Errata

Modernisation de la rue Notre-Dame à Montréal
par le ministère des Transports
Montréal AUD6211 06 057

NFPA 502

Limited Access Highways, Tunnels, Bridges, Elevated Roadways, and Air Right Structures

1996 Edition

Reference: Appendix C, Equations C-1 and C-2
Errata No.: 502-96-1

The Committee on Motor Vehicle and Highway Fire Protection notes the following correction for the 1996 edition of NFPA 502, *Recommended Practice on Fire Protection for Limited Access Highways, Tunnels, Bridges, Elevated Roadways, and Air Right Structures.*

1. In Appendix C, equations C-1 and C-2 to determine critical velocity should read:

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

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

where

A = Area perpendicular to flow	[ft 2 (m 2)].
C_p = The specific heat of air	[Btu/lb R (kJ/kg K)].
g = The acceleration caused by gravity	[ft/sec-sec (m/s-s)].
H = The height of the duct or tunnel at the fire	[ft (m)].
K_1 = 0.606.	
K_g = Grade factor (see chart below).	
Q = The heat the fire is adding directly to the air at the fire site	[Btu/sec (MW)].
T = The temperature of the approach air	[R (K)].
T_f = The average temperature of the fire site gases	[R (K)].
V_c = Critical velocity	[ft/sec (m/s)].
ρ = The average density of the approach (upstream) air	[lb/ft 3 (kg/m 3)].

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NFPA 502

Recommended Practice on Fire Protection for

Limited Access Highways, Tunnels, Bridges, Elevated Roadways, and Air Right Structures

1996 Edition

This edition of NFPA 502, *Recommended Practice on Fire Protection for Limited Access Highways, Tunnels, Bridges, Elevated Roadways, and Air Right Structures*, was prepared by the Technical Committee on Motor Vehicle and Highway Fire Protection and acted on by the National Fire Protection Association, Inc., at its Annual Meeting held May 20–23, 1996, in Boston, MA. It was issued by the Standards Council on July 18, 1996, with an effective date of August 9, 1996, and supersedes all previous editions.

This edition of NFPA 502 was approved as an American National Standard on July 26, 1996.

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 Annual Meeting.

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

The recommended practice was reconfirmed in 1992.

The recommended practice was revised in 1996 to incorporate a totally revised chapter on tunnels and make other revisions and changes to correlate the new material in tunnel and air right structure requirements with existing chapters in the document.

The reworking of the document as related to tunnels and air right structures was to bring it up to current technology and practices.

The development of this 1996 edition was accomplished by an NFPA 502 Task Group appointed by the Chairman of the Technical Committee in October 1993. This task group effort was conducted by the following individuals:

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This list represents the membership at the time the Committee was balloted on the text of this edition. Since that time, changes in the membership may have occurred.

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

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, mobile homes and travel trailers, 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.

Contents

NFPA 502

Recommended Practice on Fire Protection for

Limited Access Highways, Tunnels, Bridges, Elevated Roadways, and Air Right Structures

1996 Edition

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

Information on referenced publications can be found in Chapter 11 and Appendix H.

Chapter 1 General

1-1 Scope. This recommended practice is intended primarily for the guidance of those individuals responsible for the design, construction, operation, maintenance, and fire protection of limited access highways, tunnels, bridges, elevated roadways, depressed roadways, and air right structures. It also applies, to a lesser extent, to buildings and structures that are exposed to the hazards of the operational zones.

1-1.1 This recommended practice does not apply to requirements for the following:

(a) Parking garages;

(b) Bus terminals;

(c) Truck terminals;

(d) Any other facility in which motor vehicles travel or are parked.

1-1.2 To the extent where a facility, including those listed in 1-1.1(a) through (d), introduces hazards of a similar nature to those addressed in this document, this recommended practice can be used as a guide.

1-2 Purpose. The purpose of this document is to establish minimum criteria that provide a reasonable degree of protection from fire and its related hazards.

1-3 Equivalency. Nothing in this recommended practice is intended to prevent the use of systems, methods, or devices that are of equivalent or superior quality, strength, fire resistance, effectiveness, durability, and safety to those prescribed by this recommended practice, provided technical documentation is submitted to the authority having jurisdiction to demonstrate equivalency and provided the system, method, or device is approved for the intended purpose.

1-4 Characteristics of Fire Protection. Fire protection on limited access highways, in tunnels, and on bridges is achieved through a composite of facility design, operating equipment, hardware, software, subsystems, and procedures integrated to provide requirements for the protection of life and property from the effects of fire. The level of fire protection desired for the entire facility should be achieved by integrating the requirements developed through use of this document for each subsystem.

1-5 Application.

1-5.1 The provisions of this document are considered necessary to provide a reasonable level of protection from loss of life and property from fire and explosion. They reflect the practices and the state of the art prevalent at the time this recommended practice was issued.

1-5.2 Unless otherwise noted, it is not intended that the provisions of this document be applied to facilities, equipment, structures, or installations that were existing or approved for construction or installation prior to the effective date of this recommended practice, except in those cases where it is determined by the authority having jurisdiction that the existing situation involves a distinct hazard to life or adjacent property.

1-5.3 Application of this recommended practice to alterations should be determined by the authority having jurisdiction.

1-5.4 That portion of this document that covers emergency procedures does apply to both new and existing facilities.

1-5.5 This recommended practice also can be used for upgrading fire protection facilities, except in those instances where compliance with this recommended practice is not practical or possible within the limits of the existing structure.

1-6 Safeguards During Construction. During the course of construction or major modification of any limited access highway, tunnel, or bridge structure, the provisions of NFPA 241, *Standard for Safeguarding Construction, Alteration, and Demolition Operations*, should apply.

1-7 Limited Access Highways.

1-7.1 Limited access highways present two fire protection problems. One is the protection of life and property transported by vehicles traveling on the facility, and the other is the protection of permanent installations located on, over, below, or adjacent to the facility. Protection to life is to be given primary consideration in all cases. Protection of the facility is also of major importance because of its vital role in the community.

1-7.2 Protection of related facilities such as service areas, rest areas, toll booths, and buildings used for administration, law enforcement, and maintenance presents problems that are not basically different from the fire protection problems of all such buildings. However, special consideration should be given to the fact that on, or adjacent to, limited access highways, such buildings might be located in isolated areas. *(See NFPA 30, Flammable and Combustible Liquids Code, and NFPA 30A, Automotive and Marine Service Station Code, for service stations.)*

1-7.3 Protection for people and property transported by vehicles is somewhat more complicated, since the location of emergencies cannot be predetermined; emergencies can occur at any point or simultaneously at several points along the course of any vehicle transport facility. Fire emergencies can range from incipient fires in passenger vehicles to major accidents involving loaded buses and trucks carrying hazardous materials. Heavy traffic, adverse weather conditions, and night usage escalate the problem.

1-7.4 Studies of fire protection for limited access highways indicate that there are three interdependent factors to be considered. The first is the rapid transmission of alarms to the proper authorities and a simultaneous warning to approaching vehicle operators. The second is the response of appropriate apparatus and fire-fighting personnel with minimal delay. The third is the matter of rescue operations followed by fire extinguishment or control. Where life is endangered by fire, the possibility of effective rescue operations decreases rapidly with any delay.

1-7.5 Unless an effective means of communication is provided, the reporting of fire and other emergencies by occupants of passing vehicles has little value. The distance to interchanges, service areas, and toll booths, and indecision due to lack of familiarity with such emergencies, often consumes the limited time that exists for effective action.

1-7.6 Control of traffic is a continuous problem from the start of any emergency to the time at which the occupants and vehicle(s) are removed from the facility.

1-7.7 Fire protection for limited access highways is addressed in Chapter 2.

1-8 Bridges and Elevated Roadways.

1-8.1 A fire occurring on an elevated roadway or bridge has the same characteristics as a fire occurring on a highway, but it usually is less accessible due to the elevated structure.

1-8.2 Protection of life is the primary concern. However, protection of the elevated roadway or bridge might be more important than protection of vehicles and cargo. Damage to a critical structural member from collision or exposure to high temperatures could result in dangerous weakening or complete collapse of the elevated roadway or bridge.

1-8.3 Approaches to elevated structures and bridges frequently pass directly over congested residential or high-value industrial areas. Certain hazardous materials fires on the structures could result in serious exposure fires in the occupancies beneath and in close proximity to the structures. Conversely, these occupancies, particularly those dealing with hazardous materials, can seriously expose the structures.

1-8.4 Fire protection for bridges and elevated roadways is addressed in Chapter 3.

1-8.5 Consideration is to be given to the fact that flammable liquids or vapors can flow from the roadway by gravity and thus extend the fire risk well beyond the area of the original emergency.

1-9 Depressed Roadways.

1-9.1 A depressed roadway is defined as an uncovered, below-grade roadway where emergency response access is limited or a "boat section" where walls rise to the surface above the roadway surface.

1-9.2 A fire occurring in a depressed highway poses problems similar to those of a fire in a bridge or elevated roadway, with restricted access to the scene of the fire due to the containing walls.

1-9.3 Since the majority of depressed roadways are associated with tunnels as connecting sections or open approaches, depressed roadways are addressed in Chapter 4.

1-10 Tunnels.

1-10.1 The fire protection problem created by a fire in a highway tunnel is similar to that of a fire occurring on a highway in that the emergency is complicated by existing traffic conditions, the number of passengers carried by involved vehicles, and the wide diversity of cargo transported by trucks.

A fire in a tunnel can be extremely destructive and dangerous because the confined space hinders the dissipation of heat and smoke. Additional problems connected with a fire emergency in a tunnel include access limitations for fire-fighting equipment and personnel, early fire detection and alarm transmission, control of traffic, and evacuation of the public from an enclosed facility.

1-10.2 Protection of life is the primary concern. Access points for fire personnel, emergency egress for motorists, fire detection and alarm systems designed to meet the demands of tunnel application, availability of water supply, and adequate ventilation capabilities are among the fundamentals that are to be considered in providing adequate safeguards for both the motorists and the fire fighters to help cope in an emergency. The secondary consideration is protection of the tunnel structure itself. Damage to the ventilation, lighting, or fire suppression systems can endanger lives.

1-10.3 As in the case of highways, the primary need is a means for prompt and rapid detection and notification to the authorities of the existence and location of an emergency and the development of effective response plans, reliable communications, and means of traffic control.

1-10.4 Every tunnel has its own unique characteristics. Tunnels vary in length, cross section, profile, traffic operations, and traffic volumes, among other characteristics. Tunnels can be found in either urban or rural environments and can be subaqueous, subterranean, or mountain type. Therefore, it is imperative that each of these characteristics be considered when establishing emergency/life safety system requirements.

1-10.5 For the purpose of this recommended practice, tunnel length should dictate minimum requirements as follows:

(a) Where the tunnel length exceeds 300 ft (90 m), a standpipe system should be installed to ensure that no point along the tunnel roadway is more than 150 ft (45 m) from a hose connection.

(b) Where the tunnel length exceeds 800 ft (240 m), whereby the maximum distance from any point within the tunnel to an area of safety exceeds 400 ft (120 m), all provisions of this recommended practice should apply.

1-10.6 Fire protection for tunnels is addressed in Chapter 4.

1-11 Air Right Structures.

1-11.1 Where a building is constructed using the air rights over an active motor roadway, the facility begins to resemble a tunnel from the fire protection standpoint. If the sides of the facility are closed, then the air right structure is to be considered a tunnel.

Where an air right structure is fully enclosed on both sides of the roadway, it should be treated, from a fire protection standpoint, as a tunnel. Where the air right structure is not fully enclosed, the decision to treat it as a tunnel should be made by the authority having jurisdiction after sufficient engineering analysis.

1-11.2 Air right structures, as defined in 1-11.1, present two distinctly different fire protection problems. One relates to the persons and property in the structure built above the roadway. The other relates to the persons and property using the roadway that passes under or adjacent to the air right structure.

Fire protection for structures built over the roadway presents problems similar to those involving like buildings in other locations. However, these problems can be complicated by limited access, traffic congestion, and the fire situation on the roadway under or adjacent to the structure.

1-11.3 Fire protection for the roadway under an air right structure is similar to that needed for a tunnel. Occupancy and use of the space above the ceiling of the roadway is significantly different, as outlined in 1-11.2.

1-11.4 While protection of life is the primary consideration, there are other important concerns. The structural members that support the air right building could be subjected to very high temperatures, particularly in a flammable liquids fire or explosion. Damage to these members could have a serious effect on the building. In addition, openings from the roadway such as ventilation shafts and access/egress stairways could allow the passage of flammable vapors to the air right structure with subsequent damage from fire or explosion.

1-11.5 Consideration is to be given to the fact that flammable liquids or vapors can flow from the roadway by gravity or via the drainage system and thus extend the fire risk well beyond the area of the original emergency.

1-11.6 Major structural elements that support an air right structure could be subject to physical damage from motor vehicle accidents.

1-11.7 Fire protection for air right structures is addressed in Chapter 5.

1-12 Units.

1-12.1* Metric units of measurement in this standard are in accordance with the modernized metric system known as the International System of Units (SI). The liter unit, which is outside of but recognized by SI, is commonly used in international fire protection.

1-12.2 If a value for measurement as provided in this recommended practice is followed by an equivalent value in other units, the first stated value is to be regarded as the recommendation. A given equivalent value might be an approximation.

1-12.3 SI units have been converted by multiplying the value by the conversion factor and rounding the result to the appropriate number of significant digits.

1-13 Definitions.

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

Air Right Structure. The roadway facility created when a building is built over the roadway using the roadway's air rights.

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 or untenable for any reason.

Alternative Fuels. Motor vehicle fuels other than gasoline and diesel.

Ancillary Facility. The structure usually used to house or contain operating, maintenance, or support equipment and functions.

Approved.* Acceptable to the authority having jurisdiction.

Authority Having Jurisdiction.* The organization, office, or individual responsible for approving equipment, an installation, or a procedure.

Backlayering. The reversal of the movement of smoke and hot gases contrary to the direction of the ventilation airflow.

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

Building. Any structure used or intended for supporting or sheltering any use or occupancy. The term building should be construed as if followed by the words "or portions thereof."

Central Supervising Station. The operations center where the authority controls and coordinates the facility operations from which communication is maintained with supervisory and operating personnel of the authority and with participating agencies where required.

Combustible. Capable of undergoing combustion.

Command Post. The location during an emergency, selected by the person in command, for controlling and coordinating the emergency operation.

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

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

Critical Velocity. The minimum steady-state velocity of the ventilating airflow moving toward the fire, within a tunnel, that is necessary to prevent backlayering.

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

Elevated Roadway. A roadway that is constructed on a structure that is located above the surface but that is not a bridge.

Emergency Procedures Plan. A plan developed by the authority with the cooperation of all participating agencies detailing specific actions to be performed by all those who are to respond during an emergency.

Engineering Analysis. An analysis that evaluates all the various factors that affect the fire safety of the facility or component. A written report of the analysis should be submitted to the authority indicating the fire protection method(s) recommended that will provide a level of fire safety commensurate with this recommended practice.

Facility. As used in this recommended practice, this includes limited access highways, tunnels, bridges, elevated roadways, and air right structures.

Fire Department Connection. A connection through which the fire department can pump water into the standpipe system.

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

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

Hose Valve. The valve to an individual hose connection.

Incidental Occupancy. A facility used by others who are neither employees nor motorists.

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.

Latching-Type Detector. A detector circuit configuration in which the detector cannot reset itself once it is in alarm mode. The only way of resetting (restoring) the detector to normal operating mode is at the fire alarm control panel.

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

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

Listed.* Equipment, materials, or services included in a list published by an organization 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 either that the equipment, material, or service meets identified standards or has been tested and found suitable for a specified purpose.

Motorist. A motor vehicle occupant, including both the driver and passenger.

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

Noncombustible Material. A material that, in the form in which it is used and under the conditions anticipated, does not aid combustion or add appreciable heat to an ambient fire. Materials, where tested in accordance with ASTM E 136, *Standard Test Method for Behavior of Materials in a Vertical Tube Furnace at 750 Degrees C,* and conforming to the criteria contained therein are to be considered as noncombustible.

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

Person-in-Command. A person designated by the authority or a responsible fire or police representative on the scene of an emergency who is fully responsible at the command post.

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.

Portal. The interface between a tunnel and the atmosphere through which vehicles pass.

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

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

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

Structures. Includes, but is not limited to, buildings, bridges, and underground installations.

Tunnel. An enclosed roadway for vehicular traffic with vehicular access limited to portals.

Chapter 2 Limited Access Highways

2-1 General. The limited access highway poses unique challenges for the fire fighter. The primary problem is the limitation of access to the facility and the possible remote location of the highway.

2-2 Alarm Transmission. Alarm transmission can be provided by the installation of outdoor-type telephone boxes, coded alarm telegraph stations, radio transmitters, sensing equipment, or other suitable devices. The means of transmission should be made conspicuous by indicating lights or other suitable markers and should be located in a way that allows users to park their vehicles clear of the roadway.

Mile markers or other readily available location reference markers should be installed along the highway to allow motorists to provide authorities with reasonably accurate locations for accident or emergency areas.

2-3 Fire Protection.

2-3.1 Arrangements for the response of nearby fire companies and emergency squads should be made. Means of access that allows the entrance of outside aid companies to the facility should be provided, and procedures for utilizing such access should be included in the emergency plan. Appropriate precautions should be taken at these points of entry to alert and control traffic to allow safe entrance by emergency equipment. It is important that fire apparatus responding to fires on limited access roads be equipped with booster tanks [500 gal (1900 L) minimum] and foam-production equipment or an equivalent amount of dry chemical.

2-3.2 All ancillary facilities that support the operation of limited access highways such as maintenance/service buildings, toll plazas, pump stations, and electrical substations should be protected as required by all applicable NFPA standards and local building codes.

2-3.3 Fire extinguishers should be provided at highway installations and buildings in accordance with NFPA 10, *Standard for Portable Fire Extinguishers*.

2-4 Emergency Planning.

2-4.1 It is important that a designated authority carry out a complete and coordinated program of fire protection that includes written preplanned response and standard operating procedures.

2-4.2* Emergency traffic control procedures should be established to regulate traffic.

2-4.3 To derive the maximum benefit from the fire protection program, comprehensive training programs are necessary for all personnel and agencies expected to participate in fire-fighting operations and hazardous materials emergencies. Such a program should involve a competent supervisory staff experienced in fire-fighting techniques and hazardous materials emergencies.

2-4.4 Contacts should be made with roadside businesses and responsible persons living along limited access highways to elicit their cooperation in the reporting of fires and other emergencies. The objective of such contacts should be to establish a positive system for the reporting of emergencies. Those who agree to participate in the system are to 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.

2-4.5 Emergency procedures and the development of an emergency response plan are addressed in Chapter 9.

Chapter 3 Bridges and Elevated Roadways

3-1 General. Elevated roadways and bridges pose both a vertical and a horizontal access problem for fire-fighting activities. In addition, the potential for a fire under the structure that impacts the integrity of the structure is to be considered.

3-2 Alarm Transmission.

3-2.1 Alarm transmission can be provided by the installation of outdoor-type telephone boxes, coded alarm telegraph stations, radio transmitters, sensing equipment, or other suitable devices. The means of transmission should be made conspicuous by indicating lights or other suitable markers and should be located in a way that allows users to park their vehicles clear of the roadway.

Signs or mile markers should be installed along the bridge to allow motorists to provide authorities with reasonably accurate locations for accident or emergency areas.

3-2.2 A traffic control procedure should be established so that vehicles will either stop or proceed with caution. It is essential that traffic does not block or otherwise interfere with the response of emergency and fire equipment.

3-3 Fire Apparatus, Standpipe Systems, Water Supplies, and Equipment. Suitable fire apparatus should be available within 1 mi (1.6 km) of all points on elevated roadways and bridges in urban areas; use of ladders by municipal fire fighters may be permitted where elevated structures and bridges are accessible from beneath. The design of apparatus intended for use only on bridges or elevated structures should be based on the conditions encountered. Apparatus responding to fires on bridges and elevated roadways should be equipped with potassium bicarbonate-based dry chemical/aqueous film-forming foam (AFFF) or similar self-contained fire-fighting equipment. In addition, the vehicle should have booster tanks [500 gal (1900 L) minimum].

3-3.1 The responding fire apparatus should be equipped to deliver a foam solution at a minimum rate of 125 gpm (475 L/min) for a minimum duration of 15 minutes. If hydrant or standpipe water is not available, suitable arrangements should be made to transport water in tankers so that the delivery rate of foam can be maintained. Additional supplies of foam should be readily available from mutual aid fire departments or other sources so that the application can be continued for an additional 45 minutes if necessary. These units also should carry multipurpose dry chemical extinguishers and an extinguishing agent for Class D metal fires. Mutual aid, supplier, or manufacturer reserve capability should be available.

3-3.2 In urban locations, hose outlets (hydrants) from the municipal water supply should be located at both ends of bridges. Where more than one agency has the responsibility for providing fire protection, every effort should be made to standardize hose connectors. If this is not possible, suitable adapters should be readily available. In addition, where the length or width of the bridge is such that hose lines of more than 400 ft (120 m) cannot be provided from the hydrants, a standpipe system, in accordance with Chapter 6, should be provided. In certain instances, it might be desirable for duplicated systems to be installed on each side of the roadway and to be cross-connected. Where freezing conditions prevail, systems should be of the dry type. Signs should indicate the location of street-level hydrants.

3-3.3 Sand should be provided for use during icy weather conditions. Suitable absorbent materials should be provided for controlling the spill of hazardous materials. On bridges and elevated roadways, consideration should be given to drainage systems to channel spilled hazardous materials to areas that cannot cause additional hazards. For example, expansion joints should be designed to prevent spillage to the area below.

3-4 Control of Hazardous Materials. Control of hazardous materials is addressed in Chapter 10.

3-5 Emergency Planning.

3-5.1 It is important that a designated authority carry out a complete and coordinated program of fire protection that should include preplanned emergency response procedures to be contained in an emergency response plan.

3-5.2 To derive the maximum benefit from the fire protection program, comprehensive training programs are necessary for all personnel and agencies expected to participate in fire-fighting operations and hazardous materials emergencies. Such a program should involve a competent supervisory staff experienced in fire-fighting techniques and hazardous materials emergencies.

3-5.3 Emergency procedures and the development of an emergency response plan are addressed in Chapter 9.

Chapter 4 Tunnels

4-1 General. A tunnel is an enclosed roadway for motor vehicle traffic in which access is limited to portals, which poses some unique fire-fighting challenges due to both the restricted access to the fire site and the confined nature of a tunnel.

4-2 Detection and Alarm.

4-2.1 At least one and preferably two means should be provided to detect fire and transmit an alarm to a local 24-hour monitoring facility, an approved central station, or the local fire department.

4-2.1.1 Manual fire alarm pull stations of the double-action type that are mounted on weatherproof boxes should be installed at intervals of not more than 300 ft (100 m) and at all cross passages and means of egress from the tunnel. The stations should be accessible to both the public and tunnel personnel. The manual fire alarm pull stations should be made conspicuous by lights installed directly above each pull station. Pull stations should be reset with a key. All manual fire alarm pull stations should use an identical key. Each alarm should be transmitted to a local 24-hour monitoring facility, an approved central station, or the local fire department. The alarm is to indicate the location of the pull station. Confirmation of receipt of the sent alarm should be provided at the pull station by a light. Voice communication at the pull station should be considered if a local 24-hour monitoring facility is available.

4-2.1.2 Closed-circuit television systems (CCTV) together with traffic flow indication should be used to detect and identify fires only in tunnels with 24-hour, full-time supervision. Rooms within ancillary structures (pump rooms, utility rooms, cross passages, ventilation structures) and areas not covered by CCTV should be supervised by automatic fire alarm systems.

4-2.1.3 Manual fire alarm pull stations or automatic fire alarm systems should be used in tunnels without 24-hour, full-time supervision. The systems should be in compliance with NFPA 72, *National Fire Alarm Code*.

Exception: Signals for the purpose of evacuation and relocation of occupants are not necessary.

4-2.2 Fire detection in an automatic fire alarm system should identify the location of the fire clearly and should identify the device initiating any alarm (false or otherwise) clearly. The initiating device should have a light that remains on until the device is reset. Automatic fire detection should be provided in all normally unoccupied spaces such as utility rooms, cross passages, stairways, and ventilation structures.

Automatic fire detection within the tunnel should be zoned to correspond with the tunnel ventilation zones and should also identify the location of the fire to within 50 ft (15.3 m).

Portals should be provided with a remote fire alarm annunciator panel at a suitable location accessible to the fire service. Remote annunciator panels should indicate the zone in alarm and should display the location of that alarm.

4-2.3 Fire Alarm Control Panel. Means should be provided for the installation of a fire alarm control panel (FACP). The FACP should be zoned and should be of the positive, noninterfering, successive (PNIS) type. One zone entering into an alarm should not interfere with any other zone entering into an alarm and should annunciate all alarms. The FACP should have battery backup power. All FACP should be locked, should use an identical key, and should be in compliance with NFPA 72, *National Fire Alarm Code*. The fire alarm zones should correspond to the ventilation zones in the tunnel. The FACP should be in a suitable enclosure for the environment. The FACP should be approved. All FACPS should be fed by a single-phase, three-wire system. The circuit breakers protecting this system should not be configured in a common trip mode of operation. Each circuit breaker should operate independently of all other circuit breakers.

4-2.4 Inspection, Testing, and Maintenance. Means should be provided for the fire detection alarm systems, including all associated appurtenances, to be inspected, tested, and maintained in accordance with NFPA 72, *National Fire Alarm Code*.

4-3 Traffic Control and Surveillance.

4-3.1 For tunnel lengths greater than 300 ft (90 m), a traffic surveillance and control system should be provided. This system should be capable of monitoring and controlling traffic within and approaching the tunnel.

4-3.2 Tunnels longer than 300 ft (90 m) should provide the capability to automatically prevent approaching traffic from entering the tunnel when a fire alarm is activated. This capability should consist of traffic signals in proximity to the portal. The system should be reset to normal operation when the fire site is cleared. Control of this system can be either from within the tunnel or from a remote location.

4-3.3 Tunnels longer than 800 ft (240 m) should provide additional capabilities to divert traffic from entering the direct approaches to the tunnel and to clear traffic downstream of the fire site.

(a) Traffic beyond the direct approaches to the tunnel should be diverted by means of signs. This also could necessitate preempting traffic signals to prevent traffic from entering the approaches. This can be accomplished by omitting traffic movements or otherwise directing traffic to alternate roadways.

(b) Traffic within the tunnel approaching the fire site should be stopped prior to the fire site until it is safe to proceed. The controls used should be spaced for safe braking requirements. Visibility requirements should be in accordance with the MUTCD.

(c) The control systems should be configured to control all modes in which the tunnel is operated.

(d) Controls should be provided so that traffic beyond the fire site can proceed to exit the tunnel. If signals are provided for this function, their display should be green.

(e) If contraflow operation is permitted during emergency vehicle response periods, the control systems should be configured to control traffic in each direction.

(f) If traffic exiting the tunnel is obstructed by intersectional traffic signals in the area of the exit, such signals should be preempted to eliminate the obstruction.

(g) The return of the traffic controls to normal operation should follow prearranged protocol between the tunnel system operator and authority having jurisdiction.

4-4 Emergency Communications. Radio communication systems, such as highway advisory radio (HAR) and AM/FM commercial station overrides, are recommended to the motorist as communications routes for all tunnels over 800 ft (240 m) and should provide identification of the emergency and actions the motorist should take. All messaging systems for tunnels over 800 ft (240 m) should be capable of real time composition and selection by the emergency response authority and should not be of the recorded type. Areas of refuge or assembly, if available, should be provided with reliable two-way voice communication to the emergency response authority.

4-5 Emergency Response Apparatus and Equipment.

4-5.1 Emergency response apparatus should be available within the general site of the emergency, thus providing a rapid response. Where the tunnel is a high-capacity urban tunnel, it might be appropriate to house the apparatus at one or both of the tunnel portals.

4-5.2 Suitable apparatus, if appropriate, should be available at the tunnel portal(s). Apparatus should be designed for double-end lifting operation and equipped with "dollies" for towing disabled vehicles from the tunnel. The apparatus should carry a potassium bicarbonate-based dry chemical/aqueous film-forming (AFFF) or similar self-contained fire-fighting system or means to obtain water from a standpipe system, or any combination thereof. It also should carry portable extinguishers, complete self-contained breathing apparatus, cutting torches, forcible entry tools, hose, chains, coffin hoists, tarpaulins, and other appropriate hand tools. The apparatus should be equipped with a radio.

4-5.3 The responding fire apparatus should be equipped to deliver a foam solution at a minimum rate of 125 gpm (475 L/min) for a minimum duration of 15 minutes. If hydrant or standpipe water is not available, suitable arrangements should be made to transport water in tankers so that the delivery rate of foam can be maintained. Additional supplies of foam should be readily available from mutual aid fire departments or other sources so that the application can be continued for an additional 45 minutes if necessary. These units also should carry multipurpose dry chemical extinguishers and an extinguishing agent for Class D metal fires. Mutual aid, supplier, or manufacturer reserve capability should be available.

4-6 Fire Standpipe and Water Supply. The fire standpipe and water supply are addressed in Chapter 6.

4-7 Portable Fire Extinguishers. Portable fire extinguishers, each with at least a nominal 20-lb (9-kg) capacity for multipurpose agent, should be placed on both sides of the roadway in well-marked, flush-wall cabinets at intervals of not more than 300 ft (90 m). Portable fire extinguishers should be provided in accordance with NFPA 10, *Standard for Portable Fire Extinguishers*.

4-8 Emergency Ventilation. Emergency ventilation is addressed in Chapter 7.

4-9 Drainage System.

4-9.1 A drainage system should be provided in tunnels to collect, store, or discharge, or any combination of these functions, influent emanating from within the tunnel. In addition to water discharged from the fire protection system and liquids from accidental spills, this influent also might include water from tunnel cleaning operations and water from incidental seepage.

4-9.2 The drainage collection system should consist of an embedded main drain pipe with grate-covered inlets regularly spaced along the curb rather than a continuous open gutter, which could allow spills of hazardous material, such as flammable liquids that could ignite, to propagate along the length of the tunnel.

4-9.3 The spacing of connections to the gravity line should be at a maximum of 100 ft (30 m) on centers.

4-9.4 Components of the drainage collection system, including the main drainlines, should be noncombustible (steel, ductile iron, or concrete). Polyvinyl chloride (PVC), fiberglass pipe, or other combustible material should not be permitted.

4-9.5 The collection system should 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.

4-9.6 Storage tanks and pump stations should be classified for hazard in accordance with NFPA 70, *National Electrical Code®*. All motors, starters, level controllers, and system controls should be specified to conform to the intrinsic requirements of the hazard classification.

4-9.7 Storage tanks and pump stations should be monitored for hydrocarbons. Detection of hydrocarbons in the drainage influent should initiate both a local and remote alarm.

4-10 Control of Hazardous Materials. Control of hazardous materials is addressed in Chapter 10.

4-11 Emergency Planning.

4-11.1 It is important that a designated authority carry out a complete and coordinated program of fire protection that should include preplanned response and standard operating procedures in the form of an emergency response plan.

4-11.2 To derive the maximum benefit from the fire protection program, comprehensive training programs are necessary for all personnel and agencies expected to participate in fire-fighting operations and hazardous materials emergencies. Such a program should involve a competent supervisory staff experienced in fire-fighting techniques and hazardous materials emergencies.

4-11.3 Emergency procedures and development of emergency response plans are addressed in Chapter 9.

4-12 **Alternative Fuels.**

4-12.1 The majority of the vehicles currently in the U.S. traffic population are fueled by either gasoline or diesel fuel. Vehicles powered by alternative fuels have been introduced, but, at this time, the portion of the vehicle population powered by alternative fuels remains too small to impact the normal ventilation of tunnels; however, there can be an impact on the emergency ventilation. (*See Appendix F.*)

4-12.2 **Mitigation Measures.** As the use of alternative fuels in road vehicles has gradually increased, each tunnel operating agency has dealt with the issue of whether to allow vehicles through the tunnels for which it is responsible. Most tunnel agencies throughout the world do allow the passage of alternative fuel vehicles.

The mitigation measures that can be taken by the tunnel designer relate primarily to the ventilation system, which, in most circumstances, can provide sufficient air to dilute the fuel below any troublesome levels adequately. It might be necessary to establish a minimum level of ventilation to provide this dilution under all circumstances. The other measure to be taken is to reduce or eliminate any irregular surfaces of the tunnel ceiling or structure where a pocket of gas could collect and remain undiluted, thus posing a potential explosive hazard.

4-13 **Safeguards During Construction.** During the course of construction or major modification of any structure, the provisions of NFPA 241, *Standard for Safeguarding Construction, Alteration, and Demolition Operations*, should apply.

Exception: Where specifically addressed in this recommended practice.

4-13.1 **Temporary Fire Detection and Alarm System.** A temporary fire detection and alarm system should be installed and maintained during construction. The system should consist of heat detectors; manual pull stations spaced not more than 200 ft (60 m) apart; indication appliances consisting of horn and light combination units spaced to be clearly visible/heard in all areas of construction; a fire alarm control panel; a backlighted graphic annunciator that depicts (graphically) the entire area under construction; and an approved fire alarm master box connected to the local authority having jurisdiction. All system controls and devices should be in compliance with NFPA 72, *National Fire Alarm Code*.

Chapter 5 Air Right Structures

5-1 **General.** An air right structure imposes limitations on the ability of a fire fighter to fight a fire similar to those of a tunnel, due to its limited access and restricted work space.

5-2 **Detection and Alarm Transmission.**

5-2.1 Where the air right structure approximates the physical characteristics of a tunnel, an alarm system similar to that of a tunnel should be considered. (*See Chapter 4.*)

5-2.2 **Traffic Control and Surveillance.**

5-2.2.1 Where the air right structure approximates the physical characteristics of a tunnel, a traffic control and surveillance system should be considered. (*See Chapter 4.*)

5-2.2.2 A traffic control system should be provided. It may be permitted to be interlocked with the fire alarm system. The system should be capable of operation from a remote control source or from either end of the roadway passing under the air right structure. The traffic control system should be designed for use by authorized personnel only.

5-3 **Fire Apparatus, Equipment.** Fire apparatus responsible for air right structure roadways are to be equipped to deal with flammable liquid and hazardous materials fires and incidents effectively. They should be equipped to carry foam, potassium-based dry chemical/aqueous film-forming foam (AFFF), or similar systems and should be suited to the unique characteristics of the structure. If the air right structure roadway approximates the physical characteristics of a tunnel, fire apparatus similar to the type used for tunnels should be used.

5-4 **Fire Standpipe Systems and Water Supply Systems.** Standpipe systems for roadways within air right structures should be designed and installed as a Class I system in accordance with NFPA 14, *Standard for the Installation of Standpipe and Hose Systems*. (*See Chapter 6.*)

5-5 **Portable Fire Extinguishers.** Portable multipurpose fire extinguishers, each with a minimum nominal 20-lb (9-kg) capacity, should be placed on both sides of the roadway in well-marked, flush-wall cabinets at intervals of not more than 300 ft (90 m). Consideration should be given to incorporating removal detection of an extinguisher into the alarm system.

5-6 **Emergency Ventilation.** Emergency ventilation is addressed in Chapter 7.

5-7 **Drainage System.** A drainage system designed in accordance with Section 4-9 should be provided for roadways beneath air right structures.

5-8 **Control of Hazardous Materials.** Control of hazardous materials is addressed in Chapter 10.

5-9 **Structural Factors.**

5-9.1 All structural elements that support buildings over roadways or provide separation between the buildings and roadways, or both, should have a 4-hour fire resistance rating in accordance with ASTM E 119, *Standard Test Methods for Fire Tests of Building Construction and Materials*.

Exception: Buildings with a fire resistance rating greater than 4 hours.

5-9.2 Structural members should be protected from physical damage from vehicle-based accidents. An inspection and repair program should be kept in force to monitor and maintain the protection of the structure.

5-9.3 Structural support elements on centerlines of roadways should not be permitted.

5-9.4 Buildings above roadways should be designed with consideration for the fact that the roadway below the air right structure is a potential source of heat, smoke, and toxic gases. The structural elements should be designed in such a way as to shield the air right buildings from these potential hazards. The design of the building should neither increase nor create any risk to those using the roadway below.

5-10 Emergency Planning.

5-10.1 It is important that a designated authority carry out a complete and coordinated program of fire protection that includes written preplanned response and standard operating procedures.

5-10.2 To derive the maximum benefit from the fire protection program, joint comprehensive training exercises are necessary for all personnel and agencies expected to participate in fire-fighting operations and hazardous materials emergencies. The training program should involve a competent supervisory staff experienced in fire-fighting techniques and hazardous materials emergencies.

5-10.3 Emergency procedures and development of emergency response plans are addressed in Chapter 9.

Chapter 6 Fire Standpipe and Water Supply

6-1 Standpipe Systems.

6-1.1 Standpipe systems for tunnels, bridges, and elevated and limited access roadways should be designed and installed as Class I systems in accordance with NFPA 14, *Standard for the Installation of Standpipe and Hose Systems.*

6-1.2 Standpipe systems should be permitted to be either wet or dry, depending upon climatic conditions, fill times, or the requirements of the authority having jurisdiction, or any combination thereof.

6-1.3 Where wet standpipe systems are required in areas subject to freezing conditions, the water should be heated and circulated, and all piping and fittings exposed to such conditions should be heat-traced and insulated.

6-1.4 Wet standpipe systems should be provided with suitable interconnection and bypass valve arrangements to allow isolation and repair of any segment without impairment to the operation of the remainder of the system.

6-1.5 Dry standpipe systems should be designed to ensure that the delivery time of water to any hose connection on the system is less than 10 minutes. Dry standpipe systems should have provisions for complete draining after use. Combination air relief/vacuum valves should be installed at each high point on the system.

6-1.6 Dry standpipes should be installed in a manner that provides accessibility for inspection and repair and should be protected from damage by moving vehicles.

6-2 Design Capacity.

6-2.1 Standpipe systems should be designed to provide a minimum water supply of 250 gpm (16 L/s) at 100 psi (690 kPa) residual at the most remote hose connection with a minimum of two hose connections flowing for a total flow of 500 gpm (32 L/s) at 65 psi (450 kPa) residual.

6-2.2 Maximum residual pressure at any hose connection should be limited to 175 psi (1207 kPa) by means of an approved pressure regulating device.

6-3 Water Supply.

6-3.1 Wet standpipe systems (automatic or semiautomatic) should be connected to an approved water supply capable of supplying the system demand for a minimum of 1 hour.

6-3.2 Dry standpipe systems should have an approved water supply capable of supplying the system demand for a minimum of 1 hour and accessible to a fire department pumper within 100 ft (30 m) of each fire department connection.

6-3.3 Acceptable water supplies include the following:

(a) Municipal or privately owned waterworks systems having adequate pressure and flow rate and a level of integrity acceptable to the authority having jurisdiction;

(b) Automatic or manually controlled fire pumps connected to an approved water source;

(c) Pressure-type or gravity-type storage tanks installed in accordance with NFPA 22, *Standard for Water Tanks for Private Fire Protection.*

6-4 Fire Department Connections.

6-4.1 Fire department connections should be of the threaded two-way or three-way type or should consist of one 4-in. quick-connect coupling located at ground surface level and accessible to a fire department pumper.

6-4.2 Each standpipe zone should have a minimum of two fire department connections located remotely from each other.

6-4.3 Fire department connections should be protected from vehicular damage by means of bollards or other suitable barriers.

6-4.4 Wherever possible, fire department connection locations should be coordinated with emergency access/egress locations.

6-5 Hose Connections.

6-5.1 Hose connections should be spaced so that no location on the protected roadway is more than 150 ft (45 m) from the hose connection. Hose connection spacing should not exceed 275 ft (85 m). Hose connections should be located so that they are conspicuous and convenient yet reasonably protected from damage by errant vehicles or vandals.

6-5.2 Hose connections should have 2½-in. (63.5-mm) external threads in conformance with NFPA 1963, *Standard for Fire Hose Connections*, and the authority having jurisdiction. Hose connections should be equipped with caps to protect hose threads.

6-6 Fire Pumps. Fire pumps should be supplied as necessary and should be installed in accordance with NFPA 20, *Standard for the Installation of Centrifugal Fire Pumps.*

6-7 Identification Signage.

6-7.1 Identification signage for standpipe systems and components should be developed with input from the authority having jurisdiction. Identification signage should, as a minimum, identify the name and limits of the roadway served.

6-7.2 Identification signage should be conspicuous and affixed to, or immediately adjacent to, ground surface level fire department connections and each roadway hose connection.

6-8 Standpipe Installation in Tunnels Under Construction.

6-8.1 A standpipe system, either temporary or permanent in nature, should be installed in tunnels under construction before the tunnel has exceeded a length of 200 ft (60 m) beyond any access shaft and should be extended as tunnel work progresses.

6-8.2 Temporary standpipes, which can be used by contractors to furnish water for construction purposes, should be equipped with hose outlets and valves with $2^1/_2$-in. (63.5-mm) hose thread conforming to NFPA 1963, *Standard for Fire Hose Connections*, and can have suitable reducers or adapters attached for connection of contractor's hose. Such reducers or adapters should be readily removable using the fire fighter's hose spanner wrenches.

6-8.3 Permanent standpipes or temporary standpipes installed in tunnels during construction should be provided with risers to approved fire department connections at ground surface level.

6-8.4 Permanent or temporary standpipes installed during the construction phase should be supported securely and adequately and should be of sufficient strength to withstand the pressure and thrust forces to which they are subjected.

6-8.5 Temporary standpipes should remain in service until the permanent standpipe installation is complete.

Chapter 7 Emergency Tunnel Ventilation

7-1 General. Ventilation systems and procedures should be developed to allow maximum utilization of the tunnel ventilation system for the removal and control of smoke during fires. The ventilation equipment should be heat resistant so it is capable of operating even under sustained fire exposure temperatures. The design of the ventilation system should provide for excess ventilation to accomplish this purpose. The ventilation procedures should be designed to assist in the evacuation of motorists from the tunnel.

7-2 Design. The design objectives of the emergency ventilation system should be as follows:

(a) To provide a stream of noncontaminated air to passengers in a path of egress away from a fire (*see Appendix C*);

(b) To produce airflow rates to prevent backlayering of smoke in a path of egress away from a fire;

(c) To limit the air temperature in a path of egress away from fire to 140°F (60°C) or less;

(d) To provide excess ventilation capabilities to achieve the temperature limitation specified in Section 7-2(c);

(e) To prevent or minimize adverse effects on air right structures and their occupants from fire products such as heat, smoke, and toxic gases.

7-3 Memorial Tunnel Fire Ventilation Test Program. The Memorial Tunnel Fire Ventilation Test Program is a full-scale test program conducted under the auspices of the United States Federal Highway Administration (FHWA) 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 can have an impact on the design criteria for highway tunnel emergency ventilation. (*See Appendix C.*)

7-4 Criteria. The design heat release rate produced by a vehicle should be used to design the emergency ventilation system.

7-5 Fans. Ventilation fans used for emergency service, their motors, and all related components exposed to the ventilation airflow should be designed to operate in an ambient atmosphere of 482°F (250°C) for at least 1 hour.

7-5.1 Fans should be fixed or variable speed type driven by single speed, multiple fixed speed, or variable frequency drive motors. They should be permitted to be reversible and should be both locally and remotely controlled, as approved. They should be connected to two power feeders derived from two separate sources. Power feeders from a utility furnishing power for fans should be isolated from each other and should originate from separate and distinct utility sources to the extent possible.

7-5.2 Remote control operation of the tunnel ventilation fans at an approved location accessible to authorized fire and emergency personnel should be provided.

7-5.3 Local fan motor starters and related operating control devices should be located away from the direct airstream of the fans to the greatest extent practical.

7-5.4 Discharge/outlet openings for emergency fans should be positioned a sufficient distance from supply air intake openings to prevent recirculation. If this is not possible due to area constraints, intake openings then should be protected by other approved means or devices to prevent smoke from reentering the system.

7-5.5 Operation and fail-safe verification of proper operation of emergency fans should be effected from a remote location with indication provided for all modes of operation for each fan, as well as from a local control isolated from the direct airstream of the fans. Thermal overload protective devices should not be located on motor controls of fans dedicated solely to emergency ventilation. Local controls should allow overriding of the remote control. Local control should be capable of operating the fans in all modes in the event the remote controls become inoperable.

7-6 Controls — Fire Detection and Alarm System Operation. A fire-fighter fan control override control station should be provided to give full control of the running speed of all tunnel fans to the local authority having jurisdiction. The location and marking of the fan override control station should be determined by the authority having jurisdiction.

Chapter 8 Electrical Systems

8-1 General.

8-1.1 The electrical systems should support personnel life safety, emergency operations, and normal operations.

8-1.2 The systems should maintain illumination, communications, and ventilation, identify areas of refuge/exit and exit routes, and provide remote annunciation/alarm and drainage under all operating and emergency modes associated with the roadway.

8-2 Wiring. All wiring materials and installation should conform to NFPA 70, *National Electrical Code*, as modified in this recommended practice.

8-3 Materials.

8-3.1 Materials manufactured for use as conduits, raceways, ducts, cabinets, and equipment enclosures and their surface finish materials, as installed, should be capable of being subjected to temperatures up to 600°F (316°C) for 1 hour and should not support combustion under the same temperature condition.

8-3.2 The systems should not use materials within the confined spaces of limited access roadways that produce toxic by-products during electric circuit failure or when subjected to an external fire. PVC conduit and vinyl- (PVC) insulated/jacketed conductors or cables should not be used in tunnels, plenums, or enclosed spaces.

8-3.3 All insulations should conform to NFPA 70, *National Electrical Code*, and should be of the moisture- and heat-resistant types with temperature ratings corresponding to the conditions of application.

8-3.4 All conductors should be completely enclosed in armor sheaths, conduits, or enclosed raceways, boxes, and cabinets. Conductors in a raceway can be embedded in concrete or run in protected electrical duct banks, but they should not be installed in an exposed manner or surface mounted in air plenums that could carry air at the elevated temperatures accompanying fire emergency conditions.

8-4 Power Source. The power source for all systems should be of a capacity and configuration commensurate with the purpose of the system. The following systems should be provided with emergency power:

(a) Emergency lighting;

(b) Means of egress/refuge lighting;

(c) Exit signs;

(d) Communications as defined herein;

(e) Tunnel drainage and fire pump(s).

Consideration should be given to providing emergency power to support ventilation of tunnels where such tunnels are needed to support the passage of vehicles during loss of normal power.

The recommendations for emergency sources should be as defined in NFPA 70, *National Electrical Code*. In addition, the normal and emergency source should be wired to system equipment so that a single event or fire minimizes the affect on the operation of the overall system. (It is expected that the operations of all systems within the vicinity of a fire will fail. This provision is intended to limit the area of this failure.)

8-5 Reliability. The primary source of electric service should be from the local electric utility.

Exception: A separate service may be permitted to be an emergency source, provided it can be demonstrated that a single event within the utility system cannot affect both the primary and emergency source.

8-6 Standby System. It should be recognized that normal service within the utility system affects one source at a time. It is not the intent of the emergency recommendation to address an event within the roadway while one source is not available. However, an additional source supporting select systems can be permitted to be provided near the roadway system to maintain operations.

8-7 Lighting.

8-7.1 Roadway illumination should meet the requirements of ANSI/IES RP-8, *American National Standard Practice for Roadway Lighting*, and ANSI/IES RP-22, *American National Standard Practice for Tunnel Lighting*. In addition, means of egress, exits, and emergency lighting should be in accordance with NFPA *101®*, *Life Safety Code®*. Emergency tunnel lighting illumination levels should not be less than 0.2 footcandles [0.22 lux] (minimum average) throughout personnel egress paths.

8-7.2 There are several issues that are related to the available equipment and features of a limited access roadway. The most significant is the emergency response agency(ies). In rural areas where response units are often made up of volunteers, longer response times can be expected. Under these conditions, self-rescue should be considered. Lighting of special features (such as fire pull stations, extinguishers, and telephones) and special feature instructional signage should be provided with emergency lighting.

8-8 Life Safety During Construction. The construction or renovation of a tunnel or other below grade roadway should include the basic worker safety provisions of OSHA 29 *Code of Federal Regulations*, 1910S, "Underground Construction, Caisson, and Compressed Air," and OSHA 29 *Code of Federal Regulations*, 1910S, "Electrical, Safety-Related Work Practices." In addition, systems should be installed that support the construction operations in a safe manner. The method of lighting, heating, ventilation, and drainage should support the expected number of construction personnel and consider the equipment, the task, and the duration of the work. The primary underground power source should be electric. Electric power distribution should be configured so that system failure or an emergency condition allows for the safe evacuation of the facility.

Chapter 9 Emergency Procedures

9-1 General. The agency that is responsible for the safe and efficient operation of the facility should anticipate and plan for emergencies that could involve the system. Participating agencies should be invited and should assist with the preparation of the emergency procedure plan.

9-2 Emergencies. The following types of emergencies should be considered cause for invoking the emergency procedure plan:

(a) Fire or a smoke condition in a vehicle or in the facility;

(b) Fire or a smoke condition adjoining or adjacent to the facility;

(c) Collision involving one or more vehicles;

(d) Loss of electric power resulting in loss of illumination and ventilation;

(e) Evacuation of motorists from vehicles under adverse conditions where they need assistance;

(f) Panic of motorists;

(g) Disabled vehicles under adverse conditions;

(h) Serious flooding condition due to water main break, heavy rain, poor drainage, loss of electric power, or failure of pumping equipment;

(i) Structural collapse or imminent collapse that threatens safety;

(j) Seepage and spillage of petroleum products or flammable, toxic, or irritating vapors;

(k) Serious vandalism or other criminal acts, such as a bomb threat;

(l) First aid or medical attention needed by motorists;

(m) Extreme weather conditions, such as heavy snow, rain, high winds, high heat, low temperatures, or sleet and ice conditions, causing disruption of operation;

(n) Earthquake.

9-3 Emergency Response Plan.

9-3.1 The emergency response plan should include, but should not be limited to, the following:

(a) Name of plan;

(b) Name of responsible agency;

(c) Dates adopted, reviewed, and revised;

(d) Policy, purpose, scope, and definitions;

(e) Participating agencies, top officials, and signatures of executives signing for each agency;

(f) Safety during emergency operations;

(g) Purpose and operation of central supervising station and alternate central supervising station;

(h) Purpose and operation of command post and auxiliary command post;

(i) Communications: radio, telephone, and messenger service available at central supervising station and command post; also, efficient operation of these facilities;

(j) Fire detection, fire protection, fire extinguishing equipment, and access/egress and ventilation facilities available; details of the type, amount, location, and method of utilization;

(k) Procedures for fire emergencies; various types of fire emergencies, agency in command, and procedures to follow;

(l) Maps and plans of the roadway system and of all surface and connecting streets;

(m) Any additional information and data that the participating agencies desire to have in the plan.

9-3.2 A sample emergency response plan outline is provided in Appendix E.

9-4 Participating Agencies. Participating agencies that should be summoned by operators to cooperate and assist, depending upon the nature of an emergency, include:

(a) Ambulance service;

(b) Building department;

(c) Fire department;

(d) Medical service;

(e) Police department;

(f) Public works, bridges, streets, sewers;

(g) Sanitation department;

(h) Utility companies (e.g., gas, electricity, telephone, steam);

(i) Water supply;

(j) Local transportation companies.

The agencies and names will vary depending upon the governmental structure and laws of the community.

9-5 Central Supervising Station. If the facility has a central supervising station (CSS) for the operation and supervision of the facility, 9-5.1 through 9-5.7 should apply.

9-5.1 The CSS should be staffed by trained and qualified personnel and should be provided with the essential apparatus and equipment to communicate with, supervise, and coordinate all personnel.

9-5.2 The CSS should provide the capability to communicate rapidly with participating agencies. Agencies such as fire, police, ambulance, and medical service should have direct telephone lines or designated telephone numbers used for emergencies involving the facility.

9-5.3 Equipment should be available and used for recording radio and telephone communications and CCTV transmissions during an emergency.

9-5.4 CSS personnel should be thoroughly familiar with the emergency procedure plan and trained to employ it effectively.

9-5.5 An alternate site(s) that can function efficiently during an emergency in the event the CSS is out of service for any reason should be selected and equipped, or equipment should be readily available.

9-5.6 The CSS should be located in an area separated from other occupancies by construction having a 2-hour fire resistance rating. The area should be used for the CSS and similar activities and should not be jeopardized by adjoining or adjacent occupancies.

9-5.7 The CSS should be protected by fire detection, protection, and extinguishing equipment to provide early detection and extinguishment of any fire in the CSS.

9-6 Liaison.

9-6.1 An up-to-date list of all liaison personnel from participating agencies should be maintained by the operating agency and should be part of the emergency procedure plan.

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

9-6.2 The list should be reviewed at least once every 3 months to verify the ability to contact the liaison without delay.

9-7 Command Post.

9-7.1 During an emergency where it is necessary to invoke the emergency procedure plan, a command post should be established by the person in command for the supervision and coordination of all personnel, equipment, and resources at the scene of the emergency.

9-7.2 The emergency procedure plan should delineate clearly the authority or participating agency that is in command and responsible for supervision, correction, or alleviation of the emergency.

9-7.3 The command post should be located at a site convenient for responding personnel, easily identifiable, and suitable for supervising, coordinating, and communicating with participating agencies.

9-7.4 Each participating agency should assign a liaison to the command post.

9-7.5 Effective use should be made of radio, telephone, and messenger service to communicate with participating agencies.

9-7.6 To identify the command post easily during day or night and under bad weather conditions, designated markers should be employed. The emergency procedure plan should prescribe the specific identification markers to be used for the command post and its assigned personnel.

9-8 Auxiliary Command Post.

9-8.1 Where it is necessary for an emergency operation to use an auxiliary command post because of the extent of the operation, the person in command should establish an auxiliary command post(s) that can function as a subordinate control point.

9-8.2 Where authorized, a participating agency (not in command) should establish an auxiliary command post to assist with the supervision and coordination of its personnel and equipment.

9-9 Training, Exercises, Drills, and Critiques.

9-9.1 Operating agency and participating agency personnel should be trained to function efficiently during an emergency. They should be thoroughly familiar with all aspects of the emergency procedure plan.

9-9.2 Exercises and drills should be conducted at least twice per year to prepare the authority and participating agency personnel for emergencies. Critiques should be held after the exercises, drills, and actual emergencies.

9-10 Records. Written records and telephone, radio, and CCTV recordings should be kept at the CSS, and written records should be kept at the command post and auxiliary command post(s) during fire emergencies, exercises, and drills.

Chapter 10 Control of Hazardous Materials

10-1 General. The facility operating agency should adopt rules and regulations applicable to the transportation of hazardous materials. A program should be maintained for enforcing these regulations. In developing such regulations, consideration should be given to the following:

(a) The availability of a suitable alternative route(s) meeting federal requirements as prescribed in Title 49, *Code of Federal Regulations*, 177.825, "Routing and Training Requirements for Class 7 (Radioactive) Materials," and Title 49, *Code of Federal Regulations*, Part 397, Subpart C, "Routing of Non-Radioactive Hazardous Materials."

(b) Title 49, Department of Transportation, *Code of Federal Regulations*, Subtitle B, Parts 100 to 199;

(c) The fire and accident experience of other similar facilities;

(d) Past fire and accident experience on the facility and adjacent roads, or, in the case of a new facility, the past fire and accident experience on roads in the area;

(e) Anticipated traffic volumes in peak and off-peak periods;

(f) The need for inspection of vehicles and cargo and the availability of a safe place to conduct inspections with a minimum of traffic interference;

(g) The 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;

(h) A plan developed by an operating agency in a dense urban area is referenced in Appendix H. This might not be suitable for all such facilities.

Chapter 11 Referenced Publications

11-1 The following documents or portions thereof are referenced within this recommended practice and should be considered part of the recommendations of this document. The edition indicated for each reference is the current edition as of the date of the NFPA issuance of this document.

11-1.1 NFPA Publications. National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.

NFPA 10, *Standard for Portable Fire Extinguishers*, 1994 edition.

NFPA 14, *Standard for the Installation of Standpipe and Hose Systems*, 1996 edition.

NFPA 20, *Standard for the Installation of Centrifugal Fire Pumps*, 1996 edition.

NFPA 22, *Standard for Water Tanks for Private Fire Protection*, 1996 edition.

NFPA 30, *Flammable and Combustible Liquids Code*, 1996 edition.

NFPA 30A, *Automotive and Marine Service Station Code*, 1996 edition.

NFPA 70, *National Electrical Code*, 1996 edition.

NFPA 72, *National Fire Alarm Code*, 1996 edition.

NFPA *101*, *Life Safety Code*, 1994 edition.

NFPA 241, *Standard for Safeguarding Construction, Alteration, and Demolition Operations*, 1996 edition.

NFPA 1963, *Standard for Fire Hose Connections*, 1993 edition.

11-1.2 Other Publications.

11-1.2.1 ASHRAE Publication. American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., 1725 Tullie Circle, Atlanta, GA 30329.

ASHRAE *Handbook — Applications*, 1995 edition.

11-1.2.2 ASTM Publications. American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

ASTM E 119, *Standard Test Methods for Fire Tests of Building Construction and Materials*, A-1995.

ASTM E 136, *Standard Test Method for Behavior of Materials in a Vertical Tube Furnace at 750 Degrees C*, A-1994.

11-1.2.3 IES Publications. Illuminating Engineering Society, 345 East 47th Street, New York, NY 10017.

ANSI/IES RP-8, *American National Standard Practice for Roadway Lighting*, 1983.

ANSI/IES RP-22, *American National Standard Practice for Tunnel Lighting*, 1987.

11-1.2.4 U.S. Government Publications. Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20401.

Title 29, *Code of Federal Regulations*, Subtitle B, Chapter XVII, Part 1910, Subpart S, "Underground Construction, Caissons, and Compressed Air," 1994.

Title 29, *Code of Federal Regulations*, Subtitle B, Chapter XVII, Part 1910, Subpart S, "Electrical," 1994.

Title 49, Department of Transportation, *Code of Federal Regulations*, 177.810, "Vehicle Tunnels."

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

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

Title 49, Department of Transportation, *Code of Federal Regulations*, Part 397, Subpart D, "Routing of Class 7 (Radioactive) Materials."

Title 49, Department of Transportation, *Code of Federal Regulations*, Part 397, Subpart E, "Preemption Procedures."

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

"Guidelines for Applying Criteria to Designate Routes for Transporting Hazardous Materials," DOT/RSPA/OHMT-89-02-1989.

"Guidelines for Selecting Preferred Highway Routes for Highway Route-Controlled Quantity Shipments of Radioactive Materials."

US DOT, Federal Highway Administration, Pub # FHWA-SA-94-083. Available through National Technology, September 1, 1994. Information Service, Springfield, VA 21661

11-1.2.5 MUTCD. *Manual on Uniform Traffic Control Devices for Streets and Highways.*

Appendix A Explanatory Material

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

A-1-12.1 See ASTM E 380, *Standard Practice for Use of the International System of Units (SI) (the Modernized Metric System)*, and ANSI/IEEE 268, *American National Standard for Metric Practice.*

A-1-13 Approved. The National Fire Protection Association does not approve, inspect, or certify any installations, procedures, equipment, or materials; nor does it approve or evaluatetesting 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 concerned with product evaluations that is in a position to determine compliance with appropriate standards for the current production of listed items.

A-1-13 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-1-13 Listed. The means for identifying listed equipment may vary for each organization concerned with product evaluation, some of which 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-1-13 Point of Safety. The egress population to be served should be determined by engineering analysis.

A-2-4.2 Such procedures have the dual purpose of preventing the involvement of additional vehicles in the original accident and of slowing traffic during inclement weather conditions.

Appendix B Air Quality Criteria in Emergencies

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

B-1 General.

B-1.1 In this appendix, criteria for the protection of the motorist, employee, and fire fighter during emergency situations are provided with regard to air quality, temperatures, and velocities.

B-1.2 To a large extent, the quantitative aspects of the criteria for emergency situations is arbitrary because there are no universally accepted tolerance limits pertaining to air quality, temperatures, and velocities. In fact, tolerance limits vary with age, health, weight, sex, and acclimatization. Most of the studies on human tolerance to adverse situations have dealt with exposure tests on healthy, acclimated adults. These individuals can survive in environments potentially harmful to the less physically fit. Criteria should instead be established based on the tolerances of higher risk groups: infants, the aged, and those suffering from respiratory or cardiac ailments. Little information is available on the physiological tolerance limits of people with health impediments, especially for short-term but intense exposures.

B-2 Emergency Air Quality Criteria.

B-2.1 During tunnel emergencies involving fire or generation of smoke, the products of combustion produce gases and aerosols, some of which are potentially toxic or incapacitating. The aerosols in smoke also tend to limit visibility. In the event of fire, the intended purpose of all emergency ventilation equipment, therefore, is to provide control of smoke migration and an effective means to purge smoke and supply fresh air to motorists and fire department personnel during evacuation and early fire-fighting operations.

B-2.2 Since some emergency situations could conceivably occur where all motorists cannot be provided with fresh air for the entire length of an evacuation route, criteria are needed to maintain air quality for those passengers. Such a situation would exist, for example, where two fire incidents have occurred in a tunnel. Because fresh air might come from only one direction, motorists positioned between the incidents could be exposed to air containing some combustion products, while motorists located in areas beyond either incident receive fresh air. Sufficient fresh air, however, needs to be supplied to motorists downwind of a fire to dilute adequately any harmful combustion product.

B-2.2.1 The usual way in which potentially harmful gases or aerosols enter the human body is through the respiratory tract. The physiological reactions of a person depend on the contaminant and its concentration and exposure time and will vary for each person. A person's reaction to potentially harmful combustion products is proportional to a characteristic of the environment that is quantified by the concentration-time product, CT.

B-2.2.2 During design, the ventilation engineer does not know how much of the smoke and combustion products will be made airborne or the exposure time of passengers in the smoke. These quantities depend on the nature of the emergency, the construction materials, and the tunnel's overall emergency policies. Nevertheless, emergency ventilation systems need to be sized, and some guidance is provided by approximating the concentration-time product, CT, for different airflow rates. (*See Subway Environmental Design Handbook, Vol. I, Principles and Applications.*)

B-3 Emergency Air Temperature Criteria.

B-3.1 It is anticipated that the 140°F (60°C) air temperature will place a physiological burden on a few motorists, but the exposure also is anticipated to be brief and to produce no lasting harmful effects. Motorists should not be exposed to maximum air temperatures exceeding 140°F (60°C) during emergencies. The heat released from a fire depends on the type and amount of material burning as well as the rate at which it burns. In a tunnel, the materials capable of supporting combustion are engine fuel, plastics, oil, wood, paper, cardboard, and bituminous products.

B-3.2 Studies of the severity of tunnel fires with respect to human environmental criteria demonstrate that the air temperature in the absence of toxic smoke is a limiting criterion for human survival.

B-4 Emergency Air Velocity Criteria. The purpose of ventilation equipment in a tunnel emergency is to sweep out heated air and to remove the smoke caused by any fire. In essentially all emergency cases, protection of the motorists and employees is enhanced by prompt activation of emergency ventilation procedures as planned in advance.

B-4.1 When emergency ventilation air is needed in evacuation routes, it might be necessary to expose passengers to air velocities higher than those permitted by normal nuisance considerations. The only upper limit to the ventilation rate occurs when the air velocity becomes great enough to create a hazard to persons walking in that airstream. According to the descriptions of the effects of various air velocities given in the Beaufort scale, motorists under emergency conditions can tolerate as much as 2200 ft/min (11 m/s).

B-4.2 The minimum air velocity within the tunnel section experiencing the fire emergency should be sufficient to mitigate backlayering of the smoke (i.e., a flow of smoke in the upper cross section of the tunnel that is opposite in direction to the forced ventilation air).

B-4.3 Increasing the airflow rate in the tunnel decreases the airborne concentration of potentially harmful chemical compounds (referred to hereinafter by the general term "smoke"). The decrease in concentration is beneficial to those exposed to the compounds. However, a situation could arise in which the smoke source is completely removed and poses no threat of exposure to passengers, and actuating any fans would draw the smoke to the evacuation routes. Under these conditions, the fans should not be activated until it is safe to do so. To make decisions under these circumstances, a rapid and thorough communication system is needed so that the responsible personnel can make judgments based on information available that are consistent with established emergency policies.

B-4.4 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 Btu of the vehicle.

Appendix C Critical Velocity Calculations

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

The simultaneous solution of equations C-1 and C-2, by iteration, determines the critical velocity. The critical velocity is the minimum steady-state velocity of the ventilation air moving toward the fire that is necessary to prevent backlayering:

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

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

where:

A = Area perpendicular to the flow [ft² (m²)].
C_p = The specific heat of air [Btu/lb R (kJ/kg K)].
g = The acceleration caused by gravity [ft/sec-sec (m/s-s)].
H = The height of the duct or tunnel at the fire site [ft (m)].
K_1 = 0.606.
K_g = Grade factor (see chart below).
Q = The heat the fire is adding directly to the air at the fire site [Btu/hr (MW)].
T = The temperature of the approach air [°F (°C)].
T_f = The average temperature of the fire site gases [°F (°C)].
V_c = Critical velocity [ft/min (m/s)].
ρ = The average density of the approach (upstream) air [lb/ft³ (kg/m³)].

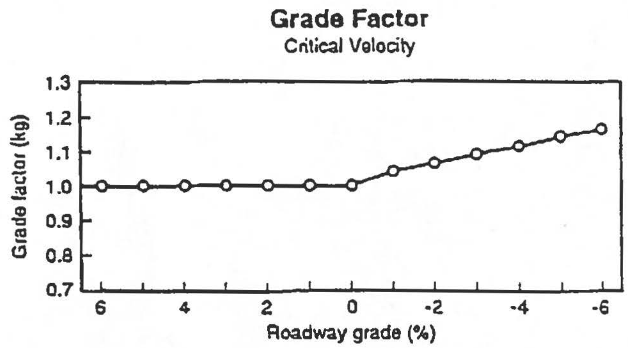

Figure C-1 Grade factor for determining critical velocity.

Appendix D Fire Sprinklers in Highway Tunnels

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

D-1 General. This appendix provides design considerations for fire sprinklers in road tunnels.

D-1.1 Currently, the use of and effectiveness of fire sprinklers in vehicular roadway tunnels is 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 or severity of the fire. Furthermore, it is felt that vehicular tunnel conditions cannot exploit sprinkler system strengths and could turn most of their advantages into disadvantages.

D-1.2 The major concerns expressed by tunnel authorities regarding fire sprinkler use and effectiveness include the following:

(a) Typical fires usually occur under vehicles or inside passenger or engine compartments designed to be waterproof from above; therefore, overhead sprinklers would have no extinguishing effect.

(b) A thin water spray on a very hot fire, if any delay occurs between ignition and sprinkler activation, will produce large quantities of superheated steam without materially suppressing the fire. This steam has the potential to be more damaging than smoke.

(c) 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.

(d) Because of stratification of the hot gases 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.

(e) Even a light spray from sprinklers would catch motorists unaware and would be in excess of that which windshield wipers could clear (even if they were on), possibly causing the roadway to become dangerously slippery.

(f) Water squirting from the ceiling of a subaqueous tunnel could suggest tunnel failure and induce panic in motorists.

(g) The use of sprinklers could cause the delamination of the smoke layer and induce turbulence and mixing of the air and smoke, thus threatening the safety of persons in the tunnel.

(h) Testing of a fire sprinkler system on a periodic basis to determine its state of readiness is impractical and costly.

D-1.3 Because of the concerns detailed in D-1.2, the use of sprinklers in highway tunnels generally is not recommended. However, three recently commissioned U.S. vehicular 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 was motivated solely by the fact that these tunnels will be operated to allow the unescorted passage of vehicles carrying/hauling hazardous cargo.

D-2 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-3 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 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-5 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.

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.

Appendix E Emergency Response Plan Outline

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

E-1	General.
E-1.1	Purpose.
E-1.2	Background.
E-2	Emergency Response Plan.
E-2.1	General.
E-2.2	Elements of the Plan.
E-2.2.1	Central Supervising Station (CSS).
E-2.2.2	Alternate CSS.
E-2.2.3	Incident/Activity Identification Systems.
E-2.2.4	Emergency Command Posts.
E-2.3	Operational Considerations.
E-2.4	Types of Incidents.
E-2.5	Possible Locations of Incidents.
E-2.6	Incidents on Approach Roadways.
E-2.7	Incidents within Tunnel or Facility.
E-3	Coordination with Other Responsible Agencies.
E-3.1	Fire Fighting Operational Procedures.
E-3.2	Traffic Management.
E-3.3	Medical Evacuation Plan.
E-3.4	Emergency Alert Notification Plan.

Appendix F Alternative Fuels

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

F-1 General. Most vehicles currently in the traffic population are powered by either spark-ignited or compression-ignited engines. Vehicles that use alternative fuels such as CNG, LPG, and LNG are being introduced into the vehicle population, but their percentage of the population is still too low for their characteristics to be a significant influence in the design of highway tunnel ventilation with regard to vehicle emissions. However, growing concerns regarding the safety of some of these vehicles operating within tunnels might soon affect the fire-related life safety design aspects of highway tunnels.

It is evident that there will be continued growth in the use of vehicles powered by alternative fuels (i.e., fuels other than gasoline or diesel). Of these potential alternative fuels, liquefied petroleum gas (LPG) currently is the most widely used, although the use of both compressed natural gas (CNG) and liquefied natural gas (LNG) are 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:

(a) Methanol;
(b) Hydrogen;
(c) Ethanol;
(d) Coal-derived liquids;
(e) Propane;
(f) Biological materials;
(g) Natural gas;
(h) Reformulated gasoline;
(i) Electricity;
(j) "Clean" diesel.

The alternative fuels considered most viable in the near future are compressed natural gas (CNG), liquefied petroleum gas (LPG), liquefied natural gas (LNG), and methanol.

F-2 Compressed Natural Gas. CNG has some excellent physical and chemical properties that make it clearly a safer automotive fuel than gasoline or LPG, 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 about 2 percent for LPG and 1 percent for gasoline vapor. Thus, considerable fuel leakage is necessary in order to render the mixture combustible. Moreover, fires involving combustible mixtures of CNG are relatively easy to contain and extinguish.

Since natural gas is lighter than air, in the event of a leak, it normally dissipates harmlessly into the atmosphere instead of pooling. However, in a tunnel environment, this can lead to pockets of gas collecting in the overhead structure. Also, since natural gas can ignite only in a range of 5 percent to 15 percent volume of natural gas in air, leaks are not likely to ignite because of a lack of sufficient oxygen.

Additionally, the fueling system for CNG is one of the safest in existence. The vigorous 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 LPG 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 comparable to that of gasoline. LPG normally is delivered as a liquid and can be stored at 100.4°F (38°C) on vehicles under a design pressure of 250 psi to 312.5 psi (1624 kPa to 2154 kPa). It is a natural gas and petroleum derivative. On one hand, it is costly to store because a pressure vessel is required. On the other hand, if engulfed in a fire, its heating could result in a rapid increase in pressure, even if the outside temperature is not excessive relative to its vapor pressure characteristics. Rapid pressure increase can be mitigated by venting the excessive buildup of pressure through appropriate relief valves.

F-4 Methanol (Alcohol-Fueled Vehicles). Currently, methanol is used primarily as a chemical feed-stock for the production of chemical intermediates and solvents. Under the EPA's restrictions, it is being used as a substitute for lead-based octane enhancers in the form of methyl tertiary-butyl ether (MTBE) and as a viable method for vehicle emission control. MTBE is not consumed 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 above non-diluted methanol in an enclosed tank are explosive at 50°F to 109.4°F (10°C to 43°C). A methanol flame is invisible, so a colorant or gasoline has to be added to enable detection.

Appendix G The Memorial Tunnel Fire Ventilation Test Program

This Appendix is not a part of the recommendations 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). This involves creating a safe evacuation path for both motorists and any operating personnel located within the tunnel. The secondary purpose of smoke control ventilation is to assist fire-fighting personnel in accessing the fire site, by again providing a clear path to the site if possible.

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

Despite this increasing focus on life safety and fire control in modern highway tunnels, no uniform standards for fire emergency ventilation or other fire control means within highway 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. Accordingly, the design approach currently utilized to detect, control, and suppress fire and smoke within highway tunnels has become a controversial issue among tunnel design engineers, owners, operators, and fire fighters throughout the world.

While most highway tunnels have ventilation systems with smoke control operating modes, there is 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. The American Society of Heating, Refrigerating and Air-Conditioning Engineers Technical Committee 5.9 report, ASHRAE TC 5.9, "Enclosed Vehicular Facilities," had identified the need for a comprehensive full-scale test program in the early 1980s.

Technical Committee 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. This 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 bi-directional), 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.

Establishing specific approaches to permit effective reconfiguration for both new and existing tunnel facilities was deemed of equal importance. The goals and test matrices developed and documented in the "Phase 1 Concept Report" evolved into the described test plan.

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 rate and system configuration that provides effective smoke control during a tunnel fire.

It was even more important to establish specific operational strategies to permit 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-level airflow on the effectiveness of fire suppression systems (such as foam deluge sprinklers) can be better determined on the basis of full-scale test results.

G-4 The Test Facility. The Memorial Tunnel is a two-lane, 2800-ft (854-m) 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 interstate highway in 1987. The existing ventilation equipment was removed to allow 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 200,000 cfm (94.4 m^3/s), and they 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, as well as all the 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 100 gal (400 L) — to 100 MW — equivalent to a hazardous material fire or flammable spill of approximately 200 gal (800 L) — were produced. The fires were generated in four floor-level steel pans in which a metered flow of No. 2 fuel oil up to 2 in. (5 cm) deep was floated on top of a 6-in. (15-cm) layer of water.

Engineering estimates concluded that a fire heat release rate of approximately 10 MW would be produced when an exposed fire surface area of 16 ft^2 (1.5 m^2) is provided. The total surface area of the pans used for a 100-MW fire is 478 ft^2 (44.4 m^2).

The actual burning rate differed somewhat from that used for the engineering estimate, due to effects such as heat re-radiation 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 configured and tested under varying flow rates and varying heat release rates, with one or two zones of ventilation, included:

(a) Transverse ventilation;

(b) Partial transverse ventilation;

(c) Transverse ventilation with point extraction;

(d) Transverse ventilation with oversized exhaust ports;

(e) Natural ventilation;

(f) Longitudinal ventilation with jet fans.

When the first four series of tests in Section G-4(a) through (f) were completed, the tunnel ceiling was removed to conduct the natural ventilation tests, followed by the installation of jet fans at the crown of the tunnel for the longitudinal jet fan-based ventilation tests.

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

G-6 Data Collection. All of the 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. Various trend graphs and reports were generated from the data acquisition system. The DAS consisted of five data acquisition units (DAUs), three located in the tunnel and two in the portal electrical equipment rooms. The DAS central processing units (CPUs), operator consoles, dataloggers, printer, and tape drives were located in the control trailer. The accuracy of the DAS input/output cards is ±0.05 percent.

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 from 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.

There were instrument trees located at ten tunnel cross sections, which were designed to measure airflow to a modified ASHRAE traverse method. At these locations, Type K thermocouples with an expected accuracy of ± 0.75 percent were located at each air velocity sensor and measured air temperature from 32°F to 2500°F (0°C to 1370°C).

Additional temperature measurements also were taken at five other tunnel cross sections and at two locations (15 m) 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 designed to measure very low pressure ranges from 0 psi to 1/4 psi (0 Pa to 61 Pa). 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 located in the electrical equipment rooms. Sample gases were analyzed within the analysis cabinets for two ranges of CO, CO_2, and total hydrocarbon context (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 capable of detecting carbon monoxide, total hydrocarbon, oxygen, and methane were provided for personnel safety when entering the tunnel after fire tests.

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

These weather-related parameters were monitored for over 1 1/2 years to track weather conditions to assist in planning, scheduling, and conducting the tests.

G-7 Instrumentation. Specific instrumentation was provided to monitor and record the following variables during the fire tests:

(a) Air temperature;

(b) Air velocity;

(c) Gas concentrations.

G-8 Cameras. The closed-circuit television (CCTV) system originally included six cameras, two located within 203 ft to 217 ft (62 m to 66 m) of the fire area, two located outside of the tunnel (near the portals), and two located on the north and south meteorological towers. Another roadway-level camera was added during the tests that was located 1100 ft (335 m) north of the fire to secure added video footage of smoke movement.

Each of the four outdoor cameras had pan-tilt-zoom capabilities. They were used to monitor the fire area, visibility obscuration, and smoke stratification. Instrumentation to monitor and record important parameters of the fire suppression system, the chilled water system used for equipment cooling, and the compressed air and fuel oil systems also were included.

G-9 Conclusions. The Memorial Tunnel Fire Ventilation Test Program represents a unique opportunity to evaluate and develop design methods and operational strategies leading to safe underground transportation facilities. This comprehensive test program, which began with the initial fire tests in September 1993 and concluded with the final tests in March 1995, produced much-needed data that was acquired in a full-size facility, under controlled conditions and over a wide range of system parameters.

The results of the test program were processed and made available to the professional community for use in the development of emergency tunnel ventilation design and emergency operational procedures in late 1995, titled: "Memorial Tunnel Fire Ventilation Test Program Test Report," prepared for Massachusetts Highway Department, prepared by Bechtel/Parsons Brinckerhoff, November, 1995.

Appendix H Referenced Publications

H-1 The following documents or portions thereof are referenced within this recommended practice for informational purposes only and thus are not considered part of the recommendations of this document. The edition indicated for each reference is the current edition as of the date of the NFPA issuance of this document.

H-1.1 NFPA Publications. National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.

NFPA 30, *Flammable and Combustible Liquids Code*, 1996 edition.

NFPA 130, *Standard for Fixed Guideway Transit Systems*, 1995 edition.

NFPA 259, *Standard Test Method for Potential Heat of Building Materials*, 1993 edition.

H-1.2 Other Publications.

H-1.2.1 ANSI Publication. American National Standards Institute, 11 West 42nd Street, New York, NY 10036.

ANSI/IEE 268, *American National Standard for Metric Practice*, 1992.

H-1.2.2 ASHRAE Publication. American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., 1725 Tullie Circle, Atlanta, GA 30329.

ASHRAE TC 5.9, "Enclosed Vehicular Facilities."

H-1.2.3 ASTM Publications. American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

ASTM E 136, *Standard Test Method for Behavior of Materials in a Vertical Tube Furnace at 750 Degrees C*, A-1994.

ASTM E 380, *Standard Practice for Use of the International System of Units (SI) (the Modernized Metric System)*, 1993.

H-1.2.4 *Transportation Regulations at Tunnel and Bridge Facilities Hazardous Materials*, The Port Authority of New York and New Jersey, One World Trade Center, New York, New York 10048, November 23, 1987.

H-1.2.5 *Subway Environmental Design Handbook, Vol. I, Principles and Applications*, 2nd edition, 1976, Associated Engineers — A Joint Venture: Parsons Brinckerhoff Quade & Douglas, Inc., Delew Cather and Company; Kaiser Engineers, under the direction of Transit Develop Corporation, Inc.

Index