NFPA® 502

Standard for Road Tunnels, Bridges, and Other Limited Access Highways

2011 Edition

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An International Codes and Standards Organization

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NFPA® 502

Standard for

Road Tunnels, Bridges, and Other Limited Access Highways

2011 Edition

This edition of NFPA 502, *Standard for Road Tunnels, Bridges, and Other Limited Access Highways,* was prepared by the Technical Committee on Road Tunnel and Highway Fire Protection and acted on by NFPA at its June Association Technical Meeting held June 7–10, 2010, in Las Vegas, NV. It was issued by the Standards Council on August 5, 2010, with an effective date of August 25, 2010, and supersedes all previous editions.

This edition of NFPA 502 was approved as an American National Standard on August 25, 2010.

Origin and Development of NFPA 502

A tentative standard, NFPA 502T, *Standard for Limited Access Highways, Tunnels, Bridges, and Elevated Structures*, was prepared by the Technical Committee on Motor Vehicle Fire Protection and was adopted by the National Fire Protection Association on May 16, 1972, at its Annual Meeting in Philadelphia, PA. It was withdrawn in November 1975. In 1980, the committee rewrote the document as a recommended practice and included a chapter on air-right structures. It was adopted at the 1981 NFPA Annual Meeting.

Minor revisions to Chapters 2 through 5, primarily to water supply and fire apparatus requirements, were made in the 1987 edition.

The recommended practice was reconfirmed in 1992.

The 1996 edition incorporated a totally revised chapter on tunnels. Other revisions were made to correlate the new material in tunnel and air-right structure requirements with existing chapters and to update NFPA 502 with respect to current technology and practices.

The 1998 edition was developed by a task group appointed by the chairman of the Technical Committee on Motor Vehicle and Highway Fire Protection.

With the planned revision from a recommended practice to a standard, the task group reviewed and completely revised all chapters of the document, with special emphasis on incorporating the lessons learned following completion of the full-scale fire ventilation test program at the Memorial Tunnel in West Virginia. Specific to the Memorial Tunnel Fire Ventilation Test Program, changes were made to Chapter 7, "Tunnel Ventilation During Fire Emergencies." The title of the standard was also changed to more accurately reflect the contents and to properly identify the major focus of the standard. The previous title, *Recommended Practice on Fire Protection for Limited Access Highways, Tunnels, Bridges, Elevated Roadways, and Air-Right Structures,* was changed to *Standard for Road Tunnels, Bridges, and Other Limited Access Highways.*

The 2001 edition contained a significant editorial rewrite and reorganization of the document.

Technical changes regarding emergency communication, emergency egress and lighting in tunnels, and tunnel ventilation were incorporated into the 2001 edition. Further changes were made to clarify the application of the standard based on tunnel length.

The 2004 edition included new requirements for the protection of concrete and steel tunnel structures, specific requirements for emergency lighting, and clarification of the travel distance to emergency exits in tunnels. The 2004 edition also updated the vehicle tunnel fire data in Annex A to more recent international research.

The 2008 edition added specific requirements for fire tests for tunnel structural elements and included revisions that further clarified the categorization of road tunnels; revisions regarding ventilation, tenable environment, and hazardous goods transport; and a revision of the discussion topics in Annex E on fixed fire suppression systems.

The 2011 edition further develops performance-based design approaches for tunnels. Table 7.2 has been updated to provide a more comprehensive review of the required systems for tunnels based on tunnel category. Chapter 9 has been added to address the design of water-based fire-fighting systems. Additional changes to the document include the addition of system commissioning and periodic testing as well as updated annex material addressing design factors for life safety and property protection.

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

Committee Scope: This Committee shall have primary responsibility for documents on fire prevention and fire protection measures to reduce loss of life and property damage for road tunnels, air-right structures, bridges, and limited access highways. Excluded from this scope is the protection for facilities for the storage, repair, and parking of motor vehicles.

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

Changes other than editorial are indicated by a vertical rule beside the paragraph, table, or figure in which the change occurred. These rules are included as an aid to the user in identifying changes from the previous edition. Where one or more complete paragraphs have been deleted, the deletion is indicated by a bullet (•) between the paragraphs that remain.

A reference in brackets [ ] following a section or paragraph indicates material that has been extracted from another NFPA document. As an aid to the user, the complete title and edition of the source documents for extracts in mandatory sections of the document are given in Chapter 2 and those for extracts in informational sections are given in Annex M. 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 publications can be found in Chapter 2 and Annex M.

Chapter 1 Administration

1.1 Scope.

1.1.1 This standard provides fire protection and fire life safety requirements for limited access highways, road tunnels, bridges, elevated highways, depressed highways, and roadways that are located beneath air-right structures.

1.1.2 This standard establishes minimum requirements for each of the identified facilities.

1.1.3 This standard does not apply to the following facilities:

(1) Parking garages
(2) Bus terminals
(3) Truck terminals
(4) Any other facility in which motor vehicles travel or are parked

1.1.4 This standard is applicable where a facility, including those specified in 1.1.3(1) through 1.1.3(4), is deemed appropriate by the authority having jurisdiction.

1.2 Purpose. The purpose of this standard is to establish minimum criteria that provide protection from fire and its related hazards.

1.3 Application.

1.3.1* The provisions of this standard are necessary to provide protection from loss of life and property from fire.

1.3.2 The authority having jurisdiction determines the application of this standard to facility alterations and fire protection system upgrades.

1.3.3 The portion of this standard that covers emergency procedures applies to both new and existing facilities.

1.4 Retroactivity. The provisions of this standard reflect a consensus of what is necessary to provide an acceptable degree of protection from the hazards addressed in this standard at the time the standard was issued.

1.4.1 Unless otherwise specified, the provisions of this standard shall not apply to facilities, equipment, structures, or installations that existed or were approved for construction or installation prior to the effective date of the standard. Where specified, the provisions of this standard shall be retroactive.

1.4.2 In those cases where the authority having jurisdiction determines that the existing situation presents an unacceptable degree of risk, the authority having jurisdiction shall be permitted to apply retroactively any portions of this standard deemed appropriate.

1.4.3 The retroactive requirements of this standard shall be permitted to be modified if their application clearly would be impractical in the judgment of the authority having jurisdiction, and only where it is clearly evident that a reasonable degree of safety is provided.

1.5 Equivalency. Nothing in this standard is intended to prevent the use of systems, methods, or devices of equivalent or superior quality, strength, fire resistance, effectiveness, durability, and safety over those prescribed by this standard, provided sufficient technical data demonstrates that the applied method material or device is equivalent to or superior to the requirements of this standard with respect to fire performance and safety.

1.5.1 Technical documentation shall be submitted to the authority having jurisdiction to demonstrate equivalency.

1.5.2 The system, method, or device shall be approved for the intended purpose.

1.5.3 Alternative methods or devices approved as equivalent shall be recognized as being in compliance with this standard.

1.6 Units.

1.6.1* Metric units of measure in this standard are in accordance with the modernized metric system known as the International System of Units (SI). The liter unit (L), which is outside of but recognized by SI, is commonly used in the international fire protection industry. The appropriate units and conversion factors are specified in Table A.1.6.1.

1.6.2 If a value for measurement as provided in this standard is followed by an equivalent value in other units, the first stated value shall be regarded as the requirement. A given equivalent value can be an approximation.

Chapter 2 Referenced Publications

2.1 General. The documents or portions thereof listed in this chapter are referenced within this standard and shall be considered part of the requirements of this document.

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

NFPA 1, *Fire Code,* 2009 edition.
NFPA 10, *Standard for Portable Fire Extinguishers,* 2010 edition.
NFPA 11, *Standard for Low-, Medium-, and High-Expansion Foam,* 2010 edition.
NFPA 13, *Standard for the Installation of Sprinkler Systems,* 2010 edition.
NFPA 14, *Standard for the Installation of Standpipe and Hose Systems,* 2010 edition.
NFPA 15, *Standard for Water Spray Fixed Systems for Fire Protection,* 2007 edition.
NFPA 16, *Standard for the Installation of Foam-Water Sprinkler and Foam-Water Spray Systems,* 2007 edition.
NFPA 18, *Standard on Wetting Agents,* 2011 edition.
NFPA 20, *Standard for the Installation of Stationary Pumps for Fire Protection,* 2010 edition.
NFPA 22, *Standard for Water Tanks for Private Fire Protection,* 2008 edition.
NFPA 24, *Standard for the Installation of Private Fire Service Mains and Their Appurtenances,* 2010 edition.
NFPA 25, *Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems,* 2011 edition.
NFPA 70®, *National Electrical Code*®, 2011 edition.
NFPA 72®, *National Fire Alarm and Signaling Code,* 2010 edition.
NFPA 80, *Standard for Fire Doors and Other Opening Protectives,* 2010 edition.
NFPA 92A, *Standard for Smoke-Control Systems Utilizing Barriers and Pressure Differences,* 2009 edition.
NFPA *101*®, *Life Safety Code*®, 2009 edition.
NFPA 110, *Standard for Emergency and Standby Power Systems,* 2010 edition.
NFPA 111, *Standard on Stored Electrical Energy Emergency and Standby Power Systems,* 2010 edition.
NFPA 241, *Standard for Safeguarding Construction, Alteration, and Demolition Operations,* 2009 edition.
NFPA 262, *Standard Method of Test for Flame Travel and Smoke of Wires and Cables for Use in Air-Handling Spaces,* 2007 edition.
NFPA 750, *Standard on Water Mist Fire Protection Systems,* 2010 edition.
NFPA 820, *Standard for Fire Protection in Wastewater Treatment and Collection Facilities,* 2008 edition.
NFPA 1561, *Standard on Emergency Services Incident Management System,* 2008 edition.
NFPA 1670, *Standard on Operations and Training for Technical Search and Rescue Incidents,* 2009 edition.
NFPA 1963, *Standard for Fire Hose Connections,* 2009 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 E 136, *Standard Test Method for Behavior of Materials in a Vertical Tube Furnace at 750°C,* 2009.

2.3.2 FHWA Publications. Federal Highway Administrations, 1200 New Jersey Ave, SE, Washington, DC 20590

Manual on Uniform Traffic Control Devices, 2009 edition.

2.3.3 IEEE Publications. Institute of Electrical and Electronics Engineers, Three Park Avenue, 17th Floor, New York, NY 10016-5997.

FT 4/IEEE 1202, *Standard for Flame-Propagation Testing of Wire and Cable*, 2006 Edition.

2.3.4 Military Specifications. Department of Defense Single Stock Point, Document Automation and Production Service, Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MIL-C-24643, *General Specification for Cable and Cords, Electrical, Low Smoke, for Shipboard Use,* 1996.

2.3.5 OSHA Publications. Occupational Safety and Health Administration, 200 Constitution Avenue, NW, Washington, DC 20210

Code of Federal Regulations Standard 1910.146, Permit Required Confined Spaces.

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

ANSI/UL 1685, *Standard Vertical Cable Tray Propagation and Smoke Release Test for Electrical and Optical Fiber Cables,* 2007, Revised December 2007.

ANSI/UL Subject 1724, *Outline of Investigation for Fire Tests for Electrical Circuit Protective Systems*, 2006.

ANSI/UL 2196, *Standard for Safety for Tests for Fire Resistive Cables*, 2001, Revised December 2006.

2.3.7 Other Publications.

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

Efectis-R0695, Fire Testing Procedure for Concrete Tunnel Linings, 2008.

2.4 References for Extracts in Mandatory Sections.

NFPA 10, *Standard for Portable Fire Extinguishers,* 2010 edition.
NFPA 70®, *National Electrical Code*®, 2011 edition.
NFPA 402, *Guide for Aircraft Rescue and Fire-Fighting Operations,* 2008 edition.
NFPA 1561, *Standard on Emergency Services Incident Management System,* 2008 edition.
NFPA 1901, *Standard for Automotive Fire Apparatus,* 2009 edition.
NFPA 5000®, *Building Construction and Safety Code*®, 2009 edition.

Chapter 3 Definitions

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

3.2.4* 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.

3.2.5 Shall. Indicates a mandatory requirement.

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

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

3.3 General Definitions.

3.3.1 Agency. The organization legally established and authorized to operate a facility.

3.3.2 Alteration. For road tunnels, bridges, and limited access highways, a modification, replacement, or other physical change to an existing facility.

3.3.3 Alternative Fuel. A motor vehicle fuel other than gasoline and diesel.

3.3.4 Ancillary Facility(ies). A structure(s) usually used to house or contain operating, maintenance, or support equipment and functions.

3.3.5* Backlayering. The reversal of movement of smoke and hot gases counter to the direction of the ventilation airflow.

3.3.6 Bridge. A structure spanning and providing a highway across an obstacle such as a waterway, railroad, or another highway.

3.3.7* Building. Any structure used or intended for supporting or sheltering any use or occupancy.

3.3.8 Cable Tray System. A unit or assembly of units or sections and associated fittings forming a structural system used to securely fasten or support cables and raceways. [**70,** 392.2]

3.3.9 Combustible. Capable of undergoing combustion.

3.3.10 Command Post (CP). The location at the scene of an emergency where the incident commander is located and where command, coordination, control, and communications are centralized. [**402,** 2008]

3.3.11 Commissioning. A systematic process that provides documented confirmation that specific and interconnected fire protection, life safety, and emergency systems function according to the intended design criteria set forth in the project documents and satisfy the owner's operational needs, including compliance requirements of any laws, regulations, codes, and standards requiring fire protection, life safety, and emergency systems.

3.3.12 Critical Velocity. The minimum steady-state velocity of the ventilation airflow moving toward the fire, within a tunnel or passageway, that is required to prevent backlayering at the fire site.

3.3.13 Deluge System. An open fixed fire suppression system activated either manually or automatically.

3.3.14 Dry Standpipe. A standpipe system designed to have piping contain water only when the system is being utilized.

3.3.15 Dynamic Vehicle Envelope. The space within the tunnel roadway that is allocated for maximum vehicle movement.

3.3.16 Emergency Communications. For road tunnels, bridges, and limited access highways, radio, telephone, and messaging throughout the facility. Emergency communications, where required, shall be by the installation of outdoor-type telephone boxes, coded alarm telegraph stations, radio transmitters, or other approved devices.

3.3.17 Emergency Exits. Portal or "exit," including egress stairs or egress corridors leading to an area outside of the tunnel; or cross-passages leading to an adjacent nonincident tunnel.

3.3.18 Emergency Response Plan. A plan developed by an agency, with the cooperation of all participating agencies, that details specific actions to be performed by all personnel who are expected to respond during an emergency.

3.3.19* Engineering Analysis. An analysis that evaluates all factors that affect the fire safety of a facility or a component of a facility.

3.3.20 Equivalency. An alternate means of providing an equal or greater level of safety than that afforded by strict conformance to prescribed codes and standards.

3.3.21 Facility. A limited access highway, road tunnel, bridge, or elevated highway.

3.3.22 Fire Apparatus. A vehicle designed to be used under emergency conditions to transport personnel and equipment, and to support the suppression of fires and mitigation of other hazardous situations. [**1901,** 2009]

3.3.23 Fire Department Connection. A connection through which the fire department can pump supplemental water into the sprinkler system, standpipe, or other system, furnishing water for fire extinguishment to supplement existing water supplies.

3.3.24 Fire Emergency. The existence of, or threat of, fire or the development of smoke or fumes, or any combination thereof, that demands immediate action to correct or alleviate the condition or situation.

3.3.25 Fire Growth Rate. Rate of change of the fire's heat release.

3.3.26 Fire Heat Release Rate. The rate at which heat energy is generated by burning expressed as Btu/sec or megawatts (MW).

3.3.27 Fire Smoke Release Rate. Rate of smoke release for a given fire scenario expressed as a function of time.

3.3.28 Fire Suppression. The application of an extinguishing agent to a fire at a level such that open flaming is arrested; however, a deep-seated fire will require additional steps to assure total extinguishment.

3.3.29* Fixed Water-Based Fire-Fighting System. A system permanently attached to the tunnel that is able to spread a water-based extinguishing agent in all or part of the tunnel.

3.3.30 Highway. Any paved facility on which motor vehicles travel.

3.3.30.1* ***Depressed Highway.*** An uncovered, below-grade highway or boat section where walls rise to the grade surface and where emergency response access is usually limited.

3.3.30.2 ***Elevated Highway.*** A highway that is constructed on a structure that is above the surface but that does not cross over an obstacle as in the case of a bridge.

3.3.30.3* ***Length of Bridge or Elevated Highway.*** The linear distance measured along the centerline of a bridge or elevated highway structure from abutment to abutment.

3.3.30.4 ***Limited Access Highway.*** A highway where preference is given to through-traffic by providing access connections that use only selected public roads and by prohibiting crossings at grade and at direct private driveways.

3.3.31 Hose Connection. A combination of equipment provided for the connection of a hose to a standpipe system that includes a hose valve with a threaded outlet.

3.3.32 Hose Valve. The valve to an individual hose connection.

3.3.33 Incident Commander. The individual in overall command of an emergency incident. [**1561,** 2008]

3.3.34 Length of Tunnel. The length from face of portal to face of portal that is measured using the centerline alignment along the tunnel roadway.

3.3.35 Mandatory Requirement. A requirement prefaced by the word "shall" within the standard.

3.3.35.1 ***Conditionally Mandatory Requirement.*** A requirement that is based on the results of an engineering analysis.

3.3.35.2 ***Nonmandatory Requirement.*** A requirement that is not prefaced by the word "shall" and most likely contained in an annex, a footnote, or fine-print note of the standard.

3.3.36 Motorist. A motor vehicle occupant, including the driver and passenger(s).

3.3.37* Noncombustible Material. A material that, in the form in which it is used and under the conditions anticipated, will not ignite, burn, support combustion, or release flammable vapors when subjected to a fire or heat. Materials that are reported as passing ASTM E 136, *Standard Test Method for Behavior of Materials in a Vertical Tube Furnace at 750°C*, or other equivalent standards shall be considered noncombustible materials.

3.3.38 Operations Control Center. A dedicated operations center where the agency controls and coordinates the facility operations and from which communication is maintained with the agency's supervisory and operating personnel and with participating agencies where required.

3.3.39 Participating Agency. A public, quasi-public, or private agency that has agreed to cooperate with and assist the authority during an emergency.

3.3.40* Point of Safety. For road tunnels, bridges, and limited access highways, an exit enclosure that leads to a public way or safe location outside the structure, or an at-grade point beyond any enclosing structure, or another area that affords adequate protection for motorists.

3.3.41 Portable Fire Extinguisher. A portable device, carried or on wheels and operated by hand, containing an extinguishing agent that can be expelled under pressure for the purpose of suppressing or extinguishing fire. [**10,** 2010]

3.3.42 Portal. The interface between a tunnel and the atmosphere through which vehicles pass; a connection point to an adjacent facility.

3.3.43 Queue. A line of stored vehicles.

3.3.44 Raceway. An enclosed channel of metal or nonmetallic materials designed expressly for holding wires, cables, or busbars, with additional functions as permitted in *NFPA 70*. Raceways include, but are not limited to, rigid metal conduit, rigid nonmetallic conduit, intermediate metal conduit, liquidtight flexible conduit, flexible metallic tubing, flexible metal conduit, electrical nonmetallic tubing, electrical metallic tubing, underfloor raceways, cellular concrete floor raceways, cellular metal floor raceways, surface raceways, wireways, and busways. [**70,** 2011]

3.3.45 Rijkswaterstaat (RWS). The fire test procedure and time/temperature curve described in report, Efectis-R0695, 2008.

3.3.46 Road Tunnel. An enclosed roadway for motor vehicle traffic with vehicle access that is limited to portals.

3.3.47 Roadway. The volume of space that is located above the pavement surface through which motor vehicles travel.

3.3.48 Self-Rescue. People leaving the hazardous area or dangerous situation without any professional (fire fighters, rescue personnel, etc.) help.

3.3.49 Structure. That which is built or constructed and limited to buildings and non-building structures as defined herein. [***5000,*** 2009]

3.3.49.1* ***Air-Right Structure.*** A structure other than a skywalk bridge that is built over a roadway using the roadway's air rights. [***5000,*** 2009]

3.3.50 Tenable Environment. In a road tunnel, an environment that permits evacuation or rescue, or both, of occupants for a specific period of time.

Chapter 4 General Requirements

4.1* Characteristics of Fire Protection. The level of fire protection necessary for the entire facility shall be achieved by implementing the requirements of this standard for each subsystem.

4.2 Safeguards During Construction. During the course of construction or alteration of any facility addressed in this standard, the provisions of NFPA 241 shall apply.

4.3 Fire Protection and Fire Life Safety Factors. The requirements under this standard for life safety and those required to achieve structural protection differ. The requirements for ensuring human safety during the evacuation and rescue phases are substantially different from the requirements to protect the structural components of the facility.

4.3.1 Regardless of length of the facility, as a minimum, the following factors shall be fully considered as part of an engineering analysis of the fire protection and life safety requirements for the facilities covered by this standard for the protection of life in the facility:

(1) Users of the facility
(2) Restricted vehicle access and egress
(3) Fire emergencies ranging from minor incidents to major catastrophes
(4) Fire emergencies occurring at one or more locations inside or in close proximity to the facility
(5) Fire emergencies occurring in remote locations at a long distance from emergency response facilities
(6) Exposure of emergency systems and structures to elevated temperatures
(7) Traffic congestion and control during emergencies
(8) Built-in fire protection features, such as the following:
  (a) Fire alarm and detection systems
  (b) Standpipe systems
  (c) Water-based fire-fighting systems
  (d) Ventilation systems
  (e) Emergency communications systems
(9) Facility components, including emergency systems
(10) Evacuation and rescue requirements
(11) Emergency response time
(12) Emergency vehicle access points
(13) Emergency communications to appropriate agencies
(14) Vehicles and property being transported
(15) Facility location, such as urban or rural (risk level and response capacity)
(16) Physical dimensions, including roadway profile
(17) Natural factors, including prevailing wind
(18) Anticipated cargo
(19) Impact to buildings or landmarks near the facility

4.3.2* Limited Access Highways. Fire protection for limited access highways shall comply with the requirements of Chapter 5.

4.3.3 Bridges and Elevated Highways. Fire protection for bridges and elevated highways shall comply with the requirements of Chapter 6.

4.3.4* Depressed Highways. Standpipe systems or fire extinguishers, or both, shall be installed on depressed highways where physical factors prevent or impede access to the water supply or fire apparatus.

4.3.5* Road Tunnels. Fire protection for road tunnels shall comply with the requirements of Chapter 7.

4.3.6* Roadway Beneath Air-Right Structures. Fire protection for roadways that are located beneath air-right structures shall comply with the requirements of Chapter 8.

4.3.7* Ancillary Facilities. All related ancillary facilities that support the operation of limited access highways, depressed highways, bridges and elevated highways, and road tunnels shall be protected as required by all applicable NFPA standards and applicable building codes except as modified in this standard.

4.4 Emergency Response Plan.

4.4.1 A designated authority shall carry out a complete and coordinated program of fire protection that shall include written preplanned emergency response procedures and standard operating procedures.

4.4.2 Emergency traffic-control procedures shall be established to regulate traffic during an emergency.

4.4.3 Emergency procedures and the development of an emergency response plan shall be completed in accordance with the requirements of Chapter 13.

4.5 Emergency Communications. Emergency communications, where required by the authority having jurisdiction, shall be provided by the installation of outdoor-type telephone boxes, coded alarm telegraph stations, radio transmitters, or other approved devices that meet the following requirements:

(1) They shall be made conspicuous by means of indicating lights or other approved markers.
(2) They shall be identified by a readily visible number plate or other approved device.
(3) They shall be posted with instructions for use by motorists.
(4) They shall be located in approved locations so that motorists can park vehicles clear of the travel lanes.
(5) Emergency communication devices shall be protected from physical damage from vehicle impact.
(6) Emergency communication devices shall be connected to an approved constantly attended location.

4.6 Signage. Signs, mile markers, or other approved location reference markers shall be installed along the highway to allow motorists to provide authorities with accurate locations for accident or emergency areas.

4.7 Commissioning.

4.7.1 The agency shall require the development of a commissioning plan to facilitate the verification of the operational readiness of all installed fire protection, life safety, and emergency systems required by this standard, other applicable NFPA standards, and as required within the basis of design (BOD) for construction.

4.7.2 The commissioning plan shall be reviewed and approved by the AHJ where required.

4.7.3 The commissioning plan shall document the procedures to be used for the testing of the specific individual fire protection, life safety, and emergency systems, including procedures and requirements to verify operational readiness of integrated and/or interconnected fire protection, life safety, and emergency systems.

Chapter 5 Limited Access Highways

5.1 General. This chapter shall provide fire protection requirements for limited access highways.

5.2* Fire Apparatus.

5.2.1 Arrangements for the response of nearby fire companies and emergency squads shall be made a part of the emergency response planning process.

5.2.2 Where a means of access that allows outside aid companies to enter the facility is provided, procedures for using such access shall be included in the emergency response plan.

5.2.3 Precautions shall be taken at the points of entry to alert and control traffic to allow emergency equipment to enter safely.

5.3* Fire Hydrants. (Reserved)

Chapter 6 Bridges and Elevated Highways

6.1* General.

6.1.1 This chapter shall provide fire protection requirements for bridges and elevated highways.

6.1.2 Bridges or elevated highways and spaces below bridges and elevated highways that are fully enclosed and meet the definition of a tunnel and the tunnel length requirements of Section 7.2 shall meet the requirements of Chapter 7.

6.2* Application. For the purpose of this standard, bridge or elevated highway length shall dictate the minimum fire protection requirements.

6.2.1 For bridges or elevated highways less than 300 m (1000 ft) in length, the provisions of this standard shall not apply.

6.2.2 Where a bridge or elevated highway does not fully enclose the roadway on both sides, the decision to consider it as a road tunnel shall be made by the AHJ after an engineering analysis in accordance with 4.3.1.

6.2.3 In rural areas, Sections 6.4 and 6.7 of this standard shall not apply.

6.3 Protection of Structural Elements.

6.3.1 Regardless of bridge or elevated highway length, all primary structural elements shall be protected in accordance with this standard in order to:

(1) Maintain life safety
(2) Mitigate structural damage and prevent progressive structural collapse
(3) Minimize economic impact

6.3.2 Critical structural members shall be protected from collision and high-temperature exposure that can result in dangerous weakening or complete collapse of the bridge or elevated highway.

6.3.3 For through truss and suspension bridges or elevated highways, an engineering analysis shall be prepared to determine acceptable risk, including possible collapse scenarios.

6.4 Incident Detection.

6.4.1 Manual Fire Alarm Boxes.

6.4.1.1 Where the length of a bridge or elevated highway exceeds 3.2 km (2 miles), a manual fire alarm box shall be mounted in a NEMA Enclosure Type 4X or equivalent box at intervals of not more than 1.0 km (0.6 mile).

6.4.1.2 The location of the manual fire alarm boxes shall be approved by the AHJ.

6.4.1.3 The alarm shall indicate the location of the manual fire alarm box at the monitoring station.

6.4.1.4 The system shall be installed, inspected, and maintained in compliance with *NFPA 72*.

6.4.2 Closed-Circuit Television (CCTV) Systems.

6.4.2.1 Where the length of a bridge or elevated highway exceeds 300 m (1000 ft), a CCTV system shall be installed on the bridge.

6.4.2.2 The CCTV system shall be capable of viewing the entire length of the bridge or elevated highway from a single monitoring station using multiple cameras and camera locations.

6.5 Traffic Control.

6.5.1 Traffic control procedures shall be established so that vehicles either stop or proceed with caution.

6.5.2 Traffic shall not be permitted to block or otherwise interfere with response of emergency and fire equipment. Traffic incident management shall be in conformance with Chapter 6I of the *Manual on Uniform Traffic Control Devices*, latest edition.

6.6 Standpipe, Fire Hydrants, and Water Supply.

6.6.1* Applicability. Where the length of a bridge or elevated highway exceeds 300 m (1000 ft), a horizontal standpipe system shall be installed on the structure in accordance with the requirements of Chapter 9.

6.6.2 Where the transverse width of a bridge or elevated highway exceeds 30 m (100 ft), or the travel direction lanes are physically separated by a barrier, and the structure meets the requirements of 6.6.1 above, the standpipe system shall be installed on each side of the bridge or elevated highway.

6.7 Portable Fire Extinguishers.

6.7.1 Where the length of a bridge or elevated highway exceeds 3.2 km (2 miles), a portable fire extinguisher, with a rating of 2-A:20-B:C mounted in an NFPA 10–compliant cabinet, shall be installed at intervals of not more than 1.0 km (0.6 mile). No portable extinguisher shall be placed within 0.6 km (0.4 mile) of the end of the bridge or elevated highway.

6.7.2 To facilitate safe use by the public, the maximum weight of each extinguisher shall be 9 kg (20 lb).

6.7.3 Portable fire extinguishers shall be selected, installed, inspected, and maintained in accordance with NFPA 10.

6.7.4 The location of the portable fire extinguishers shall be approved by the AHJ.

6.8 Drainage.

6.8.1 On bridges and elevated highways, drainage systems to channel and collect spilled hazardous or flammable liquids shall be designed to drain areas that cannot cause additional hazards.

6.8.2 Expansion joints shall be designed to prevent spillage to the area below the bridge or elevated highway.

6.8.3 Bridges or elevated highways with combustible expansion joint or bearing system material, vulnerable to a spill of flammable liquids, shall have a roadway surface drainage system capable of intercepting a spill.

6.9 Hazardous Locations. Confined spaces meeting the definition of NFPA 1670 shall be labeled in accordance with CFR 1910.146.

6.10 Control of Hazardous Materials. Control of hazardous materials shall be in accordance with the requirements of Chapter 14.

Chapter 7 Road Tunnels

7.1* General.

7.1.1 This chapter shall provide fire protection and life safety requirements for road tunnels.

7.1.2* In the design and operation of the tunnel, the interdependence of measures primarily intended to protect the structural elements of tunnels from the effects of fires, and those measures primarily intended to ensure the protection of life, shall be considered.

7.2* Application. For the purpose of this standard, factors described in 4.3.1 shall dictate fire protection and fire life safety requirements. The minimum fire protection and fire life safety requirements, based on tunnel length, are categorized below and summarized in Table 7.2, to assist the search for requirements listed elsewhere in this standard:

(1) Category X — Where tunnel length is less than 90 m (300 ft), traffic control systems shall be installed in accordance with the requirements of Section 7.6.

Table 7.2 Road Tunnel Fire Protection Reference

		Tunnel Categories				
Fire Protection Systems	**NFPA 502 Sections**	**X** *[See 7.2(1).]*	**A** *[See 7.2(2).]*	**B** *[See 7.2(3).]*	**C** *[See 7.2(4).]*	**D** *[See 7.2(5).]*
Fire Detection						
Detection, identification, and location of fire in tunnel	7.4	CMR	CMR	MR	MR	MR
Manual fire alarm boxes	7.4.1.2	CMR	CMR	MR	MR	MR
CCTV systems	7.4.1.1	CMR	CMR	CMR	CMR	CMR
Automatic fire detection systems	7.4.1.4	CMR	CMR	CMR	CMR	CMR
Fire alarm control panel	7.4.2	CMR	CMR	MR	MR	MR
Communications Systems						
Radio	7.5	CMR	CMR	MR	MR	MR
Telephone	7.4.5	CMR	CMR	MR	MR	MR
Traffic Control						
Stop traffic approaching tunnel portal	7.6.1	MR	MR	MR	MR	MR
Stop traffic from entering tunnel's direct approaches	7.6.2	—	—	MR	MR	MR
Fire Protection						
Fire apparatus[a]	7.7	NMR	NMR	NMR	NMR	NMR
Fire standpipe	7.7	CMR	MR	MR	MR	MR
Water supply	9.2	CMR	MR	MR	MR	MR
Fire department connections	9.3	CMR	MR	MR	MR	MR
Hose connection	9.4	CMR	MR	MR	MR	MR
Fire pumps[b]	9.5	CMR	CMR	CMR	CMR	CMR
Portable fire extinguishers	7.8	CMR	CMR	MR	MR	MR
Water-based fire-fighting system[c]	7.9	NMR	NMR	NMR	NMR	CMR
Emergency ventilation system[d]	7.10	CMR	CMR	CMR	CMR	MR
Tunnel drainage system[d]	7.11	CMR	CMR	MR	MR	MR
Hydrocarbon detector	7.11.7	CMR	CMR	MR	MR	MR
Means of Egress						
Emergency egress	7.14.1.1	CMR	CMR	MR	MR	MR
Exit identification	7.14.1.2	CMR	CMR	MR	MR	MR
Tenable environment	7.14.2/7.14.4.3	CMR	CMR	MR	MR	MR
Emergency exits (includes cross-passageways)[e]	7.14.6	CMR	CMR	CMR	MR	MR
Electrical Systems						
General	11.1	CMR	CMR	MR	MR	MR
Emergency power	11.4	CMR	CMR	MR	MR	MR
Emergency lighting	11.6	CMR	CMR	MR	MR	MR
Exit signs	11.6.8	CMR	CMR	MR	MR	MR
Security plan	11.7	CMR	CMR	MR	MR	MR
Emergency Response Plan						
Emergency response plan	12.3	MR	MR	MR	MR	MR

MR: Mandatory requirement. CMR: Conditionally mandatory requirement. NMR: Nonmandatory requirement.
Note: The purpose of Table 7.2 is to provide assistance in locating road tunnel fire protection requirements contained within this standard. If there is any conflict between the requirements defined in the standard text and this table, the standard text shall always govern.
[a]Not mandatory to be at tunnel; however, they must be near to minimize response time.
[b]If required, must follow Section 9.5.
[c]If installed, must follow Section 7.9.
[d]Section 10.1 allows engineering analysis to determine requirements.
[e]Emergency exit spacing must be supported by an egress analysis.

(2) Category A — Where tunnel length is 90 m (300 ft) or greater, standpipe systems and traffic control systems shall be installed in accordance with the requirements of Chapter 11, Section 7.6, and Chapter 12, respectively.
(3) Category B — Where tunnel length equals or exceeds 240 m (800 ft) and where the maximum distance from any point within the tunnel to a point of safety exceeds 120 m (400 ft), all provisions of this standard shall apply, unless noted otherwise in this document.
(4) Category C — Where the tunnel length equals or exceeds 300 m (1000 ft), all provisions of this standard shall apply unless noted otherwise in this document.
(5) Category D — Where the tunnel length equals or exceeds 1000 m (3280 ft), all provisions of this standard shall apply.

7.3 Protection of Structural Elements.

7.3.1 Regardless of tunnel length, acceptable means shall be included within the design of the tunnel to protect all primary structural concrete and steel elements in accordance with this standard in order to:

(1) Mitigate structural damage and prevent progressive structural collapse
(2) Minimize economic impact due to tunnel closure

7.3.2* The structure shall be capable of withstanding the Rijkswaterstaat (RWS) time–temperature curve or other recognized standard time–temperature curve that is acceptable to the AHJ following an engineering analysis.

7.3.3 During a 120-minute period of fire exposure, the following failure criteria shall be satisfied:

(1)*Tunnels with concrete structural elements shall be designed or protected such that explosive spalling is prevented.
(2) Steel or cast iron tunnel linings shall be protected such that the lining temperature shall not exceed 300°C (572°F).

7.3.4 Structural fire protection material, where provided, shall satisfy the following performance criteria:

(1) Tunnels with cast in situ concrete structural elements protected such that:
   (a) The temperature of the concrete surface does not exceed 380°C (716°F).
   (b) The temperature of the steel reinforcement within the concrete [assuming a minimum cover of 25 mm (1 in.)] does not exceed 250°C (482°F).
(2) The material shall be noncombustible in accordance with ASTM E 136 or equivalent internationally recognized standard.
(3) The material shall have a minimum melting temperature of 1350ºC (2462ºF).
(4) The material shall meet the fire protection requirements with less than 5 percent humidity by weight and also when fully saturated with water, in accordance with the approved time–temperature curve.

7.4 Fire Alarm and Detection.

7.4.1 Tunnels described in categories B, C, and D shall have at least one manual means of identifying and locating a fire in accordance with the requirements of 7.4.1.3. Tunnels described in categories B, C, and D without 24-hour supervision shall have an automatic fire detection system in accordance with 7.4.1.4.

7.4.1.1* Closed-circuit television (CCTV) systems with traffic-flow indication devices or surveillance cameras shall be permitted for use to identify and locate fires in tunnels with 24-hour supervision.

7.4.1.2 Ancillary spaces within tunnels defined in categories B, C, and D (such as pump stations and utility rooms) and other areas shall be supervised by automatic fire alarm systems in accordance with 7.4.1.4.

7.4.1.3 Manual Fire Alarm Boxes.

7.4.1.3.1 Manual fire alarm boxes mounted in NEMA Enclosure Type 4 (IP 65) or equivalent boxes shall be installed at intervals of not more than 90 m (300 ft) and at all cross-passages and means of egress from the tunnel.

7.4.1.3.2 The manual fire alarm boxes shall be accessible to the public and the tunnel personnel.

7.4.1.3.3 The location of the manual fire alarm boxes shall be approved.

7.4.1.3.4 The alarm shall indicate the location of the manual fire alarm boxes at the monitoring station.

7.4.1.3.5 The system shall be installed, inspected, and maintained in compliance with *NFPA 72*.

7.4.1.4 Automatic Fire Detection Systems.

7.4.1.4.1* Automatic fire detection systems shall be installed in accordance with *NFPA 72* and approved by the AHJ.

7.4.1.4.2 Where a fire detection system is installed in accordance with the requirements of 7.4.1.4.1, signals for the purpose of evacuation and relocation of occupants shall not be required.

7.4.1.4.3 The performance of automatic fire detection systems shall include details of the fire signature required to initiate the alarm.

7.4.1.4.4 Automatic fire detection systems shall be capable of identifying the location of the fire within 15 m (50 ft).

7.4.1.4.5 Spot detectors shall have a light that remains on until the device is reset.

7.4.1.4.6 Automatic fire detection systems within a tunnel shall be zoned to correspond with the tunnel ventilation zones where tunnel ventilation is provided.

7.4.2 Fire Alarm Control Panel. An approved fire alarm control panel (FACP) shall be installed, inspected, and maintained in accordance with *NFPA 72*.

7.5* Emergency Communications Systems.

7.5.1 In new and existing tunnels and ancillary structures, wherever necessary for dependable and reliable communications, a separate radio network capable of two-way radio communication for fire department personnel to the fire department communication center shall be provided.

7.5.2 A radio network shall be comprised of base transmitters, repeaters and receivers, antennas, mobile transmitters and receivers, portable transmitters and receivers, and ancillary equipment.

7.6 Tunnel Closure and Traffic Control.

7.6.1 All road tunnels, as defined by this standard, shall be provided with a means to stop approaching traffic.

7.6.2 Road tunnels longer than 240 m (800 ft) shall be provided with means to stop traffic from entering the direct approaches to the tunnel, to control traffic within the tunnel, and to clear traffic downstream of the fire site following activation of a fire alarm within the tunnel. The following requirements shall apply:

(1) Direct approaches to the tunnel shall be closed following activation of a fire alarm within the tunnel. Approaches shall be closed in such a manner that responding emergency vehicles are not impeded in transit to the fire site.
(2) Traffic within the tunnel approaching (upstream of) the fire site shall be stopped prior to the fire site until it is safe to proceed as determined by the incident commander.
(3)*Means shall be provided downstream of an incident site to expedite the flow of vehicles from the tunnel. Where it is not possible to provide such means, under all traffic conditions, the tunnel shall be protected by a fixed fire-fighting system or other suitable means to establish a tenable environment to permit safe evacuation and emergency services access.
(4) Operation shall be returned to normal as determined by the incident commander.

7.7 Fire Apparatus. Annex K provides additional information on fire apparatus for road tunnels.

7.8 Standpipe, Fire Hydrants, and Water Supply. Standpipe, fire hydrants, and water supply systems in road tunnels shall be provided in accordance with the requirements of Chapter 10.

7.9* Portable Fire Extinguishers.

7.9.1 Portable fire extinguishers, with a rating of 2-A:20-B:C, shall be located along the roadway in approved wall cabinets at intervals of not more than 90 m (300 ft).

7.9.2 To facilitate safe use by motorists, the maximum weight of each extinguisher shall be 9 kg (20 lb).

7.9.3 Portable fire extinguishers shall be selected, installed, inspected, and maintained in accordance with NFPA 10.

7.10 Water-Based Fire-Fighting Systems. See Chapter 10.

7.11 Emergency Ventilation. Tunnel ventilation systems employed during fire emergencies shall comply with the requirements of Chapter 11.

7.12* Tunnel Drainage System.

7.12.1* A drainage system shall be provided in tunnels to collect, store, or discharge effluent from the tunnel, or to perform a combination of these functions.

7.12.2 The drainage collection system shall be designed so that spills of hazardous or flammable liquids cannot spread or cause flame propagation. The system shall intercept tunnel roadway drainage from an arrangement of side gutter catch basins or other drain inlets, such that the length of surface drain path from any potential spill point to the drain inlet is minimized.

7.12.3 Components of the drainage conveyance and collection system, including the main drain lines, shall be noncombustible (e.g., steel, ductile iron, or concrete).

7.12.4 Polyvinyl chloride (PVC), fiberglass pipe, or other combustible material shall not be permitted.

7.12.5* The drainage conveyance and collection system shall have sufficient capacity to receive, as a minimum, the rate of flow from all design roadway sources without causing flooding of the roadway.

7.12.5.1 The minimum design flow rate shall include, where applicable, the design spill rate for fuel or other hazardous liquids, the standpipe system discharge rate, any fixed fire-fighting system discharge rate, environmental sources (rain, snow, etc.), tunnel washing, and any other catchments sharing the tunnel drainage system piping.

7.12.5.2 Where the tunnel roadway drainage system discharges by gravity or by pumped discharge, it shall be provided with a separator sufficient for the design spill rate for the hazardous liquids and with adequate storage capacity.

7.12.6 Hazardous Locations.

7.12.6.1 Storage tanks and wet wells and service chambers of pump stations shall be classified for hazardous locations in accordance with *NFPA 70* and NFPA 820.

7.12.6.2 All motors, starters, level controllers, system controls, and other miscellaneous electrical equipment, such as components of the lighting system in the pump station, shall conform to the requirements of the hazard classification.

7.12.7 Hydrocarbon Detection.

7.12.7.1 Storage tanks and pump stations shall be monitored for hydrocarbons.

7.12.7.2 Detection of hydrocarbons in the tunnel drainage effluent shall initiate both a local and a remote alarm.

7.13 Alternative Fuels. Annex G provides additional information on alternative fuels.

7.14 Control of Hazardous Materials. Control of hazardous materials shall comply with the requirements of Chapter 14.

7.14.1* Fire size, growth rate, and smoke generated shall be permitted to be reduced where a design analysis can show that the pool size of the combustible or flammable liquid can be limited by proper design of the roadway cross slope, the roadway grade, the drainage inlets, and the drainage conveyance pipe or trough.

7.14.1.1 If fire is to be controlled by drainage method(s), this shall be coordinated with tunnel drainage in accordance with Section 7.12.

7.15 Means of Egress.

7.15.1 General.

7.15.1.1* The means of egress requirements for all road tunnels and those roadways beneath air-right structures that the authority having jurisdiction determines are similar to a road tunnel shall be in accordance with NFPA *101*, Chapter 7, except as modified by this standard.

7.15.1.2* Reflective or lighted directional signs indicating the distance to the two nearest emergency exits shall be provided on the side walls at distances of no more than 25 m (82 ft).

7.15.2* Tenable Environment. A tenable environment shall be provided in the means of egress during the evacuation phase in accordance with the emergency response plan for a specific incident.

7.15.3 Maintenance. The means of egress shall be maintained in accordance with NFPA 1.

7.15.4 Walking Surfaces.

7.15.4.1 The walking surfaces of the emergency exits, cross-passageways, and walkways shall be slip resistant.

7.15.4.2 Changes in elevation, ramps, and stairs shall meet the requirements of Chapter 7 of NFPA *101*.

7.15.5 Doors.

7.15.5.1 Doors to the emergency exits shall open in the direction of exit travel.

7.15.5.2 Horizontal sliding doors shall have a sign identifying them as horizontal sliding doors and indicating the direction to open.

7.15.5.3 Horizontal sliding doors shall be permitted in cross-passageways.

7.15.5.4 Cross-passage doors and exit doors immediately adjacent to the roadway shall be 1½-hour–rated doors tested in accordance with Section 7.3 and shall be installed in accordance with NFPA 80.

7.15.5.5 The force required to open the doors fully when applied to the latch side shall be as low as possible, but shall not exceed 222 N (50 lb).

7.15.5.6 Doors and hardware shall be designed to withstand positive and negative pressures created by passing vehicles.

7.15.6 Emergency Exits.

7.15.6.1 Emergency exits shall be provided throughout the tunnel. The primary purpose of emergency exits is to minimize exposure of the evacuating vehicle occupants to an untenable environment. The second purpose of emergency exits is to provide emergency response access and minimize response time.

7.15.6.2* Spacing between exits for protection of tunnel occupants shall not exceed 300 m (1000 ft). Required spacing shall be determined by consideration of the following factors:

(1) Category, including types and classes of tunnels
(2) Design fire size and fire/smoke development
(3) Egress analysis
(4) Fire life safety systems analyses to provide tenable environment in tunnel in accordance with 7.15.2. This includes type and operation of tunnel ventilation, detection, fire protection, and control systems
(5) Traffic management system
(6) Emergency response plan
(7) Consideration of uncertainties of people's behavior during a fire event and of those who are unable to self-rescue

7.15.6.3* Egress Pathway.

7.15.6.3.1 The tunnel roadway surface, when supported by a traffic management system, shall be considered as a part of the egress pathway.

7.15.6.3.2 Where walkways are provided for egress purposes, the walkway egress path shall have a minimum clear width of 1.12 m (3.6 ft), lead directly to an emergency exit, and be protected from traffic.

7.15.6.4 The emergency "exits" shall be separated from the tunnel by a minimum of a 2-hour fire-rated construction enclosure having a Class A interior finish as defined in NFPA *101*.

7.15.6.5 Emergency "exits" shall be pressurized in accordance with NFPA 92A with doors meeting the requirements of 7.15.5.

7.15.6.6 Where portals of the tunnel are below surface grade, surface grade shall be made accessible by a stair, vehicle ramp, or pedestrian ramp.

7.15.6.7 Where cross-passageways are used as an emergency exit, provisions shall be included that stop all traffic operation in the adjacent tunnel.

7.15.7 Cross-Passageways.

7.15.7.1 Where tunnels are divided by a minimum of 2-hour fire-rated construction or where tunnels are in twin bores, cross-passageways between the tunnels shall be permitted to be utilized in lieu of emergency exits.

7.15.7.2 The following requirements shall be met:

(1) Cross-passageways shall not be farther than 200 m (656 ft) apart.
(2) An emergency egress walkway with a minimum clear width of 1.12 m (3.6 ft) shall be provided on each side of the cross-passageways.
   (a) Walkways shall be protected from oncoming traffic by either a curb, a change in elevation, or a barrier.
   (b) Walkways shall be continuous the entire length of the tunnel, terminating at surface grade.
   (c) Raised walkways in tunnels shall have guards in accordance with NFPA *101*.
   (d) Intermediate rails shall not be required for walkway guards.
(3) Where portals of the tunnel are below surface grade, surface grade shall be made accessible by a stair, vehicle ramp, or pedestrian ramp.

7.15.8 Acceptance Test.

7.15.8.1 Acceptance tests for fire alarm and detection systems shall be performed in accordance with *NFPA 72* or other equivalent international standards, including performance requirements specified in the basis of design.

7.15.8.2 Acceptance tests for standpipe systems shall be performed in accordance with NFPA 14 or other equivalent international standards and performance specified in Chapter 10.

7.15.8.3 Acceptance tests for water-based fire-fighting systems shall be performed in accordance with NFPA 11, NFPA 13, NFPA 15, NFPA 16, NFPA 18, and NFPA 750 or other equivalent international standards as applicable to the system(s) installed, including performance requirements specified in the basis of design.

7.15.8.4 Acceptance tests for fire hydrants, water mains, and water supply systems shall be performed in accordance with NFPA 22, NFPA 24, or other equivalent international standards as applicable to the system(s) installed and performance specified in Chapter 10.

7.15.8.5 Acceptance tests for emergency ventilation systems shall be performed in accordance with the basis of design criteria, equipment manufacturers' specifications, agreed-upon methods acceptable to the authority having jurisdiction, and performance requirements specified in Chapter 11.

7.15.8.6 Acceptance tests for electrical systems (emergency power, emergency lighting, exit signs, etc.) shall be performed in accordance with *NFPA 70*, NFPA 110, basis of design criteria, equipment manufacturers' specifications, and performance requirements specified in Chapter 12.

7.15.8.7 Acceptance tests for communication systems and traffic control systems shall be performed in accordance with the basis of design, equipment manufacturers' specifications, and agreed-upon methods acceptable to the authority having jurisdiction.

Chapter 8 Roadways Beneath Air-Right Structures

8.1* General. This chapter shall provide fire protection and life safety requirements for roadways where a structure is built using the air rights above the road.

8.2 Application. Where required by the authority having jurisdiction, the requirements of Chapter 4 shall apply.

8.2.1 The limits that an air-right structure imposes on the emergency accessibility and function of the roadway that is located beneath the structure shall be assessed.

8.2.2 Where an air-right structure encloses both sides of a roadway, it shall be considered a road tunnel for fire protection purposes and shall comply with the requirements of Chapter 7.

8.2.3 Where an air-right structure does not fully enclose the roadway on both sides, the decision to consider it as a road tunnel shall be made by the authority having jurisdiction after an engineering analysis in accordance with 4.3.1.

8.3 Traffic Control.

8.3.1 Where the roadway beneath an air-right structure is considered a road tunnel, the traffic-control requirements of Section 7.6 shall apply.

8.3.2 The traffic-control system shall be interlocked with the fire alarm system in such a manner that the control system can be operated from either a remote source or from either end of the roadway that passes beneath the air-right structure.

8.4 Protection of Structure.

8.4.1 All structural elements that support air-right structures over roadways and all components that provide separation between air-right structures and roadways shall have a minimum 2-hour fire resistance rating in accordance with Section 7.3.

8.4.1.1* An engineering analysis shall be prepared to determine acceptable risk to include possible collapse scenarios of the air-right structure(s).

• **8.4.2** Structural members shall be protected from physical damage from vehicle impact. An inspection and repair program shall be kept in force to monitor and maintain the structure and its protection.

8.4.3 Maintenance of the structure shall be considered in the design.

8.4.4 Structural support elements shall not be within the dynamic vehicle envelope.

8.4.5 Buildings that are located above roadways shall be designed with consideration of the roadway below an air-right structure as a potential source of heat, smoke, and vehicle emissions.

8.4.6 The structural elements shall be designed to shield the air-right structure and its inhabitants from these potential hazards.

8.4.7 The design of the air-right structure shall neither increase risk nor create any risk to those who use the roadway below.

8.5 Emergency Ventilation.

8.5.1 Chapter 11 shall apply where ventilation during a fire emergency within the roadway beneath an air-right structure is required by Section 7.2.

8.5.2 The prevention or minimization of adverse effects on air-right structures and their occupants from fire products such as heat, smoke, and toxic gases shall be considered in the design of the ventilation system.

8.6 Drainage System. Where required by the authority having jurisdiction, a drainage system that is designed in accordance with the requirements of Section 7.12 shall be provided for roadways beneath air-right structures.

8.7 Control of Hazardous Materials. Control of hazardous materials shall comply with the requirements of Chapter 14.

8.8 Emergency Response Plan.

8.8.1 Where an air-right structure includes a building or facility, a mutual emergency response plan shall be developed among the operator of the air-right structure, the operator of the roadway, and the local authority having jurisdiction so that, during an emergency in either the air-right structure or the roadway, the safety of the motorists using the roadway and of the occupants of the air-right structure is enhanced.

8.8.2 Emergency response procedures and the development of emergency response plans shall comply with the requirements of Chapter 13.

8.9 Standpipe, Fire Hydrants, and Water Supply. Where the roadway beneath air-right structure length is 90 m (300 ft) or greater, fire hydrants, standpipe, and water supply systems shall be provided in accordance with the requirements of Chapter 10.

8.10 Acceptance Test.

8.10.1 Acceptance tests for standpipe systems shall be performed in accordance with NFPA 14 or other equivalent international standards and performance specified in Chapter 10.

8.10.2 Acceptance tests for fire hydrants, water mains, and water supply systems shall be performed in accordance with NFPA 22, NFPA 24, or other equivalent international standards as applicable to the system(s) installed and performance specified in Chapter 10.

8.10.3 Acceptance tests for emergency ventilation systems shall be performed in accordance with the basis of design criteria, equipment manufacturers' specifications, agreed-upon methods acceptable to the authority having jurisdiction, and performance requirements specified in Chapter 11.

8.10.4 Acceptance tests for communication systems and traffic control systems shall be performed in accordance with the basis of design, equipment manufacturers' specification, and agreed-upon methods acceptable to the authority having jurisdiction.

Chapter 9 Water-Based Fire-Fighting Systems

9.1* General.

9.1.1 Water-based fire-fighting systems shall be permitted in road tunnels as part of an integrated approach to the management of fire and life safety.

9.1.2 When water-based fire-fighting systems are installed in road tunnels, the fixed water-based fire-fighting system shall be installed, inspected, and maintained in accordance with NFPA 11, NFPA 13, NFPA 15, NFPA 16, NFPA 18, NFPA 25, and NFPA 750 or other equivalent international standards.

9.2 Design Objectives.

9.2.1 The goal of a water-based fire-fighting system shall be to slow, stop, or reverse the rate of fire growth or otherwise mitigate the impact of fire to improve tenability for tunnel occupants during a fire condition, enhance the ability of first responders to aid in evacuation and engage in manual fire-fighting activities, and/or protect the major structural elements of a tunnel.

9.2.2* Water-based fire-fighting systems shall be categorized based upon their desired performance objective in 9.2.2.1 through 9.2.2.4.

9.2.2.1* Fire Suppression System. Fire suppression is the reduction in the heat release rate of a fire by a sufficient application of water. Fire size shall remain reduced over the design discharge duration.

9.2.2.2* Fire Control System. Fire control systems shall be designed to stop or significantly slow the growth of a fire within a reasonable period from system activation such that the total heat release rate does not substantially increase over discharge duration.

9.2.2.3* Volume Cooling System. Volume cooling systems shall be designed to provide substantial cooling of products of combustion but are not intended to directly affect heat release rate.

9.2.2.4* Surface Cooling System. Surface cooling systems shall be designed to provide direct cooling of critical structure, equipment, or appurtenances without directly affecting heat release rate.

9.3 Performance Evaluation.

9.3.1* Fire test protocols shall be designed to address the performance objectives as described in 9.2.2 and the tunnel parameters described in Section 9.4.

9.3.2 Fire test protocols shall be designed to replicate and evaluate the range of the application parameters associated with transportation tunnels.

9.3.3* System components shall be listed.

9.4 Tunnel Parameters.

9.4.1 *Tunnel parameters* shall be the features of the tunnel that affect the design of a water-based fire-fighting system.

9.4.2 Tunnel Geometry. The tunnel geometry (width, ceiling height, obstruction location) shall be considered when selecting such parameters as nozzle location and nozzle positioning.

9.4.3 Ventilation. Ventilation considerations shall include natural and fire-induced forced ventilation parameters.

9.4.4 Hazard Analysis. A fire hazard analysis shall be conducted to determine both the design parameters of the water-based fire-fighting system and the type of detection and activation scheme employed. The water-based fire-fighting system shall address the anticipated vehicle types and contents, ease of ignition and reignition of the fuel, anticipated fire growth rate, and difficulty of achieving one or more of the performance objectives established in Section 9.2 or as otherwise acceptable to the AHJ.

9.4.5 Obstructions and Shielding. The presence of obstructions and the potential for shielding of water-based fire-fighting system discharge shall be addressed to ensure that system performance is not affected.

9.4.6 Ambient Conditions. The range of ambient conditions that could be experienced in the tunnel shall be identified.

9.5 System Design and Installation Documentation.

9.5.1 The system design and installation documentation shall identify the design objectives and tunnel parameters over which the system performance evaluation is valid.

9.5.2* System documentation shall clearly identify engineering safety factors incorporated into the overall system design. Safety factors shall be required to ensure that installed system performance exceeds the performance of the system as tested in accordance with Section 9.3.

9.5.3 System documentation shall also include recommended testing, inspection, and maintenance procedures and, by reference, the requirements of the relevant NFPA standard or equivalent standard acceptable to the AHJ.

9.6 Engineering Design Requirements.

9.6.1* When a water-based fire-fighting system is included as part of the overall design of a transportation tunnel, the impact of this system on other measures being part of the overall safety concept shall be evaluated. At a minimum, this evaluation shall address the following:

(1) Impact on drainage requirements
(2) Impact on tenability, including:
   (a) Increase in humidity
   (b) Reduction (if any) in stratification
(3) Integration with other tunnel systems, including:
   (a) Fire detection and alarm system
   (b) Tunnel ventilation system
   (c) Traffic control and monitoring systems
(4) Incident command structure and procedures, including:
   (a) Procedures for tunnel operators
   (b) Procedures for first responders
   (c) Tactical fire-fighting procedures
(5) Protection and dependability of the water-based fire-fighting system, including:
   (a) Impact events
   (b) Seismic events
   (c) Redundancy requirements
(6) Ongoing system maintenance and service requirements

Chapter 10 Standpipe and Water Supply

10.1 Standpipe Systems.

10.1.1 Standpipe systems shall be designed and installed as Class I systems in accordance with NFPA 14, except as modified by this standard.

10.1.2 Standpipe systems shall be inspected and maintained in accordance with NFPA 25.

10.1.3 Standpipe systems shall be either wet or dry, depending on the climatic conditions, the fill times, the requirements of the authority having jurisdiction, or any combination thereof.

10.1.4 Areas Subject to Freezing.

10.1.4.1 Where wet standpipes are required in areas subject to freezing conditions, the water shall be heated and circulated.

10.1.4.2 All piping and fittings that are exposed to freezing conditions shall be heat-traced and insulated.

10.1.4.3 Heat trace material shall be listed for the intended purpose and supervised for power loss.

10.1.5* Dry standpipe systems shall be installed in a manner so that the water is delivered to all hose connections on the system in 10 minutes or less.

10.1.6 Combination air relief–vacuum valves shall be installed at each high point on the system.

10.2 Water Supply.

10.2.1 Wet standpipe systems (automatic or semiautomatic) shall be connected to an approved water supply that is capable of supplying the system demand for a minimum of 1 hour.

10.2.2 Dry standpipe systems shall have an approved water supply that is capable of supplying the system demand for a minimum of 1 hour.

10.2.3 Acceptable water supplies shall include the following:

(1) Municipal or privately owned waterworks systems that have adequate pressure and flow rate and a level of integrity acceptable to the authority having jurisdiction
(2) Automatic or manually controlled fire pumps that are connected to an approved water source
(3) Pressure-type or gravity-type storage tanks that are installed, inspected, and maintained in accordance with NFPA 22

10.3 Fire Department Connections.

10.3.1 Fire department connections shall be of the threaded two-way or three-way type or shall consist of a minimum 100 mm (4 in.) quick-connect coupling that is accessible.

10.3.2 Each independent standpipe system shall have a minimum of two fire department connections that are remotely located from each other.

10.3.3 Fire department connections shall be protected from vehicular damage by means of bollards or other approved barriers.

10.3.4 Fire department connection locations shall be approved and shall be coordinated with emergency access and response locations.

10.4 Hose Connections.

10.4.1 Hose connections shall be spaced so that no location on the protected roadway is more than 45 m (150 ft) from the hose connection.

10.4.2 Hose connection spacing shall not exceed 85 m (275 ft).

10.4.3 Hose connections shall be located so that they are conspicuous and convenient but still reasonably protected from damage by errant vehicles or vandals.

10.4.4 Hose connections shall have 65 mm (2½ in.) external threads in accordance with NFPA 1963 and the authority having jurisdiction.

10.4.5 Hose connections shall be equipped with caps to protect hose threads.

10.5 Fire Pumps. Fire pumps shall be installed, inspected, and maintained in accordance with NFPA 20.

10.6 Identification Signs.

10.6.1 Identification signage for standpipe systems and components shall be approved by and developed with input from the authority having jurisdiction.

10.6.2 Identification signage shall, as a minimum, identify the name and limits of the roadway that is served.

10.6.3 Identification signage shall be conspicuous and shall be affixed to, or immediately adjacent to, fire department connections and each roadway hose connection.

Chapter 11 Emergency Ventilation

11.1* General. Emergency ventilation systems and tunnel operating procedures shall be developed to maximize the use of the road tunnel ventilation system for the removal and control of smoke and heated gases that result from fire emergencies within the tunnel.

11.1.1* Emergency ventilation shall not be required in tunnels exceeding 240 m (800 ft) in length, where it can be shown by an engineering analysis, using the design parameters for a particular tunnel (length, cross-section, grade, prevailing wind, traffic direction, types of cargoes, design fire size, etc.), that the level of safety provided by a mechanical ventilation system can be equaled or exceeded by enhancing the means of egress, the use of natural ventilation, or the use of smoke storage, and shall be permitted only where approved by the authority having jurisdiction.

11.1.2 For any engineering analysis performed to determine the requirement for tunnel emergency ventilation, potential fires immediately proximate to the tunnel portal, but outside the tunnel, that can have a negative impact on the tunnel environment shall be included in the engineering analysis.

11.1.3 The emergency ventilation operational procedures shall be designed to assist in the evacuation or rescue, or both, of motorists from the tunnel.

11.2* Smoke Control.

11.2.1 The emergency ventilation system shall provide a means for controlling smoke.

11.2.2 In all cases, the desired goal shall be to provide an evacuation path for motorists who are exiting from the tunnel and to facilitate fire-fighting operations.

11.2.3 In tunnels with bidirectional traffic where motorists can be on both sides of the fire site, the following objectives shall be met:

(1) Smoke stratification shall not be disturbed.
(2) Longitudinal air velocity shall be kept at low magnitudes.
(3) Smoke extraction through ceiling openings or high openings along the tunnel wall(s) is effective and shall be considered.

11.2.4 In tunnels with unidirectional traffic where motorists are likely to be located upstream of the fire site, the following objectives shall be met:

(1) Longitudinal systems
    (a) Prevent backlayering by producing a longitudinal air velocity that is greater than the critical velocity in the direction of traffic flow

(b) Avoid disruption of the smoke layer initially by not operating jet fans that are located near the fire site. Operate fans that are farthest away from the site first

(2) Transverse or reversible semitransverse systems

(a) Maximize the exhaust rate in the ventilation zone that contains the fire and minimize the amount of outside air that is introduced by a transverse system

(b) Create a longitudinal airflow in the direction of traffic flow by operating the upstream ventilation zone(s) in maximum supply and the downstream ventilation zone(s) in maximum exhaust

11.3* Memorial Tunnel Fire Ventilation Test Program. See Annex H for additional information on the Memorial Tunnel Fire Ventilation Test Program.

11.4 Design Objectives. The design objectives of the emergency ventilation system shall be to control, to extract, or to control and extract, smoke and heated gases as follows:

(1) A stream of noncontaminated air is provided to motorists in a path of egress away from a fire *(see Annex C)*.
(2) Longitudinal airflow rates are produced to prevent backlayering of smoke in a path of egress away from a fire *(see Annex D)*.

11.5* Basis of Design. The design of the emergency ventilation system shall be based on a fire scenario having defined heat release rates, smoke release rates, and carbon monoxide release rates, all varying as a function of time. The selection of the fire scenario shall consider the operational risks that are associated with the types of vehicles expected to use the tunnel.

11.5.1* The design fire size [heat-release rate produced by a vehicle(s)] shall be used to design the emergency ventilation system.

11.5.2* The selection of the design fire size (heat release rate) shall consider the types of vehicles that are expected to use the tunnel.

11.6 Fans.

11.6.1* Tunnel ventilation fans that are to be used during fire emergencies and exposed to elevated temperatures, their motors, and all related components that are exposed to the ventilation airflow shall be designed to remain operational for a minimum of 1 hour in an airstream temperature of 250°C (482°F).

11.6.1.1 Where design calculations carried out as required in Section 11.5 show higher temperatures, those higher temperatures shall be used for equipment selection.

11.6.2 Tunnel ventilation fans, such as jet fans, that can be directly exposed to fire within the tunnel roadway shall be considered expendable.

11.6.3* The design of ventilation systems where fans can be directly exposed to a fire shall incorporate fan redundancy.

11.6.4 The emergency ventilation system shall be capable of reaching full operational mode within a maximum of 180 seconds of activation.

11.6.5 Reversible fans shall be capable of completing full rotational reversal within 90 seconds.

11.6.6 Discharge and outlet openings for emergency fans shall be positioned away from any supply air intake openings to prevent recirculation.

11.6.7 Where separation is not possible, intake openings shall be protected by other approved means or devices to prevent smoke from re-entering the system.

11.7 Dampers.

11.7.1 All dampers, actuators, and accessories that are exposed to the elevated exhaust airstream from the roadway fire shall be designed to remain fully operational in an airstream temperature of 250°C (482°F) for at least 1 hour.

11.7.1.1 Where design calculations carried out as required in Section 11.5 show higher temperatures, those higher temperatures shall be used for equipment selection.

11.7.2 All moving and other critical components of the damper shall be designed to allow for expansion and contraction throughout the maximum anticipated temperature range.

11.7.3 The bearings of multibladed dampers shall be located outside of the airstream.

11.7.4 The actuators and bearings shall be isolated from the heated airstream.

11.7.5 The requirements of 11.7.3 and 11.7.4 shall not apply where the application warrants a special type of bearing, or where it is impossible to locate the bearings in a position that is clear of the airstream, as in the case of single-point extraction dampers.

11.7.6 All other dampers designed for use during a fire emergency shall be equipped with power actuators that are capable of being manually or automatically controlled.

11.8 Sound Attenuators.

11.8.1 Sound attenuators that are located in the elevated airstream from the roadway, such as those used in semitransverse exhaust systems and fully transverse exhaust ducts, shall be capable of withstanding an airstream temperature of 250°C (482°F).

11.8.1.1 Where design calculations carried out as required in Section 11.5 show higher temperatures, those higher temperatures shall be used for equipment selection.

11.8.1.2 All components of the attenuator shall remain structurally intact and in place after the required 1 hour of operation.

11.8.2 The sound-absorbing fill material used in the baffles shall be noncombustible, nontoxic, and stable at the temperatures specified in 11.8.1.

11.9 Controls.

11.9.1 The fans shall be locally controllable in addition to any automatic or remote control so that the equipment can be manually operated. Where both the local and remote controls provide the capability to operate the fans in an emergency mode, local control shall be capable of overriding remote control.

11.9.1.1 Local control shall be the switching devices at the motor control.

11.9.2 Control devices including motor starters, motor drives, and motor disconnects shall be isolated from the fan airstream to the greatest extent practical.

11.10 Flammable and Combustible Liquids Intrusion.

11.10.1 General. Prevention of accidental intrusion of flammable and combustible liquids due to spills shall be provided in accordance with 11.10.2 and 11.10.3.

11.10.2 Vehicle Roadway Terminations. Vent or fan shafts utilized for ventilation of tunnels shall not terminate at grade on any vehicle roadway.

11.10.3 Median and Sidewalk Terminations. Vent and fan shafts shall be permitted to terminate in the median strips of divided highways, on sidewalks designed to accept such shafts, or in open space areas provided that the following conditions are met:

(1) The grade level of the median strip, sidewalk, or open space is at a higher elevation than the surrounding grade level.
(2) The grade level of the median strip, sidewalk, or open space is separated from the roadway by a concrete curb at least 152.4 mm (6 in.) in height.

Chapter 12 Electrical Systems

12.1 General.

12.1.1* The electrical systems shall support life safety operations, fire emergency operations, and normal operations.

12.1.2* Emergency circuits installed in a road tunnel and ancillary areas shall remain functional for a period of not less than 1 hour for the anticipated fire condition, meeting one of the following methods:

(1) A fire-resistive cable listed for 2 hours in accordance with ANSI/UL 2196 or other equivalent internationally recognized standards to 950°C (1742°F) when approved by the AHJ.
(2) Circuits embedded in concrete or protected by a 2-hour fire barrier system in accordance with UL 1724. The cables or conductors shall be thermoset and shall be suitable to maintain functionality at the temperature within the embedded conduit or fire barrier system.

12.1.3 The requirement of 12.1.2 shall not apply to bidirectional antennas used for emergency communication circuits.

12.1.4 The electrical systems shall maintain ventilation, lighting, communications, drainage, fire suppression, fire alarm and fire detection, exit signs, traffic control, and others for areas of refuge, exits, and exit routes, under all normal and emergency modes associated with the facility.

12.1.5* The fire and life safety electrical systems shall be designed and installed to resist lateral forces induced by earthquakes (seismic forces) in the appropriate seismic zone and to continue to function after the event.

12.1.6 An electrical single-line diagram shall be posted within the main electrical room.

12.1.6.1 The diagram shall include utility short-circuit duty, all sources, uninterrupted power supplies (UPSs), or standby source and interlocking schemes, and other data per IEEE standards for single-line diagrams.

12.1.7 Labels, nameplates, or tags shall be affixed to switchboards, panelboards, motor controllers, switches, and breakers that correspond to the single line. The equipment or device operating instructions shall be available to operating personal.

12.2 Wiring Methods.

12.2.1 All wiring materials and installations shall conform to *NFPA 70* except as herein modified in this standard.

12.2.1.1 All cables and conductors shall be of the moisture-resistant and heat-resistant types with temperature ratings that correspond to the conditions of application.

12.2.1.2 All cables and conductors shall be listed for use in wet locations.

12.2.1.3 All cables and conductors used in road tunnels shall be resistant to the spread of fire and shall have reduced smoke emissions by one of the following methods:

(1) All wires and cables shall be listed and shall comply with the FT4/IEEE 1202 exposure requirements for cable char height, total smoke released, and peak smoke release rate of ANSI/UL 1685.
(2) Wires and cables listed as having adequate fire-resistant and low smoke-producing characteristics, by having a flame travel distance that does not exceed 1500 mm (4.9 ft), generating a maximum peak optical density of smoke of 0.5 and a maximum average optical density of smoke of 0.15 when tested in accordance with NFPA 262.
(3) Wires and cables tested to equivalent internationally recognized standards approved by the AHJ.

12.2.1.4 All cables and conductors used in road tunnels shall emit less than 2 percent acid gas when tested in accordance with MIL-C 24643 or in accordance with an equivalent internationally recognized standard approved by the AHJ.

12.3 Installation Methods.

12.3.1 All wiring shall be protected by means of metallic armor/sheath, metal raceway, electrical duct banks embedded in concrete, or other methods approved by the AHJ.

12.3.1.1 All wiring installed in ancillary facilities shall not require additional physical protection as described in 12.3.1 provided that they are installed in a cable tray and are listed for cable tray use.

12.3.2 All wiring, raceways, equipment, and supports installed in a road tunnel and ancillary areas shall meet the following:

(1) PVC coatings of any type shall not be permitted on exposed metallic armor/sheath, raceways, equipment, or supports.
(2) PVC conduits shall be permitted when covered with a minimum of 100 mm (4 in.) concrete when approved by the AHJ. All conduit ends inside of pull boxes and junction boxes shall be fire stopped.
(3) All insulated cables and conductors installed in supply air duct shall be enclosed in a metal raceway, or be Type MI cable, or Type MC cable employing a smooth or corrugated impervious metal sheath. PVC coatings of any type shall not be permitted.

12.3.3* All wiring and cables installed in supply air ducts shall meet one of the following:

(1) Shall be listed as having adequate fire-resistant and low smoke-producing characteristics when tested in accordance with NFPA 262 or equivalent international recognized standard
(2) Shall be installed in nonmetallic conduits that are embedded in concrete with all conduit ends fire stopped where they enter pull boxes or splice boxes
(3) Shall be installed in intermediate metal conduit, or rigid metal conduit without an overall nonmetallic covering, or flexible metallic tubing no longer than 6 ft in length
(4) Shall be Type MI cable, or Type MC cable employing a smooth or corrugated impervious metal sheath without an overall nonmetallic covering

12.3.3.1 All equipment and supports installed in supply air ducts shall be metallic without nonmetallic coverings.

12.3.4* Conduits, equipment, and supports installed in exhaust air ducts that can be exposed to elevated temperatures shall be metallic without nonmetallic covering. Where nonmetallic conduit is permitted by the AHJ, it shall be embedded in concrete with all conduit ends fire stopped where they enter pull boxes or splice boxes.

12.3.5 Labels, or tags, shall be affixed to essential circuit feeders with numbering that is consistent with the posted single line diagram of 12.1.6.

12.4* Emergency Power. Road tunnels complying with Category B–D in Section 7.2 shall be provided with emergency power in accordance with Article 700 of *NFPA 70*. For emergency and standby power systems, other than separate service, see NFPA 110.

12.4.1 The following systems shall be connected to the emergency power system:

(1) Emergency lighting
(2) Tunnel closure and traffic control
(3) Exit signs
(4) Emergency communication
(5) Tunnel drainage
(6) Emergency ventilation
(7) Fire alarm and detection
(8) Closed-circuit television or video
(9) Fire fighting

12.5* Reliability.

12.5.1 The electrical systems of tunnels and dual-level bridges in excess of 1000 m (3280 ft) in length shall have redundant facilities for the purpose of monitoring and control.

12.5.2 The electrical systems shall be designed to allow for routine maintenance without disruption of traffic operation.

12.5.3 Wiring in manholes shall be protected from spillage of flammable liquids or fire-fighting products by the installation of manhole covers with sealing and locking capability.

12.5.4 Conductors in manholes shall be protected from spillage of flammable liquids or fire-fighting products by the installation of manhole covers with sealing and locking capability.

12.6 Emergency Lighting.

12.6.1* Emergency lighting systems shall be installed and maintained in accordance with *NFPA 70*, NFPA 110, and NFPA 111.

12.6.2 Emergency lights, exit lights, and essential signs shall be included in the emergency lighting system and shall be powered by an emergency power supply.

12.6.3 Emergency luminaires, exit lights, and signs shall be wired from emergency distribution panels in separate raceways.

12.6.4 Emergency lighting levels for roadways and walkways shall be maintained in those portions of the tunnel that are not involved in an emergency.

12.6.5* There shall be no interruption of the lighting levels for greater than 0.5 second.

12.6.6 The emergency illumination level to be provided for roadway and walkway surfaces shall be a minimum average maintained value of 10 lx (1 fc) and, at any point, not less than 1 lx (0.1 fc), measured at the roadway and walkway surface.

12.6.6.1 A maximum-to-minimum illumination uniformity ratio of 40 to 1 shall not be exceeded.

12.6.7 Lighting shall be provided to highlight special emergency features including, but not limited to, fire alarm boxes, extinguishers and telephones, and special feature instructional signage.

12.6.8* Exit Signs.

12.6.8.1 Externally illuminated exit signs shall be illuminated by not less than 54 lx (5 fc) and employ a contrast ratio of not less than 0.5.

12.6.8.2 Internally illuminated exit signs shall produce a minimum luminance of 8.6 cd/m^2 (2.5 fl).

12.7* Security Plan. A security plan for the protection of the electrical supply substation to the facility shall be developed by the agency.

Chapter 13 Emergency Response

13.1 General. The agency that is responsible for the safe and efficient operation of the facility shall anticipate and plan for emergencies that could involve the system. Designers and contractors shall solicit input from the operators and emergency response agencies during the design and construction phases on the emergency operations of the facility. The designers and contractors shall also be invited to assist in the preparation of the emergency response plan along with the other participating agencies.

13.2 Emergencies. The following typical incidents shall be considered during the development of facility emergency response plans:

(1) Fire or a smoke condition in one or more vehicles or in the facility
(2) Fire or a smoke condition adjoining or adjacent to the facility
(3) Collision involving one or more vehicles
(4) Loss of electric power that results in loss of illumination, ventilation, or other life safety systems
(5) Rescue and evacuation of motorists under adverse conditions
(6) Disabled vehicles
(7) Flooding of a travel way or an evacuation route
(8) Seepage and spillage of flammable, toxic, or irritating vapors and gases
(9) Multiple casualty incidents
(10) Damage to structures from impact and heat exposure
(11) Serious vandalism or other criminal acts, such as bomb threats and terrorism
(12) First aid or medical attention for motorists
(13) Extreme weather conditions, such as heavy snow, rain, high winds, high heat, low temperatures, or sleet and ice, that cause disruption of operation
(14) Earthquake
(15) Hazardous materials accidentally or intentionally being released into the tunnel

13.3* Emergency Response Plan. An emergency response plan shall be submitted for acceptance and approval by the authority having jurisdiction and shall include, as a minimum, the following:

(1) Name of plan and the specific facility(ies) the plan covers
(2) Name of responsible agency
(3) Names of responsible individuals
(4) Dates adopted, reviewed, and revised
(5) Policy, purpose, scope, and definitions
(6) Participating agencies, senior officials, and signatures of executives authorized to sign for each agency
(7) Safety during emergency operations
(8) Purpose and operation of operations control center (OCC) and alternative location(s) as applicable:
    (a) Procedure for staffing the backup location(s) shall be specified.
    (b) Procedure to control risk while the OCC does not have staff until the backup facility can take over.
(9) Purpose and operation of command post and auxiliary command post
(10) Communications (e.g., radio, telephone, and messenger service) available at central supervising station and command post; efficient operation of these facilities
(11) Fire detection, fire protection, and fire-extinguishing equipment; access/egress and ventilation facilities available; details of the type, amount, location, and method of ventilation
(12) Procedures for fire emergencies, including a list of the various types of fire emergencies, the agency in command, and the procedures to follow
(13) Maps and plans of the roadway system, including all local streets
(14) Any additional information that the participating agencies want to include
(15) Emergency response plan shall recognize the need to assist people who are unable to self-rescue, and establish specific response procedures.

13.3.1 The emergency procedure plan shall clearly identify the authority or participating agency that is in command and responsible for supervision, correction, or alleviation of the emergency.

13.3.2 The emergency response plan shall include emergency response procedures, precautions, and training requirements for incidents involving alternative fuel vehicles. *(See Annex G.)*

13.4* Participating Agencies. Participating agencies and organizations that shall be considered to coordinate and assist, depending on the nature of the emergency, shall include the following:

(1) Ambulance service
(2) Building department
(3) Fire department (brigade)
(4) Medical service
(5) Police department
(6) Public works (e.g., bridges, streets, sewers)
(7) Sanitation department
(8) Utility companies (e.g., gas, electric, telephone, steam)
(9) Water supply
(10) Local transportation companies
(11) Private industry with heavy construction equipment available
(12) Land management agencies
(13) Towing companies
(14) Highway operators (e.g., departments of transportation)
(15) U.S. Coast Guard
(16) Military
(17) Federal Aviation Administration (FAA)

13.5* Operations Control Center (OCC). Subsections 13.5.1 through 13.5.8 shall apply where the facility has an OCC for the operation and supervision of the facility.

13.5.1 The OCC shall be staffed by qualified, trained personnel and shall be provided with the essential apparatus and equipment to communicate with, supervise, and coordinate all personnel.

13.5.1.1* The OCC shall serve as a proprietary supervising station to allow direct receipt of alarms. This provides more rapid alarm information, and allows integrated alarm and device/system activation without delays.

13.5.1.2 For the OCC to be a proprietary supervising station, it shall meet the relevant requirements of *NFPA 72* and shall meet the UL listing or equivalent for a proprietary monitoring station.

13.5.1.3 Systems monitored by the proprietary supervising station shall have a compliant proprietary monitoring alarm system.

13.5.2 The OCC shall provide the capability to communicate rapidly with participating agencies.

13.5.3 Participating agencies such as fire, police, ambulance, and medical service shall have direct telephone lines or designated telephone numbers that are to be used for emergencies that involve the facility.

13.5.4 Equipment shall be available and shall be used for recording radio and telephone communications and CCTV transmissions during an emergency.

13.5.5 OCC personnel shall be thoroughly familiar with the emergency procedure plan and shall be trained to implement it effectively.

13.5.6 Alternate location(s) shall be provided in the event the OCC is out of service for any reason and shall be equipped or have equipment readily available to function as required by the operating agency and have all necessary documents, records, and procedures available to duplicate the functions of the primary OCC.

13.5.7* The OCC shall be located in an area that is separated from other occupancies by construction that has a 2-hour fire resistance rating.

13.5.8 The OCC shall be protected by fire detection, fire protection, and fire-extinguishing equipment to provide early detection and suppression of fire in the OCC.

13.6 Liaisons.

13.6.1 An up-to-date list of all liaison personnel from participating agencies shall be maintained by the operating agency and shall be part of the emergency procedure plan.

13.6.2 The list of liaison personnel shall include the full name, title, agency affiliation, business telephone number(s), and home telephone number of the primary liaison, as well as an alternate liaison.

13.6.3 The liaison personnel list shall be reviewed at least once every 3 months to verify that the list is current.

13.7 Emergency. Emergency incidents shall be managed in accordance with NFPA 1561.

13.8 Training, Exercises, Drills, and Critiques.

13.8.1 Operating agency and participating agency personnel shall be trained to function efficiently during an emergency.

13.8.2 Qualified personnel shall be thoroughly trained in all aspects of the emergency procedure plan, including operation of mechanical, electrical, and fire and life safety systems.

13.8.3* To optimize the emergency response plan, comprehensive training programs shall be conducted for all personnel and agencies that are expected to participate in emergencies.

13.8.4 Exercises and drills shall be conducted at least twice a year to prepare the operating agency and participating personnel for emergencies.

13.8.4.1 The authority having jurisdiction shall approve the scope and content of the drill for meeting the intent of 13.8.4.

13.8.5 Critiques shall be held after exercises, drills, and actual emergencies.

13.8.6 Limited Access Highways.

13.8.6.1 Contacts shall be made with roadside businesses and responsible persons who live along limited access highways to elicit their cooperation in reporting fires and other emergencies.

13.8.6.2 The objective of such contacts shall be to establish a positive system for reporting emergencies.

13.8.6.3 Those who agree to participate in the system shall be provided with specific information on the procedures for reporting and a means for determining and reporting the location of the emergency as precisely as possible.

• **13.9 Records.** Written records and telephone, radio, and CCTV recordings shall be kept at the central supervisory station (CSS), and written records shall be kept at the command post and auxiliary command post(s) during fire emergencies, exercises, and drills.

13.9.1 Revisions. Emergency response plan, documents, software, and other forms of records that have data that expires and/or may change and be needed for emergency management by the OCC or emergency responders shall be revised on a scheduled and timely basis, and as part of drills and exercises, but not less than annually.

13.9.1.1 Information that is critical to the success of fire and life safety emergency management, such as responsible individuals and contact personnel, shall be completed as the information changes.

Chapter 14 Regulated and Unregulated Cargoes

14.1 General.

14.1.1* The authority having jurisdiction shall adopt rules and regulations that apply to the transportation of regulated and unregulated cargoes.

14.1.2 Design and planning of the facility shall address the potential risk presented by regulated and unregulated cargoes as permitted by 14.1.1.

14.1.3* Development of such regulations shall address the following:

(1) Population density
(2) Type of highway
(3) Types and quantities of hazardous materials
(4) Emergency response capabilities
(5) Results of consultation with affected persons
(6) Exposure and other risk factors
(7) Terrain considerations
(8) Continuity of routes
(9) Alternative routes
(10) Effects on commerce
(11) Delays in transportation
(12) Climatic conditions
(13) Congestion and accident history

Chapter 15 Periodic Testing

15.1 Periodic Testing.

15.1.1 Fire protection, life safety, emergency ventilation, communication, traffic control, and electrical systems shall be inspected and tested for operational readiness and performance in accordance with the frequency requirements of the applicable NFPA standards or in accordance with 15.1.2.

15.1.2 Integrated and/or interconnected fire protection, life safety, and emergency systems shall be inspected and tested for operational readiness and performance in accordance with the frequency requirements established by the basis of design or intervals not to exceed five years.

Annex A Explanatory Material

Annex A is not a part of the requirements 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.1.3.1 The requirements of this standard reflect the practices and the state of the art prevalent at the time this standard was issued.

A.1.6.1 SI units have been converted by multiplying the U.S. unit value by the conversion factor and rounding the result to the appropriate number of significant digits *(see Table A.1.6.1)*. See IEEE/ANSI SI 10.

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

Table A.1.6.1 Conversion Factors

U.S. Units	SI Conversions
1 inch (in.)	25.4 millimeters (mm)
1 foot (ft)	0.3048006 meter (m)
1 square foot (ft^2)	0.09290304 square meter (m^2)
1 foot per minute (fpm)	0.00508 meter per second (m/sec)
1 foot per second squared (ft/sec^2)	0.3048 meter per second squared (m/sec^2)
1 cubic foot per minute (ft^3/min)	0.000471947 cubic meter per second (m^3/sec)
1 gallon per minute (gpm)	0.06309020 liter per second (L/sec)
1 pound (lb)	0.45359237 kilogram (kg)
1 pound per cubic foot (lb/ft^3)	16.01846 kilograms per cubic meter (kg/m^3)
1 inch water gauge (in. wg)	0.249089 kilopascal (kPa)
1 pound per square inch (psi)	6.894757 kilopascals (kPa)
1 degree Fahrenheit (°F)	(°F – 32)/1.8 degrees Celsius (°C)
1 degree Rankine (°R)	1/1.8 Kelvin (K)
1 Btu per second (Btu/sec)	1.05505 watts (W)
1 Btu per second (Btu/sec)	0.001 055 853 megawatts (MW)
1 Btu per pound degree Rankine (Btu/lb°R)	4.1868 joules per kilogram Kelvin (J/kg K)
1 footcandle(fc)	10.76391 lux (lx)
1 pound-force (lbf)	4.448 222 newtons (N)
1 gallon (gal)	3.785411784 liters (L)
1 cubic foot per minute per lane foot ($ft^3/min{\cdot}lf$)	0.001 55 cubic meters per second per lane meter ($m^3/sec{\cdot}lm$)
1 Btu per hour square foot ($Btu/hr{\cdot}ft^2$)	3.154 591 watts per square meter (W/m^2)

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.3.2.4 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.3.3.5 Backlayering. See Figure A.3.3.5(a) through Figure A.3.3.5(c).

A.3.3.7 Building. The term should be interpreted as if followed by the words "or portions thereof."

A.3.3.19 Engineering Analysis. A written report of the analysis that recommends the fire protection method(s) that provides a level of fire safety commensurate with this standard is submitted to the authority having jurisdiction.

A.3.3.29 Fixed Water-Based Fire-Fighting System. This term includes sprinkler systems, water spray systems, and water mist systems.

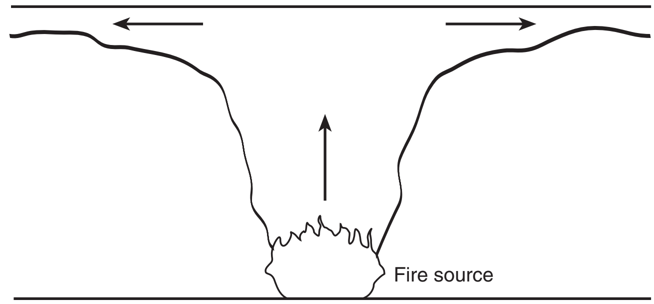

FIGURE A.3.3.5(a) Tunnel Fire Under Natural Ventilation and Zero Percent Grade.

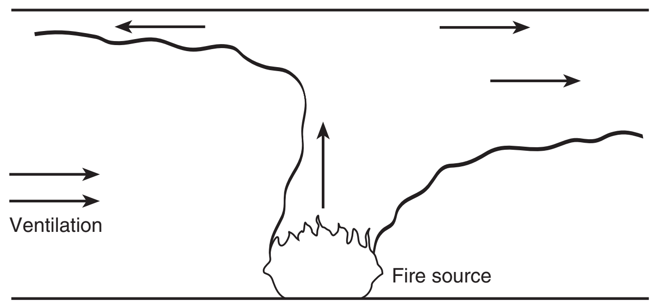

FIGURE A.3.3.5(b) Underventilated Tunnel Fire Causing Backlayering.

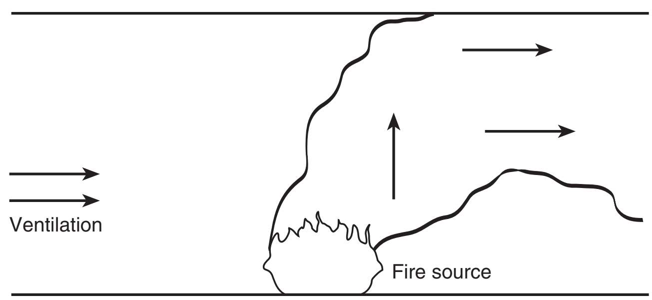

FIGURE A.3.3.5(c) Tunnel Fire Sufficiently Ventilated to Prevent Backlayering.

A.3.3.30.1 Depressed Highway. See Figure A.3.3.30.1.

A.3.3.30.3 Length of Bridge or Elevated Highway. Definitions associated with length of bridge or elevated highway include the following:

(1) Abutment. A retaining wall supporting the ends of the bridge or elevated highway.
(2) Approach. The part of the bridge that carries traffic from the land to the main parts of the bridge or elevated highway that does not meet the definition of a bridge or elevated highway.
(3) Bearing. A device at the ends of beams that is placed on top of a pier or abutment. The ends of the beam rest on the bearing.

A.3.3.37 Noncombustible Material. Standards other than ASTM E 136, *Standard Test Method for Behavior of Materials in a*

FIGURE A.3.3.30.1 Depressed Highway.

Vertical Tube Furnace at 750°C, exist that are used to assess noncombustibility of materials. They include: ASTM E 2652, *Standard Test Method for Behavior of Materials in a Vertical Tube Furnace at 750°C with a Cone-Shaped Airflow Stabilizer;* ISO 1182, *Reaction to Fire Tests for Building and Transport Products — Non-Combustibility Test;* and BS 476–4, *Fire Tests on Building Materials and Structures, Non-Combustibility Test for Materials.*

A.3.3.40 Point of Safety. The egress population to be served should be determined by an engineering analysis.

A.3.3.49.1 Air-Right Structure. See Figure A.3.3.49.1.

A.4.1 Fire protection for limited access highways, road tunnels, and roadways beneath air-right structures and on bridges and elevated highways can be achieved through a combination of facility design, operating equipment, hardware, software, subsystems, and procedures that are integrated to provide requirements for the protection of life and property from the effects of fire.

A.4.3.2 Limited access highways can include other facilities covered by this standard.

A.4.3.4 The majority of depressed highways are associated with road tunnels that serve as connecting sections or open approaches.

A.4.3.5 Smoke and heated gases from a fire that do not readily disperse can seriously impede emergency response operations.

FIGURE A.3.3.49.1 Air-Right Structure.

A.4.3.6 Smoke dispersion during a roadway fire emergency is similar to that during a fire in a road tunnel.

Fire protection for structures built over roadways are not covered by this standard, except for the separation between the air-right structure and the roadway beneath the air-right structure. However, fire protection and fire life safety problems are complicated by limited access, by traffic congestion, and by any fire situation on the roadway that is located below or adjacent to the building.

A.4.3.7 Protection of related ancillary facilities such as service areas, rest areas, toll booths and plazas, pump stations and substations, and buildings used for administration, law enforcement, and maintenance presents problems that basically do not differ from fire protection problems for all buildings. However, special consideration should be given to the fact that where located on, or adjacent to, limited access highways, such buildings can be located in isolated areas. *(See NFPA 30 and NFPA 30A.)*

A.5.2 Recommendations regarding suitable fire apparatus for limited access highways can be found in Annex K.

A.5.3 Where a municipal or privately owned waterworks system is available, consideration should be given to providing fire hydrants along limited access highways at spacing not to exceed 305 m (1000 ft). The minimum required water supply for fire hydrants should not be less than 3780 L/min (1000 gpm) at 1.4 bar (20 psi) from each of two hydrants flowing simultaneously.

A.6.1 Guidelines regarding suitable fire apparatus for bridges and elevated highways can be found in Annex K.

A.6.2 Bridge or elevated highway approaches, on soil embankment fills or soil fills retained by retaining walls, with limited access, can be treated similar to a bridge or elevated highway as defined in this standard, at the discretion of the AHJ based on a risk assessment.

A.6.6.1 Where a horizontal standpipe is required on a bridge or elevated highway under this standard, a vertical standpipe riser and fire department connection can be used to supply the standpipe from above or below. Where a horizontal standpipe system is required under Chapter 6, it should extend the full length of the bridge or elevated highway.

A.7.1 Chapter 7 also covers requirements, where appropriate, for the fire protection and fire life safety of depressed highways.

A.7.1.2 Measures used to protect the structural elements and nonstructural elements of a tunnel may change the heat flux characteristics of the area of the tunnel by changing the rate of energy flow in the area of the measures. Such methods for protecting elements of the tunnel can be very effective in protecting these elements from failure during a fire. They range from protective linings by inhibiting heat flux to sacrificial coatings and sacrificial additives that consume energy through phase changes within the concrete.

In changing these heat flux characteristics these measures necessarily have the potential to alter the tunnel environment.

These changes should be considered when ensuring that life is protected within the tunnel during the evacuation and rescue phases.

Conversely, measures used to ensure life is protected may also alter the measures necessary to protect the structural and nonstructural elements of the tunnel by likewise altering the heat flux (such as via phase changes in water where water-based fire-fighting systems are used).

Accordingly, the interdependence of these measures must be considered in the design and operation of a tunnel.

A.7.2 The categorizing of road tunnels is also influenced by their level of traffic congestion as evidenced by the tunnel's peak hourly traffic count, as shown in Figure A.7.2.

A.7.3.2 Any fire protection material should satisfy the following performance criteria:

(1) Be resistant to freezing and thawing
(2) Withstand dynamic suction and pressure loads
(3) Withstand both hot and cold thermal shock from fire exposure and hose streams
(4) Meet all applicable health and safety standards
(5) Not itself become a hazard during a fire
(6) Be resistant to water ingress

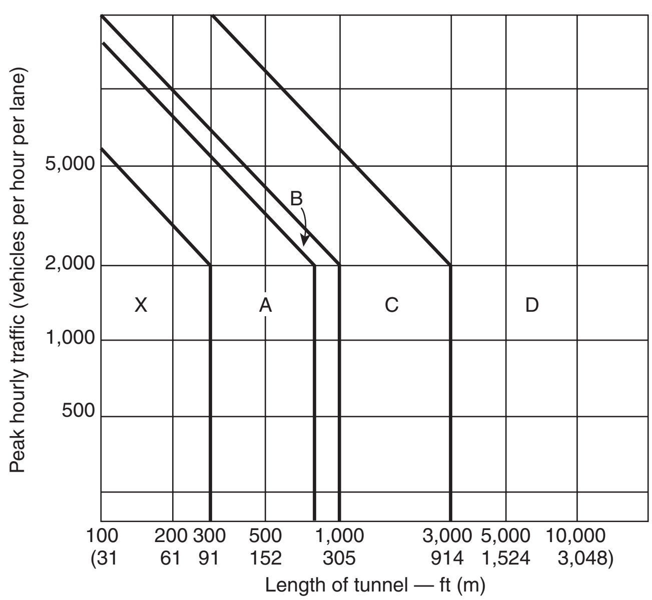

FIGURE A.7.2 Urban and Rural Tunnel Categories.

The time–temperature development is shown in Table A.7.3.2(a) and in Figure A.7.3.2(a).

An engineering analysis for the purposes of determining the appropriate time–temperature curve should consider the following:

(1) Tunnel geometry
(2) Types of vehicles anticipated
(3) Types of cargoes
(4) Any additional fire mitigation measures
(5) Expected traffic conditions

The RWS fire curve is representative of actual tunnel fires for various combustibles, not necessarily hazardous materials or flammable liquids. This fire curve was initially developed during extensive testing conducted by the Dutch Ministry of Transport (Rijkswaterstaat, RWS) in cooperation with the Netherlands Organization for Applied Scientific Research (TNO) in the late 1970s, and later proven in full-scale fire tests in the Runehamar tunnel tests in Norway in September 2003, conducted as part of the European Union (EU)–funded research project, Cost-effective Sustainable and Innovative Upgrading Methods for Fire Safety in Existing Tunnels (UPTUN), in association with SP Technical Research Institute of Sweden and the Norwegian Fire Research Laboratory (SINTEF/NBL).

Table A.7.3.2(a) Furnace Temperatures

Time (min)	Temperature °C	Temperature °F
0	20	68
3	890	1634
5	1140	2084
10	1200	2192
30	1300	2372
60	1350	2462
90	1300	2372
120	1200	2192

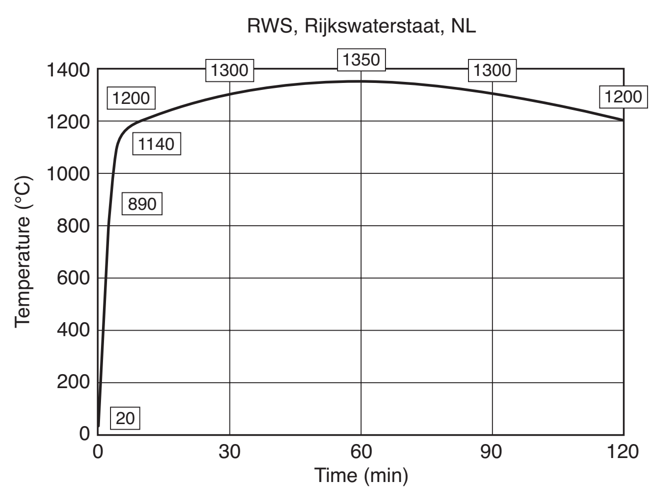

FIGURE A.7.3.2(a) RWS Time–Temperature Curve.

As shown in Table A.7.3.2(b), four tests were carried out on fire loads of nonhazardous materials using timber or plastic, furniture, mattresses, and cardboard cartons containing plastic cups.

All tests produced time–temperature developments in line with the RWS curve as shown in Figure A.7.3.2(b).

All fires produced heat release rates of between 70 MW for cardboard cartons containing plastic cups and 203 MW for timber/plastic pallets.

Figure A.7.3.2(c) depicts the T1 Fire Test curve in comparison to various accepted time/temperature curves.

The RWS requirements are adopted internationally as a realistic design fire curve that is representative of typical tunnel fires.

The level of fire resistance of structures and equipment should be proven by testing or reference to previous testing.

Fire test reports are based on the following requirements:

(1) Concrete slabs used for the application of fire protection materials for fire testing purposes have dimensions of at least 1400 mm × 1400 mm (55 in. × 55 in.) and a nominal thickness of 150 mm (6 in.).
(2) The exposed surface is approximately 1200 mm × 1200 mm (47 in. × 47 in.).
(3) The fire protection material is fixed to the concrete slab using the same fixation material (anchors, wire mesh, etc.) as will be used during the actual installation in the tunnel.
(4) In the case of board protection, a minimum of one joint in between two panels should be created, to judge if any thermal leaks will occur in a real fire in the tunnel.
(5) In the case of spray materials, the number of applications (number of layers) should be registered when preparing the test specimen. This number of layers should be considered when the spray material is applied in a real tunnel.
(6) Temperatures are recorded by thermocouples in the following locations:
    (a) At the interface between the concrete and the fire protection material
    (b) At the bottom of the reinforcement
    (c) On the nonexposed face of the concrete slab

The installation of fire protection materials should be done with anchors having the following properties:

(1) The diameter should be limited to a maximum of M6, to reduce the heat sink effect through the steel anchor into the concrete. It has been reported that thicker anchors can create a local spalling effect of the concrete. This local

Table A.7.3.2(b) Fire Test Data

Test	Time from Ignition to Peak HRR (min)	Linear Fire Growth Rate (R-Linear Regression Coefficient) (MW/min)	Peak HRR (MW)	Estimated HRR from Laboratory Tests (No Target / Inclusive Target) (MW)
1	18.5	20.5 (0.997)	200 (average)	186/217
2	14.3	29.0 (0.991)	158 (average)	167/195
3	10.4	17.0 (0.998)	124.9	—
4	7.7	5–70 17.7 (0.996)	70.5	79/95

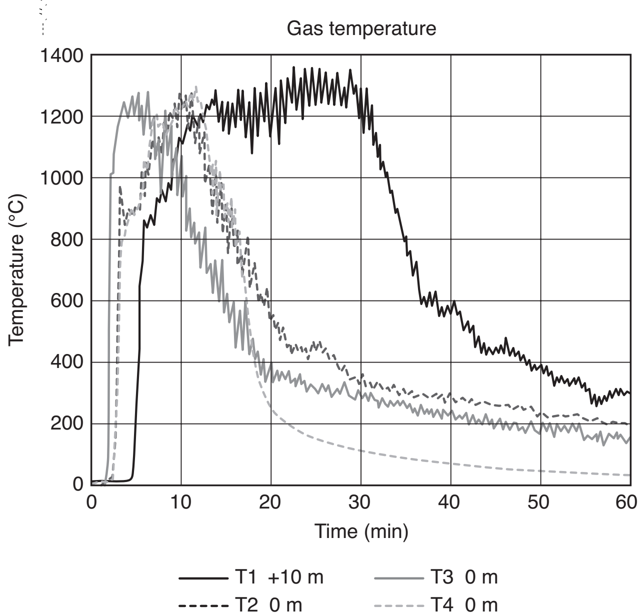

FIGURE A.7.3.2(b) Test Fire Curves.

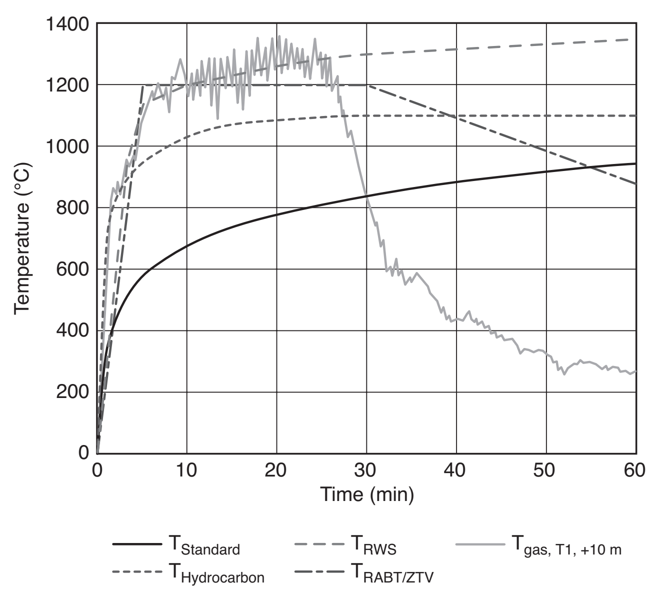

FIGURE A.7.3.2(c) Various Time–Temperature Curves and Fire Test Curve.

effect is only temporary because the spalling spreads over the surface once a small part of the concrete is directly exposed to fire.
(2) The use of stainless steel anchors is recommended. Types that can be used are A4, 316, 1.4401, and 1.4571. In some countries, even higher requirements are applied, such as 1.4529.
(3) If necessary, a washer should be used to avoid a pull-through effect when the system is exposed to dynamic loads.
(4) The anchors should be suitable for use in the tension zone of concrete (cracked concrete).
(5) The anchors should be suitable for use under dynamic loads.

A.7.3.3(1) Explosive Spalling. Explosive spalling is the result of a combination of rising pore pressures and thermal gradients in the cross-section. At the front of heat penetration, a "moisture clog" (area with high pore pressure) develops inside the concrete. Part of the moisture is pushed further into the colder part of the concrete due to the pressure gradient at the back of the clog. If the heated surface is under compression due to a thermal gradient, the complete heated surface may be blown away. This type of spalling is especially likely to occur on structural members heated from more than one side, such as columns and beams. When moisture clogs are advancing into the concrete from all heated sides, at some point in time the moisture clogs will meet in the center of the cross-section, giving a sudden rise in pore pressure, which may cause large parts of the cross-section to explode. This type of spalling can also occur after a considerable duration of the fire if the concrete surface has been protected with an insulating layer.

A.7.4.1.1 The requirement in this clause for 24-hour supervision presumes that the supervision is effective for both the identification of an incident and for an effective incident response initiated by the supervising entity.

A.7.4.1.4.1 In road tunnels where 24-hour supervision is not provided, consideration should be given to integrating the required automatic fire detection system with the operation of the traffic control system to alert motorists that there is a fire in the tunnel.

The activation of the fire detection system could activate those traffic control devices necessary to notify motorists of a fire in the tunnel, to stop approaching traffic from entering the tunnel, and notify motorists inside the tunnel that they are approaching the fire.

As a minimum, the traffic control devices that should be considered for integration with the fire alarm system include the variable message signs located on the approach roadways, at the tunnel entrance portal and inside the tunnels, and lane use signals at the portal and in the tunnel.

A.7.5 Radio communications systems, such as highway advisory radio (HAR) and AM/FM commercial station overrides, can be provided to give motorists information regarding the nature of the emergency and the actions the motorist should take. All messaging systems should be capable of real-time composition. The communications system can also feature a selection of prerecorded messages for broadcasting by the emergency response authority. Areas of refuge or assembly, if available, should be provided with reliable two-way voice communications to the emergency response authority.

A.7.6.2(3) Consideration should be given to the various scenarios that affect flow from the tunnel and the various means to mitigate their impact. These means include the control of heat and smoke or the installation of fixed water-based fire-fighting systems.

A.7.9 Consideration should be given to incorporating into the alarm system a means for detecting the removal of an extinguisher.

A.7.12 This section is not intended to apply to ground water or soil drainage systems that have no connection to the roadway drainage system and have no exposure to the environment in the tunnel.

A.7.12.1 This effluent can include water from tunnel-cleaning operations and water from incidental seepage, in addition to the water discharged from the fire protection system and liquids from accidental spills.

A.7.12.5 If fixed fire suppressions are installed, then consideration must also be given to the flows from those systems.

A.7.14.1 Large flammable and combustible liquid fires in tunnels are typically oxygen-limited fires; however, another method to control the fire is to control the surface area of the pool spill by draining the liquid before the spill surface area grows to size. Controlling the surface area would reduce fire size, burn time, fire growth rate, and the consequent smoke propagation by reducing the burning area of the liquid, considering the following:

(1) A single large flammable/combustible liquid tanker is approximately 8000 U.S. gallons from a single tank, or 16,000 gallons from a combination truck and trailer tanker.
(2) The drainage and pool containment approach would normally be used for moderate-sized leaks up to approximately 250 gpm (which is roughly equivalent to a 3 in. pipe opening near the bottom of a gasoline tanker).
(3) For larger spills, i.e., possibly several thousand gallons over a very short time frame, the drainage and pool containment system would need to include slope considerations and significantly large drainage capacity. This type of spill might occur from overturned tanker accidents that open a large hole or gash in the container wall.
(4) Design assumptions for the spill rate, quantity, and type of expected flammable liquid must be approved by the AHJ.
(5) Flammable and combustible liquid controls would need to be channeled through an approved "fire trap" arrangement in advance of any separation, and detention or diversion areas to prevent fire from propagating beyond the tunnel or to prevent the fire from propagating into the pump station wet wells located inside the tunnel.
(6) Oil/water separators allow control of most of the flammable/combustible liquids to be isolated from water, thereby reducing the quantity of flammable/combustible liquid needed to be managed.
(7) If flammable liquid detention is used, the detention capacity must be sized to accommodate all the flammable/combustible liquid entering the system. If adequate separation is not provided, the detention must be sized to include the flammable/combustible liquid as well as the other liquids, notably rain/snow, leaks, and fire suppression water from both handlines and the fixed suppression system(s).
(8) If the flammable/combustible liquid is not detained, it should be diverted to a remote holding area with specific precautions to prevent ignition sources and environmental concerns. Size of remote areas would need to be proportionately larger if no separation is included.
(9) Pumps and other ancillary electrical equipment used to move the flammable and combustible liquid should conform to the requirements of the hazard classification.

A.7.15.1.1 Only the exit design and construction requirements from NFPA *101* should be applied to tunnels. It is not the intent of these requirements to apply the requirements for travel distances and accessible means of egress in NFPA *101* to road tunnels.

However, the protection of mobility-impaired individuals and their impact on the egress should be addressed as part of the emergency response plans in Chapter 13 and Annex E.

A.7.15.1.2 Consideration should be given to the height of the sign above the walking surface (e.g., raised walkway or curbed walkway) as it affects visibility during a fire emergency.

A.7.15.2 The duration of the evacuation phase may be affected by travel distances to emergency exits. For additional information on tenable environments in road tunnels, see Annex B.

A.7.15.6.2 The calculation of appropriate exit spacing should be the subject of emergency egress analysis. Independent of the results of such analysis, the distance between such exits should not be more than 300 m (1000 ft). Typically, for urban tunnels, such analysis has resulted in exit spacings of much shorter separations, both within the U.S. and internationally. There is not considered to be any "minimum" exit separation; however, most typical exit separations are between 30 m (100 ft) and 200 m (656 ft). Appropriate exit separation distances can only be determined by engineering analysis of emergency egress requirements.

"Types and classes of tunnels" refers to parameters such as structural type, number of bores, depth of cover, tunnel location, traffic mix, etc.

A.7.15.6.3 The maximum means of egress travel speed should be computed for reduced visibility due to a smoke-filled environment. The travel speed for such an environment is in the range of 0.5–1.5 m/s (100–300 fpm) depending on visibility, illuminance, design of exit signs, and egress pathway.

A.8.1 Air-right structures impose on the accessibility and operation of the roadway during emergency operations.

A.8.4.1.1 Acceptable risks could be modified by increasing fire resistance and/or installing a fixed fire-fighting system.

A.9.1 For additional information on fixed water-based fire-fighting systems in road tunnels, see Annex E.

A.9.2.2 When determining how to incorporate a water-based fire-fighting system into the design of a tunnel, it is critical to explicitly determine the type of performance the water-based fire-fighting system is expected to provide. As part of this process, it is necessary to decide if the water-based fire-fighting system should improve tenability during the evacuation phase, improve tenability for fire fighters conducting manual fire-fighting activities, increase the effectiveness of the ventilation systems, or simply improve the fire resistance of the tunnel structure.

In general, the performance of water-based fire-fighting systems installed in transportation tunnels can be grouped into the four categories addressed in 9.2.2.1 through 9.2.2.4.

A.9.2.2.1 Fire suppression systems are designed to arrest the rate of fire growth and significantly reduce the energy output of the fire shortly after operation. Suppression mode systems are very suitable for improving the ability of first responders to engage in search and rescue as well as manual fire-fighting activities. Suppression systems, if operated early enough in the fire event, may improve the ability of and time available for tunnel occupants to evacuate.

A.9.2.2.2 Fire control systems are designed significantly to reduce or stop the rate of fire growth, but not necessarily to reduce the energy output of an established fire. Fire control water-based fire-fighting systems are most suitable for providing structural protection and, if operated early enough, may improve the ability of first responders to engage in manual fire fighting. They also provide additional time for tunnel evacuation depending upon the anticipated fire size at system activation.

A.9.2.2.3 Volume cooling systems are designed to reduce the temperature of heated products of combustion, and of systems and tunnel structure, but may not have any direct effect on fire size or fire growth rate. Volume cooling systems are most suitable for providing structural protection and improving the efficiency of ventilation systems, and may provide additional time for tunnel evacuation and first responder access depending upon anticipated fire size at system activation and fire growth rates.

A.9.2.2.4 Surface cooling systems are designed to provide cooling of specific objects or surfaces to improve the survivability of these objects. Surface cooling systems do not have any direct effect on fire size or fire growth rate. Surface cooling systems are most suitable for providing structural protection and extending the survival time for critical tunnel components. Surface cooling systems are not expected to improve egress time or tenability, and are exclusively intended for property protection.

A.9.3.1 As there are currently no known, validated methods of predicting water-based fire-fighting system performance, evaluation of the ability of the system to meet defined performance objectives under the specific tunnel parameters must be determined on the basis of full-scale fire testing.

A.9.3.3 Listing or approval of individual components is required to ensure that standards of quality and performance are maintained. The intent of this requirement is not to mandate that system components be listed or approved for use in tunnels, but rather that they be listed for use as part of a water-based fire-fighting system. However, it should be noted that being listed or approved for use as a component in a water-based fire-fighting system does not guarantee that the component is suitable for use within the tunnel environment.

A.9.5.2 While full-scale fire testing is an important part of the process of system performance verification, this testing cannot account for all possible fire scenarios, installation configurations, or other unique aspects of a given installation. Engineering safety factors should be considered for the tested system to account for these unknown variables.

A.9.6.1 Transportation tunnels are highly integrated structures. The impact of water-based fire-fighting systems on life safety and the overall performance and behavior of critical tunnel systems must be evaluated as part of the tunnel design process.

A.10.1.5 Calculations, including transit and fill times, should be submitted to the authority having jurisdiction to support this requirement.

Further assistance is provided in "A Basis for Determining Fill Times for Dry Fire Lines in Highway Tunnels," published by ASME.

A.11.1 Tunnel ventilation systems that are installed in road tunnels are an important element of tunnel fire protection systems. Ventilation systems are installed in road tunnels to maintain an acceptable level of traffic-generated pollutants within the tunnel roadway.

Ventilation systems that are designed to control the contaminant levels within road tunnels (normal operations) can be configured several ways, employing either central fans or local fans.

A.11.1.1 For guidance on developing an appropriate engineering analysis, the user should reference the performance-based alternatives in NFPA *101*.

A.11.2 A description of the various ventilation configurations for normal operations is contained in Annex I.

Smoke control can be achieved either by capturing and removing the smoke through air ducts or by pushing it through the tunnel and out a portal. The approach used will depend on the type of ventilation systems elected and on the mode of traffic operation and the surrounding environment.

A.11.3 The Memorial Tunnel Fire Ventilation Test Program (MTFVTP), a full-scale test program, was conducted under the auspices of the United States Federal Highway Administration (FHWA), the Massachusetts Highway Department (MHD), and the American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. (ASHRAE) to evaluate the effectiveness of various tunnel ventilation systems and ventilation airflow rates to control the smoke from a fire. The results of this program had an impact on the design criteria for road tunnel emergency ventilation. Information from the MTFVTP has been employed in the development of this standard. A description of the MTFVTP and its results are contained in Annex H.

A.11.5 It has been recognized that fixed water-based fire-fighting systems are effective in limiting the spread of fire and thus controlling the fire size.

A.11.5.1 Representative fire heat-release rates that correspond to the various vehicle types are provided in Table A.11.5.1.

Each engineering objective should have an appropriate design fire curve adapted to take into account project-specific factors directly relating to the engineering objective to be achieved, and these may include:

(1) Tunnel geometry
(2) Traffic characteristics (e.g., percentage of heavy goods vehicles, fire load, fuel containment, and fuel type)
(3) Tunnel operational philosophy (e.g., bidirectional flow and congestion management)
(4) Fire protection systems
(5) Fire properties and characteristics
(6) Environmental conditions

The design fire is not necessarily the worst fire that may occur. Engineering judgment should be used to establish the probability of occurrence and the ability to achieve practical solutions. Therefore, different design scenarios are often used for various safety systems.

A.11.5.2 The design fire size selected has an effect on the magnitude of the critical air velocity necessary to prevent backlayering. A method for calculating the critical velocity is described in Annex D.

A.11.6.1 Various means can be utilized to ensure that temperatures do not exceed the operational temperature limits of fans and other devices to be used in fire emergencies, including physical separation or the use of water-based fire-fighting systems to limit fire gas temperatures.

Table A.11.5.1 Fire Data for Typical Vehicles

Vehicles	Peak Fire Heat Release Rates (MW)	Time to Peak HRR (min)
Passenger car	5–10	0–30
Multiple passenger cars (2–4 vehicles)	10–20	13–55
Bus	20–30	7–10
Heavy goods truck	70–200*	10–18
Tanker	200–300	—

Notes:
(1) The designer should consider the rate of fire development (peak heat release rates may be reached within 10 minutes), the number of vehicles that could be involved in the fire, and the potential for the fire to spread from one vehicle to another.
(2) Temperatures directly above the fire can be expected to be as high as 1000°C to 1400°C (1832°F to 2552°F).
(3) The heat release rate may be greater than in the table if more than one vehicle is involved.
(4) A design fire curve should be developed in order to satisfy each specific engineering objective in the design process (e.g., fire and life safety, structural protection, etc.).
*Maximum registered for open truck.
Source: Ingason, "Design Fires in Tunnels," *Safe and Reliable Tunnels*, 2006.

A.11.6.3 Because the fan or group of fans closest to the fire site is likely to be rendered inoperable by the fire, additional fans should be included in the ventilation design.

A.12.1.1 The power distribution system should be maintained through an approved annual maintenance program. The electrical distribution maintenance program should be consistent with NFPA 70B.

A.12.1.2 The actual duration required for the circuits to be operative will depend upon the duration required for the circuits to be operative for the emergency evacuation and rescue phase — and, in some circumstances, incident management and structural protection. Factors such as the length of the tunnel, evacuation pathways, the use of fixed water-based fire suppression systems, and the proximity of emergency services may influence this period of time.

A.12.1.5 Guidance for seismic protection can be found in the following documents:

(1) AISC 325, *LRFD Manual of Steel Construction*
(2) ASTM E 580, *Application of Ceiling Suspension Systems for Acoustical Tile and Lay-in Panels in Areas Requiring Moderate Seismic Restraint*
(3) IEEE 693-2005, *Recommended Practices for Seismic Design of Substations*
(4) USACE TI 809-04, *Seismic Design for Buildings*
(5) ANSI/UL 1598, *Luminaires*
(6) ASCE/SEI 7, *Minimum Design Loads for Buildings and Other Structures*, 2005 Edition
(7) EN 61508-1, *Functional Safety of Electrical/Electronic/Programmable Electronic Safety-Related Systems,* 2001

A.12.3.3 Consideration must be given to the wiring methods and other materials installed in supply air ducts to ensure that the supply air is not contaminated with smoke. The cables must still meet the requirements of Section 11.2, but because they can be exposed to constant air flow they must also be tested to NFPA 262 or an equivalent internationally recognized standard when not installed in conduits or armor. Cables that meet the requirements of NFPA 262 can be supported by a covered cable tray without additional protection as long as the cables are listed for cable tray use. Emergency circuits installed in supply air ducts must meet the requirements of 11.1.3.

A.12.3.4 Consideration must be given to all conduits, equipment, and supports installed in exhaust air ducts because of elevated air temperatures. It is not implied that the circuit remains functional when exposed to the elevated temperatures but rather the elements (conduit, equipment, support) inside the exhaust air duct not lose structural integrity, thereby interrupting the ventilation system. For normal circuit wiring, the cables and conductors must comply with Section 11.2. It should be understood that wiring meeting the requirements of Section 11.2 could fail due to the elevated temperature. Emergency circuits installed in exhaust air ducts must meet the requirements of 11.1.3.

A.12.4 It is expected that the operations of all systems within the vicinity of a fire can fail. Section 12.4 is intended to limit the area of such failure.

A.12.5 The reliability of the system should be verified by a short-circuit and coordination study, for normal circuits and alternative circuits. The initial study should be verified every 5 years.

A.12.6.1 The emergency lighting system should be maintained in accordance with IESNA DG4, NECA/IESNA 502, and NFPA 70B.

A.12.6.5 Lighting can be maintained without interruption by duplicate independent power systems, uninterruptible power supplies, and standby generators.

A.12.6.8 Symbols specified in NFPA 170, Table 4.2, shall be included in the egress signage to inform the non-English-speaking portion of the population using the tunnel.

A.12.7 The security of the electrical supply substation to the facility should be in accordance with the recommendations in IEEE 1402.

The following documents should be consulted for developing the security plan:

(1) NFPA 730, *Guide for Premises Security*
(2) NFPA 731, *Standard for the Installation of Electronic Premises Security Systems*
(3) *NFPA 1600, Standard on Disaster/Emergency Management and Business Continuity Programs*

A.13.3 See the sample emergency response plan outline provided in Annex F. Although facilities covered by this standard are not considered places of public assembly, the emergency response plan should recognize the need to evacuate individuals, regardless of their physical condition.

A.13.4 The participating agencies and organizations can vary depending on the governmental structure and laws of the community.

A.13.5 Federal NIOSH 2003–136, "Guidance for Filtration and Air-Cleaning Systems to Protect Building Environments from Airborne Chemical, Biological, or Radiological Attacks," recommends engineering steps to be implemented in design and operational procedures for "extraordinary incidences," which include building protection from airborne chemical, biological, and radiation attacks.

A.13.5.1.1 Expanding the OCC functions for it to be a proprietary supervising station will allow faster and more coordinated control and monitoring of the various fire and life safety systems. This will expedite emergency functioning by eliminating delays from a central supervising station company. However, a proprietary station has significant requirements under *NFPA 72* that should be fully understood before adopting this as a policy and practice.

A.13.5.7 The area should be used for the central supervisory station (CSS) and similar activities and should not be jeopardized by adjoining or adjacent occupancies.

A.13.8.3 Such programs should involve a competent supervisory staff that is experienced in fire fighting, life safety techniques, and hazardous materials emergencies. Operator workstation simulation software can be developed for training to model all elements of the emergency response plan and size/life safety tunnel features.

A.14.1.1 When developing rules and regulations, fire, accident, and research experience of the vehicles and cargo of the type expected within the tunnel and particularly of goods and vehicles not normally characterized as hazardous or otherwise regulated should be considered. Some types of cargoes not normally considered hazardous can, under certain circumstances in confined spaces within tunnels, behave like or be the equivalent of hazardous materials in terms of rate of fire growth, intensity of the fire, discharge of noxious materials, destruction of infrastructure, and a threat to users' safety.

A.14.1.3 The following provides further details on the listed items in 14.1.3:

(1) *Population density.* The population potentially exposed to a hazardous material release should be estimated from the density of the residents, employees, motorists, and other persons in the area, using census tract maps or other reasonable means for determining the population within a potential impact zone along a designated highway route. The impact zone is the potential range of effects in the event of a release. Special populations such as schools, hospitals, prisons, and senior citizen homes should, among other things, be considered in the determination of the potential risk to the populations along a highway routing. Consideration also should be given to the amount of time during which an area experiences a heavier population density.
(2) *Type of highway.* The characteristics of alternative hazardous material highway routing designations should be compared. Vehicle weight and size limits, underpass and bridge clearances, roadway geometrics, number of lanes, degree of access control, and median and shoulder structures are examples of characteristics that should be considered.
(3) *Types and quantities of hazardous materials.* An examination should be made of the type and quantity of hazardous materials normally transported along highway routes that are included in a proposed hazardous material routing designation. Consideration should be given to the relative impact zone and the risks of the types and quantities of hazardous materials.
(4) *Emergency response capabilities.* In consultation with the proper fire, law enforcement, and highway safety agencies, consideration should be given to the emergency

response capabilities that might be needed as a result of a hazardous material routing designation. The analysis of the emergency response capabilities should be based on the proximity of the emergency response facilities and their capabilities to contain and suppress hazardous material releases within the impact zones.

(5) *Results of consultation with affected persons.* Consideration should be given to the comments and concerns of affected persons and entities during public hearings and consultations conducted in accordance with 14.1.3.

(6) *Exposure and other risk factors.* The exposure and risk factors associated with any hazardous material routing designations should be defined. The distance to sensitive areas should be considered. Sensitive areas include, but are not limited to, homes and commercial buildings; special populations in hospitals, schools, handicapped facilities, prisons, and stadiums; water sources such as streams and lakes; and natural areas such as parks, wetlands, and wildlife reserves.

(7) *Terrain considerations.* Topography along and adjacent to the proposed hazardous material routing designation that might affect the potential severity of an accident, the dispersion of the hazardous material upon release, and the control and cleanup of released hazardous material should be considered.

(8) *Continuity of routes.* Adjacent jurisdictions should be consulted to ensure routing continuity for hazardous material across common borders. Deviations from the most direct route should be minimized.

(9) *Alternative routes.* Consideration should be given to the alternative routes to, or resulting from, any hazardous material route designation. Alternative routes should be examined, reviewed, or evaluated to the extent necessary to demonstrate that the most probable alternative routing resulting from a routing designation is safer than the current routing.

(10) *Effects on commerce.* Any hazardous material routing designation made in accordance with this section should not create an unreasonable burden on interstate or intrastate commerce.

Annex B Tenable Environment

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

B.1 General. The purpose of this annex is to provide guidelines for the evaluation of tenability within the tunnel evacuation paths. Current technology is capable of analyzing and evaluating all unique conditions of each path to provide proper ventilation for pre-identified emergency conditions. The same ventilating devices might or might not serve both normal operating conditions and pre-identified emergency requirements. The goals of the ventilation system, in addition to addressing fire and smoke emergencies, are to assist in the containment and purging of hazardous gases and aerosols such as those that could result from a chemical or biological release.

B.2 Environmental Conditions. Some factors that should be considered in maintaining a tenable environment for periods of short duration are discussed in B.2.1 through B.2.5.

B.2.1 Heat Effects. Exposure to heat can lead to life threat in three basic ways:

(1) Hyperthermia
(2) Body surface burns
(3) Respiratory tract burns

For use in the modeling of life threat due to heat exposure in fires, it is necessary to consider only two criteria — the threshold of burning of the skin and the exposure at which hyperthermia is sufficient to cause mental deterioration and thereby threaten survival.

Note that thermal burns to the respiratory tract from inhalation of air containing less than 10 percent by volume of water vapor do not occur in the absence of burns to the skin or the face; thus, tenability limits with regard to skin burns normally are lower than for burns to the respiratory tract. However, thermal burns to the respiratory tract can occur upon inhalation of air above 60°C (140°F) that is saturated with water vapor.

The tenability limit for exposure of skin to radiant heat is approximately 2.5 kW/m^2. Below this incident heat flux level, exposure can be tolerated for 30 minutes or longer without significantly affecting the time available for escape. Above this threshold value, the time to burning of skin due to radiant heat decreases rapidly according to equation B.2.1a.

$$t_{Irad} = 4q^{-1.36} \qquad \textbf{(B.2.1a)}$$

where:

t_{Irad} = time to burning of skin due to radiant heat (minutes)

q = radiant heat flux (kW/m^2)

As with toxic gases, an exposed occupant can be considered to accumulate a dose of radiant heat over a period of time. The fraction equivalent dose (FED) of radiant heat accumulated per minute is the reciprocal of t_{Irad}.

Radiant heat tends to be directional, producing localized heating of particular areas of skin even though the air temperature in contact with other parts of the body might be relatively low. Skin temperature depends on the balance between the rate of heat applied to the skin surface and the removal of heat subcutaneously by the blood. Thus, there is a threshold radiant flux below which significant heating of the skin is prevented but above which rapid heating occurs.

Based on the preceding information, it is estimated that the uncertainty associated with the use of equation B.2.1a is ±25 percent. Moreover, an irradiance of 2.5 kW/m^2 would correspond to a source surface temperature of approximately 200°C (392°F), which is most likely to be exceeded near the fire, where conditions are changing rapidly.

Calculation of the time to incapacitation under condition of exposure to convected heat from air containing less than 10 percent by volume of water vapor can be made using either equation B.2.1b or equation B.2.1c.

As with toxic gases, an exposed occupant can be considered to accumulate a dose of convected heat over a period of time. The FED of convected heat accumulated per minute is the reciprocal of t_{Iconv}.

Convected heat accumulated per minute depends on the extent to which an exposed occupant is clothed and the nature of the clothing. For fully clothed subjects, equation B.2.1b is suggested:

$$t_{Iconv} = \left(4.1 \times 10^{8}\right) T^{-3.61} \qquad \textbf{(B.2.1b)}$$

where:

t_{Iconv} = time (minutes)

T = temperature (°C)

For unclothed or lightly clothed subjects, it might be more appropriate to use equation B.2.1c:

$$t_{Iconv} = \left(5.0 \times 10^{7}\right)T^{-3.4} \qquad \textbf{(B.2.1c)}$$

where:
t_{Iconv} = time (minutes)
T = temperature (°C)

Equations B.2.1b and B.2.1c are empirical fits to human data. It is estimated that the uncertainty is ±25 percent.

Thermal tolerance data for unprotected human skin suggest a limit of about 120°C (248°F) for convected heat, above which there is, within minutes, onset of considerable pain along with the production of burns. Depending on the length of exposure, convective heat below this temperature can also cause hyperthermia.

The body of an exposed occupant can be regarded as acquiring a "dose" of heat over a period of time. A short exposure to a high radiant heat flux or temperature generally is less tolerable than a longer exposure to a lower temperature or heat flux. A methodology based on additive FEDs similar to that used with toxic gases can be applied. Providing that the temperature in the fire is stable or increasing, the total fractional effective dose of heat acquired during an exposure can be calculated using equation B.2.1d:

$$\text{FED} = \sum\left(\frac{1}{t_{Irad}} + \frac{1}{t_{Iconv}}\right)\Delta t_{t_1}^{t_2} \qquad \textbf{(B.2.1d)}$$

where:
t_{Irad} = time (min)
t_{Iconv} = time (min)
$\Delta t_{t_1}^{t_2}$ = change in time (min)
FED = fraction equivalent dose

Note 1: In areas within an occupancy where the radiant flux to the skin is under 2.5 kW/m^2, the first term in equation B.2.1d is to be set at zero.

Note 2: The uncertainty associated with the use of equation B.2.1d would depend on the uncertainties associated with the use of the three earlier equations.

The time at which the FED accumulated sum exceeds an incapacitating threshold value of 0.3 represents the time available for escape for the chosen radiant and convective heat exposures.

Consider an example with the following characteristics:

(1) Evacuees are lightly clothed.
(2) There is zero radiant heat flux.
(3) The time to FED is reduced by 25 percent to allow for uncertainties in equations B.2.1b and B.2.1c.
(4) The exposure temperature is constant.
(5) The FED is not to exceed 0.3.

Equations B.2.1c and B.2.1d can be manipulated to provide the following equation:

$$t_{exp} = \left(1.125 \times 10^{7}\right)T^{-3.4} \qquad \textbf{(B.2.1e)}$$

where:
t_{exp} = time of exposure to reach a FED of 0.3 (minutes)
T = temperature (°C)

This gives the results in Table B.2.1.

Table B.2.1 Exposure Time and Incapacitation

Exposure Temperature		Maximum Exposure Time Without Incapacitation (min)
°C	°F	
80	176	3.8
75	167	4.7
70	158	6.0
65	149	7.7
60	140	10.1
55	131	13.6
50	122	18.8
45	113	26.9
40	104	40.2

B.2.2 Air Carbon Monoxide Content. Air carbon monoxide (CO) content is as follows:

(1) Maximum of 2000 ppm for a few seconds
(2) Averaging 1150 ppm or less for the first 6 minutes of the exposure
(3) Averaging 450 ppm or less for the first 15 minutes of the exposure
(4) Averaging 225 ppm or less for the first 30 minutes of the exposure
(5) Averaging 50 ppm or less for the remainder of the exposure

These values should be adjusted for altitudes above 984 m (3000 ft).

B.2.3 Smoke Obscuration Levels. Smoke obscuration levels should be continuously maintained below the point at which a sign internally illuminated with a luminance of 8.6 cd/m^2 (2.5 fl) is discernible at 30 m (100 ft) and doors and walls are discernible at 10 m (33 ft).

B.2.4 Air Velocities. Air velocities in the enclosed tunnel should be greater than or equal to 0.76 m/sec (150 fpm) and less than or equal to 11.0 m/sec (2200 fpm).

B.2.5 Noise Levels. Noise levels should be a maximum of 115 dBA for a few seconds and a maximum of 92 dBA for the remainder of the exposure.

B.3 Geometric Considerations. Some factors that should be considered in establishing a tenable environment in evacuation paths are as follows:

(1) The evacuation path requires a height clear of smoke of at least 2.0 m (6.56 ft). The current precision of modeling methods is within 25 percent. Therefore, in modeling methods a height of at least 2.5 m (8.2 ft) should be maintained above any point along the surface of the evacuation pathway.
(2) The application of tenability criteria at the perimeter of a fire is impractical. The zone of tenability should be defined to apply outside a boundary away from the perimeter of the fire. This distance will depend on the fire heat–release rate and could be as much as 30 m (100 ft).

B.4 Time Considerations. The project should develop a time-of-tenability criterion for evacuation paths with the approval of the authority having jurisdiction. Some factors that should be considered in establishing this criterion are as follows:

(1) The time for fire to ignite and become established
(2) The time for fire to be noticed and reported

(3) The time for the entity receiving the fire report to confirm existence of fire and initiate response
(4) The time for all people who can self-rescue to evacuate to a point of safety
(5) The time for emergency personnel to arrive at the station platform
(6) The time for emergency personnel to search for, locate, and evacuate all those who cannot self-rescue
(7) The time for fire fighters to begin to suppress the fire

If a project does not establish a time-of-tenability criterion, the system should be designed to maintain the tenable conditions for at least 1 hour.

B.5 Egress Calculations. Egress calculations should consider the changes in walking speed produced by smoke.

Annex C Temperature and Velocity Criteria

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

C.1 General.

C.1.1 This annex provides criteria for the protection of motorists, employees, and fire fighters with regard to air temperature and velocity during emergency situations.

C.1.2 The quantitative aspects of the criteria for emergency situations are largely arbitrary because there are no universally accepted tolerance limits that directly pertain to air temperature and velocity. Instead, tolerance limits vary with age, health, weight, sex, and acclimatization.

C.2 Air Temperature Criteria.

C.2.1 Motorists should not be exposed to maximum air temperatures that exceed 60°C (140°F) during emergencies. It is anticipated that an air temperature of 60°C (140°F) places a physiological burden on some motorists, but the exposure also is anticipated to be brief and to produce no lasting harmful effects.

C.2.2 Studies of the severity of tunnel fires with respect to human environmental criteria demonstrate that air temperature in the absence of toxic smoke is a limiting criterion for human survival.

C.3 Air Velocity Criteria.

C.3.1 The purpose of ventilation equipment in a tunnel emergency is to sweep out heated air and to remove the smoke caused by fire. In essentially all emergency cases, protection of the motorists and employees is enhanced by prompt activation of emergency ventilation procedures as planned.

C.3.2 When ventilation air is needed in evacuation routes, it might be necessary to expose motorists to air velocities that are high. The only upper limit on the ventilation rate occurs when the air velocity is great enough to create a hazard to persons walking in such an airstream. According to the descriptions of the effects of various air velocities in the Beaufort scale, motorists under emergency conditions can tolerate velocities as great as 11 m/sec (2200 fpm).

C.3.3 The minimum air velocity within a tunnel section that is experiencing a fire emergency should be sufficient to prevent backlayering of smoke (i.e., the flow of smoke in the upper cross-section of the tunnel in the opposite direction of the forced ventilation air).

C.3.4 Increasing the airflow rate in the tunnel decreases the airborne concentration of potentially harmful chemical compounds (referred to by the general term *smoke*). The decrease in concentration is beneficial to people exposed to smoke. However, a situation can arise in which the source is completely removed and smoke poses no threat of exposure to motorists; actuating any fans can draw the existing smoke to the evacuation routes. Under these conditions, fans should not be activated until it is safe to do so. A rapid and thorough communications system is needed so that the responsible personnel can make proper judgments.

C.3.5 The effectiveness of an emergency ventilation system in providing a sufficient quantity of noncontaminated air and in minimizing the hazard of smoke backlayering in an evacuation pathway is a function of the fire load. The fire load in a tunnel results from the burning rate of a vehicle(s), which, in turn, is a function of the combustible load (in British thermal units) of the vehicle.

Annex D Critical Velocity Calculations

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

D.1 General. The simultaneous solution of the following equations, by iteration, determines the critical velocity. The critical velocity, V_c, is the minimum steady-state velocity of the ventilation air moving toward a fire that is necessary to prevent backlayering.

$$V_c = K_1 K_g \left(\frac{gHQ}{\rho C_p A T_f} \right)^{1/3}$$

$$T_f = \left(\frac{Q}{\rho C_p A V_c} \right) + T \qquad \textbf{(D.1)}$$

where:
V_c = critical velocity [m/sec (fpm)]
K_1 = 0.606 (Froude number factor, $Fr^{-1/3}$)
K_g = grade factor *(see Figure D.1)*
g = acceleration caused by gravity [m/sec^2 (ft/sec^2)]
H = height of duct or tunnel at the fire site [m (ft)]
Q = heat fire is adding directly to air at the fire site [kW (Btu/sec)]
ρ = average density of the approach (upstream) air [kg/m^3 (lb/ft^3)]
C_p = specific heat of air [kJ/kg K (Btu/lb°R)]
A = area perpendicular to the flow [m^2 (ft^2)]
T_f = average temperature of the fire site gases [K (°R)]
T = temperature of the approach air [K (°R)]

Figure D.1 provides the grade factor for (K_g) in equation D.1.

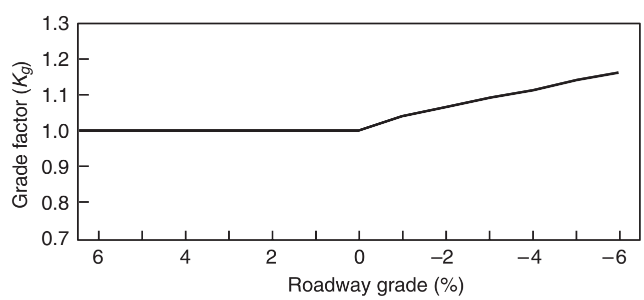

FIGURE D.1 Grade Factor for Determining Critical Velocity.

Annex E Water-Based Fixed Fire-Fighting Systems in Road Tunnels

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

E.1 General. This annex provides considerations for the incorporation of water-based fixed fire-fighting systems in road tunnels.

E.2 Water-Based Fixed Fire-Fighting Systems. Equipment permanently attached to a road tunnel that, when operated, has the intended effect of reducing the heat-release and fire growth rates, is able to spread an extinguishing agent in all or part of the tunnel using a network of pipes and nozzles.

Fixed water-based fire-fighting systems should be used as a component of an integrated fire engineering approach to fire protection to reduce the rate of fire growth and the ultimate heat-release rate.

Examples of water-based fixed fire-fighting systems include deluge systems, mist systems, and foam systems.

E.3 Background. NFPA 502 has included material regarding water-based fixed fire-fighting systems (formerly called sprinkler systems) since the 1998 edition. This material had been contained in a separate annex in each edition since then.

The World Road Association, PIARC, addressed the subject of fixed fire-fighting systems (formerly called sprinkler systems) in road tunnels in the reports presented at the World Road Congresses held in Sydney (1983), Brussels (1987), and Montreal (1995). In addition, the subject of fixed fire-fighting systems was addressed in PIARC's technical reports titled *Fire and Smoke Control in Road Tunnels*, *Systems and Equipment for Fire and Smoke Control in Road Tunnels*, and *Road Tunnels: An Assessment of Fixed Fire-Fighting Systems*.

No European country currently installs fixed fire-fighting systems in road tunnels on a regular basis. In some road tunnels in Europe, fixed fire suppression systems have been used for special purposes. Catastrophic road tunnel fires have encouraged a re-evaluation of these systems for use in future road tunnels in Europe. Below is a list of tunnels in Europe that currently have fixed water-based fire-fighting systems installed:

(1) Austria
   (a) Mona Lisa Tunnel
   (b) Felbertauern Tunnel
(2) France: A86 Tunnel
(3) Italy: Brennero Tunnel
(4) The Netherlands: Roermond Tunnel
(5) Norway
   (a) Válreng Tunnel
   (b) Fløyfjell Tunnel
(6) Spain
   (a) M30 Tunnels
   (b) Vielha Tunnel
(7) Sweden: Tegelbacken Tunnel

Tests on fixed fire-fighting systems have recently been conducted by France, the Netherlands, and UPTUN and SOLIT.

In Australia, deluge-type fixed water-based fire-fighting systems are installed in all major urban road tunnels. It is the Australian view that it is more likely that small fires could — if not suppressed — develop more often into large (and uncontrollable) fires, particularly since this type of fire development is more typical than the occurrence of instantaneously large fires. Below is a list of road tunnels in Australia that have fixed water-based fire-fighting systems installed:

(1) Sydney Harbor Tunnel
(2) M5 East Tunnel
(3) Lanecove Tunnel
(4) Eastern Distributor
(5) City Link Tunnel
(6) Graham Farmer Tunnel
(7) M4 Tunnel
(8) Adelaide Hills Tunnel
(9) Mitchham/Frankstone Tunnel
(10) North/South Busway Tunnel
(11) North/South Tunnel

Fixed water-based fire-fighting systems have been installed in road tunnels for more than four decades in Japan. The decision for a specific tunnel project has to be based on the Japanese safety standards. In Japan, fixed fire suppression systems are required in all tunnels longer than 10,000 m (32,808 ft) and in shorter tunnels longer than 3000 m (9843 ft) with heavy traffic.

Six road tunnels in North America are equipped with water-based fixed fire-fighting systems: the Battery Street Tunnel, the I-90 First Hill Mercer Island Tunnel, the Mt. Baker Ridge Tunnel, and the I-5 Tunnel, all in Seattle, Washington; the Central Artery North Area (CANA) Route 1 Tunnel in Boston, Massachusetts; and the George Massey Tunnel in Vancouver, British Columbia.

The decision to provide water-based fixed fire-fighting systems in these tunnels was motivated primarily by the fact that these tunnels were planned to be operated to allow the unescorted passage of vehicles carrying hazardous materials as cargo. See Table E.3.

E.3.1 In the past, the use and effectiveness of water-based fixed fire-fighting systems in road tunnels were not universally accepted. It is now acknowledged that water-based fixed fire-fighting systems are highly regarded by fire protection professionals and fire fighters and can be effective in controlling a fuel road tunnel fire by actually limiting the spread of the fire. One of the reasons why most countries were reluctant to use water-based fixed fire-fighting systems in road tunnels is that most fires start in the motor compartment of a vehicle, and water-based fixed fire-fighting systems are of limited use in suppressing the fire until the fire is out in the open. Water-based fixed fire-fighting systems can be used, however, to cool down vehicles, to stop the fire from spreading to other vehicles (i.e., to diminish the fire area and property damage), and to stop secondary fires in tunnel lining materials. Experiences from Japan show that water-based fixed fire-fighting systems have been extremely effective in cooling down the area around the fire, so that fire fighting can be performed more effectively.

E.3.2 There is general agreement that, in many cases, the inclusion of water-based fire-fighting systems can act as a valuable component of the overall fire and life safety system in a tunnel. Some of the benefits and capabilities of water-based fire-fighting systems include the following:

(1) *Minimizing fire spread.* Water-based fire-fighting suppression or control systems prevent fire spread to other vehicles so that the fire does not grow to a size that cannot be attacked by the fire service.
(2) *Fire suppression and cooling.* If designed accordingly, a water-based fire-fighting suppression system suppresses the fire and cools the tunnel environment to provide more time for evacuation and enable fire fighters to access the fire. Early operation of a water-based fire-fighting

Table E.3 Road Tunnel Fixed Fire-Fighting Systems in North America

Tunnel	Location	Route	Opened to Traffic	Length		Bores/ Lanes	Fixed Fire Suppression System Type	System Zones
				m	ft			
Battery Street	Seattle, Washington	SR99	1952	671	2200	2/4	Deluge water	14
I-90 First Hill Mercer Island	Seattle, Washington	I-90	1989	914	3000	3/8	Deluge foam	37
Mt. Baker Ridge	Seattle, Washington	I-90	1989	1067	3500	3/8	Deluge foam	50
CANA Northbound	Boston, Massachusetts	U.S. 1	1990	470	1540	1/3	Deluge foam	15
CANA Southbound	Boston, Massachusetts	U.S. 1	1990	275	900	1/3	Deluge foam	9
I-5 Tunnel	Seattle, Washington	I-5	1988	167	547	1/12	Deluge foam	9
George Massey Tunnel	Vancouver, British Columbia	99	1959	630	2067	2/4	Sprinkler system	N/A

system is important in achieving this objective. For example, a heavy goods vehicle fire needs only 10 minutes to exceed 100 MW and 1200°C (2192°F), which are fatal conditions.

(3) *Improved conditions for first responders.* The cooling and radiation-shielding effects of water sprays aid in manual fire-fighting and rescue operations by reducing the thermal exposure.
(4) *Improved performance of ventilation systems.* The cooling of hot products of combustion provided by properly designed water-based fire suppression systems may increase the actual capacity of ventilation systems due to the higher density of cooled products of combustion.

E.3.3 The impact of water-based fire-fighting systems may have additional consequences beyond those listed in E.3.2 that should be considered. For example:

(1) *Reduced stratification.* The cooling and loss of buoyancy resulting from the discharge of water-based fire-fighting systems may lead to destratification of the smoke layer, where such stratification occurs. Normal air movement in the tunnel accelerates this process. However, by limiting the spread of fires, water-based fire-fighting systems reduce the total quantity and rate of smoke generated.
(2) *Testing and maintenance requirements.* Water-based fire-fighting systems will require some maintenance. Proper system design can minimize these requirements. A full discharge test is normally performed only at system commissioning. During routine testing, the system can be configured to discharge flow to the drainage system.

E.4 Recommendations.

E.4.1 Application. The installation of water-based fixed fire-fighting systems should be considered where an engineering analysis demonstrates that the level of safety can be equal to or exceeded by the use of water-based fixed fire-fighting systems and is a part of an integrated approach to the management of safety. The tunnel operator and the local fire department or authority having jurisdiction should consider the advantages and disadvantages of such systems as they apply to a particular tunnel installation.

E.4.2 System Operation. To help ensure against accidental discharge, the water-based fixed fire-fighting system can be designed as a manually activated deluge system with an automatic release after a time delay. To prevent development of a major fire, the time delay should not exceed 3 minutes. The sprinkler-system piping should be arranged using interval zoning so that the discharge can be focused on the area of incident without necessitating discharge for the entire length of the tunnel. Each zone should be equipped with its own proportioning valve set to control the appropriate water and foam mixture percentage.

Nozzles should provide an open deluge and be spaced so that coverage extends to roadway shoulders and, if applicable, maintenance and patrol walkways. The system should be designed with enough water and/or foam capacity to allow operation of at least two zones in the incident area. Zone length should be based on activation time as determined by the authorities having jurisdiction and should be coordinated with detection and ventilation zones. Piping should be designed to allow drainage through nozzles after flow is stopped.

E.4.3 System Control. It can be assumed that a full-time, attended control room is available for any tunnel facility in which safe passage necessitates the need for fixed fire suppression system protection. Therefore, consideration should be given to human interaction in the fixed fire suppression system control and activation design to ensure against false alarm and accidental discharge. Any automatic mode of operation can include a discharge delay to allow incident verification and assessment of in-tunnel conditions by trained operators.

E.4.3.1 An integrated graphic display of the fixed fire-fighting system zones, fire detection system zones, tunnel ventilation system zones and limits, and emergency access and egress locations should be provided at the control room to allow tunnel operators and responding emergency personnel to make appropriate response decisions.

E.5 Australia, Japan, U.S., and Recent Research Work.

E.5.1 A simplified design, based on a predetermined water application rate, has been employed in Australia and Japan. While the design density utilized varies somewhat, and has not been subject to rigorous evaluation testing, preliminary testing as well as anecdotal and historical evidence suggest that this may be a valid design approach. Examples of testing of systems employing a simplified application rate based design are provided in E.5.3–E.5.6.

E.5.2 When employing a fixed discharge density as the design basis, the following installation parameters may be acceptable:

(1) Zoned water spray system in accordance with NFPA 15, *Standard for Water Spray Fixed Systems for Fire Protection*
(2) A defined application rate acceptable to the authority having jurisdiction
(3) Use of appropriate deluge nozzles
(4) Zone length depending on the type of vehicle permitted to enter the tunnel
(5) Hydraulic design for three zones discharging simultaneously

For the tunnels listed in Table E.3, a water density of 10 mm/min (0.25 gpm/ft^2) was used for the Battery Street tunnel, with two zones operating; and a foam-water density of 6.5 mm/min (0.16 gpm/ft^2) was used for the Seattle I-90 and I-5 tunnels.

E.5.3 There are a range of deluge nozzles with varying performance characteristics. The selection of an appropriate deluge nozzle requires consideration of a range of tunnel-specific factors including:

(1) Ventilation regime (e.g., wind speeds and direction)
(2) Tunnel height
(3) Nozzle installation height
(4) Expected fire load
(5) Environmental conditions (e.g., corrosion and freezing)

E.5.4 Japanese authorities have conducted a series of fire tests to study the use of water spray for tunnel protection, and some of these studies have been reported. For example, a series of tests were conducted in an operating road tunnel with a large cross-section area (115 m^2 [1238 ft^2]) using a 5 MW gasoline pool fire where the performance of three different types of spray systems was investigated. The water density used in the tests was 6 mm/min (0.15 gpm/ft^2), which was much lower than that used in the European tunnels (i.e., half of that used in the Benelux tunnel tests). Other Japanese test programs involved fire sizes from 4 m^2 (43 ft^2) and 9 m^2 (97 ft^2) gasoline pool fires to a bus fire in an operating road tunnel. The results of these tests showed that the air temperature in the tunnel was quickly decreased to the ambient air temperature with the activation of the spray system. There was no report on smoke distribution and steam generation during fire suppression.

E.5.5 In an examination of the effectiveness of sprinklers during fire suppression in tunnel incidents, the authorities in the Netherlands conducted a series of fire tests with sprinklers in the Benelux tunnel. The test tunnel was an operating road tunnel, 9.8 m (32 ft) wide and 5.1 m (17 ft) high. Various fire scenarios were used to simulate stationary vehicle fires, including a van loaded with wood cribs, a high goods vehicle (HGV) fire loaded with wood pallets, and an aluminum truck cabin loaded with wood cribs. No liquid fuel fire was used in the tests. The fire size in the test program ranged from 15 MW to 40 MW. Two sprinkler zones were installed in the test tunnel. The length of Zone I was 17.5 m (57.4 ft) and Zone II was 20 m (66 ft) long. The discharged water quantity was 12.5 mm/min (.5 in./min). Activation time of the sprinklers in the tests ranged from 6 min to 22 min after ignition of the fire source. In order to focus on the study of the air cooling and steam formation generated by sprinklers, the mechanical longitudinal ventilation in the tunnel was not activated during tests. The air speed in the tunnel was approximately 0–1 m/s (0–197 fpm) in three tests, and approximately 3 m/s (590 fpm) in one test.

For all tests, the air temperature upstream and downstream of the fire decreased from approximately 250–350°C (482–662°F) to 20–30°C (68–86°F) in a very short period of time after sprinkler activation, which prevented the fire spread from one vehicle to others. The smoke layer was disturbed with the activation of the sprinklers, and visibility was almost entirely obstructed. It took 5 to 15 min to improve visibility. No significant steam formation and no deflagration were observed in the test program.

E.5.6 One example for the use of water-based fighting for tunnel protection is to use foam additives to protect against possible flammable liquid fuel or chemical fires. The feasibility of the use of foam–water sprinkler systems against pool fires was investigated in large-scale fire tests conducted in the Memorial Tunnel. Diesel pool fires with heat release rates of 10, 20, 50, and 100 MW were used in the test program. The water density with foam additives (3% AFFF) ranged from 2.4 mm/min (.1 in./min) to 3.8 mm/min (.15 in./min). It was reported that the fires were extinguished in less than 30 s in all four tests. The effectiveness of the deluge foam-water sprinkler system was not affected by a longitudinal ventilation velocity of 4.2 m/s (827 fpm). No details on the changes in air temperature, smoke distribution, and steam generation during suppression were reported.

E.5.7 UPTUN was a large multinational European research project that tested water mist systems in the Hobøl Test Tunnel in Norway and Virgolo Tunnel in Italy. Fire sizes were limited to 25 MW in shielded pool and wood pallet fires. The zone length was 30 m (98 ft). Heat release rates were reduced by up to 50 percent upon activation of the systems. During testing at the Virgolo Tunnel, fire fighters were fitted with sensors to monitor their physiological response whilst working close to the fires. Reports are available in the public domain.

E.5.8 For the German research project SOLIT, more than 50 fire tests were carried out in the test tunnel of San Pedro Des Anes, involving pool fires of up to 35 MW and covered truck fuel packages with a potential heat release rate of 200 MW. As well as the water mist systems, several types of detection systems were tested in combination with a longitudinal ventilation velocity of 6 m/s (1181 fpm). Some tests were also performed with semi-transverse ventilation. The maximum activated length of the tested system was 45 m (148 ft). Cooling and attenuation of radiant heat by the water mist kept the heat release rate of the fire below 50 MW. Conditions were such that fire brigade intervention was possible at all times.

E.6 Fire Test Protocols. While there are not currently any standard fire test protocols for the evaluation of water-based fire-fighting systems intended for installation in road tunnels, ongoing work in Europe has resulted in an "ad hoc" series of tests intended to quantify system performance.

E.6.1 Class B Fire Scenario.

E.6.1.1 The purpose of the Class B scenario is to evaluate the ability of the system to provide cooling for cases where significant reduction in fire size is challenging, such as shielded hydrocarbon pool fires.

E.6.1.2 The Class B fire scenario should be based upon a partly shielded pool fire with a nominal steady state output of at least 25 MW.

E.6.2 Class A Fire Scenario. The Class A fire scenario is intended to evaluate the ability of a water-based fixed fire-fighting system to provide fire suppression or fire control. This scenario employs a simulated heavy goods vehicle filled with wooden pallets.

E.6.3 All tests should be supervised by an accredited independent third party. The final test report should be prepared and signed by the third party. The test report should include, at the very least, details of the following:

(1) Name and address of the independent third party that has been considered acceptable by the authorities having jurisdiction
(2) Detailed drawings of the test tunnel
(3) Detailed drawings of the tested water-based fire-fighting system
(4) Layout parameters for the tested water-based fire-fighting system
(5) Type and size of fire loads
(6) Method of ignition of fire loads
(7) Details of the position of the fire loads in the tunnel
(8) Preburn time
(9) Method of activation of the water-based fire-fighting system
(10) Ventilation conditions (type, velocity)
(11) Temperatures continuously before, during, and after testing at distances of 5 m (16.4 ft), 10 m (32.1 ft), 20 m (65.6 ft), and 40 m (131.2 ft) on the downstream side and at distances of 5 m (16.4 ft), 10 m (32.1 ft), 20 m (65.6 ft), and 40 m (131.2 ft) on the upstream side; distances are measured from the end of the fire load; temperatures are measured at two positions in the cross-section of the tunnel at heights of 1 m (3.3 ft), 2 m (6.6 ft), and 3 m (10 ft) above the road surface and 0.15 m below the ceiling
(12) Radiant heat continuously before, during, and after testing at both ends of the activated WFS section
(13) O_2, CO_2, and CO and water vapor concentration continuously before, during, and after testing approximately 40 m (131.2 ft) at the downstream side of the fire over the cross-section
(14) Estimates of fire heat release rate based upon oxygen consumption calorimetery measurements made during the test
(15) Visibility in the tunnel before, during, and after the tests

Annex F Emergency Response Plan Outline

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

F.1 Outline. The following is an outline for a typical emergency response plan:

(1) General
  (a) Purpose
  (b) Background
(2) Emergency response plan
  (a) General
  (b) Elements of the plan
    i. Central supervising station (CSS)
    ii. Alternate CSS
    iii. Incident and activity identification systems
    iv. Emergency command posts
  (c) Operational considerations
  (d) Types of incidents
  (e) Possible locations of incidents
  (f) Incidents on approach roadways
  (g) Incidents within tunnel or facility
(3) Coordination with other responsible agencies
  (a) Fire-fighting operational procedures
  (b) Traffic management
  (c) Medical evacuation plan
  (d) Emergency alert notification plan

Annex G Alternative Fuels

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

G.1 General. Most vehicles currently used in the United States are powered by either spark-ignited engines (gasoline) or compression-ignited engines (diesel). Vehicles that use alternative fuels such as compressed natural gas (CNG), liquefied petroleum gas (LP-Gas), and liquefied natural gas (LNG) are entering the vehicle population, but the percentage of such vehicles is still not large enough to significantly influence the design of road tunnel ventilation with regard to vehicle emissions. However, it is possible that growing concerns regarding the safety of some alternative-fuel vehicles that operate within road tunnels will affect the fire-related life safety design aspects of highway tunnels. See Chapter 11 for requirements for road tunnel ventilation during fire emergencies.

There are a number of standard requirements for these types of systems, and the requirements derive from existing requirements for storage and transport of CNG tanks.

The creation of accepted consensus-based standards for hydrogen tanks is an ongoing process. However, there are current international draft standards available, which provide some insight to what will be required outside the U.S. in the near future.

In the U.S., the primary standards used are FMVSS 304 and ANSI NGV2. Both of these standards were developed for the approval of compressed natural gas. It is currently being investigated whether FMVSS 304 can be used for hydrogen fuel tanks. In addition, an ANSI HGV standard is under development, which will mirror the NGV standard, but incorporate specific tests for hydrogen gas vehicle containers and system components.

The tests in both of these standards include full-scale fire tests of the containers and their pressure relief devices (PRDs), as well as component reliability testing, such as pressure cycling, impact resistance, drop tests, and hydrostatic burst testing. In addition to the required tests, a quality-control system is required to be administered by an independent third party to ensure that the fuel system components are manufactured in the same manner as when they were approved through testing. Further, the fuel system would be listed and labeled, such that it would be easily recognizable to an AHJ as having met these requirements.

In the long run, it should be feasible for regulators to only allow vehicles that carry an approved listing and label to travel through a road tunnel. In the short term, this is unrealistic, since the standards process is under development and there is some level of controversy as to the minimum acceptable design parameters. As a result, in the short term, the decision will be in the hands of the AHJ as to the mitigation measures for dealing with alternative fuels in road tunnels.

Section G.2 provides some highlighted information about selected alternative fuels, Section G.3 provides some additional information about possible mitigation measures, and Section G.4 provides a brief discussion of applicable codes and standards, as well as recent research into the hazards of alternative fuels.

G.2 Alternative Fuels. It is evident that the use of vehicles powered by alternative fuels (i.e., fuels other than gasoline or diesel) will continue to increase. Of the potential alternative fuels, LP-Gas currently is the most widely used, although the use of both CNG and LNG is growing. Under the Energy Policy Act of 1992 and the Clean Air Act Amendment of 1990, the following are considered potential alternative fuels:

(1) Methanol
(2) Hydrogen
(3) Ethanol
(4) Coal-derived liquids
(5) Propane
(6) Biological materials
(7) Natural gas
(8) Reformulated gasoline
(9) Electricity
(10) Clean diesel

The alternative fuels that are considered most viable in the near future are CNG, LP-Gas, LNG, methanol, hydrogen, and electric hybrid.

G.2.1 Compressed Natural Gas. CNG has some excellent physical and chemical properties that make it a safer automotive fuel than gasoline or LP-Gas, provided well-designed carrier systems and operational procedures are followed. Although CNG has a relatively high flammability limit, its flammability range is relatively narrow compared to the ranges for other fuels.

In air at ambient conditions, a CNG volume of at least 5 percent is necessary to support continuous flame propagation, compared to approximately 2 percent for LP-Gas and 1 percent for gasoline vapor. Therefore, considerable fuel leakage is necessary in order to render the mixture combustible. Furthermore, fires involving combustible mixtures of CNG are relatively easy to contain and extinguish.

Since natural gas is lighter than air, it normally dissipates harmlessly into the atmosphere instead of pooling when a leak occurs. However, in a tunnel environment, such dissipation can lead to pockets of gas that collect in the overhead structure. In addition, since natural gas can ignite only in the range of 5 percent to 15 percent volume of natural gas in air, leaks are not likely to ignite due to insufficient oxygen.

Another advantage of CNG is that its fueling system is one of the safest in existence. The rigorous storage requirements and greater strength of CNG cylinders compared to those of gasoline contribute to the superior safety record of CNG automobiles.

G.2.2 Liquefied Petroleum Gas (LP-Gas). There is a growing awareness of the economic advantages of using LP-Gas as a vehicular fuel. These advantages include longer engine life, increased travel time between oil and oil filter changes, longer and better performance from spark plugs, nonpolluting exhaust emissions, and, in most cases, mileage that is comparable to that of gasoline. LP-Gas is normally delivered as a liquid and can be stored at 38°C (100.4°F) on vehicles under a design pressure of 1624 kPa to 2154 kPa (250 psi to 312.5 psi). LP-Gas is a natural gas and petroleum derivative. One disadvantage is that it is costly to store because a pressure vessel is needed. Also, where LP-Gas is engulfed in a fire, a rapid increase in pressure can occur, even if the outside temperature is not excessive relative to the gas–vapor pressure characteristics. Rapid pressure increase can be mitigated by venting the excessive buildup through relief valves. In Australia a significant proportion of the vehicle fleet uses LPG-powered vehicles. Alternative-powered vehicles are marked by colored labels on their registration plates. No restrictions on use of such vehicles exist in Australia. In Australia, the only impact on managing these vehicles is by alternative procedures for incident response by emergency services.

G.2.3 Methanol. Currently, methanol is used primarily as a chemical feedstock for the production of chemical intermediates and solvents. Under EPA restrictions, it is being used as a substitute for lead-based octane enhancers in the form of methyl tertiary-butyl ether (MTBE) and as a viable method for vehicle emission control. MTBE is not available as a fuel substitute but is used as a gasoline additive.

The hazards of methanol production, distribution, and use are comparable to those of gasoline. Unlike gasoline, however, methanol vapors in a fuel tank are explosive at normal ambient temperature. Saturated vapors that are located above nondiluted methanol in an enclosed tank are explosive at 10°C to 43°C (50°F to 109.4°F). A methanol flame is invisible, so a colorant or gasoline needs to be added to enable detection.

G.2.4 Hydrogen. Hydrogen is one of the most attractive alternative fuels due to its clean-burning qualities, the abundant source of availability, and the potential higher efficiency. Hydrogen can be used to power vehicles in the form of fuel cells or as replacement fuel in internal combustion engines. 2.2 lb (1 kg) hydrogen gas has about the same energy as 1 gallon gasoline. For an adequate driving range of 300 miles (450 km) or more, a light-duty fuel cell vehicle must carry 11 to 29 lb (5 to 13 kg) of hydrogen. Storage technologies currently under development include high-pressure tanks for compressed hydrogen gas up to 70 MPa (10,000 psi), insulated tanks for cryogenic liquid hydrogen below −423°F (−253°C), and chemical bonding of hydrogen with another material such as metal hydrides.

In comparison with gasoline, hydrogen has a much wider flammability range (4 percent to 75 percent by volume) and detonability limit. The minimum ignition energy of hydrogen in air is about an order of magnitude (by a factor of 10) less than that of gasoline vapor. A static electric spark such as by the human body or from a vehicle tailpipe is sufficient to ignite hydrogen. As the density is only about 7 percent of air, hydrogen release in atmosphere usually results in rapid dispersion and mixing to a nonhazardous concentration. However, accumulation of hydrogen in stagnant space that cannot be ventilated is a fire and explosion hazard. A minimum separation distance from the ceiling or explosion proofing should be considered for such electrical equipment.

Gaseous hydrogen leak tends to be vertical and the flammability mixture be localized before being quickly dispersed; whereas liquid hydrogen leak may pool and spread similarly as gasoline, but at a much higher evaporation rate, which results in temperature decrease in surroundings and causes condensation of water vapor. Since hydrogen gas is invisible and odorless, on-board detection and incident shutoff system must be provided in fuel-cell vehicles. Similarly, emergency response to an incident involving hydrogen fuel leak or fire requires necessary training, such as recognizing the hydrogen tank, high-voltage battery, or ultracapacitor pack that may be present on the incident vehicle.

G.2.5 Electric Hybrid. Executive Order 13423 signed in 2007 directed federal agencies to use plug-in hybrid electric vehicles (PHEVs) when their cost becomes comparable to non-PHEVs. PHEV combines the benefits of pure electric and hybrid electric vehicles, which allows on-board energy storage device be charged either by plugging into the electric grid or through an auxiliary power unit (APU) using replenishable fuels including certain types of alternative fuels such as CNG or hydrogen. Hybrid electric vehicles (HEV) offer better fuel economy and lower emission than vehicles using fossil fuels, while electricity produces zero tailpipe emission. Efficiency in energy storage, transmission, and conversion is critical regardless of electric vehicle types. Both battery EV and gasoline-electric HEV have been commercially available for a number of years. Due to the introduction of electric drive, energy storage, and conversion system in the powertrain, one of the safety considerations is associated with the high-voltage system (e.g., 600 VDC) used for the powertrain, such as electric shock and short-circuit; the other is the heat generated during battery charging and discharging, which also tends to give off toxic fumes and hydrogen gas; another safety consideration is accidental spill of battery electrolyte. Note also that a number of materials used in the battery, such as lithium, could burn at very high temperature if ignited. These issues have long been recognized and addressed in relevant SAE documents, i.e., SAE J2344, and UL standards, including battery thermal management and monitoring, proper electrical insulation and structural isolation of the battery compartment, and automatic disconnect for the energy storage system. Similarly, these have also been recognized for maintenance, training, and emergency response.

G.3 Mitigation Measures. As the use of alternative fuels in road vehicles increases, each road tunnel operating agency or AHJ must deal with the issue of whether to permit such vehicles to pass through the tunnel for which it is responsible. Most road tunnel agencies throughout the world do permit the passage of alternative-fuel vehicles.

The mitigation measures that can be taken by the road tunnel designer relate primarily to the ventilation system, which, in most circumstances, can provide sufficient air to dilute the escaped fuel to a level that is nonhazardous. It is necessary to establish a minimum level of ventilation to provide such dilution under all circumstances. To ensure that the ventilation system provides adequate capacity to provide such dilution under all circumstances, the AHJ is responsible for evaluating each tunnel on a case-by-case basis, which might be handled by risk analysis, computer (zone, CFD, etc.) modeling, experimental testing, or all of the above. This assessment should consider all relevant tunnel characteristics (i.e., tunnel length, cross-sectional area, etc). Other measures include reducing or eliminating any irregular surfaces of the tunnel ceiling or structure where a pocket of gas can collect and remain undiluted, thus posing a potential explosion hazard. Additional precautions can be taken by installing permanent alternative-fuel detection devices within tunnels at high points or within ceiling cavities as appropriate where escaped fuel can accumulate.

The use of alternative-fuel vehicles within tunnels generates challenges that require resolution. Identification of alternative-fuel vehicles is critical in the development of personnel training and emergency response procedures for accidents involving such vehicles. Specific emergency response procedures, precautions, and training requirements for each of the alternative-fuel vehicles must be prepared and included as part of the emergency response plan. A good example of this type of plan is referenced in M.2.1: *California Fuel Cell Partnership – Emergency Response Guide: Fuel Cell Vehicles and Hydrogen Fueling Stations*.

Precautions must be taken by first responders to identify if the vehicle is powered by alternative fuels. Vehicle identification shall consist of vehicle display graphics. An identification standard for each of the alternative fuels needs to be established. Emergency response personnel shall be provided with training specific to the alternative-fuel vehicle they are responding to and be provided with specialty response equipment such as, but not limited to, self-contained breathing apparatus, high-voltage gloves, static dissipative equipment, and infrared cameras to visualize a vehicle fire.

Additional precautions must be taken before attempting to rescue occupants from a disabled or damaged alternative-fuel vehicle or trying to remove a damaged vehicle. It is important to make sure that the system is no longer running and that there are no indications of an alternative-fuel release. If extrication of a passenger is necessary, all precautions are to be taken into consideration and manufacturers' shutdown procedures must be followed to ensure high-voltage lines or alternative-fuel (natural gas, hydrogen) lines are not cut.

G.4 Informational References. Published research exists to help assess the relative hazard of specific alternative fuels (and fuel systems) and to help develop consensus safety standards for regulators. Subsection M.2.1 references several codes and standards used for alternative fuels as well as a few website resources for new standards in development. Subsection M.2.2 contains a short list of published research in the area of alternative fuels.

This list of references represents a brief summary of some applicable documents, with some emphasis on hydrogen, as that seems to be the fastest growing technology. This list is not meant to be exhaustive. On the other hand, it is meant to be a starting point for document users to understand some of the hazards of alternative fuels, potential mitigation measures, as well as necessary future research.

Annex H The Memorial Tunnel Fire Ventilation Test Program

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

H.1 General. The primary purpose of controlling smoke in a tunnel is to protect life (i.e., to allow safe evacuation of the tunnel). Such protection involves creating a safe evacuation path for motorists and operating personnel who are within the tunnel. The secondary purpose of smoke-control ventilation is to assist fire-fighting personnel in accessing the fire site by providing a clear path to the fire site, if possible.

A tunnel ventilation system is not designed to protect property, although the effect of ventilation in diluting smoke and heated gases, which removes some of the heat, results in reduced damage to facilities and vehicles. The ongoing reduction of vehicle emissions has shifted the focus of the ventilation engineer from a design based on the dilution of emission contaminants to a design based on the control of smoke in a fire emergency.

Despite the increasing focus on life safety and fire control in modern road tunnels, no uniform standards for fire emergency ventilation or other fire control means within road tunnels have been established in the United States.

H.2 Ventilation Concepts. The ventilation concepts that have been applied to highway tunnels have been based on theoretical and empirical values, not on the results of full-scale tests. Therefore, the design approach that is currently used to detect, control, and suppress fire and smoke in road tunnels has become controversial among tunnel design engineers, owners, operators, and fire fighters throughout the world.

While most road tunnels have ventilation systems with smoke-control operating modes, there were limited scientific data to support opinions or code requirements regarding the capabilities of various types of ventilation systems to control heat and smoke effectively.

H.3 Investigations. Engineering investigations of ventilation operating strategies and performance in full-scale fire situations were authorized by the Massachusetts Highway Department (MHD) and the U.S. Federal Highway Administration (USFHA) to be performed in the Memorial Tunnel in West Virginia as a part of the Boston Central Artery/Tunnel Project. The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Technical Committee TC 5.9, "Enclosed Vehicular Facilities," identified the need for a comprehensive full-scale test program in the early 1980s.

Technical Committee TC 5.9 was commissioned in 1989 to form a subcommittee, the Technical Evaluation Committee (TEC), to develop a Phase 1 concept report and work scope. The report outlined the objectives of the testing program, which included identification of appropriate means to account for the effects of fire size, tunnel grade and cross-section, direction of traffic flow (unidirectional or bidirectional), altitude, type of ventilation system, and any other parameters that could have a significant influence on determining the ventilation capacity and operational procedures needed for safety in a fire situation.

The establishment of specific approaches to allow for effective reconfiguration of both new and existing tunnel facilities was deemed of equal importance. The goals and test matrices that were developed and documented in the Phase 1 concept report evolved into the test plan described in the following paragraphs.

The purpose of the Memorial Tunnel Fire Ventilation Test Program (MTFVTP) was to develop a database that provides tunnel design engineers and operators with an experimentally proven means to determine the ventilation rates and ventilation system configurations that provide effective smoke control, smoke removal, or both, during a tunnel fire emergency.

A more important purpose of the MTFVTP was to establish specific operational strategies to allow effective reconfiguration of ventilation parameters for existing tunnel facilities. While the life safety issue is paramount, it should be recognized that significant cost differentials exist among the various types of ventilation systems. In the instance where more than one ventilation configuration offers an acceptable level of fire safety, the project's overall life cycle cost needs to be addressed to identify the option with the optimum cost benefit.

In addition, the impact of ventilation systems that cause horizontal roadway airflow on the effectiveness of fire suppression systems (such as foam deluge sprinklers) can be better determined by performing full-scale tests.

H.4 The Test Facility. The Memorial Tunnel is a two-lane, 854 m (2800 ft) highway tunnel located near Charleston, West Virginia, originally built in 1953 as part of the West Virginia Turnpike (I-77). The tunnel has a 3.2 percent uphill grade from the south to the north tunnel portal. The original ventilation system was a transverse type, consisting of a supply fan chamber at the south portal and an exhaust fan chamber at the north portal.

The tunnel has been out of service since it was bypassed by an open-cut section of a new six-lane highway, Interstate 77, in 1987. As part of the MTFVTP, the existing ventilation equipment was removed to allow the installation of new variable-speed, reversible, axial-flow central ventilation fans. The equipment rooms were modified to accept the ventilation components needed to allow supply or exhaust operation from both ends of the tunnel.

There are six fans, three each in the modified north and south portal fan rooms. Each of the fans has a capacity to supply or exhaust 94.4 m^3/sec (200,000 ft^3/min), and the fans are fitted with vertical discharges to direct the smoke away from the test facility and the nearby interstate highway.

The existing overhead air duct, formed by a concrete ceiling above the roadway, is split into longitudinal sections that can serve as either supply or exhaust ducts, and a mid-tunnel duct bulkhead has been installed to allow a two-zone ventilation operation. Openings in the duct dividing wall and duct bulkhead have been designed to create airflow patterns similar to those that would be observed if the dividing wall was not present. The width of the ducts varies linearly along the length of the tunnel to provide maximum area at the point of connection to the fan rooms above the tunnel portals.

High-temperature insulation was applied extensively to various structural elements, including the concrete ceiling and ceiling hangers, all utilities, instrumentation support systems, wiring, gas-sampling lines, closed-circuit television (CCTV) camera cabinets, and all other related items that are exposed to high tunnel fire temperatures.

H.5 Fire Size. Fires with heat-release rates ranging from 20 MW (equivalent to a bus or truck fire) to 50 MW [equivalent to a flammable spill of approximately 400 L (100 gal)] to 100 MW [equivalent to a hazardous material fire or flammable spill of approximately 800 L (200 gal)] were produced. The fires were generated in floor-level steel pans.

The actual burning rate differed somewhat from that used for the engineering estimate, due to effects such as heat reradiation from the tunnel walls and varying ventilation flow rates. Therefore, the measured tunnel conditions were interpreted to determine a measured heat-release rate. The ventilation systems that were configured and tested under varying flow rates and varying heat-release rates, with one or two zones of ventilation, included the following:

(1) Transverse ventilation
(2) Partial transverse ventilation
(3) Transverse ventilation with point extraction
(4) Transverse ventilation with oversized exhaust ports
(5) Natural ventilation
(6) Longitudinal ventilation with jet fans

When the first four series of tests in H.5(1) through H.5(6) were completed, the tunnel ceiling was removed to conduct the natural ventilation tests, which were followed by the installation of jet fans at the crown of the tunnel to conduct the longitudinal jet fan–based ventilation tests.

A fire suppression system intended to be available to suppress the fire in an emergency was installed; however, it was also used during several tests to evaluate the impact of ventilation airflow on the operation of a foam suppression system.

H.6 Data Collection. All measured values were entered into a data acquisition system (DAS) that monitored and recorded data from all field instruments for on-line and historical use.

The measurement of tunnel air temperature was accomplished through the use of thermocouples located at various cross-sections throughout the length of the tunnel.

In total, there were approximately 1450 instrumentation-sensing points. Each sensing point was monitored and recorded once every second during a test, which lasted 20 minutes to 45 minutes.

Approximately 4 million data points were recorded during a single test. All test data was recorded on tapes in a control center trailer, where control operators monitored and controlled each test.

Instrument trees located at ten tunnel cross-sections were designed to measure airflow to a modified ASHRAE traverse method. Additional temperature measurements were taken at five other tunnel cross-sections and at two locations outside of the tunnel portals. The measurement of air velocity in the tunnel under test conditions was accomplished through the use of differential pressure instrumentation. Temperatures in the vicinity of the bidirectional pilot tubes and the ambient pressure were combined with the measured pressure to calculate the air velocity.

A gas-sampling system extracted sample gas from specific tunnel locations to analysis cabinets that were located in the electrical equipment rooms. Sample gases were analyzed within the analysis cabinets for CO, carbon dioxide (CO_2), and total hydrocarbon content (THC). The analyzers were housed in climate-controlled cabinets.

To ensure personnel safety, methane gas could be detected at the test fire location through the use of individual in-situ electromechanical cell-type analyzers at the control trailer. In addition, portable detectors that were capable of detecting CO, total hydrocarbon, oxygen, and methane were provided for the safety of personnel who entered the tunnel after fire tests.

Two meteorological towers that were located outside of the north and south tunnel portals included instrumentation that monitored and recorded ambient dry- and wet-bulb air temperatures, barometric pressure, wind speed, and wind direction.

The weather-related parameters were monitored for over 1½ years to track weather conditions to assist in planning, scheduling, and conducting the tests.

The CCTV system originally included six cameras: two located within the tunnel, two located outside of the tunnel (near the portals), and two located on the north and south meteorological towers. During the tests, another camera was added north of the fire to show smoke movement.

H.7 Conclusions. The MTFVTP represented a unique opportunity to evaluate and develop design methods and operational strategies that lead to safe underground transportation facilities. The comprehensive test program, which began with the initial fire tests in September 1993 and concluded in March 1995, produced data that was acquired in a full-size facility, under controlled conditions, and over a wide range of system parameters.

The findings and conclusions are categorized by ventilation system type and are summarized as follows.

H.7.1 Longitudinal Tunnel Ventilation Systems. A longitudinal ventilation system employing jet fans is highly effective in managing the direction of the spread of smoke for fire sizes up to 100 MW in a 3.2 percent grade tunnel.

The throttling effect of the fire needs to be taken into account in the design of a jet fan longitudinal ventilation system.

Jet fans that were located 51.8 m (170 ft) downstream of the fire were subjected to the following temperatures for the tested fire sizes:

(1) 204°C (400°F) — 20 MW fire
(2) 332°C (630°F) — 50 MW fire
(3) 677°C (1250°F) — 100 MW fire

Air velocities of 2.54 m/sec to 2.95 m/sec (500 fpm to 580 fpm) were sufficient to preclude the backlayering of smoke in the Memorial Tunnel for fire tests ranging in size from 10 MW to 100 MW.

H.7.2 Transverse Tunnel Ventilation Systems. It has been standard practice in the tunnel ventilation industry to design tunnel ventilation systems for fire emergencies that are based on fan capacities expressed in cubic meters per second per lane meter (m^3/sec · lm) [cubic feet per minute per lane foot (ft^3/min · lf)]. However, the MTFVTP has demonstrated that longitudinal airflow is a major factor in the ability of a ventilation system to manage and control the movement of smoke and heated gases that are generated in a fire emergency.

It was demonstrated in the MTFVTP that dilution as a sole means for temperature and smoke control was not very effective. Some means of extraction should be incorporated. Extraction and longitudinal airflow, where combined, can significantly increase the effectiveness of a road tunnel ventilation system in managing and controlling the movement of smoke.

H.7.3 Single-Zone Transverse Ventilation Systems. Single-zone, balanced, full-transverse ventilation systems that were operated at 0.155 m^3/sec · lm (100 ft^3/min · lf) were ineffective in the management of smoke and heated gases for fires of 20 MW and larger.

Single-zone, unbalanced, full-transverse ventilation systems generated some longitudinal airflow in the roadway. The result of this longitudinal airflow was to offset some of the effects of buoyancy for a 20 MW fire. The effectiveness of unbalanced, full-transverse ventilation systems is sensitive to the fire location, since there is no control over the airflow direction.

H.7.4 Multiple-Zone Transverse Ventilation Systems. The two-zone transverse ventilation system that was tested in the MTFVTP provided control over the direction and magnitude of the longitudinal airflow. Airflow rates of 0.155 m^3/sec · lm (100 ft^3/min · lf) contained high temperatures from a 20 MW fire within 30 m (100 ft) of the fire in the lower elevations of the roadway and smoke within 60 m (200 ft).

H.7.5 Smoke and Heated Gas Movement. The spread of hot gases and smoke was significantly greater with a longer fan response time. Hot smoke layers were observed to spread very quickly — 490 m to 580 m (1600 ft to 1900 ft) during the initial 2 minutes of a fire.

Natural ventilation resulted in the extensive spread of smoke and heated gases upgrade of the fire, but relatively clear conditions existed downgrade of the fire. The spread of smoke and heated gases during a 50 MW fire was considerably greater than for a 20 MW fire. The depth of the smoke layer increased with fire size.

A significant difference was observed between smoke spread with the ceiling removed (arched tunnel roof) and with the ceiling in place. The smoke and hot gas layer migrating along the arched tunnel roof did not descend into the roadways as quickly as in the tests that were conducted with the ceiling in place. Therefore, the time for the smoke layer to descend to a point where it poses an immediate life safety threat is dependent on the fire size and tunnel geometry; specifically, it depends on the tunnel height. In the Memorial Tunnel, smoke traveled between 290 m and 365 m (950 ft and 1200 ft) along the arched tunnel roof before cooling and descending toward the roadway.

The restriction of visibility caused by the movement of smoke occurs more quickly than does a temperature that is high enough to be debilitating. In all tests, exposure to high levels of carbon monoxide was never more critical than smoke or temperature.

The effectiveness of the foam suppression system (AFFF) that was tested was not diminished by high-velocity longitudinal airflow [4 m/sec (800 fpm)]. The time taken for the suppression system to extinguish the fire, with the nozzles located at the ceiling, ranged from 5 seconds to 75 seconds.

The maximum temperatures experienced at the inlet to the central fans that were located closest to the fire [approximately 213 m (700 ft) from the fire] were as follows:

(1) 107°C (225°F) — 20 MW fire
(2) 124°C (255°F) — 50 MW fire
(3) 163°C (325°F) — 100 MW fire

In a road tunnel, smoke management necessitates either direct extraction at the fire location or the generation of a longitudinal velocity in the tunnel that is capable of transporting the smoke and heated gases in the desired direction to a point of extraction or discharge from the tunnel. Without a smoke management system, the direction and rate of movement of the smoke and heated gases are determined by fire size, tunnel grade (if any), prefire conditions, and external meteorological conditions.

H.7.6 Enhancements. The ability to extract smoke quickly and from a location that is as close as possible to the fire can significantly reduce the migration of smoke and heat in undesirable directions and can facilitate two-way traffic operations. Localized extraction is possible with the addition of single-point extraction (SPE) openings or oversized exhaust ports (OEP) to transverse ventilation systems.

SPE systems apply to two-way traffic flow with a dependency on the location, size, and spacing of the SPE openings. Smoke and heat that are drawn from the fire to the SPE can pass over or possibly around stalled traffic and vehicle occupants. An SPE that is located upgrade of the fire is very effective in temperature and smoke management. Where the SPE was located downgrade of the fire, only minimal improvement in temperature and smoke conditions over a single-zone, partial transverse exhaust system was achieved.

A single-point opening of 28 m^2 (300 ft^2) was most effective in temperature and smoke management of the tested SPE sizes. Significantly greater smoke and heat spread were observed with a 9.3 m^2 (100 ft^2) opening, compared to the 28 m^2 (300 ft^2) opening.

In the one test in which two single-point openings that were located north of the fire were used, a stagnation zone formed, resulting in smoke accumulation between the extraction openings.

For 20 MW fires, partial transverse exhaust ventilation that was operated with 0.155 m^3/sec · lm (100 ft^3/min · lf), and supplemented with a large [27.9 m^2 (300 ft^2)] single-point opening, limited the smoke and heated gas migration to within 61 m (200 ft) of the fire. A partial transverse exhaust system that was supplemented with oversized exhaust ports and operated with 0.132 m^3/sec · lm (85 ft^3/min · lf) limited high temperatures to within 31 m (100 ft) of the fire and sustained the smoke layer above the occupied zone.

For 50 MW fires, partial transverse exhaust ventilation that was operated with 0.170 m^3/sec · lm (110 ft^3/min · lf), and supplemented with a large [27.9 m^2 (300 ft^2)] single-point opening, limited the smoke and heated gas migration to within 85 m (280 ft) of the fire.

The results of the test program were processed and made available to the professional community for use in the development of emergency tunnel ventilation design and emergency operational procedures in late 1995 in a report titled "Memorial Tunnel Fire Ventilation Test Program Test Report." In addition, a comprehensive test report was prepared and is available in a CD-ROM format.

Annex I Tunnel Ventilation System Concepts

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

I.1 General. Ventilation is necessary in most road tunnels to limit the concentrations of contaminants to acceptable levels within the tunnel. Ventilation systems are also used to control smoke and heated gases that are generated during a tunnel fire emergency. Some short tunnels are ventilated naturally (without fans); however, such tunnels could necessitate a ventilation system to combat a fire emergency.

I.1.1 This annex provides fire protection engineers with a basic understanding of the various ventilation system concepts usually employed in the ventilation of road tunnels.

I.1.2 The systems used for mechanical or fan-driven ventilation are classified as longitudinal or transverse. A longitudinal ventilation system achieves its objectives through the longitudinal flow of air within the tunnel roadway, while a transverse ventilation system achieves its objectives by means of the continuous uniform distribution or collection, or distribution and collection, of air throughout the length of the tunnel roadway. A transverse ventilation system also experiences some longitudinal airflow; the quantity depends on the type of system. It is recognized that many combinations of longitudinal and transverse ventilation systems exist.

I.2 Longitudinal Ventilation Systems.

I.2.1 A longitudinal ventilation system introduces air into, or removes air from, the tunnel roadway at a limited number of points, such as a portal or a shaft, or at another single location, thus creating a longitudinal flow of air along the tunnel roadway. *[See Figure I.2.1(a) through Figure I.2.1(e).]*

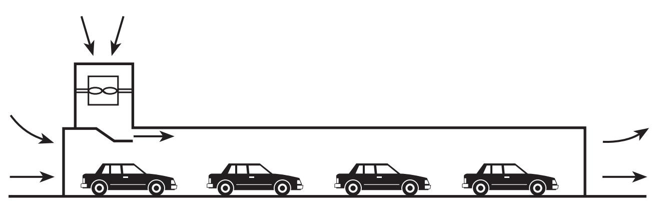

FIGURE I.2.1(a) Longitudinal Ventilation System with Central Fans and Saccardo Nozzle at Entry Portal.

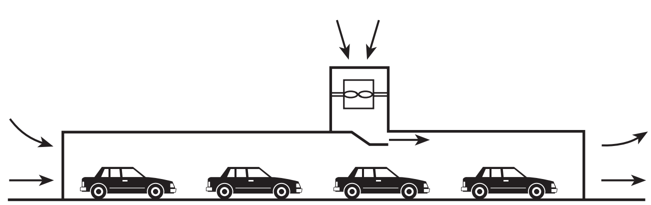

FIGURE I.2.1(b) Longitudinal Ventilation System with Central Fans and Saccardo Nozzle at Midtunnel Location.

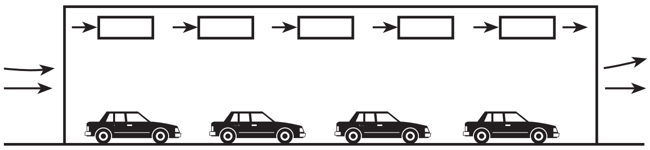

FIGURE I.2.1(c) Longitudinal Ventilation System with Jet Fans.

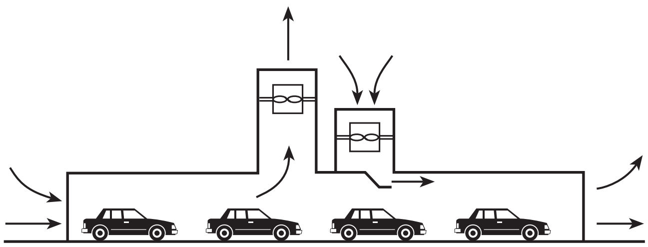

FIGURE I.2.1(d) Longitudinal Ventilation System with Central Fans, Saccardo Nozzle, and Exhaust Shaft.

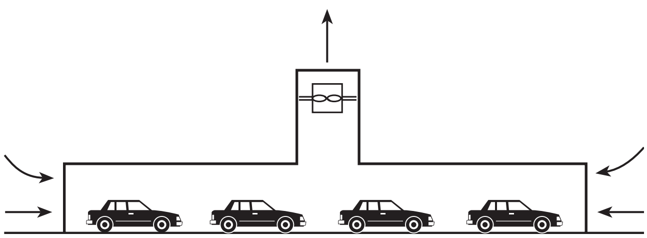

FIGURE I.2.1(e) Longitudinal Ventilation System with Central Fans and Exhaust Shaft.

I.2.2 Longitudinal ventilation systems can be subclassified as those that use central fans *[see Figure I.2.1(a), Figure I.2.1(d), and Figure I.2.1(e)]* and those that employ local fans or jet fans *[see Figure I.2.1(c)]*.

I.2.2.1 Central-fan longitudinal ventilation systems employ centrally located fans to inject air into the tunnel roadway, through a supply air shaft or a high-velocity nozzle, such as a Saccardo nozzle. The air injection can take place at the entry portal [*see Figure I.2.1(a)*] or at a midtunnel location *[see Figure I.2.1(b)]*. An exhaust air shaft can be combined with the injection nozzle as shown in Figure I.2.1(d).

I.2.2.2 Jet fan–based longitudinal ventilation employs a series of axial flow fans that are typically mounted at the ceiling level of the tunnel roadway *[see Figure I.2.1(c)]*. Such fans, due to the effects of the high-velocity discharge, induce a longitudinal airflow throughout the length of the tunnel roadway.

I.2.3 In all longitudinal ventilation systems, the exhaust gas stream (containing pollutants or smoke) discharges from the exit portal or from the exhaust air shafts.

I.3 Transverse Ventilation Systems.

I.3.1 Transverse ventilation systems feature the uniform collection and/or distribution of air throughout the length of the tunnel roadway and can be of the full transverse or semitransverse type. In addition, semitransverse systems can be of the supply or exhaust type. *[See Figure I.3.1(a) through Figure I.3.1(c).]*

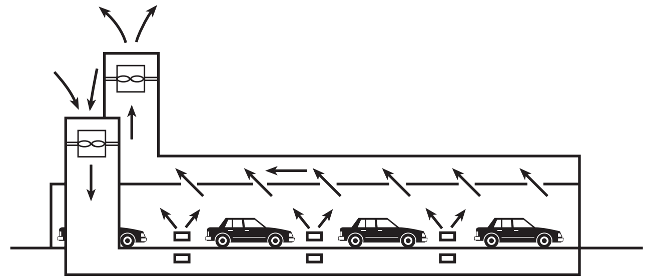

FIGURE I.3.1(a) Full Transverse Ventilation System.

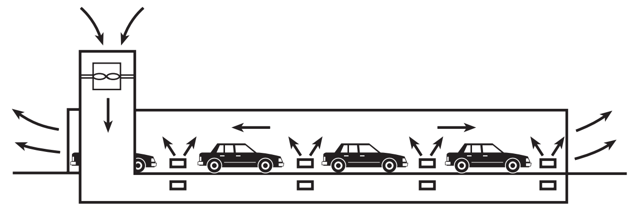

FIGURE I.3.1(b) Semitransverse Supply Ventilation System.

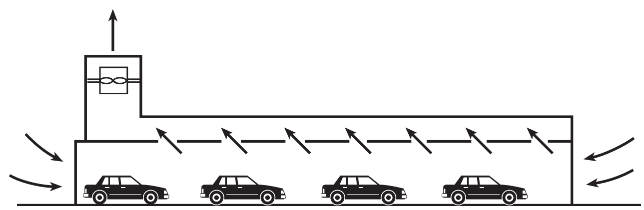

FIGURE I.3.1(c) Semitransverse Exhaust Ventilation System.

I.3.1.1 Full transverse systems are equipped with supply and exhaust airducts throughout the length of the tunnel roadway *[see Figure I.3.1(a)]*. When a full transverse system is deployed, the majority of the pollutants or smoke discharges through a stack or stacks, with a minor portion of the pollutants or smoke exiting through the portals. A full transverse ventilation system can be either balanced (exhaust equals supply) or unbalanced (exhaust is greater than supply).

I.3.1.2 Semitransverse systems are those that are equipped with only supply or exhaust elements. The exhaust from the tunnel is discharged at the portals *[supply semitransverse, see Figure I.3.1(b)]* or through exhaust stacks *[exhaust semitransverse, see Figure I.3.1(c)]*.

I.4 Single Point Extraction.

I.4.1 Single Point Extraction (SPE) systems conceptually are similar to both transverse exhaust ventilation systems (a duct system is utilized to provide the extraction means) and longitudinal ventilation systems (longitudinal airflow in the tunnel provides smoke control). SPE systems utilize one or a limited number of large extraction openings that provide localized exhaust during a fire emergency. The extraction ports or openings are equipped with control dampers. The exhaust near the fire site is achieved through the activation of the control dampers (opened or kept open) at the extraction opening or openings nearest the fire site upon detection and confirmation of the existence of a fire within the tunnel. The control dampers nearest the fire site remain open while the control dampers of the remainder of the extraction openings remain or are closed, thereby allowing the SPE system to maximize the exhaust air flow adjacent to the fire site. Figure I.4.1 shows the implementation of an SPE system in conjunction with a semitransverse exhaust ventilation system.

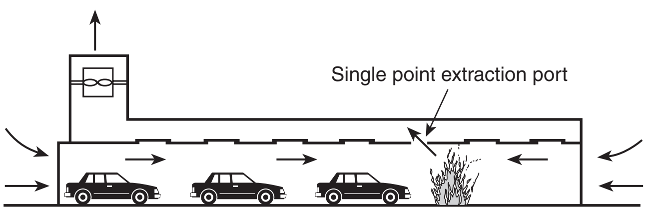

FIGURE I.4.1 Single Point Extraction with Semitransverse Exhaust Ventilation System.

I.4.2 Single point extraction systems can be supported by longitudinal ventilation systems, such as jet fan systems, to counteract the wind at the portal and direct smoke and heated gases along the tunnel and to an SPE opening as shown in Figure I.4.2.

Annex J Control of Road Tunnel Emergency Ventilation Systems

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

J.1 Introduction. Ventilation control in road tunnels is required during both normal and emergency tunnel operations. Normal tunnel operation ventilation system control is required to respond to continuing changes in tunnel environmental conditions for both stopped traffic and free-flowing traffic due to the accumulation of pollutant and particulate matter generated by the vehicle traversing the tunnel. During emergency operation the ventilation system is required to control the flow of smoke and heated gases so as to provide a safer environment for tunnel users to evacuate and for emergency services to enter the tunnel. This annex presents a guide to ventilation system control during periods of emergency operations within the tunnel.

J.2 Objectives. During normal operation, it is required to keep the pollutant level below defined threshold values.

During the performance of service and maintenance operations within the tunnel, the tunnel ventilation systems must ensure meeting the air-quality criteria for the longer required exposure of service personnel and maintenance workers.

Under normal operations of the tunnel, environmental conditions within the tunnel change rather slowly compared to the conditions within the tunnel during a fire-based incident. This annex outlines the emergency events that can occur as a fire-based incident develops and presents the operational response required to be addressed by the tunnel ventilation system in order to ensure the safety of the tunnel users.

J.3 Ventilation Operational Modes. Establishing ventilation control requirements in a roadway tunnel and, consequently, the capacity of the ventilation system, are challenging due to the difficulty of controlling many variables.

J.3.1 General. In the event of a fire, tunnel operators must implement a strategy of smoke control and management, which consists of selecting a sequence of fan operation, to respond to the highly modified airflow in the tunnel.

When the emergency service responders arrive at the fire scene, the operator must cooperate and modify, as needed, the fan operation in order to facilitate access to the site.

J.3.2 Emergency Incident Phases. During an incident emergency, two phases should be considered in developing the emergency ventilation strategies: “evacuation” and “fire control” phases. The evacuation phase involves both self-evacuation and assisted evacuation. For the duration of the self-evacuation, which starts after fire ignition and depends on the awareness and reaction of tunnel users, the natural stratification of hot gases and smoke should be maintained by ensuring zero longitudinal velocity in the fire zone. The assisted evacuation stage begins with the arrival of emergency services at the site. Throughout the fire control phase, smoke and hot gases should be managed and controlled to ensure safe evacuations.

J.3.3 Smoke Management Strategies. Smoke management should be implemented from the detection of a fire to provide a tenable environment during the various emergency phases. In developing smoke management strategies, the rate at which smoke and hot gases are produced from an incident should be taken into consideration. Smoke management strategies include dilution, extraction, and longitudinal flow.

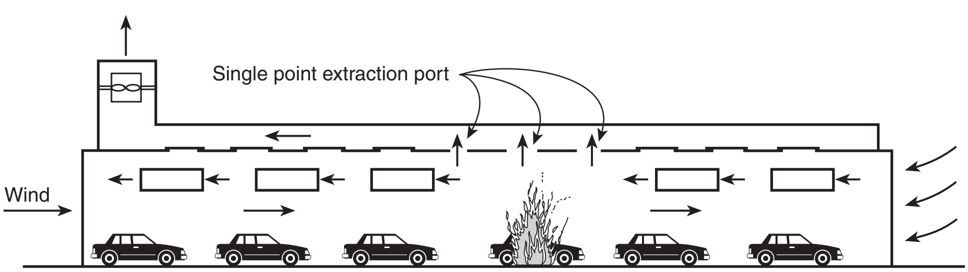

FIGURE I.4.2 Single Point Extraction with Jet Fan Longitudinal Ventilation Support.

Dilution is usually an efficient method for normal operation, with the objective being to maintain air quality and visibility under a limit value. Dilution may enhance tenability conditions by reducing concentrations of toxic gases and reducing temperature.

For the duration of emergency operation, smoke management is best accomplished by the extraction of air and smoke as close to the incident location as possible. The single point extraction (SPE) system does provide the mechanism to prevent smoke spread to the rest of the tunnel.

Longitudinal air flow moving the smoke and heated gases to a tunnel portal is also a means of managing and controlling smoke from a fire incident in a road tunnel.

J.3.4 Parameters Influencing Smoke Management. In the event of a fire incident, the airflow in a tunnel becomes highly unsteady. The airflow modifications are primarily due to the fire itself, the operation of the emergency ventilation system, and the tunnel grade. The smoke progress and its degree of stratification depend mainly on the airflow in the tunnel. The combined effects of convective heat exchange with tunnel walls and the mixing between the smoke and the fresh air layer causes the smoke to cool down and lose its stratification. Other parameters that affect the smoke flow and stratification are smoke generation rate, heat release rate, natural ventilation, and tunnel grade.

J.4 Overview of the Emergency Response Process During a Fire Emergency. The tunnel operating authority's emergency response plan and operating procedures shall clearly identify the actions and requirements to respond to a tunnel fire emergency. Rapid and appropriate ventilation system operation and control is critical to minimize the effects of smoke and heat from a tunnel fire emergency. The response process for a fire emergency includes detection, verification, and implementation of other response actions.

J.4.1 Fire Detection. Fire detection may occur by different means, including manual fire alarm boxes, closed-circuit television (CCTV) systems, or an automatic fire detection system. The fire detection system will initiate the response to a fire emergency.

J.4.2 Fire Verification and Incident Data (Information). Verification of the fire emergency is the initial action in response to the detection of a fire emergency. Tunnels with a staffed Operations Control Center (OCC) equipped with a 24-hour supervised closed-circuit television (CCTV) system can visually verify the fire emergency and gather other information regarding the emergency.

Tunnels with automatic fire detection systems installed in accordance with *NFPA 72* are required to detect fires within corresponding ventilation zones and initiate alarms at supervisory stations.

J.4.3 Emergency Response Implementation. Notification of the emergency responders of the fire emergency and initiation of the equipment response actions should be in accordance with the emergency response plan.

J.4.4 Emergency Response Plan. The tunnel operating agency should have an emergency ventilation plan that indicates the required ventilation system equipment operating modes for fire emergencies within the tunnel and immediately adjacent to the tunnel. Emergency ventilation plans can range from simple single ventilation mode plans to multiple ventilation mode plans as necessary for complex ventilation zone configurations.

J.5 Commissioning, Training, Maintenance, and Testing. The tunnel ventilation system is a critical life safety system; therefore proper commissioning, training, maintenance, and testing is vital to assess the ventilation system performance and to maximize its reliability.

Annex K Fire Apparatus

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

K.1 General. Fire apparatus that is suitable for fighting fires within the facilities covered by this standard should be available within the general facility area, thus allowing a rapid response to a fire emergency. Such apparatus should be equipped to deal effectively with flammable liquid and hazardous material fires.

K.2 Capacity. The responding fire apparatus should be appropriately equipped to fight fire within the tunnel for a minimum of 30 minutes. If a water supply is not available, suitable arrangements should be made to transport water so that the necessary apparatus delivery rate at the fire can be maintained for an additional 45 minutes.

K.3 Extinguishers. Fire-fighting units should carry multipurpose, dry-chemical extinguishers and an extinguishing agent for Class D metal fires.

K.4 Bridges and Elevated Highways. Fire apparatus that is configured for use on bridges and elevated highways should be equipped with ladders for use by fire fighters where bridges and elevated highway structures are accessible from beneath.

K.5 Road Tunnels. Where a tunnel is a high-capacity facility in a congested urban area, it can be appropriate to house fire apparatus at the tunnel portal(s). It can also be appropriate to combine the fire apparatus with the apparatus that is provided to effect retrieval and removal of disabled vehicles from the tunnel.

K.6 Emergency Response Plan. Arrangements for the response of nearby fire companies and emergency squads should be made a part of the emergency response plan *(see Chapter 13)*. A means of access that allows outside aid companies to enter the facility should be provided, and procedures for using such access should be included in the emergency response plan. Appropriate precautions should be taken at the points of entry to alert and control traffic to allow the safe entry of emergency equipment.

Annex L Motorist Education

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

L.1 The tunnel operator should consider implementing a program to educate the motorist and professional drivers on how to properly react in case of emergencies in the tunnel. Consideration should be given to radio and TV ads, brochures, and other means. A suggested brochure is shown in Figure L.1.

Be Safe Entering a Tunnel

- Listen to the radio for traffic updates.
- Turn on your headlights and take off your sunglasses.
- Obey all traffic lights, signs, and pavement markings.
- Do not stop, except in an emergency.
- Keep a safe distance from the vehicle in front.
- Never enter into a tunnel that has smoke coming out of it.
- Never drive a burning or smoking vehicle into a tunnel.

Be Safe in Traffic Congestion in a Tunnel

- Keep your distance, even if traffic is moving slowly.
- Listen to traffic updates on the radio.
- Follow the instructions given by tunnel officials and/or variable message signs.
- Note the location of fire extinguishers and emergency exits.

REMEMBER, FIRE AND SMOKE KILL — SAVE YOUR LIFE NOT YOUR CAR!

Be Safe if There Is a Fire in the Tunnel

- If your vehicle is on fire, drive out of the tunnel if possible.
- If that is not possible, stop and turn the engine off, and leave the vehicle immediately.
- Leave the keys and all personal belongings.
- Locate an emergency phone in the tunnel and call for help.
- Put out the fire using a fire extinguisher located on the tunnel wall.
- If there is no fire extinguisher, locate the nearest emergency exit and leave.

FIGURE L.1 Example of Tunnel Safety Brochure.

Annex M Informational References

M.1 Referenced Publications. The documents or portions thereof listed in this annex are referenced within the informational sections of this standard and are not part of the requirements of this document unless also listed in Chapter 2 for other reasons.

M.1.1 NFPA Publications. National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02169-7471.

NFPA 15, *Standard for Water Spray Fixed Systems for Fire Protection*, 2007 edition.

NFPA 30, *Flammable and Combustible Liquids Code*, 2008 edition.

NFPA 30A, *Code for Motor Fuel Dispensing Facilities and Repair Garages*, 2008 edition.

NFPA 70B, *Recommended Practice for Electrical Equipment Maintenance*, 2010 edition.

NFPA 72®, *National Fire Alarm and Signaling Code*, 2010 edition.

NFPA *101®*, *Life Safety Code®*, 2009 edition.

NFPA 170, *Standard for Fire Safety and Emergency Symbols*, 2009 edition.

NFPA 262, *Standard Method of Test for Flame Travel and Smoke of Wires and Cables for Use in Air-Handling Spaces*, 2007 edition.

NFPA 730, *Guide for Premises Security*, 2008 edition.

NFPA 731, *Standard for the Installation of Electronic Premises Security Systems*, 2008 edition.

NFPA 1600®, *Standard on Disaster/Emergency Management and Business Continuity Programs*, 2010 edition.

M.1.2 Other Publications.

M.1.2.1 AISC Publications. American Institute of Steel Construction, One East Wacker Drive, Suite 700, Chicago, IL 60601-1802.

AISC 325, *LRFD Manual of Steel Construction*, 2005.

M.1.2.2 ANSI Publications. American National Standards Institute, Inc., 25 West 43rd Street, 4th Floor, New York, NY 10036.

ANSI NGV2, *American National Standard for Natural Gas Vehicle Containers,* 2007.

IEEE/ANSI SI 10, *Standard for Use of the International System of Units (SI): the Modern Metric System,* 2002.

M.1.2.3 ASCE Publications. American Society of Civil Engineers, 1801 Alexander Bell Drive, Reston, VA 20191-4400.

ASCE/SEI 7, *Minimum Design Load for Buildings and Other Structures,* 2005.

M.1.2.4 ASME Publications. American Society of Mechanical Engineers, Three Park Avenue, New York, NY 10016-5990.

Harris, K. J., "A Basis for Determining Fill Times for Dry Fire Lines in Highway Tunnels," in F. J. Mintz, ed., *Safety Engineering and Risk Analysis*, SERA Vol. 6, Book No. G01033, 1996.

M.1.2.5 ASTM Publications. ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959.

ASTM E 136, *Standard Test Method for Behavior of Materials in a Vertical Tube Furnace at 750°C,* 2009.

ASTM E 580, *Application of Ceiling Suspension Systems for Acoustical Tile and Lay-in Panels in Areas Requiring Moderate Seismic Restraint*, 2006.

ASTM E 2652, *Standard Test Method for Behavior of Materials in a Vertical Tube Furnace at 750°C with a Cone-Shaped Airflow Stabilizer,* 2009.

M.1.2.6 EN Publications. European Committee for Electrotechnical Standardization (CENELEC), 35, Rue de Stassartstraat, B-1050 Brussels, Belgium.

EN 61508-1, *Functional Safety of Electrical/Electronic/Programmable Electronic Safety-Related Systems,* 2002 edition.

M.1.2.7 IEEE Publications. Institute of Electrical and Electronics Engineers, Three Park Avenue, 17th Floor, New York, NY 10016-5997.

IEEE 693, *Recommended Practices for Seismic Design of Substations*, 2005.

IEEE 1402, *IEEE Guide for Electric Power Substation Physical and Electrical Security*, 2000.

M.1.2.8 IESNA Publications. Illuminating Engineering Society of North America, 120 Wall Street, Floor 17, New York, NY 10005.

IESNA DG4, *Design Guide for Roadway Lighting Maintenance,* 2003.

NECA/IESNA 502, *Recommended Practice for Installing Industrial Lighting Systems*, 1999.

M.1.2.9 ISO Publications. International Organization for Standardization, 1, ch. De la Voie-Creuse, Case postale 56, CH-1211 Geneva 20, Switzerland.

ISO 1182, *Reaction to Fire Tests for Building Products — Non-Combustibility Test,* 2002 edition.

M.1.2.10 Massachusetts Highway Department Publications. Massachusetts Highway Department, 10 Park Plaza, Suite 3170, Boston, MA 02116.

"Memorial Tunnel Fire Ventilation Test Program Test Report," Bechtel/Parsons Brinckerhoff Quade and Douglas, Inc., November 1995.

M.1.2.11 NHTSA Publications. National Highway Traffic Safety Administration, 1200 New Jersey Ave., SE, Washington, DC 20590.

Federal Motor Vehicle Safety Standard (FMVSS) 304, Compressed Natural Gas Fuel Container Integrity.

M.1.2.12 NIOSH Publications. National Institute for Occupational Safety and Health, Centers for Disease Control, 1600 Clifton Road, Atlanta, GA 30333.

NIOSH 136, "Guide for Filtration and Air-Cleaning Systems to Protect Building Environments from Airborne Chemical, Biological, or Radiological Attacks," 2003.

M.1.2.13 PIARC Publications. AIPCR/PIARC, La Grande Arche, Paroi North, Level 5, 92055 LA DEFENSE Cedex, France.

Fire and Smoke Control in Road Tunnels, 1999.

Road Tunnels: An Assessment of Fixed Fire-Fighting Systems, 2004.

Systems and Equipment for Fire and Smoke Control in Road Tunnels, 2004.

M.1.2.14 SAE Publications. Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096.

SAE J2344, *Guidelines for Electric Vehicle Safety,* 2010 Edition.

M.1.2.15 UL Publications. Underwriters Laboratories Inc., 333 Pfingsten Road, Northbrook, IL 60062-2096.

ANSI/UL 1598, *Luminaires*, 2008.

M.1.2.16 USACE Publications. United States Army Corps of Engineers, USACE Publications Depot, ATTN: CEHEC-IM-PD, 2803 52nd Avenue, Hyattsville, MD 20781-1102.

USACE TI 809, *Seismic design for buildings*, 2004.

M.1.2.17 Other Publications.

British Standard (BS) 476-4, *Fire Tests on Building Materials and Structures Non-Combustibility Test for Materials*, 1970.

Ingason, H., "Design Fires in Tunnels," Conference Proceedings of Asiaflam 95, 77–86, Hong Kong, 15–16 March, 1995.

M.2 Informational References. The following documents or portions thereof are listed here as informational resources only. They are not a part of the requirements of this document.

NFPA 130, *Standard for Fixed Guideway Transit and Passenger Rail Systems*

British Toll Tunnels — Dangerous Traffic — List of Restrictions, 7th edition, Merseyside Passenger Transport Authority, Liverpool, United Kingdom, June 1993.

International Tunneling Association Guidelines for Structural Fire Resistance for Road Tunnels, May 2005.

Manual on Uniform Traffic Control Devices for Streets and Highways, MUTCD, U.S. Department of Transportation, 400 7th St. SW, Washington, DC 20590.

"Road Tunnels, Report of the Committee," 20th World Road Congress, Montreal, Canada, September 3–9, 1995. PIARC, La Grande Arche, Paroi north, level 5, 92055 LA DEFENSE, Cedex, France.

Subway Environmental Design Handbook, Vol. I, Principles and Applications, 2nd edition, Associated Engineers, A Joint Venture: Bechtel/Parsons Brinckerhoff Quade and Douglas, Inc.; Deleuw Cather and Company; Kaiser Engineers, under the direction of Transit Development Corporation, Inc., 1976.

M.2.1 Alternative Fuels Codes and Standards.

NFPA 2, *Hydrogen Technologies Code*

Various fuel cell vehicle standards (published and under development)

Additional information can be found at www.Fuelcellstandards.com

CSA America Inc's NGV2, *Basic Requirements for Compressed Natural Gas Vehicle (NGV) Fuel Containers*

ISO 11439, *Gas Cylinders — High Pressure Cylinders for the On-Board Storage of Natural Gas as a Fuel for Automotive Vehicles*

FMVSS 304, *Compressed natural gas fuel container integrity*

SAE J2579, *Technical Information Report for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles (published January 2008)*

List of codes and standards that apply to CNG vehicles: http://nexgenfueling.com/t_codes.html

NFPA 1975 (2009 Edition), *Standard on Station/Work Uniforms for Fire and Emergency Services*

ASTM F1506-08, *Standard Performance Specification for Flame Resistant Textile Materials for Wearing Apparel for Use by Electrical Workers Exposed to Momentary Electric Arc and Related Thermal Hazards*

California Fuel Cell Partnership – Emergency Response Guide – Fuel Cell Vehicle and Hydrogen Fueling Stations (Published August 2004)

Minnesota Recommendations for the Adoption of Uniform Hydrogen and Fuel Cell Codes and Standards: This document list websites containing information about the development of standards for hydrogen fuel: http://www.state.mn.us/mn/externalDocs/Commerce/Hydrogen_and_Fuel_Cell_Codes_and_Standards_010909111102_HydrogenAndFuelCellCodesStandards.pdf

Presentation on development of standards for hydrogen fuel from the Division of Measurement Standards in California includes lists of standards from various agencies: http://www.casap.org/2007/2007workshops/HydrogenFuelStandards.DMSWebSite.ppt

In 2008, the United National Economic Commission for Europe (UNECE) revised an Agreement Concerning the Establishing of Global Technical Regulations for Wheeled Vehicles, Equipment and Parts Which Can be Fitted and/or be Used on Wheeled Vehicles. The document lists several national regulations and industry standards that apply to hydrogen, CNG, and hybrid-electric vehicles: http://www.unece.org/trans/doc/2008/wp29grsp/SGS-4-01r1e.pdf

M.2.2 Alternative Fuels Research References.

Zalosh, Robert, Hydrogen Vehicle Post-Crash Fire Research Recommendations, February 2003, www.mvfri.org

Zalosh, Robert, *CNG and Hydrogen Vehicle Fuel Tank Failure Incidents, Testing, and Preventive Measures*, January 2008, www.mvfri.org

Stephenson, Rhoads, *Fire Investigation for Hybrid and Hydrogen-Fueled Vehicles,* International Symposium on Fire Investigation Science and Technology, June 2006.

Weyandt, Nathan, SwRI Final Report: *Analysis of Induced Catastrophic Failure of a 5000 psig Type IV Hydrogen Cylinder*, February 2005.

Weyandt, Nathan, SwRI Final Report: *Vehicle Bonfire to Induce Catastrophic Failure of a 5000 psig Hydrogen Cylinder Installed on a Typical SUV,* December 2006.

Weyandt, Nathan, SwRI Final Report: *Ignited Hydrogen Releases from a Simulated Automotive Fuel Line Leak*, December 2006.

M.3 References for Extracts in Informational Sections. (Reserved)

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Sequence of Events Leading to Issuance of an NFPA Committee Document

Step 1: Call for Proposals

- Proposed new Document or new edition of an existing Document is entered into one of two yearly revision cycles, and a Call for Proposals is published.

Step 2: Report on Proposals (ROP)

- Committee meets to act on Proposals, to develop its own Proposals, and to prepare its Report.
- Committee votes by written ballot on Proposals. If two-thirds approve, Report goes forward. Lacking two-thirds approval, Report returns to Committee.
- Report on Proposals (ROP) is published for public review and comment.

Step 3: Report on Comments (ROC)

- Committee meets to act on Public Comments to develop its own Comments, and to prepare its report.
- Committee votes by written ballot on Comments. If two-thirds approve, Report goes forward. Lacking two-thirds approval, Report returns to Committee.
- Report on Comments (ROC) is published for public review.

Step 4: Technical Report Session

- "*Notices of intent to make a motion*" are filed, are reviewed, and valid motions are certified for presentation at the Technical Report Session. ("Consent Documents" that have no certified motions bypass the Technical Report Session and proceed to the Standards Council for issuance.)
- NFPA membership meets each June at the Annual Meeting Technical Report Session and acts on Technical Committee Reports (ROP and ROC) for Documents with "certified amending motions."
- Committee(s) vote on any amendments to Report approved at NFPA Annual Membership Meeting.

Step 5: Standards Council Issuance

- Notification of intent to file an appeal to the Standards Council on Association action must be filed within 20 days of the NFPA Annual Membership Meeting.
- Standards Council decides, based on all evidence, whether or not to issue Document or to take other action, including hearing any appeals.

Committee Membership Classifications

The following classifications apply to Technical Committee members and represent their principal interest in the activity of the committee.

M *Manufacturer:* A representative of a maker or marketer of a product, assembly, or system, or portion thereof, that is affected by the standard.

U *User:* A representative of an entity that is subject to the provisions of the standard or that voluntarily uses the standard.

I/M *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.

L *Labor:* A labor representative or employee concerned with safety in the workplace.

R/T *Applied Research/Testing Laboratory:* A representative of an independent testing laboratory or independent applied research organization that promulgates and/or enforces standards.

E *Enforcing Authority:* A representative of an agency or an organization that promulgates and/or enforces standards.

I *Insurance:* A representative of an insurance company, broker, agent, bureau, or inspection agency.

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 the *User* classification.

SE *Special Expert:* A person not representing any of the previous classifications, but who has a special expertise in the scope of the standard or portion thereof.

NOTES;
1. "Standard" connotes code, standard, recommended practice, or guide.
2. A representative includes an employee.
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 members 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 appointments as it deems appropriate in the public interest, such as the classification of "Utilities" in the National Electrical Code Committee.
4. Representatives of subsidiaries of any group are generally considered to have the same classification as the parent organization.

NFPA Document Proposal Form

NOTE: All Proposals must be received by 5:00 pm EST/EDST on the published Proposal Closing Date.

For further information on the standards-making process, please contact the Codes and Standards Administration at 617-984-7249 or visit www.nfpa.org/codes.

For technical assistance, please call NFPA at 1-800-344-3555.

FOR OFFICE USE ONLY

Log #: ______

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Please indicate in which format you wish to receive your ROP/ROC ☐ **electronic** ☐ **paper** ☒ **download**
(Note: If choosing the download option, you must view the ROP/ROC from our website; no copy will be sent to you.)

Date April 1, 200X **Name** John J. Doe **Tel. No.** 716-555-1234

Company Air Canada Pilot's Association **Email**

Street Address 123 Summer Street Lane **City** Lewiston **State** NY **Zip** 14092

******If you wish to receive a hard copy, a street address MUST be provided. Deliveries cannot be made to PO boxes.***

Please indicate organization represented (if any) ______

1. (a) NFPA Document Title National Fuel Gas Code **NFPA No. & Year** 54, 200X Edition

(b) Section/Paragraph 3.3

2. Proposal Recommends (check one): ☐ new text ☒ revised text ☐ deleted text

3. Proposal (include proposed new or revised wording, or identification of wording to be deleted): [Note: Proposed text should be in legislative format; i.e., use underscore to denote wording to be inserted (<u>inserted wording</u>) and strike-through to denote wording to be deleted (~~deleted wording~~).]

Revise definition of effective ground-fault current path to read:

3.3.78 Effective Ground-Fault Current Path. An intentionally constructed, permanent, low impedance electrically conductive path designed and intended to carry ~~underground~~ <u>electric</u> fault <u>current</u> ~~conditions~~ from the point of a ground fault on a wiring system to the electrical supply source.

4. Statement of Problem and Substantiation for Proposal: (Note: State the problem that would be resolved by your recommendation; give the specific reason for your Proposal, including copies of tests, research papers, fire experience, etc. If more than 200 words, it may be abstracted for publication.)

Change uses proper electrical terms.

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6/09-B

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Please indicate in which format you wish to receive your ROP/ROC ☐ **electronic** ☐ **paper** ☐ **download**

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Company ______ **Email** ______

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