

# NFPA 502

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

### 2001 Edition



NFPA, 1 Batterymarch Park, PO Box 9101, Quincy, MA 02269-9101  
An International Codes and Standards Organization

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## NFPA 502

### Standard for

## Road Tunnels, Bridges, and Other Limited Access Highways

### 2001 Edition

This edition of NFPA 502, *Standard for Road Tunnels, Bridges, and Other Limited Access Highways*, was prepared by the Technical Committee on Motor Vehicle and Highway Fire Protection and acted on by NFPA at its May Association Technical Meeting held May 13–17, 2001, in Anaheim, CA. It was issued by the Standards Council on July 13, 2001, with an effective date of August 2, 2001, and supersedes all previous editions.

This edition of NFPA 502 was approved as an American National Standard on August 2, 2001.

### 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 It was withdrawn in November 1975.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 contains a significant editorial rewrite and reorganization of the document.

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

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**Committee Scope:** This Committee shall have primary responsibility for documents on motor vehicle fire prevention and protection measures to reduce loss of life and property damage in the operation and maintenance (repair) of such vehicles (except as specified herein); fire prevention and protection recommendations for motor freight terminals; protection for tunnels, air-right structures and bridges; and to recommend protection facilities on limited-access highways. Included as motor vehicles are trucks, buses, taxicabs, limousines, and passenger cars; excluded are the design, fire protection, and operational procedures for fire apparatus, manufactured homes and recreational vehicles, tank vehicles of all kinds for handling flammable and combustible liquids and liquefied petroleum gases, and vehicles transporting explosives and other hazardous chemicals. The construction and protection of garages is handled by the NFPA Committee on Garages.

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

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

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**NFPA 502****Standard for****Road Tunnels, Bridges, and Other Limited Access Highways****2001 Edition**

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

Changes other than editorial are indicated by a vertical rule in the margin of the pages on which they appear. These lines are included as an aid to the user in identifying changes from the previous edition. Where one or more complete paragraphs have been deleted, the deletion is indicated by a bullet between the paragraphs that remain.

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

**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 (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. Technical documentation shall be submitted to the authority having jurisdiction to demonstrate equivalency. The system, method, or device shall be approved for the intended purpose by the authority having jurisdiction.

**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.

**2.1.1 NFPA Publications.** National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101

NFPA 10, *Standard for Portable Fire Extinguishers*, 1998 edition.

NFPA 13, *Standard for the Installation of Sprinkler Systems*, 1999 edition.

NFPA 14, *Standard for the Installation of Standpipe, Private Hydrant, and Hose Systems*, 2000 edition.

NFPA 20, *Standard for the Installation of Stationary Pumps for Fire Protection*, 1999 edition.

NFPA 22, *Standard for Water Tanks for Private Fire Protection*, 1998 edition.

NFPA 70, *National Electrical Code*<sup>®</sup>, 1999 edition.

NFPA 70B, *Recommended Practice for Electrical Equipment Maintenance*, 1998 edition.

NFPA 72<sup>®</sup>, *National Fire Alarm Code*<sup>®</sup>, 1999 edition.

NFPA 101<sup>®</sup>, *Life Safety Code*<sup>®</sup>, 2000 edition.

NFPA 241, *Standard for Safeguarding Construction, Alteration, and Demolition Operations*, 2000 edition.

NFPA 820, *Standard for Fire Protection in Wastewater Treatment and Collection Facilities*, 1999 edition.

NFPA 1963, *Standard for Fire Hose Connections*, 1998 edition.

### 2.1.2 Other Publications.

**2.1.2.1 ASTM Publications.** American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM E 119, *Standard Test Methods for Fire Tests of Building Construction and Materials*, 1997.

ASTM E 136, *Standard Test Method for Behavior of Materials in a Vertical Tube Furnace at 750 Degrees C*, 1996.

**2.1.2.2 The Port Authority of New York and New Jersey Publication.** The Port Authority of New York and New Jersey, One World Trade Center, New York, NY 10048.

*Hazardous Material Transportation Regulations at Tunnel and Bridge Facilities*, November 23, 1987.

**2.1.2.3 U.S. Department of Transportation Publications.** U.S. Department of Transportation, 400 7th Street SW, Washington, DC 20590.

Title 49, *Code of Federal Regulations*, Part 177.825, "Routing and Training Requirements for Class 7 (Radioactive) Materials."

Title 49, *Code of Federal Regulations*, Part 397, Subpart C, "Routing of Non-Radioactive Hazardous Materials."

Title 49, *Code of Federal Regulations*, Subtitle B, Parts 100 to 199.

## 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 included, common usage of the terms shall apply.

### 3.2 NFPA Official Definitions.

**3.2.1\* Approved.** Acceptable to the authority having jurisdiction.

**3.2.2\* Authority Having Jurisdiction.** The organization, office, or individual responsible 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, 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.** 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 Central Supervising Station (CSS).** 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.

**3.3.8.1 Alternate Central Supervising Station.** A prearranged location that is equipped, or that can quickly be equipped, to function as the central supervising station in the event the central supervising station is inoperative, untenable, or inaccessible for any reason.

**3.3.9 Combustible.** Capable of undergoing combustion.

**3.3.10 Command Post.** A location for controlling and coordinating emergency operations, and designated as such by the person in command during an emergency.

**3.3.11 Communications.** Radio, telephone, and messenger services throughout the facility and particularly at the central supervising station and command post.

**3.3.12 Control Valve.** A valve used to control the water supply system of a standpipe system.

**3.3.13 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.

**3.3.14 Design Fire.** A fire's heat-release rate, in megawatts, designated in conjunction with the authority having jurisdiction as the design fire size.

**3.3.15 Dry Standpipe.** A standpipe system that is designed to contain water only while the system is being used.

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

**3.3.17 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.

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

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

**3.3.20 Fire Apparatus.** A vehicle used for fire suppression or support by a fire department, fire brigade, or other agency responsible for fire protection.

**3.3.21 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.

**3.3.22 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.

**3.3.23 Highway.** Any paved facility on which motor vehicles travel.

**3.3.23.1\* 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.

**3.3.23.2 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.

**3.3.23.3 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.

**3.3.24 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.

**3.3.25 Hose Valve.** The valve to an individual hose connection.

**3.3.26 Incident Commander.** The person responsible for all decisions relating to the management of the incident.

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

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

**3.3.29 MUTCD.** *Manual on Uniform Traffic Control Devices for Streets and Highways.*

**3.3.30 Noncombustible Material.** Not capable of supporting combustion.

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

**3.3.32 Person-in-Command.** A person designated by an agency or a responsible fire or police representative on the scene of an emergency who is fully responsible at the command post. (See also definition of Incident Commander.)

**3.3.33\* Point of Safety.** An enclosed fire exit 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.

**3.3.34 Portable Fire Extinguisher.** A portable device, carried by hand or on wheels and operated by hand, that contains an extinguishing agent that can be expelled under pressure for the purpose of suppressing or extinguishing a fire.

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

**3.3.36 Power Substation.** An arrangement of electric equipment that does not generate electricity but receives and converts or transforms generated energy to usable electric energy.

**3.3.37 Queue.** A line of stored vehicles.

**3.3.38 Replace-in-Kind.** Where applied to equipment and facilities, to furnish with new parts or equipment of the same type but not necessarily of identical design.

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

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

**3.3.41 Structure.** That which is built or constructed.

**3.3.41.1\* Air-Right Structure.** A structure that is built over a roadway using the roadway's air rights.

## 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, *Standard for Safeguarding Construction, Alteration, and Demolition Operations*, shall apply.

### 4.3 Fire Protection and Fire Life Safety Factors.

**4.3.1** As a minimum the following factors shall be evaluated in an engineering analysis and where applying the fire and life safety requirements for the facilities covered by this standard:

- (1) Protection of life
- (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
- (5) Fire emergencies occurring in remote locations at a long distance from emergency response facilities
- (6) Exposure of structure to elevated temperatures
- (7) Traffic congestion and control during emergencies
- (8) Built-in fire protection features, such as the following:
  - (a) Fire alarm systems
  - (b) Standpipe systems
  - (c) Sprinkler systems
  - (d) Ventilation systems
- (9) Protection of facility components
- (10) Evacuation and rescue requirements
- (11) Emergency response time
- (12) Separate emergency vehicle access points
- (13) Emergency communications to appropriate agencies
- (14) Protection of vehicles and property being transported

- (15) Facility location, such as the following:
- (a) Urban
  - (b) Rural

(16) Physical dimensions

#### 4.3.2 Limited Access Highways.

**4.3.2.1** Limited access highways can include other facilities covered by this standard.

**4.3.2.2** Fire protection for limited access highways shall comply with the requirements of Chapter 5.

#### 4.3.3 Bridges and Elevated Highways.

**4.3.3.1\*** 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.

**4.3.3.2** Fire protection for bridges and elevated highways shall comply with the requirements of Chapter 6.

#### 4.3.4\* Depressed Highways.

**4.3.4.1** The installation of standpipe systems or fire extinguishers, or both, shall be considered for use on depressed highways where physical factors prevent or impede access to the water supply or fire apparatus.

**4.3.4.2** Additional requirements for fire protection of depressed highways are described in Chapter 8.

**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.

**4.3.6.1** 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.

**4.3.6.2** 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.

**4.3.6.3** 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.

**4.3.6.4** Fire protection for roadways that are located beneath air-right structures shall comply with the requirements of Chapter 8.

### Chapter 5 Limited Access Highways

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

**5.2 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. Such devices shall 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.

**5.3 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.

#### 5.4\* Fire Apparatus.

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

**5.4.2** 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.

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

**5.5\* Ancillary Facilities.** All related ancillary facilities that support the operation of limited access highways shall be protected as required by all applicable NFPA standards and local building codes and shall not be subject to the provisions of this standard.

#### 5.6 Emergency Response Plan.

**5.6.1** 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.

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

**5.6.3** Emergency procedures and the development of an emergency response plan shall be completed in accordance with the requirements of Chapter 12.

### Chapter 6 Bridges and Elevated Highways

**6.1\* General.** This chapter shall provide fire protection requirements for bridges and elevated highways.

**6.2 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. Such devices shall 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.

**6.3 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.

#### 6.4 Traffic Control.

**6.4.1** A traffic control procedure shall be established so that vehicles either stop or proceed with caution.

**6.4.2** Traffic shall not be permitted to block or otherwise interfere with the response of emergency and fire equipment.

**6.5\* Standpipe and Water Supply.** Where the distance from an acceptable water supply source as defined in 9.2.3 to any point on the bridge exceeds 120 m (400 ft), the bridge shall be provided with a standpipe system in accordance with Chapter 9.

### 6.6 Drainage.

**6.6.1** 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.

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

**6.7\* Ancillary Facilities.** All related ancillary facilities that support the operation of bridges and elevated highways shall be protected as required by all applicable NFPA standards and local building codes and shall not be subject to the provisions of this standard.

**6.8 Control of Hazardous Materials.** Control of hazardous materials shall be in accordance with the requirements of Chapter 13.

### 6.9 Emergency Response Plan.

**6.9.1** 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.

**6.9.2** Emergency response procedures and the development of an emergency response plan shall comply with the requirements of Chapter 12.

## Chapter 7 Road Tunnels

**7.1\* General.** This chapter shall provide fire protection and life safety requirements for road tunnels.

**7.2 Road Tunnel Length.** For the purpose of this standard, tunnel length shall dictate the minimum fire protection requirements, as follows:

- (1) Where tunnel length is less than 90 m (300 ft), the provisions of this standard shall not apply.
- (2) 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 9 and Section 7.5, respectively.
- (3) Where tunnel length equals or exceeds 240 m (800 ft) and where the maximum distance from any point within the tunnel to an area of safety exceeds 120 m (400 ft), all provisions of this standard shall apply.
- (4) Where the tunnel length equals or exceeds 300 m (1000 ft) all provisions of this standard shall apply.

### 7.3 Fire Detection.

**7.3.1** At least two systems to detect, identify, or locate a fire in a tunnel, including one manual means, shall be provided.

#### 7.3.1.1 Manual Double-Action Fire Alarm Boxes.

**7.3.1.1.1** Manual double-action fire alarm boxes mounted in NEMA 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.

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

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

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

**7.3.1.1.5** The system shall be in compliance with *NFPA 72®*, *National Fire Alarm Code®*.

#### 7.3.1.2 Closed-Circuit Television System (CCTV).

**7.3.1.2.1** Closed-circuit television systems (CCTVs) with or without traffic-flow indication devices shall be permitted to identify fires in tunnels with 24-hour supervision.

**7.3.1.2.2\*** Ancillary spaces within tunnels (pump stations, utility rooms, cross passages, ventilation structures) and other areas shall be supervised by automatic fire alarm systems.

#### 7.3.1.3 Automatic Fire Detection Systems.

**7.3.1.3.1** Automatic fire detection systems installed in accordance with the requirements of *NFPA 72, National Fire Alarm Code* shall be installed in tunnels where 24-hour supervision is not provided.

**7.3.1.3.2** Where a fire detection system is installed in accordance with the requirements of 7.3.1.3.1, signals for the purpose of evacuation and relocation of occupants shall not be required.

**7.3.1.3.3** Where a fire detection system is installed in accordance with the requirements of 7.3.1.3.1, the system shall be for fire detection only.

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

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

**7.3.1.3.6** Automatic fire detection system within a tunnel shall be zoned to correspond with the tunnel ventilation zones where tunnel ventilation is provided.

**7.3.2 Fire Alarm Control Panel.** An approved fire alarm control panel (FACP) shall be provided in accordance with *NFPA 72, National Fire Alarm Code*.

### 7.4\* Communications Systems.

### 7.5 Traffic Control.

**7.5.1** Tunnels longer than 90 m (300 ft) shall be provided with a means to stop approaching traffic from entering the tunnel following activation of a fire alarm within the tunnel.

**7.5.2** 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 the fire site to expedite the flow of vehicles from the tunnel so that no traffic is queued downstream of the fire site.
- (4) Operation shall be returned to normal as determined by the incident commander.

**7.6 Fire Apparatus.** Annex I provides additional information on fire apparatus for road tunnels.

**7.7 Standpipe and Water Supply.** Standpipe and water supply systems in road tunnels shall comply with the requirements of Chapter 9.

**7.8\* Portable Fire Extinguishers.**

**7.8.1** 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).

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

**7.8.3** Portable fire extinguishers shall be in accordance with NFPA 10, *Standard for Portable Fire Extinguishers*.

**7.9\* Fire Sprinklers.** Where sprinklers are installed in road tunnels the system shall be installed in accordance with NFPA 13, *Standard for the Installation of Sprinkler Systems*.

**7.10 Ventilation During Fire Emergencies.** Tunnel ventilation systems employed during fire emergencies shall comply with the requirements of Chapter 10.

**7.11 Tunnel Drainage System.**

**7.11.1\*** 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.

**7.11.2** The drainage collection system shall be designed so that spills of hazardous or flammable liquids cannot propagate along the length of the tunnel.

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

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

**7.11.5** The collection system shall drain to a storage tank or transfer pumping station of sufficient capacity to receive, as a minimum, the simultaneous rate of flow from two fire hoses without causing flooding on the roadway.

**7.11.6 Hazardous Locations.**

**7.11.6.1** Storage tanks and pump stations shall be classified for hazardous locations in accordance with NFPA 70, *National Electrical Code*<sup>®</sup> and NFPA 820, *Standard for Fire Protection in Wastewater Treatment and Collection Facilities*.

**7.11.6.2** All motors, starters, level controllers, and system controls shall conform to the requirements of the hazard classification.

**7.11.7 Hydrocarbon Detection.**

**7.11.7.1** Storage tanks and pump stations shall be monitored for hydrocarbons.

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

**7.12\* Ancillary Facilities.** All related ancillary facilities that support the operation of road tunnels shall be protected as required by all applicable NFPA standards and local building codes and are not covered under this standard.

**7.13 Alternative Fuels.** Annex F provides additional information on alternative fuels.

**7.14 Control of Hazardous Materials.** Control of hazardous materials shall comply with the requirements of Chapter 13.

**7.15 Emergency Response Plan.**

**7.15.1** 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.

**7.15.2** Emergency response procedures and the development of an emergency response plan shall comply with the requirements of Chapter 12.

**7.16 Emergency Egress.**

**7.16.1 General.** Emergency 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 7.16.2 through 7.16.7.

**7.16.2 Identification.** Emergency exits and cross passageways shall be marked in accordance with Section 7.10 of NFPA 101<sup>®</sup>, *Life Safety Code*<sup>®</sup>.

**7.16.3 Walking Surfaces.**

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

**7.16.3.2** Changes in elevation, ramps, and stairs shall meet the requirements of Chapter 7 of NFPA 101, *Life Safety Code*.

**7.16.3.3\* Tenable Environment.** A tenable environment shall be provided in those portions of the tunnel that are not involved in an emergency and in all emergency exits and cross passageways.

**7.16.4 Doors.**

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

**7.16.4.2** Doors to cross passageways shall be permitted to open in either direction.

**7.16.4.3** Doors shall be listed fire doors with a minimum 1-hour rating and shall be installed in accordance with NFPA 80, *Standard for Fire Doors and Fire Windows*.

**7.16.4.4** Doors shall be equipped with hardware in accordance with NFPA 101, *Life Safety Code*.

**7.16.4.5** 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).

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

**7.16.5 Maintenance.** Emergency exits, cross passageways, and walkways shall be maintained to allow for their intended use.

**7.16.6 Emergency Exits.**

**7.16.6.1** Emergency exits shall be provided throughout the tunnel and spaced so that the travel distance to an emergency exit shall not be greater than 300 m (1000 ft).

**7.16.6.2\*** Emergency exits shall conform to NFPA 101, *Life Safety Code*, Chapter 7.

**7.16.6.3** The emergency exits shall be enclosed in a minimum 2-hour fire-rated enclosure having a Class A interior finish as defined in NFPA 101, *Life Safety Code*.

**7.16.7 Cross Passageways.** 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. The following requirements shall be met:

- (1) Cross passageways shall not be farther than 200 m (656 ft) apart.
- (2) Openings in cross passageways shall be protected with self-closing fire door assemblies having a minimum of a 1-hour rating and shall be installed in accordance with NFPA 80, *Standard for Fire Doors and Fire Windows*.
- (3) An emergency egress walkway with a minimum clear width of 1 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, or change in elevation or 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 7.2.2.4 of NFPA 101, *Life Safety Code*.
  - (d) Intermediate rails shall not be required for walkway guards.
- (4) Where portals of the tunnel are below surface grade, surface grade shall be made accessible by a stair, vehicle ramp, or pedestrian ramp.

## 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.

### 8.3 Traffic Control.

**8.3.1** Where the roadway beneath an air-right structure is considered a road tunnel, the traffic-control requirements of Section 7.5 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 provided separation between air-right structures and roadways shall have a minimum 4-hour fire resistance rating in accordance with ASTM E 119, *Standard Test Methods for Fire Tests of Building Construction and Materials*.

**8.4.2** Structural elements with a minimum 2-hour fire resistance rating shall be permitted where the anticipated design fire size (fire heat-release rate) is 20 MW or less and flammable liquids in bulk (hazardous) cargo are prohibited from the roadway.

**8.4.3** 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.

**8.4.4** Maintenance of the structure shall be considered in the design.

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

**8.4.6** 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.

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

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

## 8.5 Ventilation During Fire Emergencies.

**8.5.1** Chapter 10 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 7.11 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 13.

## 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 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 12.

## Chapter 9 Standpipe and Water Supply

### 9.1 Standpipe Systems.

**9.1.1** Standpipe systems for road tunnels, bridges, depressed highways, elevated highways, roadways beneath air-right structures, and limited access highways shall be designed and installed as Class I systems in accordance with NFPA 14, *Standard for the Installation of Standpipe, Private Hydrant, and Hose Systems*.

**9.1.2** The required flow rate for the standpipe system shall not be required to exceed 1920 L/min (500 gpm).

**9.1.3** 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.

**9.1.4 Areas Subject to Freezing.**

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

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

**9.1.5** Wet standpipe systems shall be provided with suitable interconnection and bypass valve arrangements to allow the isolation and repair of any segment without impairing the operation of the remainder of the system.

**9.1.6\*** 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.

**9.1.7** Dry standpipe systems shall have provisions for complete draining after use.

**9.1.8** Combination air relief/vacuum valves shall be installed at each high point on the system.

**9.1.9** Dry standpipes shall be installed in a manner that provides accessibility for inspection and repair.

**9.1.10** Standpipe systems shall be protected from damage by moving vehicles.

**9.2 Water Supply.**

**9.2.1** 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.

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

**9.2.3** 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 in accordance with NFPA 22, *Standard for Water Tanks for Private Fire Protection*

**9.3 Fire Department Connections.**

**9.3.1** Fire department connections shall be of the threaded two-way or three-way type or shall consist of one 100-mm (4-in.) quick-connect coupling that is accessible to a fire department pumper.

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

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

**9.3.4** Wherever possible, fire department connection locations shall be coordinated with emergency access and response locations.

**9.4 Hose Connections.**

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

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

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

**9.4.4** Hose connections shall have 65-mm (2½-in.) external threads in accordance with NFPA 1963, *Standard for Fire Hose Connections*, and the authority having jurisdiction.

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

**9.5 Fire Pumps.** Fire pumps shall be installed in accordance with NFPA 20, *Standard for the Installation of Stationary Pumps for Fire Protection*.

**9.6 Identification Signs.**

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

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

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

## Chapter 10 Tunnel Ventilation During Fire Emergencies

**10.1\* General.** 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.

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

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

**10.2\* Smoke Control.**

**10.2.1** The ventilation system shall provide a means for controlling smoke.

**10.2.2** 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.

**10.2.3** 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.

**10.2.4** 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 velocity that is greater than the critical velocity in the direction of traffic flow.
  - (b) Avoid disruption of the smoke layer initially not operating jet fans that are located near the fire site. First operate fans that are farthest away from the site.
- (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.

**10.3\* Memorial Tunnel Fire Ventilation Test Program.** Annex G provides additional information on the Memorial Tunnel Fire Ventilation Test Program.

**10.4 Design Objectives.** The design objectives of the emergency ventilation system shall be to control or 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 B*)
- (2) Longitudinal airflow rates are produced to prevent backlayering of smoke in a path of egress away from a fire (*see Annex C*)

#### 10.5 Criteria.

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

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

#### 10.6 Fans.

**10.6.1** 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).

**10.6.1.1** A higher temperature shall be used where the fire design calculations show that a greater airstream temperature will result.

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

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

**10.6.4** Tunnel ventilation fans that are to be used in a fire emergency shall be capable of achieving full rotational speed from a standstill within 60 seconds.

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

**10.6.6** Discharge/outlet openings for emergency fans shall be positioned away from any supply air intake openings to prevent recirculation.

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

#### 10.7 Dampers.

**10.7.1** 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.

**10.7.1.1** A higher temperature shall be used where the fire design calculations show that a greater airstream temperature will result.

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

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

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

**10.7.5** The requirements of 10.7.3 and 10.7.4 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.

**10.7.6** 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.

#### 10.8 Sound Attenuators.

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

**10.8.1.1** A higher temperature shall be used where the fire design calculations show that a greater airstream temperature will result.

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

**10.8.2** The sound-absorbing fill material used in the baffles shall be noncombustible, nontoxic, and stable at the temperatures specified in 10.8.1.

#### 10.9 Controls.

**10.9.1** 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.

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

## Chapter 11 Electrical Systems

### 11.1 General.

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

**11.1.2** The electrical systems shall maintain ventilation, illumination, communications, drainage, and water supply; shall identify areas of refuge, exits, and exit routes; and shall provide remote annunciation and alarm under all operating and emergency modes associated with the facility.

**11.2 Wiring.** All wiring materials and installations shall conform to NFPA 70, *National Electrical Code*, except as herein modified in this standard.

### 11.3 Materials.

**11.3.1** Materials that are manufactured for use as conduits, raceways, ducts, cabinets, and equipment enclosures and their surface finish materials, as installed, shall be capable of being subjected to temperatures up to 316°C (600°F) for 1 hour without supporting combustion and without loss of its structural integrity.

**11.3.2** Electrical systems that are installed within confined spaces shall not use materials that produce toxic by-products during electric circuit failure or when subjected to an external fire.

**11.3.3** PVC raceways, conduit, cable trays, wireways, vinyl-insulated/jacketed conductors or cables, and exposed PVC conduit and PVC-coated metal conduit, shall not be used in tunnels, ducts, plenums, and other enclosed spaces.

**11.3.4** All insulations shall conform to NFPA 70, *National Electrical Code*, and shall be of the moisture-resistant and heat-resistant types with temperature ratings that correspond to the conditions of application.

### 11.3.5 Conductors.

**11.3.5.1** All conductors shall be completely enclosed in armor sheaths, conduits, or enclosed raceways, boxes, and cabinets.

**11.3.5.2** Conductors in a raceway shall be permitted to be embedded in concrete or run in protected electrical duct banks.

**11.3.5.3** Conductors shall not be installed in an exposed manner.

**11.3.5.4** Conductors shall not be surface mounted in air plenums that can carry air at elevated temperatures that accompany fire conditions.

**11.4\* Power Source.** The power source for all systems shall be of a capacity and configuration commensurate with the purpose of the system. The following systems shall be provided with reliable power for a fire emergency:

- (1) Lighting
- (2) Lighting for means of egress and areas of refuge
- (3) Exit signs
- (4) Communications
- (5) Tunnel drainage and fire pump(s)
- (6) Ventilation during a fire emergency

**11.4.1** The primary and secondary sources shall be wired to system equipment so that a single event or fire produces a minimum effect on the operation of the overall system.

### 11.5 Reliability.

**11.5.1** The primary source of electric service shall be the local electric utility.

**11.5.2** A separate service shall be permitted to be the secondary source, provided it can be demonstrated that a single event within the utility system cannot affect both the primary and secondary source.

**11.5.3** Where an on-site generator is used as a secondary source of power, providing power to the systems in Section 11.4, it shall be designed, installed, maintained, and tested in accordance with NFPA 110, *Standard for Emergency and Standby Power Systems*.

### 11.6 Emergency Lighting.

**11.6.1** Emergency lighting systems shall be installed and maintained in accordance with NFPA 70, *National Electrical Code*; NFPA 110, *Standard for Emergency and Standby Power*; and NFPA 70B, *Recommended Practice for Electrical Equipment Maintenance*.

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

**11.6.3** Emergency fixtures, exit lights, and signs shall be wired separately from emergency distribution panels.

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

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

**11.6.6** The illumination levels of tunnel roadways, walkways, and walking surfaces shall not be less than 3 lx (0.28 foot-candles) at the walking surface.

**11.6.7** 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.

## Chapter 12 Emergency Response

**12.1 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. Participating agencies shall be invited to assist with the preparation of the emergency response plan.

**12.2 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/evacuation of motorists under adverse conditions
- (6) Disabled vehicles
- (7) Flooding of a travel way or an evacuation route
- (8) Seepage and spillage of petroleum products; flammable, toxic, or irritating vapors; and hazardous materials
- (9) Multiple casualty incidents
- (10) Damage to structures from impact and heat exposure
- (11) Serious vandalism or other criminal acts, such as a bomb threat
- (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

**12.3\* Emergency Response Plan.** The emergency response plan shall include, as a minimum, the following:

- (1) Name of plan
- (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 central supervising station and alternate central supervising station
- (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 and data that the participating agencies want to include in the plan

**12.4\* 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

**12.5 Central Supervising Station (CSS).** Paragraphs 12.5.1 through 12.5.8 shall apply where the facility has a central supervising station for the operation and supervision of the facility.

**12.5.1** The CSS 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.

**12.5.2** The CSS shall provide the capability to communicate rapidly with participating agencies.

**12.5.3** 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.

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

**12.5.5** CSS personnel shall be thoroughly familiar with the emergency procedure plan and shall be trained to implement it effectively.

**12.5.6** An alternate site(s) that can function efficiently during an emergency in the event that the CSS is out of service shall be selected and equipped, or equipment shall be readily available.

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

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

## **12.6 Liaison.**

**12.6.1** 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.

**12.6.2** 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.

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

## **12.7 Command Post.**

**12.7.1** When it is necessary to invoke the emergency procedure plan, a command post shall be established by the person in command for the supervision and coordination of all personnel, equipment, and resources at the scene of the emergency.

**12.7.2** 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.

**12.7.3** The command post shall be located at a site that is convenient for responding personnel, easily identifiable, and suitable for supervising, coordinating, and communicating with participating agencies.

**12.7.4** Each participating agency shall assign a liaison to the command post.

**12.7.5\*** The command post shall be readily identified and visible at all times.

## **12.8 Auxiliary Command Post.**

**12.8.1** Where necessary, the incident commander shall establish an auxiliary command post.

**12.8.2** Where necessary, a participating agency that is not in command shall establish an auxiliary command post to assist with the supervision and coordination of its personnel and equipment.

## **12.9 Training, Exercises, Drills, and Critiques.**

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

**12.9.2** Personnel shall be thoroughly trained and familiar with all aspects of the emergency procedure plan.

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

#### 12.9.4 Limited Access Highways.

**12.9.4.1** 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.

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

**12.9.4.3** 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.

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

**12.9.6** Critiques shall be held after the exercises, drills, and actual emergencies.

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

## Chapter 13 Control of Hazardous Materials

### 13.1 General.

**13.1.1** The facility operating agency shall adopt rules and regulations that apply to the transportation of hazardous materials.

**13.1.2** A program shall be maintained for enforcing such regulations.

**13.1.3** In developing such regulations, the following shall be addressed:

- (1) Availability of a suitable alternative route(s) that meets federal requirements as prescribed in Department of Transportation, Title 49, *Code of Federal Regulations*, Part 177.825, "Routing and Training Requirements for Class 7 (Radioactive) Materials," and Department of Transportation, Title 49, *Code of Federal Regulations*, Part 397, Subpart C, "Routing of Non-Radioactive Hazardous Materials"
- (2) Department of Transportation, Title 49, *Code of Federal Regulations*, Subtitle B, Parts 100 to 199
- (3) Fire and accident experience of facilities similar to the facility for which rules and regulations are being adopted
- (4) Previous fire and accident experience on the facility in question and adjacent roads; or, in the case of a new facility, previous fire and accident experience on roads in the area
- (5) Anticipated traffic volumes in peak and off-peak periods
- (6) Need for inspection of vehicles and cargo and the availability of an approved place to conduct inspections with a minimum of traffic interference
- (7) Need and desirability of escort service with due consideration of the extent to which it could disrupt the orderly flow of traffic and create additional hazards
- (8) Plan developed by an operating agency in a dense urban area, as referenced in *Hazardous Material Transportation Regulations at Tunnel and Bridge Facilities*. The suitability of such a plan for a given facility shall also be considered.

## 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 English unit value by the conversion factor and rounding the result to the appropriate number of significant digits (see *Table A.1.6.1*). See ANSI SI 10, *Standard for Use of the International System of Units (SI): the Modern Metric System*.

**Table A.1.6.1 Conversion Factors**

1 inch	in.	=	25.40 millimeters	mm
1 foot	ft	=	0.3048 meter	m
1 square foot	ft <sup>2</sup>	=	0.09290304 square meter	m <sup>2</sup>
1 foot per minute	fpm	=	0.00508 meter per second	m/sec
1 foot per second squared	ft/sec <sup>2</sup>	=	0.3048 meter per second squared	m/sec <sup>2</sup>
1 cubic foot per minute	ft <sup>3</sup> /min	=	0.000472 cubic meter per second	m <sup>3</sup> /sec
1 gallon per minute	gpm	=	0.063090200 liter per second	L/sec
1 pound	lb	=	0.45359237 kilogram	kg
1 pound per cubic foot	lb/ft <sup>3</sup>	=	16.01846 kilograms per cubic meter	kg/m <sup>3</sup>
1 inch water gauge	in. wg	=	0.249089 kilopascal	kPa
1 pound per square inch	psi	=	6.894757 kilopascal	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	=	1.055056 megawatts	MW
1 Btu per pound degree Rankine	Btu/lb°r	=	4.1868 joules per kilogram Kelvin	J/kgK
1 footcandle	fc	=	10.76391 lux	lx

**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

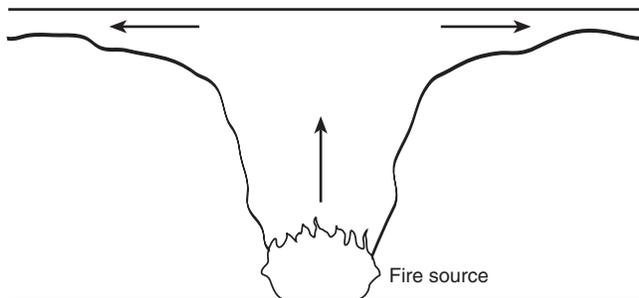
organization that is concerned with product evaluations and is thus in a position to determine compliance with appropriate standards for the current production of listed items.

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

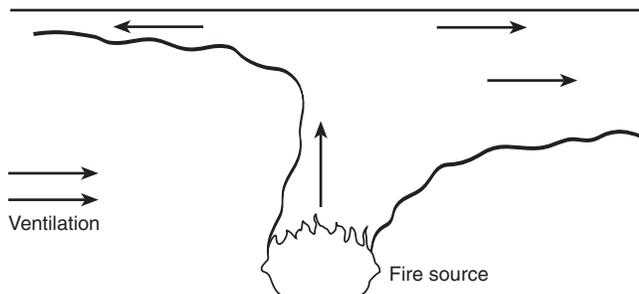
**A.3.2.4 Listed.** The means for identifying listed equipment may vary for each organization concerned with product evaluation; some organizations do not recognize equipment as listed unless it is also labeled. The authority having jurisdiction should utilize the system employed by the listing organization to identify a listed product.

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

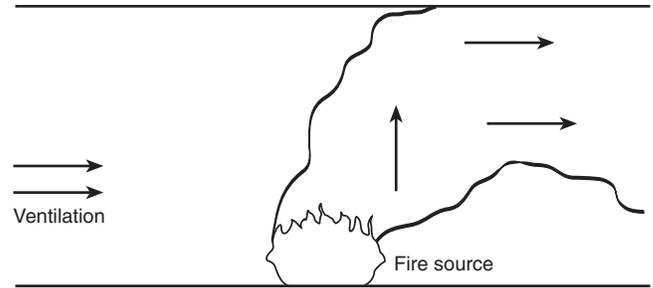
**A.3.3.7 Building.** The term should be interpreted as if followed by the words “or portions thereof.”



**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.3.3.18 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.3.3.23.1 Depressed Highway.** See Figure A.3.3.23.1.



**FIGURE A.3.3.23.1 Depressed highway.**

**A.3.3.33 Point of Safety.** The egress population to be served should be determined by engineering analysis.

**A.3.3.41.1 Air-Right Structure.** See Figure A.3.3.41.1.

**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.



**FIGURE A.3.3.41.1** Air-right structure.

**A.4.3.3.1** Elements of bridges and elevated highways frequently pass directly over residential, commercial, or industrial areas. Fire on a bridge or elevated highway could result in serious exposure to occupancies beneath and in close proximity to such a facility (structure).

Fires within occupancies beneath and in close proximity to bridges and elevated highways can also have a serious impact on the structural integrity of such a facility.

**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.

**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.5.4** Recommendations regarding suitable fire apparatus for limited access highways can be found in Annex I.

**A.5.5** Protection of related ancillary facilities such as service areas, rest areas, toll booths/plazas, pump stations/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, Flammable and Combustible Liquids Code, and NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages.*)

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

**A.6.5** In certain instances, it is recommended that duplicate systems be installed on each side of the roadway and be cross-connected.

**A.6.7** See A.5.5.

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

**A.7.3.1.2.2** Examples of these areas include the following:

- (1) Pump stations
- (2) Utility rooms
- (3) Cross passages
- (4) Ventilation structures

**A.7.4** 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.7.8** Consideration should be given to incorporating into the alarm system a means for detecting the removal of an extinguisher.

**A.7.9** For additional information on sprinklers in road tunnels, see Annex D.

**A.7.11.1** 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** See A.5.5.

**A.7.16.3.3** Some factors that should be considered in maintaining a tenable environment for periods of short duration can be defined as follows:

- (1) Air temperatures as follows: maximum of 60°C (140°F) for a few seconds, averaging 49°C (120°F) or less for the first 6 minutes of the exposure and decreasing thereafter.
- (2) Air carbon monoxide (CO) content as follows: maximum of 2000 ppm for a few seconds, averaging 1500 ppm or less for the first 6 minutes of the exposure, averaging 800 ppm or less for the first 15 minutes of the exposure, averaging 50 ppm or less for the remainder of the exposure. These values should be adjusted for altitudes above 984 m (3000 ft).
- (3) CO generated during smoke conditions that does not exceed 800 ppm based on a 30-minute evacuation period. CO concentrations should decrease as the evacuation period increases.
- (4) Smoke obscuration levels that are continuously maintained below the point at which a sign illuminated at 80 lx (7.5 ft-candles) or equivalent brightness for internally illuminated signs, is discernible at 30 m (100 ft), and doors and walls that are discernible at 10 m (33 ft).
- (5) Radiation heat flux as follows: maximum of 6305 W/m<sup>2</sup> (2000 Btu/ft<sup>2</sup>/hr) for a few seconds, averaging 1576 W/m<sup>2</sup> (500 Btu/ft<sup>2</sup>/hr) or less for the first 6 minutes of the exposure, averaging 946 W/m<sup>2</sup> (300 Btu/ft<sup>2</sup>/hr) for the remainder of the exposure.
- (6) Air velocities in the enclosed tunnel should be greater than or equal to 0.82 m/s (150 ft/min) and less than or equal to 12 m/s (2200 ft/min).
- (7) Noise levels as follows: maximum of 115 dba for a few seconds, maximum of 92 dba for the remainder of the exposure.

**A.7.16.6.2 Emergency Exits.** Only the exit design and construction requirements from NFPA 101<sup>®</sup>, *Life Safety Code*<sup>®</sup>, should be applied to tunnels. It is not the intent of these requirements to have the travel distances required within NFPA 101, *Life Safety Code*, to be applied to tunnels.

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

**A.9.1.6** 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.”

**A.10.1** 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.10.1.1** For guidance on developing an appropriate engineering analysis the user should reference the performance base alternatives in NFPA 101, *Life Safety Code*.

**A.10.2** A description of the various ventilation configurations for normal operations is contained in Annex H.

Smoke control can be achieved by either 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.10.3** 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 available

from the MTFVTP has been employed in the development of this standard. A description of the MTFVTP and its results are contained in Annex G.

**A.10.5.1** Representative fire heat-release rates that correspond to the various vehicle types are provided for guidance in Table A.10.5.1.

**A.10.5.2** The design fire size selected has an effect on the magnitude of the critical air velocity necessary to prevent back-layering. A method for calculating the critical velocity is described in Annex C.

**A.10.6.3** Since 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.11.1.1** The power distribution system should be maintained through an approved annual maintenance program. The electrical distribution maintenance program should be consistent with NFPA 70B, *Recommended Practice for Electrical Equipment Maintenance*.

**A.11.4** It is expected that the operations of all systems within the vicinity of a fire can fail. Section 11.4 is intended to limit the area of such failure.

**A.11.6.5** Lighting can be maintained without interruption by duplicate independent power systems, uninterruptible power supplies, and standby generators.

**A.12.3** See the sample emergency response plan outline provided in Annex E.

**A.12.4** The participating agencies and organizations can vary depending on the governmental structure and laws of the community.

**A.12.5.7** The area should be used for the CSS and similar activities and should not be jeopardized by adjoining or adjacent occupancies.

**A.12.7.5** Effective use should be made of radio, telephone, and messenger service to communicate with participating agencies.

**A.12.9.3** Such programs should involve a competent supervisory staff that is experienced in fire fighting, life safety techniques, and hazardous materials emergencies.

**Table A.10.5.1 Fire Data for Typical Vehicles<sup>a</sup>**

Cause of Fire	Equivalent Size of Gasoline Pool		Fire Heat-Release Rate	Smoke-Generation Rate		Maximum Temperature <sup>b</sup>	
	ft <sup>2</sup>	m <sup>2</sup>	MW	ft <sup>3</sup> /min	m <sup>3</sup> /sec	°F	°C
Passenger car	22	2	≈5	42	20	750	400
Bus/truck	86	8	≈20	127	60	1290	700
Gasoline tanker	323–1076	30–100	≈100	212–424	100–200	1830	1000

<sup>a</sup>Source: PIARC Montreal Report, 1995.

<sup>b</sup>Temperature 10 m (30 ft) downwind of the fire with the minimum air velocity necessary to prevent backlayering.

## Annex B Temperature and Velocity Criteria

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

### B.1 General.

**B.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.

**B.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.

### B.2 Air Temperature Criteria.

**B.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.

**B.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.

### B.3 Air Velocity Criteria.

**B.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.

**B.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 ft/min).

**B.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 a direction opposite to that of the forced ventilation air).

**B.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.

**B.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 C Critical Velocity Calculations

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

**C.1 General.** The simultaneous solution of equations C.1 and C.2, 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.

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

$$T_f = \left( \frac{Q}{\rho C_p A V_c} \right) + T \quad (\text{C.2})$$

where:

$A$  = Area perpendicular to the flow [ $\text{m}^2$  ( $\text{ft}^2$ )]

$C_p$  = Specific heat of air [ $\text{kJ}/\text{kg K}$  ( $\text{Btu}/\text{lb}^\circ\text{r}$ )]

$g$  = Acceleration caused by gravity  
[ $\text{m}/\text{sec}^2$  ( $\text{ft}/\text{sec}^2$ )]

$H$  = Height of duct or tunnel at the fire site [ $\text{m}$  ( $\text{ft}$ )]

$K_1 = 0.606$

$K_g$  = Grade factor (see Figure C.1)

$\dot{Q}$  = Heat fire is adding directly to air at the fire site  
[ $\text{MW}$  ( $\text{Btu}/\text{sec}$ )]

$T$  = Temperature of the approach air [ $\text{K}$  ( $^\circ\text{r}$ )]

$T_f$  = Average temperature of the fire site gases  
[ $\text{K}$  ( $^\circ\text{r}$ )]

$V_c$  = Critical velocity [ $\text{m}/\text{sec}$  ( $\text{ft}/\text{min}$ )]

$\rho$  = Average density of the approach (upstream) air  
[ $\text{kg}/\text{m}^3$  ( $\text{lb}/\text{ft}^3$ )]

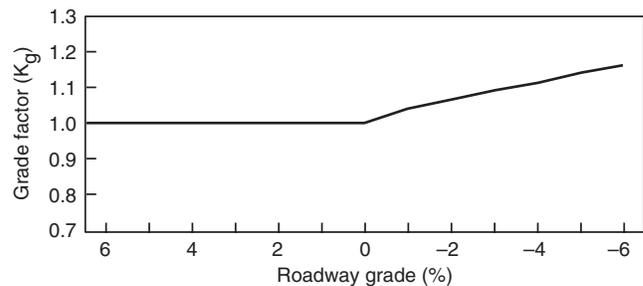


FIGURE C.1 Grade factor for determining critical velocity.

## Annex D Sprinklers in Road Tunnels

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

**D.1 General.** This annex provides considerations for the potential incorporation of sprinklers in road tunnels.

### D.2 Definitions.

**D.2.1 Sprinkler System.** For fire protection purposes, an integrated system of underground and overhead piping designed in accordance with fire protection engineering standards. The installation includes one or more automatic water supplies. The portion of the sprinkler system aboveground is a network

of specially sized or hydraulically designed piping installed in a building, structure, or area, generally overhead, and to which sprinklers are attached in a systematic pattern. The valve controlling each system riser is located in the system riser or its supply piping. Each sprinkler system riser includes a device for actuating an alarm when the system is in operation. The system is usually activated by heat from a fire and discharges water over the fire area.

**D.2.2 Deluge System.** A sprinkler system employing open sprinklers attached to a piping system connected to a water supply through a valve. When this valve opens, water flows into the piping system and discharges from all sprinklers attached thereto.

**D.3 Background.** The World Road Association (PIARC) addressed the subject of sprinklers in road tunnels in the reports presented at the World Road Congresses held in Sydney (1983), Brussels (1987), and Montreal (1995).

No European country currently uses sprinklers on a regular basis. In some tunnels in Europe, sprinklers have been used for special purposes. In Japan, sprinklers are used in long or heavily trafficked tunnels. In the United States, only a few tunnels carrying hazardous cargo have some form of sprinkler system.

Sprinklers are not installed in road tunnels in Belgium, Denmark, France, Italy, Netherlands, and the United Kingdom. In Japan, sprinkler 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. In Norway two tunnels are equipped with dry water-based sprinkler systems. In both the 800 m (2625 ft) Vålreng tunnel and the 3200 metres (10,500 ft) Fløyfjell tunnel, the sprinkler systems were designed to protect the lining material (polyurethane and ethaphome). In Sweden, sprinkler systems are only used in the Tegelbacken tunnel.

There are three United States road tunnels which have been equipped with sprinkler systems: the Central Artery North Area (CANA) Route 1 tunnels in Boston, MA and the I-90 First Hill Mercer Island and Mt. Baker Ridge tunnels in Seattle, WA. The decision to provide sprinklers in these tunnels was motivated solely by the fact that these tunnels will be operated to allow the unescorted passage of vehicles carrying hazardous materials as cargo.

The reason why most countries do not use sprinklers in tunnels is that most fires start in the motor room or in the compartment, and sprinklers are of no use until the fire is open. Sprinklers 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 lining materials. Experiences from Japan show that sprinklers are effective in cooling down the area around the fire, so that fire fighting can be more effective.

**D.3.1** Currently, the use and effectiveness of sprinklers in road tunnels are not universally accepted. Although it is acknowledged that sprinklers are highly regarded by fire protection professionals and fire departments in certain types of structures, there is much evidence to suggest that sprinklers are not only ineffective in controlling a fuel fire but can actually contribute to the spread of severity of the fire. Furthermore, it is felt that road tunnel conditions cannot exploit sprinkler system strengths and could turn most of their advantages into disadvantages.

**D.3.2** The major concerns expressed by tunnel designers and engineers worldwide (authorities) regarding fire sprinkler use and effectiveness include the following:

- (1) Typically fires in road tunnels usually occur inside vehicles or inside passenger or engine compartments designed to be waterproof from above; therefore, sprinklers would not have an extinguishing effect.
- (2) If any delay occurs between ignition and sprinkler activation, a thin water spray on a very hot fire will produce large quantities of superheated steam without material suppressing the fire. This steam has the potential to be more damaging than smoke.
- (3) Tunnels are very long and narrow, often sloped laterally and longitudinally, vigorously ventilated, and never subdivided, so heat normally will not be localized over a fire.
- (4) Because of stratification of the hot gas plume along the tunnel ceiling, a number of the activated sprinklers would not, in all probability, be located over the fire. A large number of the activated sprinklers would be located away from the fire scene, producing a cooling effect that would tend to draw this stratified layer of smoke down toward the roadway level, thus impeding the rescue and fire-fighting effort.
- (5) Water spraying from the ceiling of a subaqueous tunnel could suggest tunnel failure and induce panic in motorists.
- (6) The use of sprinklers could cause the delamination of the smoke layer and induce turbulence and mixing of the air and smoke, thus further threatening the safety of persons in the tunnel.
- (7) Testing of a fire sprinkler system on a periodic basis to determine its state of readiness is impractical and costly.

**D.3.3** Because of the concerns detailed in D.3.2, the use of sprinklers in road tunnels generally is not recommended. However, three recently commissioned U.S. road tunnels have been equipped with sprinkler systems: the Central Artery North Area (CANA) Route 1 tunnels in Boston, MA, and the I-90 First Hill Mercer Island and Mt. Baker Ridge tunnels in Seattle, WA. The decision to provide sprinklers in these tunnels will allow the unescorted passage of vehicles carrying hazardous materials as cargo.

#### **D.4 Recommendations.**

**D.4.1 Application.** The installation of sprinkler systems should be considered applicable only where the passage of hazardous cargo is considered. However, even in these cases, 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.

**D.4.2 Extinguishing Agent.** AFFF (aqueous-film-forming-foam) systems should be considered for in-tunnel sprinkler systems in lieu of water-only systems. Water-only sprinkler systems pose significant concerns where applied to roadway tunnels. The high water demand rate needs to be available from the local supply, and in-tunnel drainage piping, storage, and pumping systems all become much larger. Additionally, after deluge, the possibility of vapor explosion is dangerously increased. The strong cooling effect of a water-only system reduces the ability of the smoke to stratify at the ceiling, where it can be contained more easily by the tunnel ventilation system, and instead causes the smoke to spread over the cross section of the incident area.

**D.4.3 Sprinkler System.** To help ensure against accidental discharge, the sprinkler system should be designed as a manually activated deluge system. 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/foam mixture percentage. Sprinkler heads should provide an open deluge and be spaced so that coverage extends to roadway shoulders and, if applicable, maintenance/patrol walkways. The system should be designed with enough water and foam capacity to allow operation of at least two zones adjacent to the incident zone if the fire occurs in a "border" area. Zone length should be based on activation time as determined by the authorities having jurisdiction. Piping should be designed to allow drainage through heads after flow is stopped.

**D.4.4 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 sprinkler system protection. Therefore, consideration should be given to human interaction in the sprinkler system control and activation design to ensure against false alarm and accidental discharge. Any automatic mode of operation should include a discharge delay to allow incident verification and assessment of in-tunnel conditions by trained operators.

**D.4.4.1** An integrated graphic display of the sprinkler system zones, fire detection system zones, tunnel ventilation system limits, and emergency access and egress locations should be provided at the control room to allow tunnel operators and responding emergency personnel to make initial response decisions.

## Annex E Emergency Response Plan Outline

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

**E.1 Outline.** The following is an outline for a typical emergency response plan.

1. General
  - 1.1. Purpose
  - 1.2. Background
2. Emergency response plan
  - 2.1. General
  - 2.2. Elements of the plan
    - 2.2.1. Central supervising station (CSS)
    - 2.2.2. Alternate CSS
    - 2.2.3. Incident/activity identification systems
    - 2.2.4. Emergency command posts
  - 2.3. Operational considerations
  - 2.4. Types of incidents
  - 2.5. Possible locations of incidents
  - 2.6. Incidents on approach roadways
  - 2.7. Incidents within tunnel or facility
3. Coordination with other responsible agencies
  - 3.1. Fire-fighting operational procedures
  - 3.2. Traffic management
  - 3.3. Medical evacuation plan
  - 3.4. Emergency alert notification plan

## Annex F Alternative Fuels

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

**F.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 10 for requirements for road tunnel ventilation during fire emergencies.

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. The American Gas Association estimates that by the year 2000, approximately 50 percent of the 16 million fleet vehicles in the United States will be powered by alternative fuels such as CNG. 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, and methanol.

**F.2 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 is that the fueling system for CNG 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.

**F.3 Liquefied Petroleum 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. On one hand, it is costly to store because a pressure vessel is needed. On the other hand, 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.

**F.4 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 methyltertiary-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.

**F.5 Mitigation Measures.** As the use of alternative fuels in road vehicles has gradually increased, each road tunnel operating agency has dealt with the issue of whether to permit such vehicles to pass through the tunnels 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 can be necessary to establish a minimum level of ventilation to provide such dilution under all circumstances. 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.

## Annex G 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.*

**G.1 General.** The primary purpose for 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.

**G.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 within 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 was limited scientific data to support opinions or code requirements regarding the capabilities of various types of ventilation systems to control heat and smoke effectively.

**G.3 Investigations.** Engineering investigations of ventilation operating strategies and performance in full-scale fire situations were authorized by the Massachusetts Highway Department and the U.S. Federal Highway Administration to be performed in the Memorial Tunnel as a part of the Boston Central Artery/Tunnel Project. The American Society of Heating, Refrigerating, and Air Conditioning Engineers 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 for 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 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 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.

**G.4 The Test Facility.** The Memorial Tunnel is a two-lane, 854-m (2800-ft) highway tunnel located near Charleston, WV,

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<sup>3</sup>/sec (200,000 ft<sup>3</sup>/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, CCTV camera cabinets, and all other related items that are exposed to high tunnel fire temperatures.

**G.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 Section G.5(1) through (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.

**G.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, CO<sub>2</sub>, 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 carbon monoxide, 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 closed-circuit television (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.

**G.7 Conclusions.** The Memorial Tunnel Fire Ventilation Test Program 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.