementation. They do not need information to convince them to change.
(3) *Early Majority*. These people are rarely leaders, but they do adopt new ideas before the average person. That said, they typically need to see evidence that the innovation works before they are willing to adopt it. Strategies to appeal to this population include success stories and evidence of the innovation's effectiveness.
(4) *Late Majority*. These people are skeptical of change, and will only adopt an innovation after it has been tried by the majority. Strategies to appeal to this population include information on how many other people have tried the innovation and have adopted it successfully.
(5) *Laggards*. These people are bound by tradition and very conservative. They are very skeptical of change and are the hardest group to bring on board. Strategies to appeal to this population include statistics, fear appeals, and pressure from people in the other adopter groups.

The stages by which a person adopts an innovation, and whereby diffusion is accomplished, include awareness of the need for an innovation, decision to adopt (or reject) the innovation, initial use of the innovation to test it, and continued use of the innovation. There are five main factors that influence adoption of an innovation, and each of these factors is at play to a different extent in the five adopter categories:

(1) *Relative Advantage*. The degree to which an innovation is seen as better than the idea, program, or product it replaces.
(2) *Compatibility*. How consistent the innovation is with the values, experiences, and needs of the potential adopters.
(3) *Complexity*. How difficult the innovation is to understand and/or use.
(4) *Triability*. The extent to which the innovation can be tested or experimented with before a commitment to adopt is made.
(5) *Observability*. The extent to which the innovation provides tangible results.

There are several limitations of the DOI theory, which include the following:

(1) Much of the evidence for this theory, including the adopter categories, did not originate in public health and it was not developed to explicitly apply to adoption of new behaviors or health innovations.
(2) It does not foster a participatory approach to adoption of a public health program.
(3) It works better with adoption of behaviors rather than cessation or prevention of behaviors.
(4) It doesn't take into account an individual's resources or social support to adopt the new behavior (or innovation).

This theory has been used successfully in many fields including communication, agriculture, public health, criminal justice, social work, and marketing. In public health, the DOI theory is used to accelerate the adoption of important public health programs that typically aim to change the behavior of a social system. For example, an intervention to address a public health problem is developed, and the intervention is promoted to people in a social system with the goal of adoption (based on the DOI theory). The most successful adoption of a public health program results from understanding the target population and the factors influencing their rate of adoption.

A.13.4.10 Individual skills may include compartmentation and door control to limit fire growth and protect occupants. Company-level skills may include applying exterior fire streams. Multi-company level skills may include coordination of ventilation with fire control. Small fire behavior demonstrations, such as candles and reduced-scale fire dynamics and flow path models, can be an effective method for demonstrating foundational fire dynamics concepts in training.

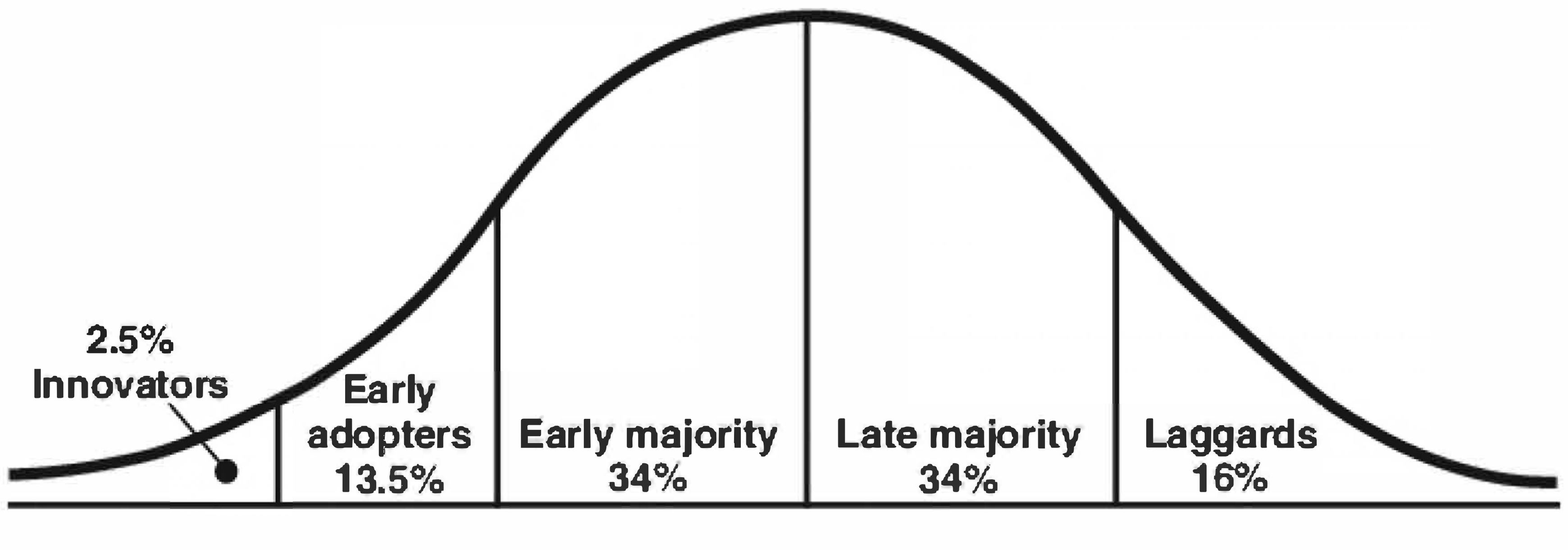

FIGURE A.13.4.1 Division of Innovation Curve. ***(Source: http://blog.leanmonitor.com/early-adopters-allies-launching-product/.)***

Annex B Template Standard Operating Procedures/Guidelines

This annex is not a part of the recommendations of this NFPA document but is included for informational purposes only.

B.1 Purpose. The purpose of this annex is provide a template to reflect written policies, procedures, and guidelines, including strategy tactics and tasks for structural fire fighting (i.e., standard operating procedures (SOP), standard operating guidelines (SOG), fire fighting procedures).

B.2 Background. In 1999, the U.S. Fire Administration published a FEMA document, "Developing Effective Standard Operating Procedures for Fire and EMS Departments." Since the publication of this report efforts have been made to improve the development of SOPs. Two reports/papers are noted here: *Development of Emergency Responder SOPs/SOGs Using Crowdsourcing to Address Electric Vehicle Fires* (July 2014) and "Development of Best Practice Standard Operating Procedures for Prevention of Fireground Injuries" (2014). The basis for this guide's template is based on work by the Fire Protection Research Foundation, which included gathering and reviewing SOPs and SOGs from a range of fire departments in North America, including career, volunteer, and combination departments.

B.3 Outline. An SOP for structural fire fighting should, at minimum, include the 12 sections identified in B.3.1 through B.3.12.

B.3.1 Title. The title should clearly indicate the type of SOP or SOG (e.g., for structural fire fighting).

B.3.2 Date of Implementation/Publication. The implementation/publication date should indicate the date on which the SOP was implemented. This will be used to inform users of the relevancy of the information contained within the SOP to determine whether a revision should be considered.

B.3.3 Revision Date. The most recent date of revision should be clearly indicated on the front page of the SOP. Note, if it is the first edition of the SOP, the revision date may be the same as the date of implementation. This revision date is intended to enable the user to know how current the information is that is contained within the SOP.

B.3.4 Name of Fire Department. The name of the fire department should be provided to clearly indicate which fire department the SOP is specifically tailored to.

B.3.5 Purpose and Scope. A purpose/scope of an SOP/SOG provides the reader with information on how the SOP should be enforced, the type of incident(s) that the procedures apply to (e.g., structure fire, motor vehicle fire, high-rise fire, and so forth), the reasoning on the development of the SOP/SOG, and which personnel the SOP/SOG applies to.

B.3.6 Table of Contents. A table of contents within the SOP/SOG gives the reader a brief view of the entire SOP/SOG. This can be useful for quickly finding or referencing a certain section of the SOP/SOG and providing organization to the document.

B.3.7 Definitions and Terminology. This section of the SOP/SOG should provide clear definitions of terminology used throughout the SOP/SOG. This additional explanatory material should provide context and assist the reader in understanding the SOP/SOG.

B.3.8 Risk Assessment. An SOP/SOG should contain considerations for applying a risk-based approach to structural firefighting. All fire-fighting and rescue operations involve an inherent level of risk to fire fighters. A basic level of risk is recognized and accepted, in a measured and controlled manner, in efforts that are routinely employed to save lives and property.

For example, the risk assessment could consider factors such as the risk to building occupants, building characteristics, fire factors, and fire-fighting capabilities. The SOP/SOG should specify the risk assessment methodologies implemented for response to any structure fire. A risk matrix should also be contained within this section of the SOP/SOG.

B.3.9 Operational Responsibilities. The operational responsibilities section provides the reader with the necessary steps to take upon arrival at the scene. Operational responsibilities may be defined based on different types of companies/units/apparatus/members. This section should include tactical considerations and safety considerations, as well as considerations specific to apparatus and corresponding personnel.

Tactical considerations are of critical importance within the SOP/SOG. It provides the reader with the appropriate fire attack methods that should be used, whether it be every situation or specific fire scenarios. Such tactics might include ventilation techniques, size-up, suppression, and so on.

Safety considerations may include specific areas of concern that the first responders should be aware of. These can be related to a certain type of incident or a commonly experienced safety concern. Safety considerations provide the first responders with a general idea of the risks associated with their firefighting activities.

B.3.10 Responsibilities of Command/Incident Management System. The SOP/SOG may contain techniques, methods, or best practices for managing basic or significant incidents. These techniques will be defined in a specific incident management section within the SOP/SOG, intended to be applied by necessary first responders. The incident management section may provide a step-by-step guideline on effective incident management or a collection of appropriate incident management techniques.

B.3.11 References. An SOP/SOG may contain reference to scientific material that was used to develop the SOP/SOG. The references will most likely pertain to fire-fighting tactics or operational responsibilities because these sections may require evidence that the material is appropriate and represents the best practices.

If the SOP/SOG contains content that has been influenced from scientific literature but does not reference a singular piece of work, this should be addressed in this section as well.

B.3.12 Appendix. The appendices are intended to provide the reader with information supplemental to the SOP/SOG material. Such appendices may include further discussion on tactics or responsibilities found in the SOP/SOG.

Annex C National Fallen Firefighters Foundation (NFFF)

This annex is not a part of the recommendations of this NFPA document but is included for informational purposes only.

C.1 "16 Firefighter Life Safety Initiatives." In 2004, the NFFF held an unprecedented gathering of the fire service leadership when more than 200 individuals assembled in Tampa, Florida to focus on the troubling question of how to prevent line-of-duty deaths and injuries. Every year approximately 100 fire fighters lose their lives in the line of duty in the United States — about one every 80 hours. Every identifiable segment of the fire service was represented and participated in the summit.

The first Firefighter Life Safety Summit marked a significant milestone, because it not only gathered all segments of the fire service behind a common goal, but it also developed the "16 Firefighter Life Safety Initiatives." The summit attendees agreed that the "16 Firefighter Life Safety Initiatives" serve as a blueprint to reduce line-of-duty deaths and injuries. In 2014, a second Life Safety Summit was held and more than 300 fire service leaders gathered. At the second Firefighter Life Safety Summit, the "16 Firefighter Life Safety Initiatives" were reaffirmed as being relevant to reduce line-of-duty deaths and injuries.

C.2 NFFF's "16 Firefighter Life Safety Initiatives."

(1) Define and advocate the need for a cultural change within the fire service relating to safety; incorporating leadership, management, supervision, accountability, and personal responsibility.
(2) Enhance the personal and organizational accountability for health and safety throughout the fire service.
(3) Focus greater attention on the integration of risk management with incident management at all levels, including strategic, tactical, and planning responsibilities.
(4) All fire fighters must be empowered to stop unsafe practices.
(5) Develop and implement national standards for training, qualifications, and certification (including regular recertification) that are equally applicable to all fire fighters based on the duties they are expected to perform.
(6) Develop and implement national medical and physical fitness standards that are equally applicable to all fire fighters, based on the duties they are expected to perform.
(7) Create a national research agenda and data collection system that relates to the initiatives.
(8) Utilize available technology wherever it can produce higher levels of health and safety.
(9) Thoroughly investigate all fire fighter fatalities, injuries, and near misses.

(10) Grant programs should support the implementation of safe practices and/or mandate safe practices as an eligibility requirement.
(11) National standards for emergency response policies and procedures should be developed and championed.
(12) National protocols for response to violent incidents should be developed and championed.
(13) Fire fighters and their families must have access to counseling and psychological support.
(14) Public education must receive more resources and be championed as a critical fire and life safety program.
(15) Advocacy must be strengthened for the enforcement of codes and the installation of home fire sprinklers.
(16) Safety must be a primary consideration in the design of apparatus and equipment.

Annex D Informational References

D.1 Referenced Publications. The documents or portions thereof listed in this annex are referenced within the informational sections of this guide and are not advisory in nature unless also listed in Chapter 2 for other reasons.

D.1.1 NFPA Publications.

NFPA 1710, *Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments*, 2020 edition.

D.1.2 Other Publications.

D.1.2.1 ASTM Publications. ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959.

ASTM E119, *Standard Test Methods for Fire Tests of Building Construction and Materials*, 2015.

D.1.2.2 NFFF Publications. National Fallen Firefighters Foundation, P.O. Drawer 498, Emmitsburg, MD 21727.

"16 Firefighter Life Safety Initiatives," 2004.

D.1.2.3 Other Publications.

Duncan, Michael D; Littau, Sally R; Kurzius-Spencer, Margaret; Burgess, Jefferey L., "Development of Best Practice Standard Operating Procedures for Prevention of Fireground Injuries," *Fire Technology;* Norwell Vol. 50, Issue 5, Springer Science & Business Media, September 2014.

Everett M. Rogers, *Diffusion of Innovations*, Fifth Edition, Free Press, New York, 2003.

Fire Protection Research Foundation, *Development of Emergency Responder SOPs/SOGs Using Crowdsourcing to Address Electrical Vehicle Fires*, Quincy MA, 2014.

United States Fire Administration, *Guide to Developing Effective Standard Operating Procedures for Fire and EMS Departments*, FA-197, Emmitsburg, MD: Department of Homeland Security, Federal Emergency Management Agency, 1999.

D.2 Informational References. The following documents or portions thereof are listed here as informational resources only. They are not directly referenced in this guide.

D.2.1 ANSI Publications. American National Standards Institute, Inc., 25 West 43rd Street, 4th Floor, New York, NY 10036.

ANSI B46.1, *Surface Texture*, 1978.

ANSI S1.13, *Methods for Measurement of Sound Pressure Level®*, 2005.

ANSI Y1.1, *Abbreviations for Use on Drawings and Text*, 1972.

ANSI Y14.SM, *Dimensioning and Tolerancing*, 1982.

ANSI Z88.2, *Practices for Respiratory Protection.*

ANSI/UL 913, *Standard for Intrinsically Safe Apparatus and Associated Apparatus for Use in Class I, II, III, Division 1, Hazardous (Classified) Locations*, sixth edition.

D.2.2 ASTM Publications. ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959.

ASTM B117, *Standard Practice for Operating Salt Spray (Fog) Apparatus*, 2003.

D.2.3 ISO Publications. International Organization for Standardization, ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland.

ISO 9001, *Quality management systems — Requirements*, 2000.

ISO/IEC 17011, *Conformity assessment — General requirements for accreditation bodies accrediting conformity assessment bodies*, 2004.

ISO/IEC 17021, *Conformity assessment — Requirements for bodies providing audit and certification of management systems*, 2006.

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*, 2005.

ISO 17493, *Clothing and equipment for protection against heat — Test method for convective heat resistance using a hot air circulating oven*, 2000.

ISO Guide 27, *Guidelines for corrective action to be taken by a certification body in the event of misuse of its mark of conformity*, 1983.

ISO Guide 62, *General requirements for bodies operating assessment and certification/ registration of quality systems*, 1996.

D.2.4 Fire Administration Publications. U.S. Fire Administration, 16825 South Seton Avenue, Emmitsburg, MD 21727.

U.S. Fire Administration, Operational Considerations for Highrise Firefighting, USFA-TR-082.

D.2.5 U.S. Government Publications. U.S. Government Publishing Office, 732 North Capitol Street, NW, Washington, DC 20401-0001.

DHHS 42, Code of Federal Regulations, Part 84, "Respiratory Protective Devices."

DOT 49, Code of Federal Regulations, 180.205, "General requirements for requalification of specification cylinders."

DOT 49, Code of Federal Regulations, 180.213, "Requalification markings."

OSHA 29, Code of Federal Regulations, 1910.134, "Respiratory Protection."

D.2.6 Other Publications.

Colburn, D, et al., "A Comparison of Cooling Techniques in Firefighters After a Live Burn Evolution," *Prehosp Emerg Care,* 15(2), 2011.

Dickinson, E. T., and M. A. Wieder, *Emergency Incident Rehabilitation*, 2nd edition. Upper Saddle River, NJ, Pearson Education, 2004.

Espinoza M., Contreras M. "Safety and Performance Implications of Hydration, Core Body Temperature and Post Incident Rehabilitation." Orange County Fire Authority (CA) December 2007.

Horn, G.P., Blevins, S., Fernhall, B., and Smith, D.L. (2013) "Core temperature and heart rate response to repeated bouts of firefighting activities" *Ergonomics.* 56(9):1465-73. doi: 10.1080/00140139.2013.818719. Epub 2013 Jul 22.

Horn, G.P., DeBlois, J., Shalmyeva, I., Smith, D.L., (2012) "Quantifying dehydration in the Fire Service using field methods and novel devices", *Prehospital Emergency Care* 16(3), 347-355. DOI: 10.3109/10903127.2012.664243.

Horn, G.P., Gutzmer, S., Fahs, C.A., Petruzzello, S.J., Goldstein, E., Fahey, G.C., Fernhall, B., Smith, D.L., (2011) "Physiological recovery from firefighting activities in rehabilitation and beyond", *Prehospital Emergency Care* 15(2), 214-225.

Hostler, D., et al., "Comparison of Active Cooling Devices with Passive Cooling for Rehabilitation of Firefighters Performing Exercise in Thermal Protective Clothing: A Report from the Fireground Rehab Evaluation (FIRE) Trial," *Prehosp Emerg Care,* 14(3), 2010.

Madrzykowski, D., and C. Weinschenk, *Understanding and Fighting Basement Fires*, UL Firefighter Safety Research Institute, Columbia, MD, March 27, 2018.

McLellan, T. M., and G. A. Selkirk, "The Management of Heat Stress for the Firefighter," Defence Research and Development Canada, 2005.

National Oceanic and Atmospheric Administration, National Weather Service Wind Chill–Temperature (WCT) Index.

Sawka, M. N., and K. B. Pandolf, "Effects of Body Water Loss on Physiological Function and Exercise Performance." C. V. Gisolfi and D. R. Lamb (eds.), *Fluid Homeostasis During Exercise.* Benchmark Press, Indianapolis, IN, 1-38 (1990).

Sawka, M. N., and K. B. Pandolf, "Physical Exercise in Hot Climates: Physiology, Performance, and Biomedical Issues," *Medical Aspects of Harsh Environments*, Vol. 1, C. B. Wenger and R. S. Pozos. Washington, DC: Borden Institute, 2002.

Smith, D. L., and S. J. Petruzzello, "Selected Physiological and Psychological Responses to Live-Fire Drills in Different Configurations of Firefighting Gear," *Ergonomics*, 41(8), 1141-1154 (1998).

Smith, D. L., S. J. Petruzzello, M. A. Chludzinski, J. J. Reed, and J. A. Woods, "Effects of Strenuous Live-Fire Firefighting Drills on Hematological, Blood Chemistry, and Psychological Measures," *Journal of Thermal Biology*, 26(4-5):375-380 (2001).

Smith, D. L., S. J. Petruzzello, and T. S. Manning, "The Effect of Strenuous Live-Fire Drills on Cardiovascular and Psychological Responses of Recruit Firefighters," Ergonomics, 44(3): 244-254 (2001).

U.S. Fire Administration (USFA). FA-114, *Emergency Incident Rehabilitation.* Emmitsburg, MD: USFA July 1992. vfdb (German Fire Protection Association); Recommendations for operational hygiene in the course of fire fighting, March 2014.

D.2.7 Internet References.

https://www.fsi.illinois.edu/content/research

https://ulfirefightersafety.org

https://www.nist.gov/el/fire-research-division-73300/firegov-fire-service

https://www.cdc.gov/niosh/fire/default.html

http://www.isfsi.org/p/cl/et/cid=1000

D.3 References for Extracts in Informational Sections. (Reserved)

Index

Sequence of Events for the Standards Development Process

Once the current edition is published, a Standard is opened for Public Input.

Step 1 – Input Stage

- Input accepted from the public or other committees for consideration to develop the First Draft
- Technical Committee holds First Draft Meeting to revise Standard (23 weeks); Technical Committee(s) with Correlating Committee (10 weeks)
- Technical Committee ballots on First Draft (12 weeks); Technical Committee(s) with Correlating Committee (11 weeks)
- Correlating Committee First Draft Meeting (9 weeks)
- Correlating Committee ballots on First Draft (5 weeks)
- First Draft Report posted on the document information page

Step 2 – Comment Stage

- Public Comments accepted on First Draft (10 weeks) following posting of First Draft Report
- If Standard does not receive Public Comments and the Technical Committee chooses not to hold a Second Draft meeting, the Standard becomes a Consent Standard and is sent directly to the Standards Council for issuance (see Step 4) or
- Technical Committee holds Second Draft Meeting (21 weeks); Technical Committee(s) with Correlating Committee (7 weeks)
- Technical Committee ballots on Second Draft (11 weeks); Technical Committee(s) with Correlating Committee (10 weeks)
- Correlating Committee Second Draft Meeting (9 weeks)
- Correlating Committee ballots on Second Draft (8 weeks)
- Second Draft Report posted on the document information page

Step 3 – NFPA Technical Meeting

- Notice of Intent to Make a Motion (NITMAM) accepted (5 weeks) following the posting of Second Draft Report
- NITMAMs are reviewed and valid motions are certified by the Motions Committee for presentation at the NFPA Technical Meeting
- NFPA membership meets each June at the NFPA Technical Meeting to act on Standards with "Certified Amending Motions" (certified NITMAMs)
- Committee(s) vote on any successful amendments to the Technical Committee Reports made by the NFPA membership at the NFPA Technical Meeting

Step 4 – Council Appeals and Issuance of Standard

- Notification of intent to file an appeal to the Standards Council on Technical Meeting action must be filed within 20 days of the NFPA Technical Meeting
- Standards Council decides, based on all evidence, whether to issue the standard or to take other action

Notes:

1. Time periods are approximate; refer to published schedules for actual dates.
2. Annual revision cycle documents with certified amending motions take approximately 101 weeks to complete.
3. Fall revision cycle documents receiving certified amending motions take approximately 141 weeks to complete.

Committee Membership Classifications[1,2,3,4]

The following classifications apply to Committee members and represent their principal interest in the activity of the Committee.

1. M *Manufacturer:* A representative of a maker or marketer of a product, assembly, or system, or portion thereof, that is affected by the standard.
2. U *User:* A representative of an entity that is subject to the provisions of the standard or that voluntarily uses the standard.
3. IM *Installer/Maintainer:* A representative of an entity that is in the business of installing or maintaining a product, assembly, or system affected by the standard.
4. L *Labor:* A labor representative or employee concerned with safety in the workplace.
5. RT *Applied Research/Testing Laboratory:* A representative of an independent testing laboratory or independent applied research organization that promulgates and/or enforces standards.
6. E *Enforcing Authority:* A representative of an agency or an organization that promulgates and/or enforces standards.
7. I *Insurance:* A representative of an insurance company, broker, agent, bureau, or inspection agency.
8. C *Consumer:* A person who is or represents the ultimate purchaser of a product, system, or service affected by the standard, but who is not included in (2).
9. SE *Special Expert:* A person not representing (1) through (8) and who has special expertise in the scope of the standard or portion thereof.

NOTE 1: "Standard" connotes code, standard, recommended practice, or guide.

NOTE 2: A representative includes an employee.

NOTE 3: While these classifications will be used by the Standards Council to achieve a balance for Technical Committees, the Standards Council may determine that new classifications of member or unique interests need representation in order to foster the best possible Committee deliberations on any project. In this connection, the Standards Council may make such appointments as it deems appropriate in the public interest, such as the classification of "Utilities" in the National Electrical Code Committee.

NOTE 4: Representatives of subsidiaries of any group are generally considered to have the same classification as the parent organization.

Submitting Public Input / Public Comment Through the Online Submission System

Following publication of the current edition of an NFPA standard, the development of the next edition begins and the standard is open for Public Input.

Submit a Public Input

NFPA accepts Public Input on documents through our online submission system at www.nfpa.org. To use the online submission system:

- Choose a document from the List of NFPA codes & standards or filter by Development Stage for "codes accepting public input."
- Once you are on the document page, select the "Next Edition" tab.
- Choose the link "The next edition of this standard is now open for Public Input." You will be asked to sign in or create a free online account with NFPA before using this system.
- Follow the online instructions to submit your Public Input (see www.nfpa.org/publicinput for detailed instructions).
- Once a Public Input is saved or submitted in the system, it can be located on the "My Profile" page by selecting the "My Public Inputs/Comments/NITMAMs" section.

Submit a Public Comment

Once the First Draft Report becomes available there is a Public Comment period. Any objections or further related changes to the content of the First Draft must be submitted at the Comment Stage. To submit a Public Comment follow the same steps as previously explained for the submission of Public Input.

Other Resources Available on the Document Information Pages

Header: View document title and scope, access to our codes and standards or NFCSS subscription, and sign up to receive email alerts.

Current & Prior Editions	Research current and previous edition information.
Next Edition	Follow the committee's progress in the processing of a standard in its next revision cycle.
Technical Committee	View current committee rosters or apply to a committee.
Ask a Technical Question	For members, officials, and AHJs to submit standards questions to NFPA staff. Our Technical Questions Service provides a convenient way to receive timely and consistent technical assistance when you need to know more about NFPA standards relevant to your work.
News	Provides links to available articles and research and statistical reports related to our standards.
Purchase Products & Training	Discover and purchase the latest products and training.
Related Products	View related publications, training, and other resources available for purchase.

Information on the NFPA Standards Development Process

I. Applicable Regulations. The primary rules governing the processing of NFPA standards (codes, standards, recommended practices, and guides) are the NFPA *Regulations Governing the Development of NFPA Standards (Regs)*. Other applicable rules include NFPA *Bylaws*, NFPA *Technical Meeting Convention Rules*, NFPA *Guide for the Conduct of Participants in the NFPA Standards Development Process*, and the NFPA *Regulations Governing Petitions to the Board of Directors from Decisions of the Standards Council*. Most of these rules and regulations are contained in the *NFPA Standards Directory*. For copies of the *Directory*, contact Codes and Standards Administration at NFPA headquarters; all these documents are also available on the NFPA website at “www.nfpa.org/regs.”

The following is general information on the NFPA process. All participants, however, should refer to the actual rules and regulations for a full understanding of this process and for the criteria that govern participation.

II. Technical Committee Report. The Technical Committee Report is defined as “the Report of the responsible Committee(s), in accordance with the Regulations, in preparation of a new or revised NFPA Standard.” The Technical Committee Report is in two parts and consists of the First Draft Report and the Second Draft Report. (See *Regs* at Section 1.4.)

III. Step 1: First Draft Report. The First Draft Report is defined as “Part one of the Technical Committee Report, which documents the Input Stage.” The First Draft Report consists of the First Draft, Public Input, Committee Input, Committee and Correlating Committee Statements, Correlating Notes, and Ballot Statements. (See *Regs* at 4.2.5.2 and Section 4.3.) Any objection to an action in the First Draft Report must be raised through the filing of an appropriate Comment for consideration in the Second Draft Report or the objection will be considered resolved. [See *Regs* at 4.3.1(b).]

IV. Step 2: Second Draft Report. The Second Draft Report is defined as “Part two of the Technical Committee Report, which documents the Comment Stage.” The Second Draft Report consists of the Second Draft, Public Comments with corresponding Committee Actions and Committee Statements, Correlating Notes and their respective Committee Statements, Committee Comments, Correlating Revisions, and Ballot Statements. (See *Regs* at 4.2.5.2 and Section 4.4.) The First Draft Report and the Second Draft Report together constitute the Technical Committee Report. Any outstanding objection following the Second Draft Report must be raised through an appropriate Amending Motion at the NFPA Technical Meeting or the objection will be considered resolved. [See *Regs* at 4.4.1(b).]

V. Step 3a: Action at NFPA Technical Meeting. Following the publication of the Second Draft Report, there is a period during which those wishing to make proper Amending Motions on the Technical Committee Reports must signal their intention by submitting a Notice of Intent to Make a Motion (NITMAM). (See *Regs* at 4.5.2.) Standards that receive notice of proper Amending Motions (Certified Amending Motions) will be presented for action at the annual June NFPA Technical Meeting. At the meeting, the NFPA membership can consider and act on these Certified Amending Motions as well as Follow-up Amending Motions, that is, motions that become necessary as a result of a previous successful Amending Motion. (See 4.5.3.2 through 4.5.3.6 and Table 1, Columns 1-3 of *Regs* for a summary of the available Amending Motions and who may make them.) Any outstanding objection following action at an NFPA Technical Meeting (and any further Technical Committee consideration following successful Amending Motions, see *Regs* at 4.5.3.7 through 4.6.5) must be raised through an appeal to the Standards Council or it will be considered to be resolved.

VI. Step 3b: Documents Forwarded Directly to the Council. Where no NITMAM is received and certified in accordance with the *Technical Meeting Convention Rules*, the standard is forwarded directly to the Standards Council for action on issuance. Objections are deemed to be resolved for these documents. (See *Regs* at 4.5.2.5.)

VII. Step 4a: Council Appeals. Anyone can appeal to the Standards Council concerning procedural or substantive matters related to the development, content, or issuance of any document of the NFPA or on matters within the purview of the authority of the Council, as established by the *Bylaws* and as determined by the Board of Directors. Such appeals must be in written form and filed with the Secretary of the Standards Council (see *Regs* at Section 1.6). Time constraints for filing an appeal must be in accordance with 1.6.2 of the *Regs*. Objections are deemed to be resolved if not pursued at this level.

VIII. Step 4b: Document Issuance. The Standards Council is the issuer of all documents (see Article 8 of *Bylaws*). The Council acts on the issuance of a document presented for action at an NFPA Technical Meeting within 75 days from the date of the recommendation from the NFPA Technical Meeting, unless this period is extended by the Council (see *Regs* at 4.7.2). For documents forwarded directly to the Standards Council, the Council acts on the issuance of the document at its next scheduled meeting, or at such other meeting as the Council may determine (see *Regs* at 4.5.2.5 and 4.7.4).

IX. Petitions to the Board of Directors. The Standards Council has been delegated the responsibility for the administration of the codes and standards development process and the issuance of documents. However, where extraordinary circumstances requiring the intervention of the Board of Directors exist, the Board of Directors may take any action necessary to fulfill its obligations to preserve the integrity of the codes and standards development process and to protect the interests of the NFPA. The rules for petitioning the Board of Directors can be found in the *Regulations Governing Petitions to the Board of Directors from Decisions of the Standards Council* and in Section 1.7 of the *Regs*.

X. For More Information. The program for the NFPA Technical Meeting (as well as the NFPA website as information becomes available) should be consulted for the date on which each report scheduled for consideration at the meeting will be presented. To view the First Draft Report and Second Draft Report as well as information on NFPA rules and for up-to-date information on schedules and deadlines for processing NFPA documents, check the NFPA website (www.nfpa.org/docinfo) or contact NFPA Codes & Standards Administration at (617) 984-7246.