NFPA® 556

Guide on Methods for Evaluating Fire Hazard to Occupants of Passenger Road Vehicles

2024 Edition

NFPA, 1 Batterymarch Park, Quincy, MA 02169-7471
An International Codes and Standards Organization

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NFPA® 556

Guide on

Methods for Evaluating Fire Hazard to Occupants of Passenger Road Vehicles

2024 Edition

This edition of NFPA 556, *Guide on Methods for Evaluating Fire Hazard to Occupants of Passenger Road Vehicles,* was prepared by the Technical Committee on Hazard and Risk of Contents and Furnishings. It was issued by the Standards Council on April 23, 2023, with an effective date of May 13, 2023, and supersedes all previous editions.

This edition of NFPA 556 was approved as an American National Standard on May 13, 2023.

Origin and Development of NFPA 556

The 2011 edition was the first for this guide. Its development was prompted in part by fire statistics associated with vehicles as well as car and van fire research documented by the National Highway Traffic Safety Administration. Those statistics and research prompted the committee's opinion that the current method of evaluating vehicle materials was unsatisfactory. NFPA 556 identified major fire safety concerns associated with passenger road vehicles and provided guidance on newer evaluation methods with the aim of decreasing the fire hazard and fire risk associated with such vehicles. In addition, NFPA 556 provided guidance and tools for those persons investigating methods to decrease the fire hazard or fire risk in passenger road vehicles and for a hazard-based assessment for the development of hazardous conditions from fire involving passenger road vehicles.

The 2016 edition contained new language for noncombustible material criteria and new language recognizing the school bus seat upholstery fire block test. Table 10.1 was revised to include test methods and tools for seat materials for school buses and additional evaluation options for windshields based on flame spread or fire resistance testing. Additional updates to terminology, definitions, and testing notations were made throughout the document to reflect industry standards and technology.

The 2020 edition contained new language for defining a limited-combustible material and recognized ASTM E2965, *Standard Test Method for Determination of Low Levels of Heat Release Rate for Materials and Products Using an Oxygen Consumption Calorimeter,* as one way to assess whether a material is a limited-combustible material. Reference documents were updated to reflect the most current editions available.

The 2024 edition contains updated statistics on vehicle fire losses from a new reference publication. Additional language detailing the hazard of pool fires has been added to Chapter 11. Reference documents were updated to reflect the most current editions available.

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Methods for Evaluating Fire Hazard to Occupants of Passenger Road Vehicles

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

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

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

Chapter 1 Administration

1.1 Scope.

1.1.1 This document addresses issues associated with the development of hazardous conditions from fire involving passenger road vehicles and the time available for safe egress or rescue.

1.1.2 This document provides guidance toward a systematic approach of the determination of the relationship between the properties of passenger road vehicles, including the materials, components and systems, and the development of hazardous conditions in the vehicle. This approach can include small-scale testing, full-scale testing of systems or entire vehicles, and computer modeling techniques in specified, well-defined scenarios.

1.1.3 The principles and concepts presented in this document provide a methodology that can be used to determine the effects of changes in design or in the properties of materials, components, and assemblies in passenger road vehicles on the development of hazardous fire conditions in passenger road vehicles in response to specified well-defined scenarios.

1.1.4 This document provides a methodology that can be used in the selection of materials and design of components and systems, with the intent of providing a desired level of fire safety to occupants in passenger road vehicles in response to specific fire scenarios.

1.1.5 The use of this document cannot eliminate all fire risk in passenger road vehicles.

1.1.6 The uncertainty of the fire hazard analysis resulting from the application of this document is a function of the accuracy, precision, and relevance of the data, correlations, test methods, calculations, and simulations used.

1.2 Purpose.

1.2.1 The purpose of this document is to provide guidance and tools for persons investigating methods to decrease the fire hazard or fire risk in passenger road vehicles by providing additional time for occupants of the passenger road vehicle to be able to exit or be rescued in case of the occurrence of a fire involving the passenger road vehicle.

1.2.2 This document is intended to provide guidance for a hazard-based assessment for the development of hazardous conditions from fire involving passenger road vehicles. This document does not provide guidance for a complete risk-based assessment. A risk analysis, taking into account the probability and consequences of an event or events, can help focus passenger road vehicle safety efforts on solutions with the greatest impact on passenger road vehicle–related deaths. Strategies for reducing fire deaths in passenger road vehicles should not adversely affect efforts to reduce the overall number of deaths in passenger road vehicles. This statistic can be gauged by comparing the estimated lives saved per year by various strategies.

1.2.3 Flammability is one of a number of material properties to be considered in the design of components for passenger road vehicles. The physical properties of materials used in passenger road vehicles affect the vehicles' overall safety (including crashworthiness and fire safety), fuel economy, emissions (both tailpipe and evaporative emissions), manufacturability, utility, and durability. Optimizing a material for flammability could result in substantial degradation of other properties of that material, which could, in turn, render that material unsuitable for use in its intended application in a passenger road vehicle. Material properties that have been found to affect the overall safety, fuel economy, emissions, manufacturability, utility, and durability of passenger road vehicles and are currently considered when selecting a material for use in a passenger road vehicle are discussed in this document. Therefore, proposed changes to flammability properties of a material or component should also consider how those changes could affect the properties discussed in this document.

Δ 1.3 Application.

1.3.1 This document applies to passenger road vehicles used to transport people who are either drivers or passengers in the passenger road vehicle.

1.3.2 This document applies to all portions of a passenger road vehicle that have the potential to affect the fire safety of drivers or passengers.

1.3.3 It is not intended that the provisions of this document be applied to compartments in vehicles such as ships, trains, airplanes, or off-road vehicles, irrespective of whether they are or are not intended for use by human passengers or drivers.

1.3.4 This document describes standard tests conducted under controlled laboratory conditions. Such tests should not be deemed to establish performance levels for all situations.

1.3.5 The choice of an effective and reliable means to achieve the fire performance objectives should be based on an evaluation that includes all conditions of the hazard and protection as well as the quantification of egress time.

1.3.6 The use of sound scientific and engineering principles and recognition of limitations in data, test procedures, fire models, and state-of-the-art scientific knowledge should be considered in the application of this document.

1.3.7 As every passenger road vehicle fire and explosion incident is in some way different and unique from all other incidents, this document is not designed to encompass all the necessary components of a complete analysis of any one scenario. Thus, not every portion of this document may be applicable to every passenger road vehicle fire scenario. It is up to the user of this document to apply the appropriate methodology to a particular passenger road vehicle fire scenario.

1.4 Units and Formulas. Table 1.4 provides the nomenclature used in this document.

Table 1.4 Nomenclature

FPI	Fire performance index (sec m^2/kW)
$H_{c,\ eff}$	Effective heat of combustion (MJ/kg)
$HRR_{a,\ avg}$	Average heat release rate per unit area over entire test period (kW/m^2)
$HRR_{180\ sec}$	Average heat release rate per unit area over a 3-minute period following ignition (kW/m^2)
$M_{sec}L_{sec}$	Mass loss
MLR_{avg}	Average mass loss rate (g/sec)
$PHRR_a$	Peak heat release rate per unit area (MJ/m^2)
$PSRR_a$	Peak smoke release rate (1/sec)
SEA	Average specific extinction area (m^2/kg)
$SmkFct$	Smoke factor
t_{ig}	Time to ignition (sec)
$t_{400\ kW}$	Predicted time to 400 kW (sec or min)
THR_a	Total heat released per unit area (kW/m^2)
TSR_a	Total smoke release (nondimensional)
TTE	Time to extinction (sec)

Chapter 2 Referenced Publications

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

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

NFPA 253, *Standard Method of Test for Critical Radiant Flux of Floor Covering Systems Using a Radiant Heat Energy Source,* 2023 edition.

NFPA 257, *Standard on Fire Test for Window and Glass Block Assemblies,* 2022 edition.

NFPA 259, *Standard Test Method for Potential Heat of Building Materials,* 2023 edition.

NFPA 260, *Standard Methods of Tests and Classification System for Cigarette Ignition Resistance of Components of Upholstered Furniture,* 2024 edition.

NFPA 261, *Standard Method of Test for Determining Resistance of Mock-Up Upholstered Furniture Material Assemblies to Ignition by Smoldering Cigarettes,* 2023 edition.

NFPA 270, *Standard Test Method for Measurement of Smoke Obscuration Using a Conical Radiant Source in a Single Closed Chamber,* 2023 edition.

NFPA 289, *Standard Method of Fire Test for Individual Fuel Packages,* 2023 edition.

NFPA 555, *Guide on Methods for Evaluating Potential for Room Flashover,* 2021 edition.

2.3 Other Publications.

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

ASTM D2859, *Test Method for Ignition Characteristics of Finished Textile Floor Covering Materials*, 2016 (2021).

ASTM D3675, *Test Method for Surface Flammability of Flexible Cellular Materials Using a Radiant Heat Energy Source*, 2022.

ASTM D6113, *Test Method for Using Cone Calorimeter to Determine Fire-Test-Response Characteristics of Insulating Materials Contained in Electrical or Optical Fire Cables*, 2021.

ASTM E84, *Test Method for Surface Burning Characteristics of Building Materials*, 2022.

ASTM E119, *Test Methods for Fire Tests of Building Construction and Materials*, 2022.

ASTM E136, *Test Method for Assessing Combustibility of Materials Using a Vertical Tube Furnace at 750°C*, 2022.

ASTM E162, *Test Method for Surface Flammability of Materials Using a Radiant Heat Energy Source*, 2022.

ASTM E603, *Guide for Room Fire Experiments*, 2017.

ASTM E648, *Test Method for Critical Radiant Flux of Floor-Covering Systems Using a Radiant Heat Energy Source*, 2019a e1.

ASTM E662, *Test Method for Specific Optical Density of Smoke Generated by Solid Materials*, 2021a e1.

ASTM E814, *Test Method for Fire Tests of Penetration Firestop Systems*, 2013a (2017).

ASTM E1321, *Test Method for Determining Material Ignition and Flame Spread Properties*, 2018.

ASTM E1354, *Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter*, 2022b.

ASTM E1474, *Test Method for Determining the Heat Release Rate of Upholstered Furniture and Mattress Components or Composites Using a Bench Scale Oxygen Consumption Calorimeter*, 2022.

ASTM E1529, *Test Methods for Determining Effects of Large Hydrocarbon Pool Fires on Structural Members and Assemblies*, 2022.

ASTM E1546, *Guide for Development of Fire-Hazard-Assessment Standards*, 2021.

ASTM E1623, *Test Method for Determination of Fire and Thermal Parameters of Materials, Products, and Systems Using an Intermediate Scale Calorimeter (ICAL)*, 2022.

ASTM E1995, *Test Method for Measurement of Smoke Obscuration Using a Conical Radiant Source in a Single Closed Chamber, With the Test Specimen Oriented Horizontally*, 2021.

ASTM E2061, *Guide for Fire Hazard Assessment of Rail Transportation Vehicles*, 2020.

ASTM E2067, *Practice for Full-Scale Oxygen Consumption Calorimetry Fire Tests*, 2022.

ASTM E2102, *Test Method for Measurement of Mass Loss and Ignitability for Screening Purposes Using a Conical Radiant Heater*, 2021.

ASTM E2280, *Guide for Fire Hazard Assessment of the Effect of Upholstered Seating Furniture Within Patient Rooms of Health Care Facilities*, 2021.

ASTM E2574/E2574M, *Test Method for Fire Testing of School Bus Seat Assemblies*, 2017 (2021).

ASTM E2652, *Test Method for Assessing Combustibility of Materials Using a Tube Furnace with a Cone-shaped Airflow Stabilizer, at 750°C*, 2018.

ASTM E2965, *Test Method for Determination of Low Levels of Heat Release Rate for Materials and Products Using an Oxygen Consumption Calorimeter*, 2022.

2.3.2 ISO Publications. International Organization for Standardization, ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland.

ISO 3795, *Road Vehicles, and Tractors and Machinery for Agriculture and Forestry — Determination of Burning Behaviour of Interior Materials*, 1989.

ISO TS 17431, *Fire Tests — Reduced Scale Model Box Test*, 2006.

2.3.3 SAE Publications. SAE International, Society of Automotive Engineers, 901 15th Street, NW, Suite 520, Washington, DC 20005.

ANSI/SAE Z–26.1, *American National Standard for Safety Glazing Materials for Glazing Motor Vehicles and Motor Vehicle Equipment Operating on Land Highways - Safety Standard*, 1996.

SAE J2464, *Electric and Hybrid Electric Vehicle Rechargeable Energy Storage System (RESS) Safety and Abuse Testing*, 2021.

2.3.4 SFPE Publications. Society of Fire Protection Engineers, 9711 Washingtonian Blvd, Suite 380, Gaithersburg, MD 20878.

SFPE Engineering Guide to Performance-Based Fire Protection, 2nd edition.

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

UL 9, *Fire Tests of Window Assemblies*, 2009, revised 2020.

UL 263, *Fire Tests of Building Construction and Materials*, 2011, revised 2022.

UL 723, *Test for Surface Burning Characteristics of Building Materials*, 2018.

UL 1479, *Fire Tests ofPenetration Firestops*, 2015, revised 2021.

UL 1685, *Vertical-Tray Fire-Propagation and Smoke-Release Test for Electrical and Optical-Fiber Cables*, 2015, revised 2020.

UL 1709, *Rapid Rise Fire Tests of Protection Materials for Structural Steel*, 2022.

UL 2556, *Wire and Cable Test Methods*, 2021.

2.3.6 US DOT Publications. Federal Motor Vehicle Safety Standards, US Department of Transportation/National Highway Traffic Safety Administration, 400 Seventh Street, SW, Washington, DC 20590.

49 CFR 571.302/FMVSS 302, "Flammability of Interior Materials," October 1, 2011.

2.3.7 Other Publications.

BS EN 13823, *Reaction to fire tests for building products. Building products excluding floorings exposed to the thermal attack by a single burning item*, British Standards Institution, London, United Kingdom.

ECE R34.01, Annex 5, Fire Risks — European Economic Community Regulation — *Fire safety of plastic fuel tanks for automobiles* (ECE R34, Annex 5, RREG 70/221/EWG, 2000/8/EG).

JIS D 1201, *Road Vehicles, and Tractors and Machinery for Agriculture and Forestry — Determination of Burning Behaviour of Interior Materials*, Japanese Standards Association, Tokyo, Japan, 1998.

Merriam-Webster's Collegiate Dictionary, 11th edition, Merriam-Webster, Inc., Springfield, MA, 2020.

National School Transportation Specifications & Procedures, Adopted by the Fifteenth National Congress on School Transportation, 2010 revised edition.

2.3.8 List of Publications.

(1) "Traffic Safety Facts 2006." National Center for Statistics and Analysis, National Highway Traffic Safety Administration.

(2) Blincoe, L. J., et al. "The Economic Impact of Motor Vehicle Crashes 2000." DOT HS 809 446, US Department of Transportation, National Highway Traffic Safety Administration, May 2002.

(3) Digges, K. H. and Stephenson, R. R. "A Research Program to Study Impact Related Fire Safety." Motor Vehicle Fire Research Institute (MVFRI) Paper Number 050448.

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(6) "Motor Vehicle Facts and Figures 2006," Alliance of the Automobile Manufacturers, Ward's, Southfield, MI, 2006.

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(11) Bundy, M., and Ohlemiller, T.J., "Full-Scale Flammability Measures for Electronic Equipment, NIST Technical Note 1461," NIST, Gaithersburg, MD, 2004.

(12) "Recommendations for testing the flammability and smoke emission characteristics of transit bus and van materials such as seating, panels, flooring, insulation, and miscellaneous." October 20, 1993. *Federal Register*, Vol. 58. No. 201.

(13) "Motor Vehicle Safety Standard No. 302, Flammability of Materials — Passenger Cars, Multipurpose Passenger Vehicles, Trucks and Buses." Washington, DC: National Highway Traffic Safety Administration. [Code of Federal Regulations § 571.302, originally *Federal Register* 34, No. 229, pp. 20434–20436 (December 31, 1969).]

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(16) Janssens, M. L., S. E. Dillon, and M. M. Hirschler. 2001. "Using the Cone Calorimeter as a Screening Tool for the NFPA 265 and NFPA 286 Room Test Procedures." *Fire and Materials 2001 Conference*, San Francisco, CA, January 22–24, 2001. London: Interscience Communications, 529–540.

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2.4 References for Extracts in Advisory Sections.

NFPA 268, *Standard Test Method for Determining Ignitability of Exterior Wall Assemblies Using a Radiant Heat Energy Source,* 2022 edition.

NFPA 270, *Standard Test Method for Measurement of Smoke Obscuration Using a Conical Radiant Source in a Single Closed Chamber,* 2023 edition.

NFPA 289, *Standard Method of Fire Test for Individual Fuel Packages,* 2023 edition.

NFPA 318, *Standard for the Protection of Semiconductor Fabrication Facilities,* 2022 edition.

NFPA 555, *Guide on Methods for Evaluating Potential for Room Flashover,* 2021 edition.

NFPA 921, *Guide for Fire and Explosion Investigations,* 2021 edition.

NFPA 5000®, Building Construction and Safety Code®, 2024 edition.

Chapter 3 Definitions

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

3.2 NFPA Definitions.

3.2.1* Approved. Acceptable to the authority having jurisdiction.

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

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

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

3.2.5 Shall. Indicates a mandatory requirement.

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

3.2.7 Standard. An NFPA standard, the main text of which contains only mandatory provisions using the word "shall" to indicate requirements and that is in a form generally suitable for mandatory reference by another standard or code or for adoption into law. Nonmandatory provisions are not to be considered a part of the requirements of a standard and shall be located in an appendix, annex, footnote, informational note, or other means as permitted in the NFPA manuals of style. When used in a generic sense, such as in the phrases "standards development process" or "standards development activities," the term "standards" includes all NFPA standards, including codes, standards, recommended practices, and guides.

3.3 General Definitions.

3.3.1 Accidental Fire. Fire for which the cause does not involve a human act with the intent to ignite or spread a fire.

3.3.2 Area of Fire Origin. See 3.3.3.

3.3.3 Area of Origin. The area where a fire began.

3.3.4 Bed (in the cargo-carrying area). A rear cargo area predominantly found in trucks.

3.3.5 Bulkhead. The separation between the passenger compartment and the engine compartment; however, bulkhead(s) may also separate other vehicle compartments.

Δ **3.3.6 Cause.** The circumstances, conditions, or agencies that brought about or resulted in the fire or explosion incident, damage to property, bodily injury, or loss of life. [**921,** 2021]

Δ **3.3.7* Combustible.** Capable of undergoing combustion. [**921,** 2021]

Δ **3.3.8 Combustion Products.** The heat, gases, volatilized liquids and solids, particulate matter, and ash generated by combustion. [**921,** 2021]

3.3.9* Contents and Furnishings of a Vehicle. Any objects in a vehicle that normally are secured or otherwise put in place for functional or decorative reasons, excluding parts of the structure of the vehicle.

3.3.10 Egress. The process of vehicle occupants traveling to location(s) outside of the vehicle.

3.3.11 Engine Compartment. The compartment where the engine and its associated parts are permanently installed.

3.3.12 Fire. An oxidation process, which is a chemical reaction resulting in the evolution of light, heat, and combustion products.

3.3.13* Fire Performance Index (as related to cone calorimeter data). Ratio of the time to ignition to the peak heat release rate (in sec m^2/kW).

3.3.14 Fire Resistance. The ability of a material, product, or assembly to withstand fire or give protection from it for a period of time.

3.3.15* Fire Scenario (Vehicular). A set of conditions that defines the development of fire, the spread of combustion products throughout a vehicle or portion of a vehicle, the reactions of people to fire, and the effects of combustion products.

Δ **3.3.16 Fire Spread.** The movement of fire from one place to another. [**921,** 2021]

3.3.17 Flame Spread. Progression of the leading edge of a flame through a gaseous mixture or across the surface of a liquid or solid.

3.3.18 Flammable. (1) Capable of burning with a flame under specified conditions, or (2) when used to designate high hazard, subject to easy ignition and rapid flaming combustion.

3.3.19 Flashover. A stage in the development of a contained fire in which all exposed surfaces reach ignition temperatures more or less simultaneously and fire spreads rapidly throughout the space.

Δ **3.3.20* Fuel Package.** A grouping of one or more furnishings or contents items, or both, whose proximity is sufficiently close that the ignition of one item can be expected to cause the spread of fire to the remaining items in the fuel package. [**555,** 2021]

Δ **3.3.21 Heat Flux.** The rate of heat transfer per unit area to a surface, typically expressed in kW/m^2 or Btu/ft^2-sec. [**268,** 2022]

3.3.22 Heat of Combustion.

Δ **3.3.22.1** ***Effective Heat of Combustion.*** The measured heat release divided by the mass loss for a specified time period. [**289,** 2023]

Δ **3.3.22.2** ***Net Heat of Combustion.*** The oxygen bomb calorimeter value for the heat of combustion, corrected for the gaseous state of product water. [**289,** 2023]

3.3.23 Heat Release Rate. The heat evolved from the specimen, per unit of time.

3.3.24 Heating, Ventilating, and Air-Conditioning System (HVAC). A system used to provide a means of supplying, returning, and exhausting air from a conditioned space.

Δ **3.3.25 Ignitability.** The propensity for ignition, as measured by the time to sustained flaming, in seconds, at a specified initial test heat flux. [**268,** 2022]

3.3.26 Ignitable Gas. Any gas or the gas phase of any material that is capable of fueling a fire and burning, including a flammable gas.

3.3.27 Ignitable Liquid. Any liquid or the liquid phase of any material that is capable of fueling a fire, including a flammable liquid, combustible liquid, or any other material that can be liquefied and burned.

3.3.28 Ignition. The initiation of combustion evidenced by glow, flame, detonation, or explosion, either sustained or transient.

Δ **3.3.29 Initial Test Heat Flux.** Amount of heat received by a specimen surface per unit area and unit time at the initiation of a test. [**268,** 2022]

Δ **3.3.30* Item.** A single combustible object within the compartment that is permanent or transient, movable, or fixed. [**555,** 2021]

3.3.31 Limited-Combustible Material. See Section 5.5.

3.3.32 Motor Vehicle. A vehicle driven or drawn by mechanical power and manufactured primarily to transport passengers or freight, for use on public streets, roads, and highways, but not a vehicle operated only on a rail line.

3.3.33 Noncombustible Material. See Section 5.4.

Δ **3.3.34 Oxygen Consumption Principle.** The expression of the relationship between the mass of oxygen consumed during combustion and the heat released. [**289,** 2023]

3.3.35 Passenger Compartment. The space inside a vehicle designed for passenger occupancy.

3.3.36 Passenger Road Vehicle. Motor vehicles for use on public streets, roads, and highways for the transport of passengers, such as automobiles (including pickups, minivans, and sports utility vehicles), buses (including school buses), fire department vehicles, trackless trolleys, and motor homes or recreational vehicles.

3.3.37 Performance-Based Analysis. An engineering approach to fire protection design based on (1) established fire safety goals and objectives, (2) deterministic and probabilistic analysis of fire scenarios, and (3) quantitative assessment of design alternatives against the fire safety goals and objectives using accepted engineering tools, methodologies, and performance criteria.

3.3.38 Prescriptive Requirements. Specific requirements for materials, products, and elements based on their compliance with a test or specification.

Δ **3.3.39 Radiant Heat.** Electromagnetic transmission of heat energy; increases the sensible temperature of any substance capable of absorbing the radiation, especially solid and opaque objects. [**921,** 2021]

Δ **3.3.40 Radiation.** Heat transfer by way of electromagnetic waves that are longer than visible light waves and shorter than radio waves. [**921,** 2021]

Δ **3.3.41 Smoke.** The airborne solid and liquid particulates and gases evolved when a material undergoes pyrolysis or combustion, together with the quantity of air that is entrained or otherwise mixed into the mass. [**318,** 2022]

Δ **3.3.42 Smoke Obscuration.** The reduction of light transmission by smoke, as measured by light attenuation. [**270,** 2023]

Δ **3.3.43 Smoldering.** Combustion without flame, usually with incandescence and smoke. [**921,** 2021]

3.3.44 Tenability. Environmental conditions in which smoke and heat are limited or otherwise restricted to maintain the impact on occupants to a level that is not life-threatening.

Δ **3.3.45 Thermoplastic.** Plastic materials that soften and melt under exposure to heat and can reach a flowable state. [**921,** 2021]

3.3.46 Untenable Conditions. Environmental conditions in which smoke or heat result in threat to life.

3.3.47* Visible Smoke. The obscuration of transmitted light caused by combustion products.

Chapter 4 Types of Vehicles

4.1 General.

4.1.1 Vehicles are often assigned to one of the following seven classes:

(1) Passenger road vehicles
(2) Freight road vehicles
(3) Rail transport vehicles
(4) Water transport vehicles
(5) Aircraft
(6) Heavy equipment vehicles
(7) Special vehicles

4.1.2 Passenger road vehicles are all those vehicles carrying passengers that travel on public roads or highways. This category contains automobiles (including pickups, minivans, and sports utility vehicles), buses (including school buses), fire department vehicles, trackless trolleys, and motor homes or recreational vehicles.

4.1.3 Freight road vehicles are trucks of various kinds.

Chapter 5 General Description of Passenger Road Vehicle Fires and Background Information

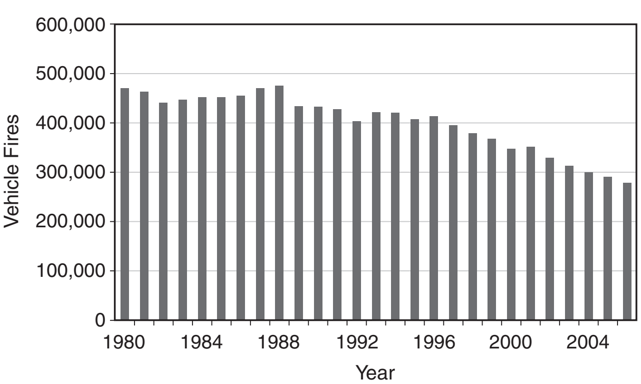
5.1 Fire Statistics.

5.1.1 The United States National Highway Traffic Safety Administration (NHTSA) indicates that approximately 43,000 people were killed and approximately 2.6 million people were injured in motor vehicle crashes in 2006. [1] In addition, property damage losses from motor vehicle crashes totaled approximately $5.9 billion in 2000, the latest year for which statistics are available. [2] Fatal Accident Reporting System (FARS) data indicates that motor vehicle crashes where fire was the most harmful event result in approximately 430 fatally injured occupants [3] per year, corresponding to approximately 1 percent of the motor vehicle crash fatalities each year.

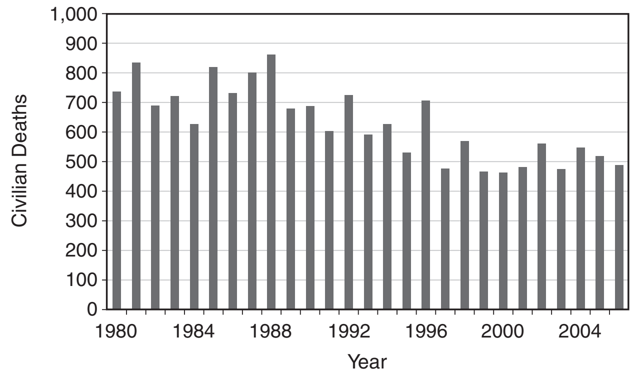
5.1.2 The NFPA survey indicates that approximately 278,000 vehicle fires occurred in 2006. [4] This is 17 percent of the total number of fires. The number of civilian deaths and injuries from vehicle fires in 2006 amounted to 490 (15 percent) and 1200 (7 percent), respectively. The direct property damage from vehicle fires in 2006 was $1.3 billion, or 12 percent of the total direct property damage from all fires. Table 5.1.2 illustrates annual average US vehicle fire losses by type of vehicle for 2002 through 2005. The statistics indicate that road vehicle fires accounted for nearly 90 percent of civilian deaths in vehicle fires. Figure 5.1.2(a) through Figure 5.1.2(d) show the evolution of vehicle fire losses over the years.

Δ Table 5.1.2 US Vehicle Fire Losses by Type of Vehicle, 2002–2005 Annual Averages

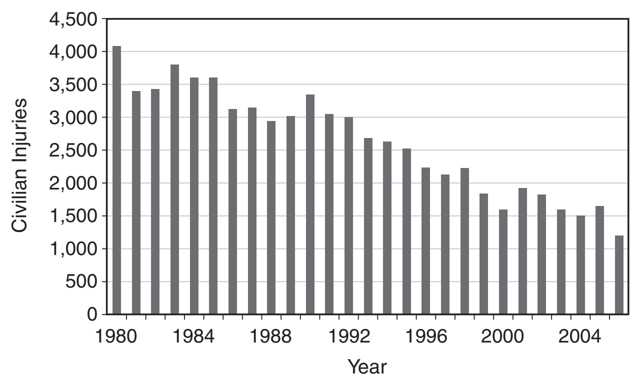
Vehicle Type	Fires	Civilian Deaths	Civilian Injuries	Damage (millions)
Passenger cars	208,600 (68%)	305 (58%)	864 (53%)	$549 (41%)
Other passenger road vehicles	54,770 (18%)	103 (20%)	392 (24%)	$238 (18%)
Freight road vehicles	24,380 (8%)	62 (12%)	183 (11%)	$240 (18%)
Other vehicles	19,060 (6%)	52 (10%)	205 (12%)	$315 (23%)



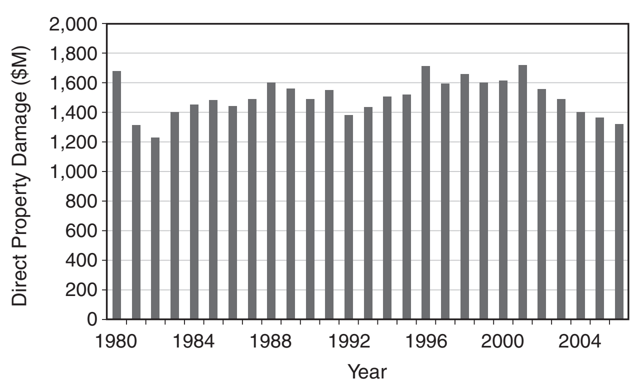
Δ FIGURE 5.1.2(a) US Vehicle Fire Trend: Number of Fires.



Δ FIGURE 5.1.2(b) US Vehicle Fire Trend: Number of Civilian Deaths.



Δ FIGURE 5.1.2(c) US Vehicle Fire Trend: Number of Civilian Injuries.



Δ FIGURE 5.1.2(d) US Vehicle Fire Trend: Direct Property Damage.

N **5.1.2.1*** NFPA statistics indicate that an estimated 212,500 vehicle fires caused 560 civilian deaths, 1,500 civilian injuries, and $1.9 billion in direct property damage in the US during 2018 [5]. In 2018, only fires in one- and two-family homes claimed more lives than vehicle fires. Vehicle fires caused 4.5 times as many deaths as nonresidential structure fires and 1.6 times as many deaths as apartment fires. The leading causes of vehicle fires were mechanical failures or malfunctions and electrical failures or malfunctions. It is important to maintain a vehicle throughout its years of use. Older vehicles accounted for three-quarters of the highway vehicle fires caused by mechanical or electrical failures or malfunctions. Collisions were the leading cause of vehicle fires that resulted in death (63 percent). For additional details and information on 2013-2017 vehicle fire statistics, see A.5.1.2.1.

5.1.3 Passenger road vehicle fires can be grouped into the following three categories:

(1) Accidental fires following a collision
(2) Accidental fires without collision
(3) Arson fires

Table 5.1.3 gives the annual average number of fires, number of civilian deaths and injuries, and direct property damage for these three categories for 2002 through 2005. The table shows that the first two categories accounted for more than 90 percent of the civilian fire deaths. Since the objective of this document is to reduce the number of passenger road vehicle fire deaths, the focus is on these two categories.

5.1.4 Table 5.1.4(a) and Table 5.1.4(b) show collision and noncollision fire statistics by area of origin. Note that the "other" category consists primarily of fires with unknown area of origin. The data presented in these tables suggest that the focus of this document should be on the following four scenarios:

(1) Accidental fire following a collision originating in the engine compartment
(2) Accidental fire following a collision involving a fuel spill
(3) Accidental fire following a collision originating in the passenger compartment
(4) Accidental fire following a collision in other or unknown areas

5.1.5 Table 5.1.5 shows the number of fire deaths and injuries by reported cause. The data in this table suggest that thermal exposure (temperature and heat flux) as well as inhalation of toxic gases must be considered when establishing tenability criteria in a passenger road vehicle fire assessment.

5.1.6 Figure 5.1.6(a) and Figure 5.1.6(b) show the number of vehicles in use in the United States, for 1991 through 2006, and the total miles of travel per year, for 1985 through 2006, respectively. [1] Table 5.1.6 shows a breakdown of material usage in the construction of passenger road vehicles based on vehicles retired from use. [6]

5.2 Materials Used in Passenger Road Vehicles.

5.2.1 Table 5.2.1 identifies the plastics most commonly used in passenger road vehicles, with their typical applications and locations. The weight of polymeric materials used in both the engine compartment and the passenger compartment of US automobiles increased from 10 kg/car (22 lb/car) in 1960 to greater than 91 kg/car (200 lb/car) in 1996. [7–9] The substitution of plastic components for metal has increased the fuel load.

Δ Table 5.1.3 US Highway Vehicle Fire Loss by Fire Category, 2002–2005 Annual Averages [4]

Fire Category	Number of Fires	Civilian Deaths	Civilian Injuries	Damage (millions)
Collision	8,100 (3%)	268 (57%)	219 (15%)	$87 (8%)
No collision	255,700 (89%)	160 (34%)	1,157 (80%)	$804 (78%)
Arson	23,900 (8%)	43 (9%)	63 (4%)	$136 (13%)
Total	287,700	471	1,439	$1,027

Table 5.1.4(a) Collision Fire Statistics by Area of Origin, 2002–2005 Annual Averages [4]

Area of Fire Origin	Number of Fires	Civilian Deaths	Civilian Injuries	Damage (millions)
Engine compartment	5700 (70%)	112 (42%)	102 (47%)	$45 (52%)
Fuel tank or fuel line	700 (9%)	70 (26%)	52 (24%)	$14 (16%)
Passenger compartment	300 (4%)	19 (7%)	15 (7%)	$3 (3%)
Other	1400 (17%)	67 (25%)	50 (23%)	$25 (29%)

Table 5.1.4(b) Noncollision Fire Statistics by Area of Origin, 2002–2005 Annual Averages [4]

Area of Fire Origin	Number of Fires	Civilian Deaths	Civilian Injuries	Damage (millions)
Engine compartment	177,400 (69%)	50 (31%)	559 (48%)	$490 (61%)
Fuel tank or fuel line	3,800 (1%)	14 (9%)	93 (8%)	$17 (2%)
Passenger compartment	26,400 (10%)	40 (25%)	207 (18%)	$112 (14%)
Other	48,100 (19%)	56 (35%)	298 (26%)	$185 (23%)

Table 5.1.5 Vehicle Deaths and Injuries by Reported Cause, 2002–2005 Annual Averages [4]

Reported Cause	Civilian Deaths	Civilian Injuries
Burns and smoke inhalation	275 (58%)	209 (15%)
Burns only	99 (21%)	658 (46%)
Smoke inhalation only	20 (4%)	233 (16%)
Other	77 (16%)	339 (24%)
Total	471	1439

Δ **Table 5.1.6 Material Usage for Vehicles Retired from Use in the United States [6] (Percentage)**

Year	Ferrous Metals	Non-ferrous Metals	Plastics	Rubber	Other Materials
1995	68.1	10.1	6.5	4.0	11.3
2000	66.3	10.6	7.3	4.3	11.5
2003	64.1	11.6	8.1	4.3	11.9
2004	63.8	11.8	8.3	4.3	11.8

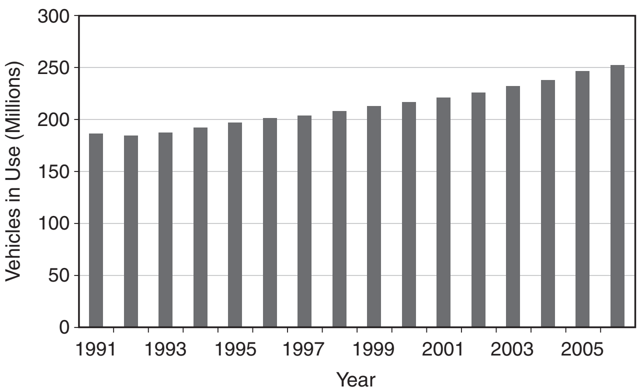


FIGURE 5.1.6(a) Number of Vehicles in Use in the United States, 1991-2006.

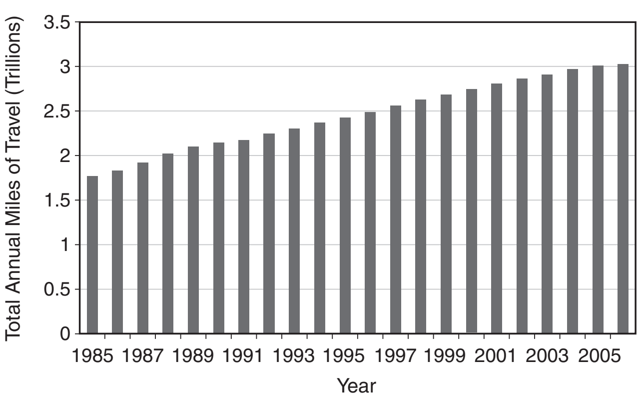


FIGURE 5.1.6(b) Total Travel Miles for Vehicles in Use in the United States [1], 1985-2006.

5.2.2 One factor affecting the severity of passenger road vehicle fire incidents is the fire performance of the materials used in constructing the vehicles. Other factors include collision or noncollision and the presence of ignitable liquids and gases. The principal properties of materials that affect fire severity are susceptibility of ignition, heat release rate once ignited, and the rate of flame spread over the surface. Additional characteristics include smoke production, effects of material orientation on burning rate, and melting and production of flaming droplets. Strategies for providing an adequate level of fire safety in passenger road vehicles include the use of prescriptive material requirements or performance-based analysis and design. A prescriptive approach would require that individual materials or component assemblies meet specified pass/fail criteria based on one or more fire tests. A performance-based approach would require that the complete vehicle meet certain performance objectives.

5.2.2.1 If materials undergo melting and also generate flaming droplets, such materials are typically deemed to present fire safety concerns because the burning material can possibly generate flames that spread to a nearby substrate/target, and thus cause the fire to move beyond the object of origin. This phenomenon has been discussed in research at NIST [10, 11], which showed that flaming melt flow can reach the floor or spread on a surface and cause radiant ignition of remote objects. Therefore, the fire hazard associated with materials that undergo melting but generate no flaming droplets may be different, depending on several variables from that of materials that both melt and generate flaming droplets.

5.2.3 The performance-based approach includes evaluation of candidate designs to assess the adequacy of the time available for escape or assisted rescue of passengers from collision and noncollision fire scenarios. This type of analysis and design process can be based on fire growth modeling and testing of final designs. To apply this method of hazard control, fire properties of candidate materials should be determined, including heat release rate and ignitability.

5.3 Current Prescriptive Testing.

5.3.1 The United States has regulatory authorities dealing with fires in transportation vehicles. The NHTSA is responsible for reducing deaths, injuries, and economic losses resulting from passenger road vehicle crashes. The Federal Transit Administration (FTA) is responsible for urban mass transportation and would thus be the agency responsible for regulating the fire safety of urban mass transit buses transporting passengers; however, it has issued guidelines, but no regulations, with respect to flammability of materials and fire safety. The primary tests included in the FTA recommendations are ASTM D3675, ASTM E162, ASTM E648, and ASTM E662. [12] Although none of these tests can be used for engineering fire properties, they can be useful in ranking relative measures of fire performance.

5.3.2* Federal Motor Vehicle Safety Standard 302 (FMVSS 302), [13] which became effective in September 1972, is the only regulatory test method for assessing the flammability of materials used in the interior of passenger road vehicles. This test method exposes a sample of material in a horizontal orientation to a Bunsen burner flame at one end. The horizontal rate of flame spread away from the burner flame is measured. To be acceptable, the flame spread rate cannot exceed 102 mm/min (4 in./min). [13, 14] This test is also used in other parts of the world, with different designations (ISO 3795 or JIS D 1201).

5.3.3 FMVSS 302 does not address heat release, smoke production, or melting of materials, including flaming drips.

Table 5.2.1 Plastics Commonly Used in Passenger Road Vehicles

Polymer	Average Weight per Vehicle (1996) (kg)	Typical Applications in Vehicles
Polyurethane (PU)	20.0	Body panel, fender, roof panel, bumpers, headliner, seat, upholstery
Polypropylene (PP)	18.1	HVAC, fan, shroud, battery tray, console radiator, cowl vent, air duct, instrument panel, package shelf
Polyvinylchloride (PVC)	9.5	Bumper trim, electrical wiring, boots, bellows, seat cover, steering wheel, floor
Polyethylene (PE)	9.1	Gas tank, bumper, electrical wire, reservoir, fuel filler pipe
Nylon (polyamide) (PA)	8.2	Fuel system, fuel line, gas cap, canister, grill head lamp support, brake, radiator, end tank engine cover, intake manifold, lamp housing
Acrylonitrile/styrene butadiene (ABS)	7.3	Bumper beam, console, cowl vent, engine cover fascia, headliner, duct
Thermoset polyester (SMC/BMC)	7.3	Door lift gate, fenders, hood, quarter panels, rear deck, spoiler, body panel
Polycarbonate (PC) and ABS	4.1	Bumper trim, electrical, grill, lamp support, lens, lamp, instrument panel console, door fender, instrument panel
Thermoplastic polyester polyethylene and polybutylene terephthalate (PET and PBT)	3.6	Body panel, hood, connector, door, fuse junction, HVAC components, fuel rail
Polystyrene (PS) / polyphenylene oxide (PPO)	3.2	Connectors, console, engine air cleaner, instrument panel
Styrene maleic anhydride polymer (SMA)	1.8	Console, head liner, instrument panel
Phenolic	1.8	Brake system, engine pulley, ash tray, transmission component
Acrylic polymers	1.4	Emblems, lamp and instrument panel lenses
Poly acetal	0.9	Radiator fan, door handle, carburetor, fuel pump, fuel filler neck
Epoxy resins	0.1	Electrical, fuel tank (filament wound), adhesives

5.3.4 FMVSS 302 provides some measure of fire growth from a match-sized ignition source. However, because it involves only horizontal flame spread, FMVSS 302 provides no direct measure of flame spread on a vertical surface. It does not provide information on how a material might respond to the levels of external radiation input that inevitably occur as a fire grows larger and begins to involve multiple surfaces that exchange radiation. Other devices such as the cone calorimeter (ASTM E1354) can provide these types of data. [15–19] These data are measures of ignition delay time and heat release rate as a function of the level of external radiative input.

5.4* Noncombustible Material. A material that complies with any of the following should be considered a noncombustible material:

(1)* A material that, in the form in which it is used and under the conditions anticipated, will not ignite, burn, support combustion, or release flammable vapors when subjected to fire or heat.
(2) A material that is reported as passing ASTM E136.
(3) A material that is reported as complying with the pass/fail criteria of ASTM E136 when tested in accordance with the test method and procedure in ASTM E2652.

5.5 Limited-Combustible Material.

5.5.1 This section is part of an NFPA guide and, therefore, is not mandatory. The term *shall* in this section is used to indicate that if provisions relating to limited-combustible materials are applied, the material needs to meet the definition of a limited-combustible material.

Δ **5.5.2*** A material shall be considered a limited-combustible material where one of the following is met:

(1) The conditions of 5.5.2.1 and 5.5.2.2, and the conditions of either 5.5.2.3 or 5.5.2.4, shall be met.
(2) The conditions of 5.5.2.5 shall be met.

[**5000:**7.1.4.2]

N **5.5.2.1** The material does not comply with the requirements for a noncombustible material in accordance with 5.4. [**5000:**7.1.4.2.1]

N **5.5.2.2** The material, in the form in which it is used, exhibits a potential heat value not exceeding 3500 Btu/lb (8141 kJ/kg) when tested in accordance with NFPA 259.[**5000:**7.1.4.2.2]

5.5.2.3 The material shall have a structural base of noncombustible material with a surfacing not exceeding a thickness of ⅛ in. (3.2 mm) where the surfacing exhibits a flame spread index not greater than 50 when tested in accordance with ASTM E84, *Standard Test Method for Surface Burning Characteristics of Building Materials*, or UL 723, *Test for Surface Burning Characteristics of Building Materials*. [**5000:**7.1.4.2.3]

Δ **5.5.2.4** The material shall be composed of materials that in the form and thickness used neither exhibit a flame spread index greater than 25 nor exhibit evidence of continued progressive combustion when tested in accordance with ASTM E84 or UL 723 and are of such composition that all surfaces that would be exposed by cutting through the material on any plane would neither exhibit a flame spread index greater than 25 nor exhibit evidence of continued progressive combustion when tested in accordance with ASTM E84 or UL 723. [**5000:**7.1.4.2.4]

5.5.2.5 Materials shall be considered limited-combustible materials where tested in accordance with ASTM E2965, *Standard Test Method for Determination of Low Levels of Heat Release Rate for Materials and Products Using an Oxygen Consumption Calorimeter*, at an incident heat flux of 75 kW/m^2 for a 20-minute exposure and both the following conditions are met:

(1) The peak heat release rate shall not exceed 150 kW/m^2 for longer than 10 seconds.
(2) The total heat released shall not exceed 8 MJ/m^2.

[**5000:**7.1.4.2.5]

5.5.2.6 Where the term *limited-combustible* is used in this document, it shall also include the term *noncombustible*. [**5000:**7.1.4.2.6]

5.6 Fire Performance Properties. The fire properties that are used to assess the fire safety of vehicles include heat release, smoke production, ignitability, flaming drips, and effects of orientation of vehicle components. A number of standardized test methods that can be used to assess these properties are available *(see Chapter 10)*. It has been demonstrated by studies of the fire properties of materials used in other fire situations in compartments and vehicles (aircraft, trains, soft furnishings) that changes in flammability characteristics affect fire safety. Examples include the materials used in rail transport and aircraft such as seating and wall panels. With regard to compartments, there is ample evidence that improved fire properties in consumer products such as upholstered furniture, mattresses, wall linings, and electric cables have resulted in lower fire losses. Real world vehicle fires are variable and difficult to predict in full detail; this arises from the very complex geometries present, especially in post-crash situations, and from the thermoplastic character of many of the materials involved. However, measures that limit the rate at which the materials can release heat can, in most cases, be expected to slow fire growth. This, in turn, allows more time for escape or rescue.

5.7 Tenability Criteria. Table 5.7 contains a generic set of tenability criteria. [20, 21] In another publication, tenability was defined as the first indication of flame spread into the passenger compartment. [22] Tenability criteria should apply irrespective of the fire scenario because tenability criteria are a function of the people exposed and the time of exposure — not the fire environment/compartment. The specific tenability criterion that is reached first in a passenger road vehicle fire could be different from that reached in a building. It has also been found in a full-scale test study that (a) the first tenability criterion breached was associated with heat, and (b) in that same study, the concentrations of carbon dioxide, carbon monoxide, and hydrogen cyanide were less than the respective threshold concentrations for computing fractional effective doses. [23]

Table 5.7 Tenability Criteria from HAZARD I and ASTM E2280

Hazard	Incapacitation Criterion	Lethality Criterion
Smoke toxicity Ct* (g/min/m^3)	450	900
Smoke toxicity FED†	0.5	1
CO concentration (ppm min)	45,000	90,000
Convected heat/temperature (EC)	65	100
Radiated heat/ heat flux (kW min/m^2)	1.0	2.5

*Smoke toxicity Ct: concentration-time product of toxic gases. If exposure is 30 minutes, smoke toxicity criteria will be 15 g/m^3 for incapacitation and 30 g/m^3 for lethality.

†Smoke toxicity FED: fractional effective dose of toxic insult required to cause lethality (if FED = 1).

Chapter 6 Approach to Evaluating Passenger Road Vehicle Fire Hazard

6.1 General. Altering a material in composition or form for improved fire performance can result in degradation of other key properties of that material. Properties that have been found to affect overall passenger road vehicle safety, fuel economy, emissions, manufacturability, utility, and durability and that should be considered when selecting materials for use in passenger road vehicles include those indicated in Table 6.1.

6.2 Basic Performance-Based Approach.

6.2.1 The performance-based approach employs a systematic analysis as depicted schematically in Figure 6.2.1. This approach is applicable to both new and existing designs. See the *SFPE Engineering Guide to Performance-Based Fire Protection*. The process begins with the establishment of fire performance design criteria that establish the limiting hazard levels for the desired fire safety *(see Chapter 7)*. Next, the candidate design for the passenger road vehicle components or systems to be evaluated is established. The relevant fire scenario for the specific analysis is selected, including the scenario elements in Figure 6.2.1. Some generic scenarios are described in Chapter 11.

6.2.2 Performance-based evaluation requires that information regarding the expected fire conditions be developed. This can be accomplished through small-scale tests or intermediate-scale tests of materials, composites, fuel packages or subsystems, or full-scale vehicle tests. Calculation methods and simulations can also be employed, based on fire performance properties such as heat release rate, ignitability, or combustion products yield. A discussion of test methods and guidance documents that could be used at this stage in the performance-based design process is found in Chapter 10.

Table 6.1 Some Key Properties for Passenger Road Vehicle Materials

Ability to meet appearance requirements
Chemical resistance
Chrome platability
Composition
Compressive strength
Density
Dimensional stability
Fire performance
Flexural modulus
Glass transition temperature
Impact strength
Melt flow rate
Melting temperature
Moisture absorption
Molding shrinkage
Paintability
Recyclability
Reinforcement type and amount
Strain at break
Stress at break
Surface defects
Tensile modulus
Thermal stability
UV resistance
Volume resistivity

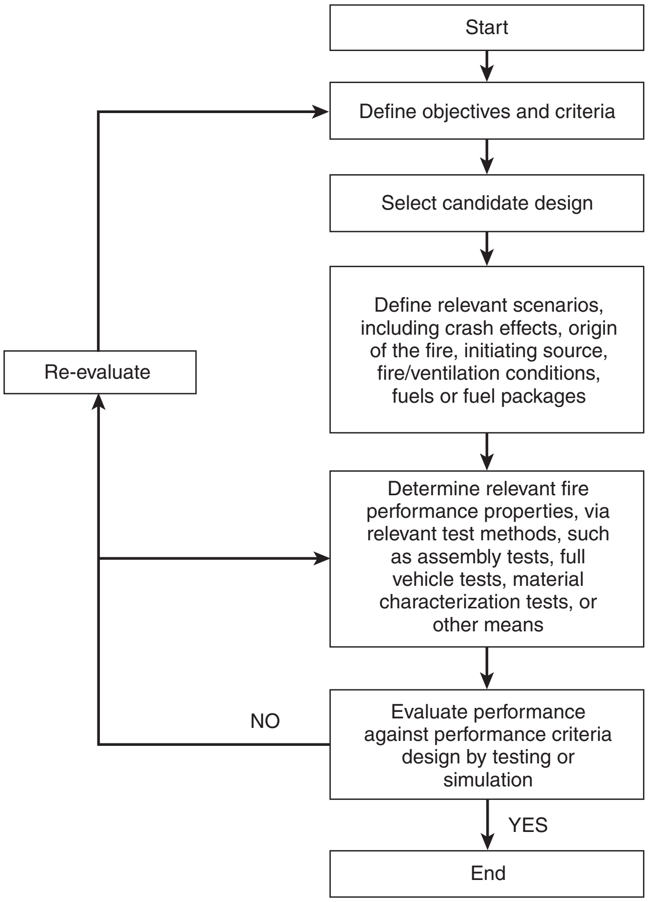


FIGURE 6.2.1 Flow Chart for the Performance-Based Approach to Be Used in This Document.

6.2.3 Fire conditions predicted by calculation, simulation, or testing are compared to the design criteria to see whether they have been satisfied. If the design criteria are not satisfied, there are several options for proceeding. The objectives and design criteria, or selected fire scenario, can be reassessed, additional fire performance data collected, or the candidate design modified and the performance-based process repeated.

6.3 Design Considerations. When evaluating material, component, or system fire properties, the designer should also consider the effects on the properties indicated in Table 6.1. Selection of materials based on their fire properties should not impair the electrical, mechanical, or physical function, or other safety properties of the passenger road vehicle. Sufficient technology and advances in plastics engineering could allow for a combination of properties to achieve both adequate fire performance and mechanical properties.

6.4* Regulatory Considerations. Use of this document should not adversely impact compliance with federal, state, local, or other applicable regulations. For example, in the United States, motor vehicle safety for light duty vehicles and school buses is regulated by NHTSA. Some specific performance requirements are established in Federal Motor Vehicle Safety Standards.

Chapter 7 Objectives and Design Criteria

7.1 Objectives.

7.1.1 The primary objective of this document is to reduce the expected loss of life due to fire in passenger road vehicles.

7.1.2 A secondary objective of this document is to reduce the likelihood of injuries from exposure to heat and smoke inhalation resulting from fire in passenger road vehicles.

7.1.3 The specified levels for each of the objectives depend on a number of factors, including the scope of the fire hazard evaluation, as well as technical limitations and potential marketing considerations.

7.1.3.1 For example, the evaluation might cover the entire nation or specific regions, all types of passenger road vehicles or a specific type, multiple ignition scenarios or a specific one, or other choices.

7.2* Design Criteria.

7.2.1 The objectives are translated into design criteria. These criteria depend on the nature of the design.

7.2.2 If the design involves replacing a material or component in a vehicle that meets the performance objectives, it is usually sufficient to demonstrate that the proposed replacement does not adversely affect the fire hazard of the vehicle. This can be done on the basis of small- or intermediate-scale tests that measure the ease of ignition, heat release rate, and production rate of smoke and other combustion products under thermal conditions that are representative of those in passenger road vehicle fires.

7.2.3 One potential set of design criteria for a new passenger road vehicle could be based on the times to untenable conditions in the passenger compartment for the relevant fire scenarios. These times could be determined on the basis of full-scale tests or mathematical modeling of passenger road vehicle fire growth and spread. Other criteria sufficient to demonstrate the adequacy of the design could involve small- or intermediate-scale testing of like components of passenger road vehicles in a similar model, style, class, or size to the design.

7.2.4 Full-scale testing, intermediate-scale testing of components or materials, or modeling might also be necessary to assess the effects of components that affect passenger road vehicle fire growth and spread due to factors other than the ignition and burning behavior of the constituent materials.

7.2.4.1 For example, the heating, ventilating, and air-conditioning (HVAC) duct system affects smoke transport and flame spread to the passenger compartment from a fire originating in the engine.

7.2.4.2 Consequently, full-scale testing or modeling might be necessary to justify replacement of the HVAC duct system with a new design.

Chapter 8 Selecting Candidate Design

8.1 General. The candidate design to be evaluated by the performance-based method may be a single material, such as a candidate headliner or dash panel facing, or a complete fuel package, such as an upholstered seating system. These design elements can be tested for fire properties as input to fire hazard calculations or simulations. Evaluation of the expected conditions with regard to a complete vehicle can be studied by full-scale testing of complete vehicles or by simulation techniques using data from small- and intermediate-scale testing of materials and fuel packages.

Chapter 9 Typical Fire Scenarios to Be Investigated

9.1 General. As with other fires, passenger road vehicle fires require a combustible material (fuel), an ignition source, and oxygen.

9.1.1 Fuels can be solid, liquid, or gas. Solid fuels tend to be combustible materials used in the construction of passenger road vehicle components or combustible materials brought into the passenger road vehicle and carried as cargo. The combustible materials used in construction of passenger road vehicles can be modified or controlled to improve the fire safety of the vehicle. The combustible construction materials that can contribute to a fire include, but are not limited to, vehicle upholstery, insulating and sound-deadening materials, electrical wiring insulation, HVAC system, and plastic body and trim. The fire properties of liquid or gaseous fuels used to power the vehicle cannot be easily modified to improve their flammability characteristics. Typical liquid fuels are gasoline, gasohol, or diesel. Gaseous fuels can include compressed natural gas (CNG), liquid propane (LP), and hydrogen. Given the performance requirements for liquid and gaseous fuels, the most common method to improve fire safety is through improved fuel containment.

9.1.2 Factors contributing to ignition, including ignition sources, are discussed in Section 9.3.

9.1.3 Oxygen in the ambient atmosphere is sufficient to sustain a passenger road vehicle fire.

9.2 Passenger Road Vehicle Motion.

9.2.1 Fires involving passenger road vehicles can occur when the passenger road vehicle is moving or when it is stationary. The primary effect of motion on a fire in a passenger road vehicle is the potential for increased ventilation to the fire.

9.2.2 A passenger road vehicle could be stationary for one of the following reasons:

(1) The engine is not running (it is off).
(2) The engine is running but the passenger road vehicle is idling.
(3) The passenger road vehicle has just undergone a collision, with the engine either still running or stopped by the collision.

9.2.3 If a fire occurs in a moving passenger road vehicle, once the driver and/or occupants become aware of the fire, the passenger road vehicle will come to rest when it is either pulled over by the driver or it stops due to malfunction.

9.3* Factors Contributing to Ignition.

9.3.1 Ignition Sources. In most cases, the sources of ignition energy in motor vehicle fires are similar to those associated with structural fires such as arcs, mechanical sparks, overloaded wiring, open flames, and smoking materials. There are, however, some unique sources that should be considered, such as the hot surfaces of the engine exhaust system. This system may consist of the exhaust manifold, exhaust pipe, one or more catalytic converters, mufflers, and tailpipes. Other hot surface ignition sources may include brakes, bearings, and turbochargers.

9.3.2 The major factors contributing to ignition in passenger road vehicles are identified in Table 9.3.2.

9.3.3* It is important to note that the major causes of passenger road vehicle fires are different from the major causes of passenger road vehicle fire fatalities. The major causes of passenger road vehicle fire fatalities (allowing for multiple entries) are as follows *(see Table 9.3.2)*:

(1) Collisions or overturns
(2) Unclassified factor contributing to ignition
(3) Flammable liquid or gas spill
(4) Leak or break
(5) Exposure fire
(6) Other causes, including misuse of materials or products, improper operation of equipment, mechanical failures, or malfunctions

9.3.4 The ignition source can be short-lived, such as an electric arc or mechanical spark, or long-term exposure such as a "pool" fire of engine oil, gasoline, diesel fuel, brake fluid, coolant, power steering fluid, or transmission fluid.

9.4 Areas of Fire Origination.

9.4.1 Whether moving or stationary, passenger road vehicle fires can originate inside the passenger compartment, in the engine compartment, in the trunk or cargo-carrying area, in the vicinity of the vehicle (e.g., pool fire or exterior exposure), from unclassified external heat sources, in the fuel tank or fuel system, or in the running gear or wheel area.

9.4.2 Fires that originate in the engine compartment can spread to the passenger compartment through the bulkhead between the engine compartment and the passenger compartment. The propagation of fire from the engine compartment is dependent on the size and number of openings in the bulkhead (e.g., brake pedal, wire harness, heater core, HVAC). In some instances, the plastic HVAC housing extends through the bulkhead, which compromises the bulkhead when fire attacks those components in the engine compartment. Directly on the other side of the bulkhead are polymeric HVAC ducts that transverse the length of the dash and provide direct openings to the passenger compartment. A summary of 13 collision-related fires showed fire originating in the engine compartment reached the passenger compartment in less than 8 minutes and in as little as 2 minutes to 4 minutes. [24]

9.4.3 Fires could originate in the vicinity of the passenger road vehicle and spread from another vehicle or some other external source.

Table 9.3.2 Highway Vehicle Fires by Factor Contributing to Ignition, 2002–2005 Annual Averages [4]

Ignition Factor	Fires [number (%)]	Civilian Deaths [number (%)]	Civilian Injuries [number (%)]	Property Damage [$ Millions (%)]
Unclassified mechanical failure or malfunction	83,000 (29)	12 (2)	194 (13)	$272 (27)
Leak or break	35,600 (12)	35 (7)	168 (12)	$98 (10)
Unclassified electrical failure or malfunction	30,500 (11)	1 (0)	57 (4)	$103 (10)
Unspecified short circuit arc	19,000 (7)	0 (0)	65 (4)	$67 (7)
Unclassified factor contributed to ignition	17,000 (6)	59 (13)	116 (8)	$90 (9)
Exposure fire	14,900 (5)	21 (4)	24 (2)	$97 (9)
Backfire	13,100 (5)	1 (0)	87 (6)	$26 (3)
Worn out	10,400 (4)	0 (0)	17 (1)	$16 (2)
Short circuit arc from defective, worn insulation	8,400 (3)	0 (0)	18 (1)	$21 (2)
Collision or overturn	8,100 (3)	268 (57)	219 (15)	$87 (8)
Abandoned or discarded materials or products	6,600 (2)	1 (0)	36 (2)	$24 (2)
Heat source too close to combustibles	6,400 (2)	8 (2)	75 (5)	$24 (2)
Flammable liquid or gas spilled	6,100 (2)	38 (8)	93 (6)	$24 (2)
Unclassified misuse of material or product	5,700 (2)	13 (3)	76 (5)	$20 (2)
Unclassified operational deficiency	4,500 (2)	2 (0)	25 (2)	$16 (2)
Short circuit arc from mechanical damage	4,400 (2)	1 (0)	20 (1)	$12 (1)
Arc, spark from operating equipment	3,600 (1)	0 (0)	25 (2)	$10 (1)
Equipment not being operated properly	2,300 (1)	10 (2)	36 (2)	$10 (1)
Cutting, welding too close to combustible	1,900 (1)	0 (0)	17 (1)	$3 (0)
Flammable liquid used to kindle fire	1,800 (1)	7 (1)	13 (1)	$11 (1)
Installation deficiency	1,800 (1)	0 (0)	14 (1)	$3 (0)
Arc from faulty contact or broken conductor	1,500 (1)	0 (0)	7 (0)	$5 (0)
Improper fueling technique	1,500 (1)	1 (0)	52 (4)	$2 (0)
Failure to clean	1,500 (1)	0 (0)	3 (0)	$2 (0)
Other known factors	10,300 (4)	21 (5)	96 (7)	$44 (4)
Totals	287,700 (100)	471 (100)	1,439 (100)	$1,027 (100)

9.4.4 Fires that originate from the fuel tank or fuel system can be associated with both collision and noncollision events and could involve materials similar to those found in the engine compartment. Fuel containment is the most appropriate measure to prevent or mitigate the consequences of such fires. Although fire resulting from ignition of a large quantity of released fuel can rapidly lead to untenable passenger compartment conditions, occupant egress is generally possible for a short period after a collision event unless occupant entrapment or incapacitation is a factor.

9.5 Fire Scenarios. This document investigates the following five fire scenarios in which fire effects can reach the passenger compartment:

(1) Fires starting inside the passenger compartment
(2) Fires starting in the engine compartment and penetrating through one or more of the following:
  (a) Engine cover (or bulkhead)
  (b) Ductwork
  (c) Windshield
(3) Fires starting in the trunk or load-carrying area and penetrating into the passenger compartment
(4) Pool fires resulting from fuel tank failure and burning under the vehicle
(5) Fires resulting from other external heat sources

Chapter 10 Evaluation Methods and Tools

10.1 General. Several evaluation methods and tools might be suitable for assessing the fire behavior of passenger road vehicle components, when associated with any of the fire scenarios discussed in this document. FMVSS 302 and other similar tests using different designations are used as the regulatory standard for the evaluation of passenger road vehicle components in the United States and some other countries. Table 10.1 identifies several, but not all, potential fire tests for consideration in assessing the fire performance of various components that could be involved in passenger road vehicle fires.

10.2* Use of Test Methods. Tests cannot be representative of actual fire conditions, but can often be used as comparative measures of component or assembly fire performance. Use of these evaluation tools might prove useful in developing or assessing the mitigation strategies discussed throughout this document. Annex A contains some descriptions and information on each one of these test methods and guides to explain the rationale for their use and the results that can be obtained from them.

Δ Table 10.1 Relevant Test Methods and Evaluation Tools

Passenger Road Vehicle Component	Evaluation Tool	Comments
Bulk of materials	ASTM E1354	Cone calorimeter
	ASTM E2965	Very low heat release calorimeter
	ASTM E1321	LIFT apparatus
Interior materials	FMVSS 302	Regulatory test
Seat materials	ASTM E1474	Cone calorimeter
Seat materials (school buses)	ASTM E2574/E2574M	Full-scale flame spread seat test
Carpets/floor coverings	ASTM D2859	Pill test
	NFPA 253 (ASTM E648)	Critical radiant flux
Wire and cable	UL 1685 and UL 2556	Cable and wire fire test
	ASTM D6113	Cone calorimeter
Fire resistance — Fuel spill from underneath	UL 263 (ASTM E119) or UL 1709 (ASTM E1529)	Time — temperature tests
Firestops in the undercarriage	ASTM E814 (UL 1479)	
Foams and fabrics (smoldering)	NFPA 260	Cigarette ignition — component test
	NFPA 261	Cigarette ignition — composite test
Windshields (fire resistance)	NFPA 257 (UL 9)	Fire-protection rating of glazing (excluding hose stream test)
Windshields (flame spread)	ANSI/SAE Z-26.1 (See Sections 5.18 and 5.19)	Flame spread of glazing
Individual fuel packages	NFPA 289	Engine compartment and passenger compartment furniture calorimeter
Flat materials	ISO TS 17431	
Transmission through the bulkhead (dash panel) and the windshield	ASTM E1354 or ASTM E1623 or BS EN 13823 (SBI)	Cone or intermediate scale calorimeter (ICAL) or single burning item
Plastic fuel tanks	ECE R34.01, Annex 5	Full-scale fire test of tanks
Batteries	SAE J2464	
Guidance	ASTM E603	Guidance for large-scale tests only
	ASTM E2061	Guidance for fire hazard assessment in transportation vehicles only (based on rail vehicles)
	ASTM E2067	Guidance for conducting large-scale heat release tests only
	ASTM E2280	Guidance for fire hazard assessment in a compartment only
	ASTM E1546	Guidance for fire hazard assessment only
Other Evaluation Methods		
Bulk of materials	ASTM E2102	Screening test for cone — mass loss cone
Carpets/floor coverings	ASTM E1995, ASTM E662, or NFPA 270	Smoke chamber tests

10.3 Relevant Test Methods and Evaluation Tools.

10.3.1 The summary of test methods included in Table 10.1 is a starting point to assist in evaluating fire hazard. Nothing in the table is intended to prevent the use of other tests, methods, guidance, or tools.

10.3.2 The user of this document is cautioned that when any test method or tool, including those indicated in Table 10.1, is used to evaluate the fire properties or performance of a material, component, or assembly, the user should be aware of the limitations or restrictions of the test method or tool. These limitations may include, but are not limited to, the following:

(1) Geometry and arrangement of test method or sample
(2) Fire exposure (e.g., initiating source, heat flux, duration)
(3) Applicability of pass/fail or performance criteria
(4) Applicability of individual portions of the test methods
(5) Applicability to intended scenario

Chapter 11 Individual Fire Scenarios

11.1 Fires Starting in the Passenger Compartment.

11.1.1 General.

11.1.1.1 Passenger compartment fires are life threatening when there are occupants in the vehicle. See Section 5.1 for statistics on fire losses. Passenger compartment fires can occur whether the vehicle is in motion or is stationary. In some cases, usually following a collision or overturn, the occupants might not be able to escape the passenger compartment without assistance.

11.1.1.2 Increased ventilation to the interior of the moving vehicle accelerates the fire growth rate inside the passenger compartment. Such increased ventilation can result from air entering through openings such as vents or windows while the vehicle is in motion, or as a result of a collision causing broken windows or bent frame members. The absence of ventilation can also have adverse effects on vehicle occupants by confining the combustion products to the vehicle's interior and causing oxygen vitiation.

11.1.1.3 NFPA statistics on factors contributing to ignition can be found in Section 9.3. However, these statistics do not identify items first ignited, ignition factors, or factors contributing to ignition by compartment or origin. Subsections 11.1.2 through 11.1.7 describe fire scenarios of fires originating in different areas inside the passenger compartment.

11.1.1.4 The spread of fire inside the passenger compartment is directly related to the quantity, composition, orientation, configuration, and fire properties of the materials in the passenger compartment. Potential ignition sources include electrical short circuits or electrical malfunctions, aftermarket consumer electronics and their power connections, smoldering of cigarettes or other smoking materials, electrical dashboard components, and heating elements in seats. [25–27] Combustible materials brought into the passenger compartment present additional potential sources of ignition and fuel. For example, a collision might result in the release of a liquid fuel brought into the passenger compartment that could be ignited and spread to components in the passenger compartment.

11.1.2* Fires Initiating in the Instrument Panel. The instrument panel in the passenger compartment is adjacent to the engine compartment. The instrument panel consists of various instrument gauges, controls, the sound system, the glove box, and HVAC openings and contains combustible materials. Behind and under the instrument panel are the HVAC ducting and electrical connections, wires, and wire bundles for the controls, gauges, and devices. Some materials used in the construction of the instrument panel have been shown to be susceptible to ignition from small ignition sources such as a match flame or cigarette lighter. Fire from the instrument panel could spread to other combustible components inside the passenger compartment. [19, 22] For example, fire from the instrument panel area could grow and potentially ignite combustible headliner materials. The headliner could then propagate fire from the front of the passenger compartment to the rear as heat and smoke accumulate below the vehicle roof. A fire from the instrument panel can also propagate through the ducting or openings or both in the instrument panel to other parts of the passenger compartment. See Figure 11.1.2 for an illustration of a fire initiating in the instrument panel.

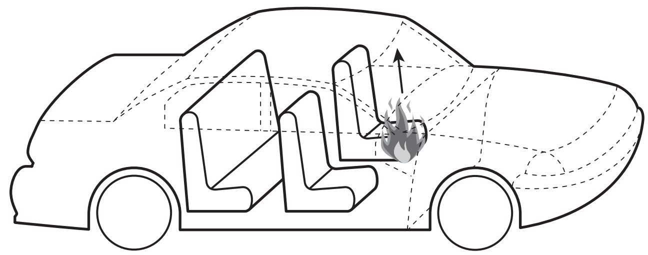


FIGURE 11.1.2 Fire Originating in the Instrument Panel (Dash).

11.1.3* Seating Area Fires.

11.1.3.1 General. Seating area fires that originate on or in the seat could grow and potentially ignite the combustible headliner materials or other combustibles. Seat materials present the largest fixed fuel load inside the passenger compartment.

11.1.3.2* Ignition Sources. Seating materials could be ignited when subjected to an ignition source, such as electrical sources or discarded smoker's materials. See Figure 11.1.3.2 for an illustration of a fire originating on the seat.

11.1.4* Fires Originating on the Floor. Floor materials could be ignited as a result of overheated electrical wires under the carpeting, overheated catalytic converters, or smoker's materials. Carpet material fires are usually of little consequence unless they are the first materials ignited. See Figure 11.1.4 for an illustration of a fire originating on the floor.

11.1.5* Fires Originating in the Headliner Area. Headliners in vehicles typically consist of padding and a substrate covered by a vinyl or fabric. The fabric-covered foam headliners from four passenger road vehicles were analyzed by cone testing with the fabric side exposed to the incident heat flux. [9] See Figure 11.1.5 for an illustration of a fire originating in the headliner area.

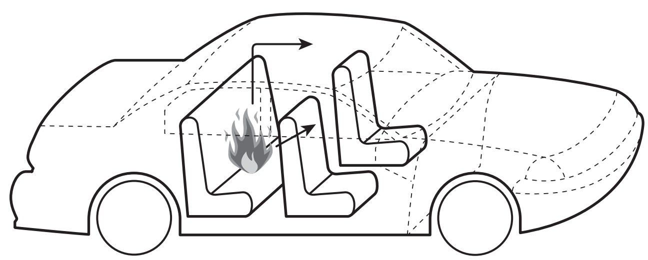


FIGURE 11.1.3.2 Fire Originating in the Vehicle Seating Area.

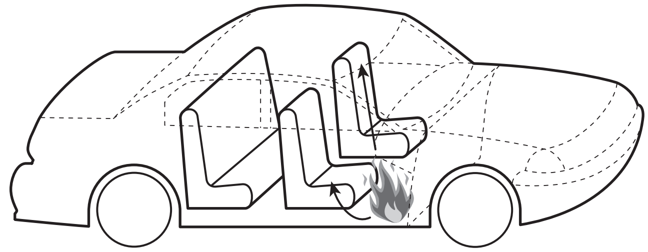


FIGURE 11.1.4 Fire Originating on the Floor.

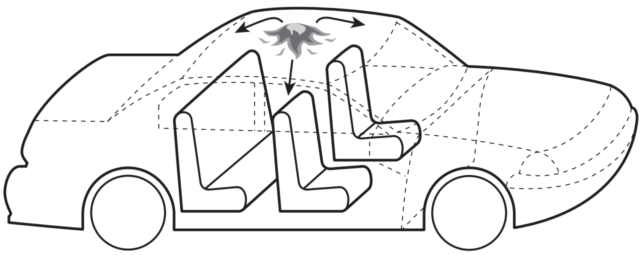


FIGURE 11.1.5 Fire Originating in the Headliner Area.

11.1.6* Fires Originating in the Compartment Door. Electrically caused fire in the window well as a result of an overheated power-operated window motor could ignite the door panel trim. See Figure 11.1.6 for an illustration of a fire originating in the compartment door.

11.1.7* Current Fire Safety Requirements. Materials in passenger compartment interiors (but not under the dash) need to meet a horizontal flame spread rate not exceeding 102 mm/min (4 in./min), when tested in accordance with FMVSS 302. [13] Chapter 5 provides commentary on FMVSS 302. Consideration of the fire safety performance of materials should include means to identify materials that have long ignition times, slow fire spread, and low rates of heat and smoke release. Materials with an enhanced fire performance that resist small ignition sources and are less likely to propagate fire are likely to reduce the severity of passenger compartment fires. In the case of school buses, some US and Canadian local education authorities require the use of seat assemblies that comply with the "paper bag fire test" (school bus seat upholstery fire block test, approved by the National Congress on School Transportation as part of the National Standards for School Buses and National Standards for School Bus Operations).

11.1.8 Mitigation Strategies. The three primary types of strategy that could mitigate the effects of fires starting in the passenger compartment are indicated in 11.1.8.1 through 11.1.8.3. Mitigation strategies can be used individually or in combination. See also 1.2.3 and Section 6.3.

11.1.8.1 Ignition Propensity. The ignition propensity of the materials contained within the passenger compartment should be decreased.

11.1.8.1.1 This decrease in ignition propensity could be achieved by choosing materials with low ignition propensity for use in each area of the passenger compartment. These materials can be chosen from materials with inherently low ignition propensity or by incorporating additives into other materials.

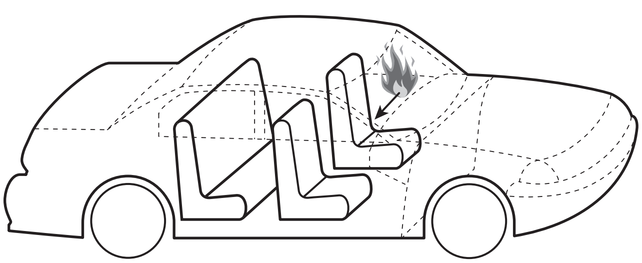


FIGURE 11.1.6 Fire Originating in the Compartment Door.

11.1.8.1.2 The lower ignition propensity should apply to all materials that are directly exposed to a potential ignition source.

11.1.8.1.3 A different criterion should apply in the case of materials not directly exposed (such as foams contained in the seats, armrests, doors, or headliners) or materials contained within the dashboard. In such cases, the ignition propensity of the composite system should be assessed.

11.1.8.2* Heat Release. The heat release of the materials contained within the passenger compartment could be decreased to provide a safer environment for the occupants in a vehicle fire.

11.1.8.2.1 This decrease in heat release could be achieved by choosing materials with low heat release propensity for use in each area of the passenger compartment. These materials can be chosen from materials with inherently low heat release propensity or by incorporating additives into other materials.

11.1.8.2.2 The lower heat release propensity should apply to all materials that are directly exposed to a potential ignition source.

11.1.8.2.3 A different criterion should apply in the case of materials not directly exposed (such as foams contained in the seats, armrests, doors, or headliners) or materials contained within the dashboard. In such cases, the heat release propensity of the composite system should be assessed.

11.1.8.3 Design Improvements. Design improvements that increase the time for passengers to escape or be rescued should be incorporated. The passenger road vehicle should continue to exhibit functionality and performance for all other safety features *(see also 1.2.3 and Section 6.3)*.

11.2 Fires Starting in the Engine Compartment.

11.2.1 General.

11.2.1.1 A majority of fires originate in the engine compartment. Between 1994 and 1998, 67.3 percent of the US highway vehicle fires were initiated in the engine compartment. [28] Fires that originate in the engine compartment may be electrical, mechanical, the result of a collision, or the result of a malfunction. They can occur when the vehicle is on and either moving or stationary or when it is off and parked. Following a collision, there is a higher tendency for a fire to originate in the engine compartment than in the passenger compartment. For comparative purposes, the 1973 National Survey of Motor Vehicle Fire statistics reported 2637 total motor vehicle fires. [29] Fifty-four percent of the postcollision fires originated in the engine compartment compared to 4 percent originating in the passenger compartment. Of the fires that were noncollision-related, 59 percent (1085) originated in the engine compartment and 35 percent (647) originated in the passenger compartment. Subsections 11.2.2 through 11.2.5 describe potential fire scenarios and ignition sources for fires starting in the engine compartment and spreading to the passenger compartment.

11.2.1.2* Table 11.2.1.2 lists materials typically found in engine compartments, together with their major polymeric composition, heat release rate, and time to ignition when tested in the cone calorimeter at an initial test heat flux of 35 kW/m^2 at end-use thickness in the horizontal orientation. Other materials contained in the engine compartment include electric cables and hoses, for which no fire test data are presently available. Other combustible materials can also unintentionally enter the engine compartment.

11.2.1.3 A fire that starts in the engine compartment could propagate into the passenger compartment through the engine cover/bulkhead, ductwork, or windshield. Collision damage can provide alternative paths for fire penetration into the passenger compartment.

11.2.2 Scenarios.

11.2.2.1 Electrical Fault (Noncollision). An electrical fault (noncollision) occurs as the result of component failure. The fault has sufficient energy to ignite nearby combustible materials in the engine compartment. The fire could then spread to other nearby combustible materials and potentially spread to the passenger compartment. Electrical faults can also occur when the engine is not operating or when the key has not been placed in the ignition. Electrical arcs from the engine ignition system or alternator occur during normal vehicle operation and can present ignition sources.

11.2.2.2 Electrical Fault (Collision). An electrical fault occurs as the result of a collision. The fault has sufficient energy to ignite nearby combustible materials in the engine compartment. The fire could then spread to other nearby combustible materials and potentially spread to the passenger compartment. Electrical faults can also occur when the engine is not operating or when the key has not been placed in the ignition.

11.2.2.3 Potential Non-Electrical Ignition Sources. Potential non-electrical ignition sources include hot exhaust surfaces, backfiring of the engine, sparks generated by friction from a collision or metal components, and overheating of bearings. Such ignition sources can exist during normal vehicle operation or during a collision.

11.2.3 Engine Compartment Fires. Engine compartment fires are fires starting in the engine compartment and penetrating through the bulkhead and/or engine cover.

11.2.3.1 Background. Traditional passenger road vehicles had separations called firewalls between the engine compartment and the passenger compartment. Such separations were of steel construction, with openings for ducting or cabling, that were, in turn, sealed off with the intention of preventing passage of fire (flames) or smoke between compartments.

11.2.3.2* In some vehicles where engines extend in part into the passenger compartments, such as in vans, the passenger compartment is separated by an engine cover that is usually combustible. This might allow fire to penetrate into the passenger compartment. Thus, in the event of a vehicle fire, conditions inside the passenger compartment (where passenger mobility is often impaired by injury) can become untenable quite rapidly.

11.2.3.3 In a van, an engine cover was analyzed and cone calorimeter fire tests were conducted on it. The engine cover was composed of two materials: a fibrous insulation material sandwiched between two layers of aluminum foil and with 4.2 percent of polyester binder, and a molded plastic material [with 42 percent plastic, composed of a styrene-butadiene rubber (70 percent) and poly (vinyl acetate) (27 percent)]. The major cone calorimeter results are contained in Table 11.2.3.3.

11.2.3.4 The separation between the passenger compartment and the engine has received different designations, including bulkhead, passenger compartment engine access cover, engine covers, and firewall. The term *firewall* is improper terminology but is commonly used. These separations offer different ways in which fire or heat can penetrate from the engine compartment into the passenger compartment, including the following:

(1) Through openings in the separation
(2) Through damage or destruction of the separation
(3) Through heat transfer

Δ Table 11.2.1.2 Summary of Test Data for Automotive Components Tested for NHTSA [22]

Part	Base Polymer	t_{ig} (sec)	$PHRR_a$ (kW/m²)
Battery cover	Polypropylene	39	297
Resonator structure	Polypropylene	64	417
Resonator intake tube	Ethylene propylene diene monomer	72	434
Air ducts	Polyethylene (A) or polypropylene (B)	68	560
Brake fluid reservoir	Polypropylene	270	499
Kick panel insulation	Polyvinylchloride	605	205
Headlight — clear lens	Polycarbonate	278	385
Headlight — black casing	Polyoxymethylene	74	158
Fender sound reduction foam	Polystyrene	12	251
Hood liner face	Polyethylene terephthalate	29	71
Windshield wiper structure	Glass-reinforced thermoset polyester resin cross-linked with styrene	252	233
Front wheel well liner	PP/PE copolymer	66	390
Air inlet	PP/PE	48	686
Hood insulator	Nylon 6 and phenolic binder (Novalac)	6	21
Radiator inlet/outlet tank	Phenolic binder (Novalac)	305	344
Engine cooling fan	Nylon 6,6	102	158
Power steering fluid reservoir	Nylon 6	129	217
Windshield with laminate	Glass with PVB laminate	157	187
Blower motor housing	Polypropylene	104	268

Table 11.2.3.3 Cone Calorimeter Data of Engine Cover Materials

At 25 kW/m^2	t_{ig} (sec)	$PHRR_a$ (kW/m^2)	THR_a (MJ/m^2)	$HRR_{180\ sec}$ (kW/m^2)	Mass Loss (g; %)
Engine cover insulation	No ignition	3.2	0.2	0.3	0.3; 3.4
	No ignition	5.2	0.5	1.2	0.2; 2.4
	No ignition	5.2	0.2	1.2	0.5; 5.5
Average	No ignition	4.5	0.3	0.9	0.3; 3.8
Engine cover molding	123	312	31.3	149.5	12.6; 24.5
	118	318	28.5	146.1	11.7; 24.1
	135	334	32.3	157.5	12.8; 23.4
	100				
Average	119	321	30.7	151	12.4; 24.0

11.2.3.5 Fire penetration through the separation can be delayed by the use of noncombustible materials or by the use of materials that offer adequate fire resistance. The separation is a system that could include openings. The openings within the separations (e.g., used for passage cable or ducts) should be adequately fire stopped to afford the same degree of fire resistance as offered by the remainder of the separation. If adequate fire resistance is offered by the separation, it is likely that premature penetration through the separation would occur only if the engine cover has been damaged (perhaps as a result of a collision).

11.2.4* Fires Penetrating Through Ductwork.

11.2.4.1 General. In most passenger road vehicles, the heating and ventilation system includes ducts that pass through the bulkhead from the engine compartment into the passenger compartment.

11.2.4.2 Ignition Scenarios. In the ignition scenario, the duct material might be exposed to flames from an engine compartment fire or from overheated electrical wiring. Table 11.2.4.2(a) and Table 11.2.4.2(b) provide cone calorimeter test data for some duct materials used in vehicles.

11.2.4.3 Initial Fire Spread. These ducts might provide a path for spread of fire and combustion products into the passenger compartment. Three possible means of fire spread to the passenger compartment can occur. If the duct is noncombustible, fire can spread through the duct's design openings. Fire can also extend through ducts by burning through the material if the duct is combustible, or might pass through any duct openings caused by collisions. See Figure 11.2.4.3 for an illustration of an engine compartment fire penetrating through HVAC and ducts.

Δ Table 11.2.4.2(a) Cone Calorimeter Data for Nine Car or Van Duct Materials at Heat Flux Indicated [26, 27, 30]

Material	t_{ig} (sec)	$PHRR_a$ (kW/m^2)	THR_a (MJ/m^2)	FPI (sec m^2/kW)	$HRR_{180\ sec}$ (kW/m^2)	$HRR_{a,\ avg}$ (kW/m^2)	$H_{c,\ eff}$ (MJ/kg)	SEA (m^2/kg)	Mass Loss (%)	TSR_a	$PSRR_a$ (1/sec)
At 25 kW/m^2											
# 1	88	325	55	0.27	259	164	38.0	758	59	1099	7.2
# 2	70	440	74	0.16	240	118	41.6	573	57	752	6.8
# 3	57	480	96	0.12	341	129	39.7	726	99	1751	9.2
# 4	83	842	72	0.10	393	459	42.0	586	90	982	10.9
# 5	67	716	78	0.09	350	—	42.7	430	77	795	1.3
# 6	57	565	78	0.10	401	—	33.2	1156	91	2731	7.6
# 7	84	544	96	0.15	352	—	42.6	363	72	830	1.3
# 8	159	515	75	0.31	281	—	31.3	212	67	515	0.9
# 9	84	405	66	0.21	269	—	43.4	258	55	394	0.7
At 40 kW/m^2											
# 1	38	356	62	0.11	267	152	36.9	771	60	1294	8.4
# 4	23	1060	43	0.02	235	530	41.9	704	81	1775	15.5
# 5	33	772	76	0.04	378	—	40.8	424	82	793	1.8
# 7	32	616	95	0.05	395	—	42.0	489	75	1115	2.0
# 8	64	853	120	0.08	451	—	38.8	234	87	742	1.5
# 9	34	492	60	0.07	279	—	40.8	395	57	579	1.5

Note: All materials have been shown to be polyolefins (polypropylene or polyethylene) without fire retardants.

Table 11.2.4.2(b) Cone Calorimeter Data for Nine Fire-Retarded Polypropylene Materials at Heat Flux Indicated

Material	t_{ig} (sec)	$PHRR_a$ (kW/m²)	FPI (sec m²/kW)	$HRR_{180\ sec}$ (kW/m²)	$H_{c,\ eff}$ (MJ/kg)	Mass Loss (%)
At 20 kW/m²						
# 1	382	236	1.62	183	23.6	68
# 2	325	168	1.93	136	29.8	64
# 3	377	207	1.82	173	24.4	65
# 4	384	195	1.97	157	25.3	65
# 5	396	301	1.32	199	24.3	63
# 6	387	215	1.80	131	25.9	64
# 7	402	228	1.76	185	27.1	61
# 8	377	207	1.82	173	26.8	61
# 9	386	202	1.91	173	27.8	61
At 40 kW/m²						
# 1	80	243	0.33	170	23.9	68
# 2	63	206	0.31	144	28.6	66
# 3	62	209	0.30	167	25.2	68
# 4	72	206	0.35	144	25.4	67
# 5	74	231	0.32	160	25.2	65
# 6	70	193	0.36	155	26.1	66
# 7	75	193	0.39	138	25.9	66
# 8	71	188	0.38	139	25.8	66
# 9	67	172	0.39	127	25.7	66

11.2.4.4 Fire Spread Within the Passenger Compartment. Once in the ducts, fire may extend to the underside of the dash assembly or penetrate through the dash via the HVAC discharge vents located at the base of the windshield or at the front of the dash. When the fire extends under the dash, the dash materials might ignite, and the subsequent fire spread would have the same effect as fire initiated under the dash in the passenger compartment. If the path of fire extension is through the vents at the base of the windshield, the next materials ignited could be the visors and headliner.

11.2.5 Fire Starting in the Engine Compartment and Penetrating Through the Windshield.

11.2.5.1 General Modes of Flame Spread. A demonstrated mode of flame spread from the engine compartment to the passenger compartment through the windshield involves fracture of the windshield. One cause of windshield fracture involves thermal stress fractures developing in the windshield as a result of radiative or convective heating. These fractures are followed by vaporization of the inner windshield polymer layer and subsequent ignition. Windshield fracture could also result from collision damage. See Figure 11.2.5.1 for an illustration of an engine compartment fire penetrating through the windshield.

11.2.5.2* Full-Scale Fire Tests Conducted at FM Global. The results of full-scale vehicle fire tests conducted at FM Global were recently published. Each test consisted of a post-collision collision-damaged passenger road vehicle. A fire was initiated in the engine compartment. Paragraph 11.2.5.3 provides details of the flame spread from the engine compartment to the passenger compartment through the windshield. Burning pieces of the shattered windshield fell into and ignited combustible materials inside the passenger compartment.

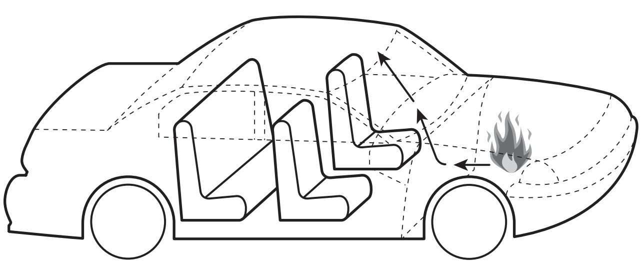


FIGURE 11.2.4.3 Engine Compartment Fire Penetrating Through HVAC and Ducts.

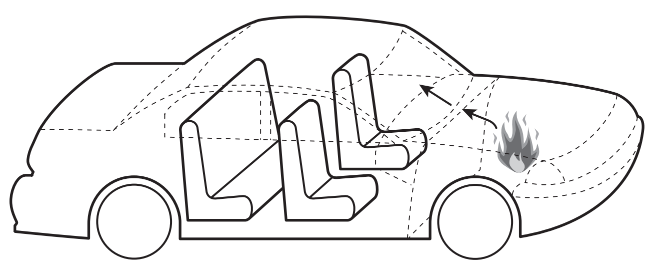


FIGURE 11.2.5.1 Engine Compartment Fire Penetrating Through the Windshield.

11.2.5.3 The heat release rate in the FM Global full-scale vehicle fire tests at the time of flame propagation into the passenger compartment was between 400 kW and 500 kW. The 400 kW fire size and the time to ignition of different components in the vehicle engine compartment when exposed to 35 kW/m^2 incident heat flux in the cone calorimeter were used in a model with simplified physics to estimate the time to reach 400 kW when the fire becomes a threat to trapped occupants. [22] The material description, time to ignition, and peak heat release rate in the cone calorimeter at a 35 kW/m^2 incident heat flux of individual components from two test vehicles are summarized in Table 11.2.5.3.

11.2.6 Current Fire Safety Requirements. Materials in engine compartments are not currently required by federal regulations to meet any fire safety test.

11.2.7 Mitigation Strategies. The three primary types of strategy that could mitigate the effects of fires starting in the engine compartment from penetrating into the passenger compartment are addressed in 11.2.7.1 through 11.2.7.3. Mitigation strategies can be used individually or in combination. See also 1.2.3 and Section 6.3.

11.2.7.1 Ignition Propensity. The first strategy is to decrease the ignition propensity of the materials contained within the engine compartment.

11.2.7.1.1 This decrease in ignition propensity could be achieved by choosing materials with low ignition propensity for use in each area of the engine compartment. These materials can be chosen from materials with inherently low ignition propensity or by incorporating additives into other materials.

11.2.7.1.2 The lower ignition propensity should apply to all materials within the engine compartment.

11.2.7.2 Heat Release. The second strategy is to decrease the heat release of the materials contained within the engine compartment.

11.2.7.2.1 A decrease in heat release could be achieved by using materials with low heat release propensity in each area of the engine compartment. These materials can be chosen from materials with inherently low heat release propensity or by incorporating additives into other materials.

11.2.7.2.2 The lower heat release propensity should apply to all materials within the engine compartment.

11.2.7.3 Design Improvements. The third strategy is to incorporate design improvements that increase the time available for passengers to escape or be rescued. The passenger road vehicle must continue to exhibit functionality and performance for all other safety features (see also 1.2.3 and Section 6.3).

11.2.7.4 Barrier Between Engine Compartment and Passenger Compartment.

11.2.7.4.1* One potential added mitigation strategy would be to separate the engine compartment from the passenger compartment by a barrier that either inhibits or prevents the passage of flame and hot gases; for example, when exposed to the fire exposure curve described in ASTM E119 or UL 263.

11.2.7.4.2 Test specimens should include a representative arrangement of penetrations of the barrier.

11.2.7.4.3 Separation penetrations should be protected so that the integrity of the barrier is not compromised.

11.2.7.5 Ductwork Mitigation Strategies. The three primary types of strategy that could mitigate the effects of fires starting

Table 11.2.5.3 Predicted Times to 400 kW Based on Cone Calorimeter Data at an Incident Heat Flux of 35 kW/m^2

Vehicle and Material	t_{ig} (sec)	$PHRR_a$ (kW/m^2)	$t_{400\ kW}$ (sec)	$t_{400\ kW}$ (min:sec)
Dodge Caravan				
Headlight assembly (clear)	278	385	1952	32:32
Battery cover	39	297	287	4:47
Resonator structure	64	417	443	7:23
Resonator intake tube	72	434	497	8:17
Air ducts	68	560	443	7:23
Brake fluid reservoir	270	499	1808	30:08
Kick panel insulation	605	205	4720	78:40
Headlight assembly (black)	74	158	603	10:03
Fender sound reduction foam	12	251	88	1:28
Hood liner face	29	71	269	4:29
Windshield wiper structure	252	233	1926	32:06
Chevy Camaro				
Front wheel well liner	66	390	465	7:45
Air inlet	48	686	306	5:06
Hood insulator	6	21	63	1:03
Radiator inlet/outlet tank	305	344	2187	36:27
Engine cooling fan	102	158	831	13:51
Power steering fluid reservoir	129	217	997	16:37
Windshield laminate	157	187	1242	20:42
Blower motor housing	104	268	775	12:55

in the engine compartment from penetrating into the passenger compartment through the ductwork are addressed in 11.2.7.5.1 through 11.2.7.5.3. Mitigation strategies can be used individually or in combination. See also 1.2.3 and Section 6.3.

11.2.7.5.1 Ignition Propensity. The fourth strategy is to decrease the ignition propensity of ductwork materials.

11.2.7.5.1.1 This decrease in ignition propensity could be achieved by choosing materials with low ignition propensity for use as ductwork materials. These materials can be chosen from materials with inherently low ignition propensity or by incorporating additives into other materials.

11.2.7.5.1.2 The lower ignition propensity should apply to all ductwork materials.

11.2.7.5.2 Heat Release. The fifth strategy is to decrease the heat release of the ductwork materials.

11.2.7.5.2.1 This decrease in heat release could be achieved by choosing materials with low heat release propensity for use as ductwork materials. These materials can be chosen from materials with inherently low heat release propensity or by incorporating additives into other materials.

11.2.7.5.2.2 The lower heat release propensity should apply to all ductwork materials.

11.2.7.5.3 Design Improvements. Design improvements that increase the time available for passengers to escape or be rescued should be incorporated. The passenger road vehicle should continue to exhibit functionality and performance for all other safety features (see also 1.2.3 and Section 6.3).

11.2.7.6* Glazing Materials. Consideration should be given to the use of glazing materials for the windshield that offer an adequate fire protection rating as well as appropriate impact resistance and other critical properties (see Section 6.1).

11.3 Fires Starting Inside the Trunk or Load-Carrying Area.

11.3.1 General. Passenger road vehicles are generally equipped with a storage compartment, usually in the rear of the vehicle. Certain types of vehicles such as hatchbacks, minivans, and sports utility vehicles often do not have a separate storage compartment. This compartment is commonly referred to as the *trunk* in passenger vehicles or the *bed* in trucks. Between 1994 and 1998 only 1.7 percent of all fires in passenger road vehicles started in the trunk or load-carrying area of the vehicle. [25]

11.3.2 Ignition Scenario. Noncollision ignition sources include carelessly used cigarettes or other smoking materials and heated equipment such as heating torches. Vehicle upholstery, trunk or bed lining materials, insulating materials, electrical wiring, and plastic body and trim can all fuel a fire originating in the storage compartment. The cargo or fuel tanks carried in the trunk or load-carrying area can also contribute to the intensity of the fire in that compartment. Portable liquid fuel containers are a particularly hazardous type of cargo.

11.3.3 Fire Spread. Fire in the trunk or load-carrying area has the potential to contribute flame, smoke, and heat to the passenger compartment either through the upholstered boundary in passenger road vehicles or the rear window in trucks. In the event that the trunk or load-carrying area is maintained in a configuration separate from the passenger compartment, fire spread can occur through the flammable upholstery, stereo system components, or other wiring or air-conditioning components. Fire spread and generation of combustion products into the passenger compartment will be noticed by vehicle occupants sooner in the event that the rear seats are lowered, in which case the trunk or load-carrying area essentially becomes an extension of the passenger compartment. See Figure 11.3.3 for an illustration of a fire starting inside a trunk.

11.3.4 Current Fire Safety Requirements. Materials in cargo compartments are not currently required by federal regulations to meet any fire safety test.

11.3.5 Mitigation Strategies. The primary strategies for mitigating the effects of fires starting in the cargo compartment are addressed in 11.3.5.1 through 11.3.5.5. Mitigation strategies can be used individually or in combination. See also 1.2.3 and Section 6.3.

11.3.5.1* Smoldering Combustion Performance of Cargo Compartment Lining Materials. Consideration should be given to the use of cargo compartment lining materials with improved smoldering combustion performance characterized by reduced ignition propensity and limited propagation.

11.3.5.2* Flaming Performance of Cargo Compartment Lining Materials. Consideration should be given to the use of textile cargo compartment lining materials that exhibit improved fire performance characterized by reduced propensity to ignition from small open flames and limited flame spread.

11.3.5.3 Ignition Propensity. The ignition propensity of the materials contained within the cargo compartment should be decreased.

11.3.5.3.1 A decrease in ignition propensity could be achieved by choosing materials with low ignition propensity for use in each area of the cargo compartment. These materials can be chosen from materials with inherently low ignition propensity or by incorporating additives into other materials.

11.3.5.3.2 The lower ignition propensity should apply to all materials that are directly exposed to a potential ignition source.

11.3.5.3.3 A different criterion should apply in the case of materials not directly exposed to a potential ignition source. In such cases, the ignition propensity of the composite system should be assessed.

11.3.5.4 Heat Release. The heat release of the materials contained within the cargo compartment could be decreased to provide a safer environment for the occupants in a passenger road vehicle fire.

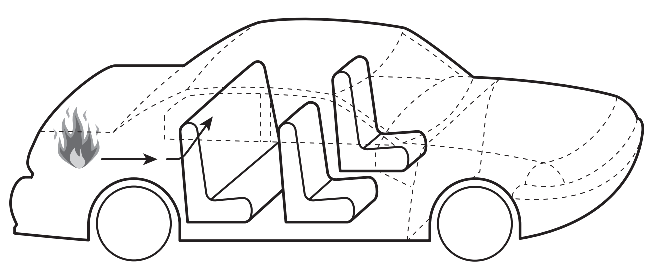


FIGURE 11.3.3 Fire Starting Inside a Trunk.

11.3.5.4.1 A decrease in heat release could be achieved by choosing materials with low heat release propensity for use in each area of the cargo compartment. These materials can be chosen from materials with inherently low heat release propensity or by incorporating additives into other materials.

11.3.5.4.2 The lower heat release propensity should apply to all materials that are directly exposed to a potential ignition source.

11.3.5.4.3 A different criterion should apply in the case of materials not directly exposed to a potential ignition source. In such cases, the heat release propensity of the composite system should be assessed.

11.3.5.5 Design Improvements. Design improvements that increase the time available for passengers to escape or be rescued should be incorporated. The passenger road vehicle should continue to exhibit functionality and performance for all other safety features (see also 1.2.3 and Section 6.3).

11.4 Pool Fires Resulting from Fuel Tank Failure and Burning Under the Vehicle.

11.4.1* Pool Fires and Spill Fires.

11.4.1.1 Collisions. Pool fires and spill fires can result from collisions associated with passenger road vehicles. These collisions can cause automotive fluids to be released within the engine compartment, near fuel system components, or on the ground underneath the passenger road vehicle. Ignition of these fluids can occur by any of the ignition processes outlined in Section 9.3. The fuel for the pool fire or spill fire can originate from any vehicles involved in the collision. See Figure 11.4.1.1 for an illustration of a pool fire burning under a passenger vehicle.

11.4.1.2 Fire-Induced Melt or Liquid Release. Pool and spill fires can also result from the melting of thermoplastic polymeric components or from the release of flammable or combustible liquids from the passenger road vehicle.

11.4.1.3 Loss of Containment. Pool and spill fires can result from the loss of containment of flammable or combustible liquids caused by mechanical, thermal, or chemical means, unrelated to any collision.

11.4.2 Hazard. The hazard posed by the pool fire depends, in large part, on the volume of the fluid spill. The hazard to occupants due to large pool fires involving a substantial portion of the passenger road vehicle is primarily due to the external fuel load and associated fire, with the fire performance of the vehicle itself being of secondary importance. The hazard of pool fires can increase if the fire consumes other fuel sources, such as trash or other debris underneath a vehicle (see Section 11.5).

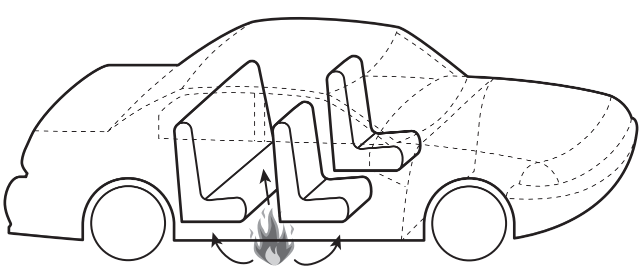


FIGURE 11.4.1.1 Pool Fire Burning Under Vehicle.

11.4.3 Heat Release. The heat release depends on the surface area of the spill. The area of the spill is highly dependent on the slope and other characteristics of the surface onto which the fuel is spilled. If the surface area of the spill is known, the heat release rate and radiant flux of the fuel can be determined. The surface area of the spill can be calculated based on an estimate of the fuel volume spilled and spill depth.

11.4.4 Current Fire Safety Requirements. Fuel tanks are not currently required by federal regulations to meet any fire safety test.

11.4.5 Mitigation Strategies. The three primary types of strategy that could mitigate the effects of fires resulting from fuel tank failure and burning under the vehicle are addressed in 11.4.5.1 through 11.4.5.3. Mitigation strategies can be used individually or in combination. See 1.2.3 and Section 6.3.

11.4.5.1 Consideration should be given to the use of vehicle fuel tanks that meet the requirements of fire exposure testing as conducted per European Standard ECE R34.01, Annex 5, for plastic fuel tanks. This standard requires fuel tanks to withstand a 2-minute fire exposure without any liquid fuel leakage.

11.4.5.2 Separation from the Passenger Compartment.

11.4.5.2.1* One potential additional mitigation strategy would be to separate the undercarriage from the passenger compartment by a barrier that either inhibits or prevents the passage of flame and hot gases; for example, when exposed to the fire exposure curve described in ASTM E1529 or UL 1709.

11.4.5.2.2 Test specimens should include a representative arrangement of penetrations of the barrier.

11.4.5.2.3 Barrier penetrations should be protected so that the integrity of the barrier is not compromised.

11.4.5.3 Design improvements that provide adequate time for passengers to escape or be rescued should be incorporated. The passenger road vehicle must continue to exhibit adequate functionality for other safety features (see also 1.2.3 and Section 6.3).

11.5 Fires Resulting from Other External Heat Sources.

11.5.1 General. As seen in Table 9.3.2, a number of fires occur as a result of heat sources that are not associated with the passenger road vehicle itself. For the purposes of this document, pool fires due to fuel tank failures are not considered to be such fires.

11.5.2 Types of Heat Sources. The best way to identify heat sources is by elimination, from a typical list of ignition factors, as shown in Table 11.5.2.

11.5.3 Analysis of Data.

11.5.3.1 If the information in Table 11.5.2 is applied to the 1994 through 1998 US averages, it appears that vehicle malfunction would correspond to the results in Table 11.5.3.1.

11.5.3.2 As Table 11.5.3.1 shows, external heat sources (other than abandoned material) account for a small but significant fraction of fires. Of further interest is the fact that they account for a consistent fraction of all fire losses (around 4 percent), which is very different from most other sources.

Table 11.5.2 Ignition Factors and Their Outcome Classification

Ignition	Outcome
Part failure, leak, or break	Vehicle malfunction
Short circuit or ground fault	Vehicle malfunction
Incendiary or suspicious	Human action
Backfire	Vehicle malfunction
Unclassified or unknown-type mechanical failure or malfunction	Vehicle malfunction
Electrical failure other than short circuit or ground fault	Vehicle malfunction
Lack of maintenance	Vehicle malfunction (human fault)
Fuel spilled or unintentionally released	Human action
Property too close	External heat source
Unclassified ignition factor	Unknown
Collision, overturn, or knock down	Collision
Combustible too close to heat	External heat source
Abandoned material	External or internal heat source
Unclassified or unknown-type operational deficiency	Vehicle malfunction
Other known ignition factor	Unknown

Δ **Table 11.5.3.1 Distribution of Loss Data from Table 5.1.2 and Figures 5.1.2(a) Through 5.1.2(d) by Ignition Factor**

Ignition Factor	Fires (%)	Civilian Deaths (%)	Civilian Injuries (%)	Property Damage (%)
Vehicle malfunction	66.20	10.80	47.80	54.80
Human action	18.70	14.20	12.90	27.70
External heat source	4.00	3.50	4.00	3.80
Collision	1.90	60.60	15.80	5.90
Abandoned material	1.60	1.40	3.00	1.10
Unknown	7.60	9.40	16.50	6.70

11.5.4 Mitigation Strategies. The main strategies for minimizing the effects of external heat sources involve hardening of the vehicle exteriors to minimize exterior ignitions.

11.5.4.1 Even if vehicle exteriors were completely resistant to ignition, external heat sources could still cause fire penetration into the passenger compartment by way of openings (such as open windows).

11.5.4.2 External heat sources can also cause ignition in the engine and storage compartments. This ignition would then lead to the type of fires addressed in Sections 11.1 and 11.3.

Chapter 12 Further Guidance

12.1 Traditional Approach. The continued use of FMVSS 302 as the sole fire safety tool is unlikely to be consistent with significant decreases in fire losses associated with passenger road vehicles. FMVSS 302 was initially intended to solve the problem of smoldering ignition caused by cigarettes, and it has been effective in doing so. With the prevalent and growing use of combustible materials in passenger road vehicles (especially cars), such a mild flaming ignition test is insufficient to show that passenger road vehicle materials meeting that test would allow passengers and drivers enough time to escape in the case of a fire.

12.2 Mitigation Strategies. Fire hazard will decrease if either materials or products are used with better fire properties or the passenger road vehicle is redesigned to minimize the speed of fire development, particularly into the passenger compartment.

12.2.1 The earlier chapters of this document have identified the major fire properties that should be controlled in the materials and products: ignitability, heat release, and smoke obscuration. Of those, heat release is the most critical one; it is also the one that is easiest to scale up and predict.

12.2.2 Most of the earlier chapters also indicate that there are some engineering design approaches that can be used to mitigate the effects of fire on passenger road vehicle occupants. These engineering solutions should be based on an overall performance evaluation. ASTM E1546 provides a framework for performing a fire hazard assessment. Also, ASTM E2061 provides an example of the application of this framework to a rail transportation vehicle. Battipaglia et al. used the ASTM E1546 framework for assessing the fire hazard of automotive materials in the engine compartment of a passenger road vehicle following a collision.

12.3 Testing to Assess Improved Fire Performance of Materials or Products.

12.3.1 There are a number of examples in the literature of full-scale tests using undamaged and collision-damaged vehicles conducted to assess the fire performance of passenger road vehicles, some of which have been referenced or described in this document. Those tests have often analyzed one or more of the scenarios outlined in this document as most likely to cause harm to passenger road vehicle occupants.

12.3.2 Quantitative full-scale tests are most useful if they assess heat release properties. ASTM E603 and ASTM E2067 provide guidance on how to set up and conduct such tests. Whenever such full-scale tests are performed, it is advisable to comprehensively measure, observe, and record all other relevant fire properties such as smoke release, combustion gas release, heat fluxes, temperatures, and mass loss so as to also get information on potential drawbacks of alternative designs, with respect to properties other than heat release.

12.3.3 Conducting full-scale tests is clearly the most representative way of understanding where deficiencies in fire safety are present in a passenger road vehicle and to develop mitigation strategies. It is also clear, however, that the high cost associated with conducting full-scale fire tests is likely to make their exclusive use difficult.

12.3.4 Testing sections, such as individual compartments or individual fuel packages, of a passenger road vehicle, for example in a furniture calorimeter, will be a way of understanding the interactions between the materials and products contained in the various sections of the passenger road vehicle. NFPA 555 contains extensive guidance on estimation techniques for heat release rate, based on smaller-scale measurements.

12.3.5 Heat Release.

12.3.5.1 The cone calorimeter (ASTM E1354) is a suitable tool for choosing materials with desired fire performance properties, especially because the test method is capable of assessing not just heat release but also most, if not all, of the properties deemed to be most critical in the same test. [15–18]

12.3.5.2 If there is a need to accurately assess very low levels of heat release, ASTM E2965 provides such information. This test method can be used to assess whether a material is a limited-combustible material.

12.3.5.3 Once again, NFPA 555 contains guidance on predictive methods.

12.3.6* A screening tool that is useful for guidance purposes is the mass loss cone fire test, ASTM E2102, because it provides ignitability data under the same fire exposure conditions as in the cone calorimeter, the mass loss data from the test probably parallels the heat release data from the cone calorimeter, and the instrument is available at significantly lower cost than the cone calorimeter.

12.3.7 Testing of the fire properties of materials or products for an individual fire property should be accompanied by an overall analysis that indicates that an apparent improvement in the fire property assessed will result in an actual improvement in fire safety in the road vehicle. This is particularly important when considering the use of fire test methods that either are unable to generate fire test results in engineering units or have been shown not to be adequately predictive of real-scale fire performance.

Annex A Explanatory Material

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

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

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

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

Δ **A.3.3.7 Combustible.** A combustible material is capable of burning, generally in air under normal conditions of ambient temperature and pressure, unless otherwise specified; combustion can occur in cases where an oxidizer other than the oxygen in air is present (e.g., chlorine, fluorine, or chemicals containing oxygen in their structure). [**921,** 2021]

A.3.3.9 Contents and Furnishings of a Vehicle. It is intended that these materials or products will include all combustible materials in the passenger road vehicle, except for the fuel used for the vehicle engine. Such contents and furnishings will include the ductwork, the engine cover, and all combustibles in the engine and storage compartments.

A.3.3.13 Fire Performance Index (as related to cone calorimeter data). This parameter has been shown to give an indication of propensity to flashover because it relates to the time to flashover.

A.3.3.15 Fire Scenario (Vehicular). This is intended to be similar to the concepts in the definition of fire scenario from NFPA *101*, but its application to passenger road vehicles should be considered.

A.3.3.20 Fuel Package. For a given group of items, there is no precise grouping that constitutes a fuel package.

A.3.3.30 Item. An item can be a collection of combustible materials such as chairs, wastebaskets with contents, or a combustible wall or floor. A precise definition of an item is not generally possible or necessary.

A.3.3.47 Visible Smoke. Visible smoke is measured in ASTM E1354, *Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter.*

N **A.5.1.2.1** Ahrens (2020) includes full statistics for the years 2013 through 2017[1]. The average 181,700 highway vehicle fires per year in 2013 through 2017 caused an average of 355 civilian deaths, 1,172 civilian injuries, and $1.3 billion in direct property damage. These fires accounted for 92 percent of all reported vehicle fires, 91 percent of vehicle fire deaths, 81 percent of vehicle fire injuries, and 74 percent of vehicle fire dollar loss. Highway vehicle fires accounted for 14 percent of reported fires of all types, 11 percent of fire deaths, 8 percent of fire injuries, and 9 percent of total fire dollar loss.

An NFPA survey indicates that US fire departments responded to an estimated 212,500 vehicle fires in the US during 2018. These fires caused an estimated 560 civilian deaths, 1,500 civilian injuries, and $1.9 billion in direct property damage. Vehicle fires accounted for 16 percent of the 1.3 million fires reported to US fire departments. Vehicle fires also caused

15 percent of all civilian fire deaths and 10 percent of all reported civilian fire injuries. In 2018, only fires in one- and two-family homes claimed more lives than vehicle fires. Vehicle fires caused 4.5 times as many deaths as nonresidential structure fires and 1.6 times as many deaths as apartment fires.

Table A.5.1.2.1(a) illustrates the annual average US vehicle fire losses by type of vehicle for 2013 through 2017. Figure A.5.1.2.1(a) and Figure A.5.1.2.1(b) show the evolution of vehicle fire losses over those years.

Passenger road vehicle fires during those years can be grouped into the following five categories by cause of ignition:

(1) Unintentional
(2) Failure of equipment or heat source
(3) Intentional
(4) Unclassified
(5) Act of nature

Table A.5.1.2.1(b) gives the annual average number of fires, number of civilian deaths and injuries, and direct property damage for these five categories for 2013 through 2017. The table shows that the first category accounted for 80 percent of the civilian fire deaths. Since the objective of this guide is to reduce the number of passenger road vehicle fire deaths, the focus is on this category.

Figure A.5.1.2.1(c) shows collision fire statistics by area of origin. Figure A.5.1.2.1(d) distributes these highway vehicle fires by major causal factors. The data shows that mechanical failures or malfunctions were the leading factors in all types of vehicle fires, followed by electrical failures or malfunctions. These fires were much less likely to be fatal than fires resulting from collisions. Almost two-thirds of car fire deaths resulted from fires caused by collisions or related events. In addition, 79 percent of the deaths from large truck fires were caused by collisions.

Figure A.5.1.2.1(e) shows highway vehicle fires by item first ignited for the period of 2013 through 2017.

A.5.3.2 The test method upon which FMVSS 302 was based, ASTM D1692, [2] was discontinued by ASTM as a standard in 1976, following a ruling by the Federal Trade Commission (FTC) that required the cessation of the use of ASTM D1692 for the marketing of plastic products. [3]

In 1979, the National Materials Advisory Board (NMAB), as part of a study of the fire hazards of polymeric materials in ground transport vehicles, reviewed tests used for assessing the flammability of materials. [4] That study stated the following about FMVSS 302:

(1) "This standard prescribes a test method that tests materials only in a horizontal orientation and is considered by test experts to be totally ineffective in providing fire safety in a real fire situation."
(2) "Although all these materials are required to pass FMVSS 302 with a horizontal burning rate not exceeding 4 in. per minute, most of them are used in a vertical configuration where the actual burning state would be expected to be several times that exhibited in the horizontal configuration."

A.5.4 The provisions of Section 5.4 do not require inherently noncombustible materials to be tested in order to be classified as noncombustible materials.

A.5.4(1) Examples of such materials include steel, concrete, masonry, and glass.

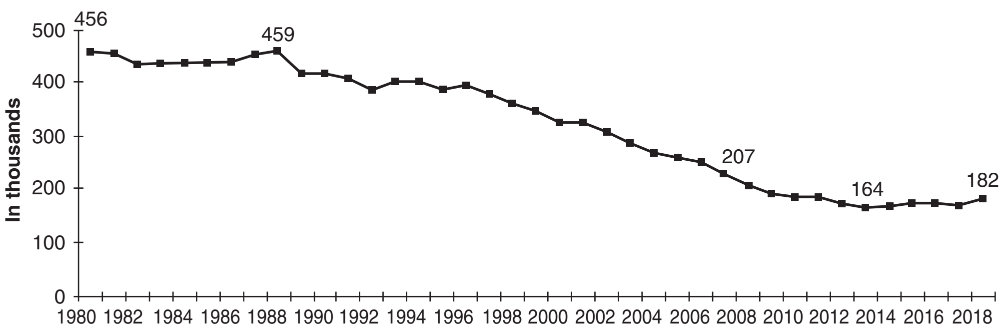
Δ **A.5.5.2** Material subject to increase in combustibility or flame spread index beyond the limits herein established through the effects of age, moisture, or other atmospheric condition is considered combustible. (See NFPA 259 and NFPA 220.) [**5000:**A.7.1.4.2]

N **Table A.5.1.2.1(a) US Vehicle Fire Losses by Type of Vehicle, 2013–2017 Annual Averages**

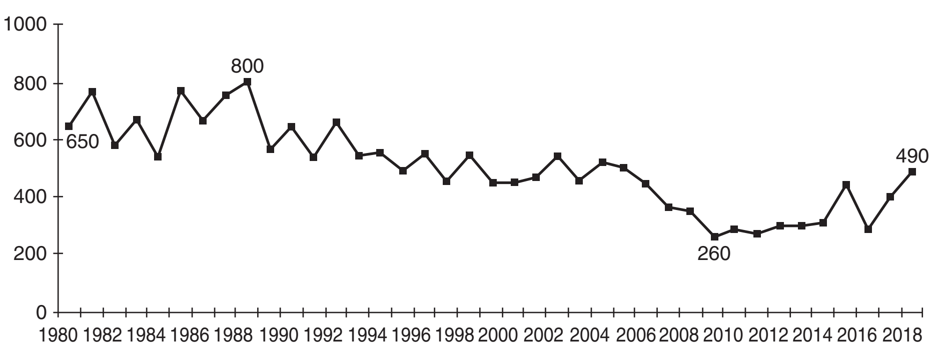
Vehicle Type	Fires	Civilian Deaths	Civilian Injuries	Damage (millions)
Passenger cars	117,370 (59%)	230 (59%)	694 (48%)	$557 (33%)
Other passenger road vehicles	43,690 (23%)	72 (18%)	411 (28%)	$287 (17%)
Freight road vehicles	20,620 (10%)	53 (14%)	156 (11%)	$415 (24%)
Other vehicles	15,820 (8%)	37 (9%)	181 (13%)	$452 (26%)

N **Table A.5.1.2.1(b) Highway Vehicle Fires by Cause of Ignition, 2013–2017 Annual Averages**

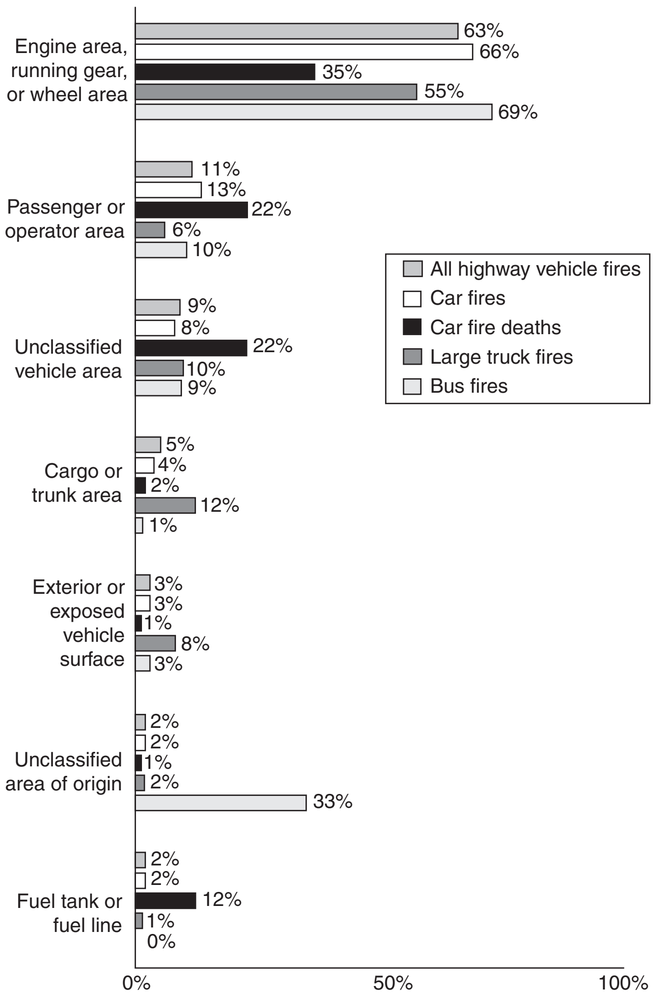
Cause	Fires	Civilian Deaths	Civilian Injuries	Direct Property Damage (in Millions)
Unintentional	102,600 (56%)	285 (80%)	845 (72%)	$677 (54%)
Failure of equipment or heat source	58,700 (32%)	23 (6%)	245 (21%)	$377 (30%)
Intentional	12,200 (7%)	34 (9%)	59 (5%)	$99 (8%)
Unclassified	7,400 (4%)	10 (3%)	21 (2%)	$102 (8%)
Act of nature	700 (0%)	3 (1%)	1 (0%)	$4 (0%)
Total	181,700 (100%)	355 (100%)	1,172 (100%)	$1,259 (100%)



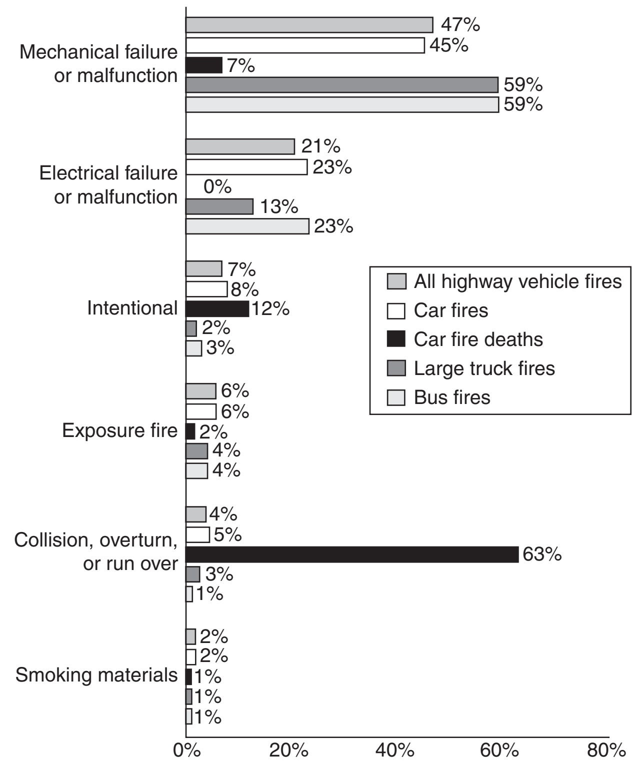
N **FIGURE A.5.1.2.1(a) US Vehicle Fire Trend: Number of Fires.**



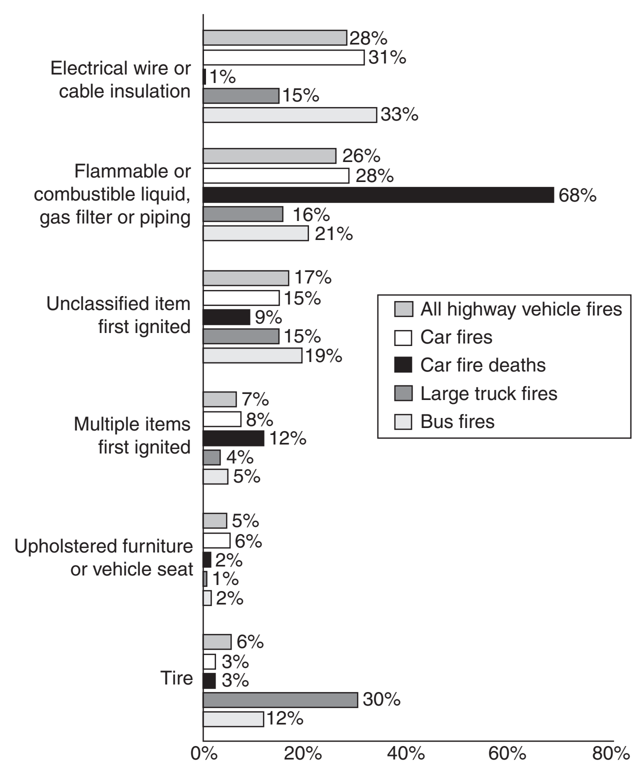
N **FIGURE A.5.1.2.1(b) US Vehicle Fire Trend: Number of Civilian Deaths.**



N **FIGURE A.5.1.2.1(c) Highway Vehicle Fires by Area of Fire Origin, 2013–2017 Annual Averages.**



N **FIGURE A.5.1.2.1(d) Highway Vehicle Fires by Major Causal Factors, 2013–2017 Annual Averages.**



N **FIGURE A.5.1.2.1(e) Highway Vehicle Fires by Item First Ignited, 2013–2017 Annual Averages.**

A.6.4 See https://www.nhtsa.gov for more information.

A.7.2 Data and methods that can assist the designer in establishing design criteria can be found in the *SFPE Handbook of Fire Protection Engineering*.

A.9.3 The term *ignition factor* was used in National Fire Incident Reporting System (NFIRS) until its version 5.0, when it was replaced by the term *factor contributing to ignition*. Version 5.0 of NFIRS changed, added, and dropped some of the codes used and some of the coding rules. Many of the former "ignition factor" items convert to "factor contributing to ignition" items. However, "incendiary" and "suspicious" convert to "intentional" in the Cause category. Fires that had been coded as incendiary or suspicious or that resulted from one of several human factors have been removed from and left blank in "factor contributing to ignition" because they are captured elsewhere. Some codes from "form of heat of ignition" (particularly electrical codes) convert to "factor contributing to ignition."

A.9.3.3 Incendiary or suspicious fires are not coded in NFIRS 5.0 as a factor contributing to ignition but were earlier coded as an ignition factor.

A.10.2 Information on Test Methods and Guides in Table 10.1. ASTM E1354, known as the cone calorimeter, is a test method that measures the response of materials exposed to controlled levels of radiant heating, with or without an external igniter. It can be used to assess the ignitability, heat release rate, mass loss rates, effective heat of combustion, and visible smoke development of materials and products. It tests the specimen in the horizontal orientation. It provides measurements of the behavior of material and product specimens under a specified radiant heat exposure in terms of the heat release rate, effective heat of combustion, mass loss rate, time to ignition, and smoke production. The heat release rate is determined by the principle of oxygen consumption calorimetry, via measurement of the oxygen consumption as determined by the oxygen concentration and flow rate in the exhaust product stream (exhaust duct). Data are reported in units for convenient use in fire models and in fire hazard and fire risk assessment.

ASTM E2965, known as the very low heat release level calorimeter, is a test method that provides a procedure for measuring the response of materials that emit low levels of heat release when exposed to controlled levels of radiant heating. It differs from the cone calorimeter, ASTM E1354, in several aspects, in terms of equipment, test specimen size, and procedure. ASTM E2965 uses a much larger test specimen size [15 cm by 15 cm (6 in. by 6 in.) instead of 10 cm by 10 cm (4 in. by 4 in.)], and the associated specimen holder. The radiant heater is much larger than that in ASTM E1354 and there is a direct connection between the plenum and the top plate of the cone heater assembly to ensure complete collection of all the combustion gases. In terms of procedure, ASTM E2965 prescribes a lower volumetric flow rate for analyses via oxygen consumption calorimetry than does ASTM E1354. This test method is intended for use on materials and products that contain only small amounts of combustible ingredients or components such as test specimens that yield a peak heat release of less than 200 kW/m^2 and total heat release of less than 15 MJ/m^2. The rate of heat release is determined by oxygen consumption calorimetry. Test specimens are exposed horizontally to heat fluxes generated by a large conical radiant heater, with external ignition, when used, by electric spark.

ASTM E1321, known as the lateral ignition and flame spread test (or LIFT), is a test method that determines material properties related to piloted ignition of a vertically oriented sample under a constant and uniform heat flux and to lateral flame spread on a vertical surface due to an externally applied radiant heat flux. The results of this test method provide a minimum surface flux and temperature necessary for ignition and for lateral flame spread, an effective material thermal inertia value, and a flame-heating parameter pertinent to lateral flame spread. The results of this test method are potentially useful to predict the time to ignition and the lateral flame spread rate on a vertical surface under a specified external flux without forced lateral airflow. Data are reported in units for convenient use in fire models and in fire hazard and fire risk assessment.

FMVSS 302 is a regulatory test method used for assessing the flammability of materials used in the interior of passenger road vehicles. This test method exposes a sample of material in a horizontal orientation to a Bunsen burner flame at one end. The horizontal rate of flame spread away from the burner flame is measured. In order to be acceptable, the flame spread rate cannot exceed 102 mm/min (4 in./min).

ASTM E1474 is an application of the cone calorimeter (ASTM E1354) to use with upholstered seating composites or components. The test uses a specific incident heat flux of 35 kW/m^2. Data are reported in units for convenient use in fire models and in fire hazard and fire risk assessment.

ASTM E2574/E2574M is a flame spread test in which a propane gas burner is applied to the top or the bottom of a school bus seat assembly. The top of the seat burner (a square gas burner) is essentially the same burner as is used in the full-scale seat test ASTM E1537 (except for the arm) and it applies the flame to the seat assembly from above. Underneath the seat burner is the same burner as is used in NFPA 286 (room-corner test). Both burners are used at a propane gas flow rate of 19.5 L/min for a total of 120 sec. The test specimens are full school bus seat assemblies and the test method measures mass loss and flame spread from seat to seat. It can also optionally be used to measure heat and smoke release. The test method is a derivation of the "paper bag fire test" (school bus seat upholstery fire block test, approved by the National Conference on School Transportation as part of the National Standards for School Buses and National Standards for School Bus Operations; National Safety Council), by replacing the paper bag with a more repeatable gas burner.

ASTM D2859, known as the methenamine pill test, is a test method for the determination of the flammability of textile materials when exposed to an ignition source (a methenamine pill). This test procedure is part of the standards for the surface flammability of carpets and rugs used by the US Consumer Product Safety Commission. The acceptance criterion in this test method requires that at least seven out of eight individual specimens of a given textile material have passed the test; that is, the charred portion of a tested specimen does not extend to within 25.4 mm (1.0 in.) of the edge of the hole in the flattening frame at any point.

ASTM E648, known as the flooring radiant panel test, presents fire test methods for measuring the critical radiant flux of horizontally mounted textile materials exposed to a flaming ignition source in a graded radiant heat energy environment in a test chamber. The radiant panel exposing the sample generates a radiant energy flux distribution ranging along the 1 m length of the test specimen from a nominal maximum of 1.0 W/cm^2 to a minimum of 0.1 W/cm^2. The test is initiated by open-flame ignition from a pilot burner. The test specimen is mounted in a typical and representative way. The test measures the critical radiant flux at flameout and provides a basis for estimating one aspect of fire exposure behavior for textiles.

UL 1685 (ASTM D5537) is a cable tray fire test that exposes 2.4 m high vertical samples of bunched cables. The test method provides a means to measure the flame spread, heat release, and smoke obscuration resulting from burning electrical or optical fiber cables when the cable specimens are subjected to a 20 kW flaming ignition source and burn freely under well-ventilated conditions. This test method provides two different protocols for exposing the cables for a 20-minute test duration. The test method is commonly used to expose cables. Data are reported in units for convenient use in fire models and in fire hazard and fire risk assessment.

ASTM D6113 is an application of the cone calorimeter (ASTM E1354) to use with electrical or optical fiber cables or other electrical materials. Data are reported in units for convenient use in fire models and in fire hazard and fire risk assessment.

UL VW-1 (contained within UL 2556) is a small vertical wire fire test that provides a means to measure the propensity of a wire, cable, or cord either to spread flame vertically along its length or to spread flame to combustible materials in its vicinity. This test method provides a protocol for exposing vertical wires, cables, or cords to an ignition source flame nominally 125 mm (5 in.) high, or nominally 500 W (1700 BTU/hr), for five 15-second applications, with periods of 15 seconds or longer between successive flame applications. The test method is commonly used to expose wires.

ASTM E119 (UL 263) is a fire test method that provides means to assess the fire-resistive properties of assemblies. The test method describes ways to evaluate the duration for which the assembly is capable of containing a fire and/or retaining its structural integrity after exposure to a standard time-temperature curve. The fire resistance rating assessed is representative of the time period during which transmission of heat, flames, smoke, or fire gases is prevented or inhibited.

ASTM E1529 (UL 1709) is also a fire test method that provides means to assess the fire-resistive properties of assemblies. In this case, the time-temperature curve used is representative of an exposure to hydrocarbon fuel (e.g., gasoline) fires.

ASTM E814 (UL 1479) is also a fire test method that provides means to assess fire-resistive properties using a standard time-temperature curve. The materials being tested in this case are fire stops, and the test is intended to evaluate whether the fire stop material is able to prevent or inhibit transmission of heat, flames, smoke, or fire gases through a penetration in a fire-resistive assembly that has been treated with an appropriate material.

NFPA 260 contains a series of fire test methods designed to evaluate the ignition resistance of upholstered seating components when exposed to smoldering cigarettes. These test methods also establish a classification system for determining smoldering ignition resistance.

NFPA 261 is a test method that applies to upholstered seating mock-ups. Mock-up testing is used in assessing the relative resistance to continuing combustion of individual materials used in upholstered seating in realistic combinations and in an idealized geometric arrangement of seating items. It is the intent of this test method to determine whether upholstered seating assemblies are relatively resistant to ignition by smoldering cigarettes. In addition, the test methods establish a classification system for determining smoldering ignition resistance.

NFPA 257, or UL 9, presents fire test methods that provide means to assess fire-resistive properties using a standard time-temperature curve. The materials being tested in this case are glazing materials contained in windows.

NFPA 289 is a fire test method for determining the contribution of individual fuel packages to heat and smoke release when exposed to various ignition sources. It measures the extent of fire growth, the heat release rate, the total heat released, the smoke obscuration, the mass loss, and the production of toxic gases. The heat release rate is determined by the principle of oxygen consumption calorimetry, via measurement of the oxygen consumption as determined by the oxygen concentration and flow rate in the exhaust product stream (exhaust duct). The test is suitable for assessing large sections of transportation vehicles or of decorative materials or systems. Data are reported in units for convenient use in fire models and in fire hazard and fire risk assessment.

ISO TS 17431, also known as the reduced-scale model box fire test, is an intermediate-scale fire test method that simulates a fire that under well-ventilated conditions starts in a corner of a small room with a single doorway and can develop until the room is fully involved in the fire.

ASTM E1623, also known as the intermediate-scale calorimeter (ICAL), is a fire test method that assesses the response of materials, products, and assemblies to controlled levels of radiant heat exposure with or without an external igniter. The properties determined by this test method include ignitability, heat release rate, mass loss rate, smoke obscuration, gas release, and flaming drips, under well-ventilated conditions. This test method is also suitable for determining many of the parameters or values needed as input for computer fire models, including effective heat of combustion, surface temperature, ignition temperature, and emissivity. The heat release rate is determined by the principle of oxygen consumption calorimetry, via measurement of the oxygen consumption as determined by the oxygen concentration and flow rate in the exhaust product stream (exhaust duct). Specimens are exposed to a constant heating flux in the range of 0 to 50 kW/m^2 in a vertical orientation. Hot wires are used to ignite the combustible vapors from the specimen during the ignition and heat release tests. Data are reported in units for convenient use in fire models and in fire hazard and fire risk assessment.

BS EN 13823, also known as the single burning item (SBI) fire test, is a method that assesses the response of materials, products, and assemblies to controlled levels of radiant heat exposure to a test specimen that forms a corner, with two vertical specimens. The properties determined by this test method include ignitability, heat release rate, mass loss rate, smoke obscuration, gas release, and flaming drips. The heat release rate is determined by the principle of oxygen consumption calorimetry, via measurement of the oxygen consumption as determined by the oxygen concentration and flow rate in the exhaust product stream (exhaust duct). Specimens are exposed to a constant heat source of 30 kW in a vertical orientation. Data are reported in units for convenient use in fire models and in fire hazard and fire risk assessment.

ECE R34.01 Annex 5, is a test used for assessing the fire performance of fuel tanks. This fire test method requires the plastic tank to withstand a pool fire for 2 minutes without leaking. In this test, the tank is mounted on the actual vehicle and filled with gasoline to 50 percent of capacity. For 1 minute, the vehicle and tank are subjected to the full intensity of a fuel-fed pool fire positioned directly beneath the tank. For the second minute, the intensity of the fire is mitigated by covering the fire pan with a screen. If the tank survives for 2 minutes, it is said to "pass."

SAE J2464 involves several tests on electrical vehicle batteries. They include a penetration test, a crush test, a radiant heat test, and a short circuit test.

ASTM E603 is a guidance document that addresses means of conducting full-scale fire experiments that evaluate the fire-test-response characteristics of materials, products, or assemblies. The guide is intended to aid in the design of the experiments and the interpretation and use of results. The guide is also useful for establishing laboratory conditions that simulate a given set of fire conditions to the greatest extent possible. The guide allows users to obtain fire-test-response characteristics of materials, products, or assemblies, which are useful data for describing or appraising their fire performance under actual fire conditions and can also be used for input into fire models and for assessing fire hazard and fire risk.

ASTM E2061 is a guide to assessing fire hazard in a transportation vehicle environment. It explains the issues to be considered and the detailed procedure to be used when assessing fire hazard in a rail transportation vehicle, as an application of the methods contained in ASTM E1546 to a specific vehicle.

ASTM E2067 is a practice that deals with methods to construct, calibrate, and use full-scale oxygen consumption calorimeters to help minimize testing result discrepancies between laboratories. The methodology described is used in a number of fire test methods and the practice facilitates coordination of generic requirements, which are not specific to the item under test. The principal fire properties obtained from the test methods using this technique are those associated with heat release from the specimens tested, as a function of time, but many other fire properties can also be determined. This practice does not provide pass/fail criteria.

ASTM E2280 is a guide to developing fire hazard assessments for upholstered seating furniture within healthcare occupancies. As such, it provides methods and contemporary fire safety engineering techniques to develop a fire hazard assessment for a specific product, applying the general principles contained in ASTM E1546.

ASTM E1546 is a guide intended for use to develop fire hazard assessments. As a guide, this document provides information on an approach to the development of a fire hazard. The general concepts in NFPA 556 are intended to follow the model of this guide.

ASTM E2102, also known as the mass loss cone, is a screening fire test method that provides measurements of mass loss and ignitability, and potentially heat release, by using the same fire exposure design as the cone calorimeter. It has been shown that the results of this test method can correlate with those of the cone calorimeter.

ASTM E662 is a fire test method that assesses the specific optical density of smoke generated by solid materials and assemblies mounted in the vertical position in thicknesses up to and including 1 in. (25.4 mm), inside a closed chamber. The materials are exposed to a radiant heater at 25 kW/m^2, in the presence or absence of a flaming ignition source. Measurement is made of the attenuation of a light beam by smoke (suspended solid or liquid particles) accumulating within the chamber due to nonflaming or flaming combustion. Results are expressed in terms of specific optical density, which is derived from a geometrical factor and the measured optical density, a measurement characteristic of the concentration of smoke. This test method is often required for assessing the smoke emitted by textiles, including floor covering materials.

NFPA 270 (ASTM E1995) is a fire test method that builds on the procedures used in ASTM E662. It replaces the radiant heater in the former test method, which can only expose specimens in a vertical orientation, with a conical radiant heater, which can expose horizontal samples, thus improving on the assessment of melting materials. The materials are exposed to a conical radiant heater at 25 or 50 kW/m^2, in the presence or absence of a flaming ignition source. The principal fire property obtained from this test method is the specific optical density of smoke, but an additional optional fire property measurable with this test method is the mass optical density, because mass loss can be obtained continuously throughout the test.

A.11.1.2 Table A.11.1.2 includes fire test data for some passenger road vehicle instrument panel materials tested horizontally at end-use thickness.

A.11.1.3 Table A.11.1.3 includes fire test data for some vehicle seating materials tested horizontally at end-use thickness.

A.11.1.3.2 Smoker's materials have been known to ignite secondary combustible sources such as paper or food packaging.

A.11.1.4 Table A.11.1.4 includes fire test data for some vehicle flooring materials tested horizontally at end-use thickness.

A.11.1.5 The fire performance properties of some headliner materials tested horizontally in end-use thickness are summarized in Table A.11.1.5. Three of the four headliners tested ignited in less than 20 seconds at an exposure of 25 kW/m^2. The time to ignition decreased and the heat release rate increased when the incident heat flux increased. All of the headliners summarized in Table A.11.1.5 passed the FMVSS 302 test. The application of the pilot flame to the edge of the headliner material resulted in localized charring and melting in area of flame impingement only. The same headliners when tested in the vertical orientation ignited in less than 15 seconds. Fire propagated up the fabric side. The backing materials such as fiberglass were mostly unaffected.

A.11.1.6 Table A.11.1.6 includes fire test data for some vehicle interior finish materials used on vehicle doors.

A.11.1.7 In 2012, ASTM approved a gas burner test (ASTM E2574/E2574M) that is based on the "paper bag fire test."

A.11.1.8.2 It has been demonstrated that plastic materials that obtain a V0 classification when tested in accordance with UL 94 exhibit improved fire safety properties with respect to small ignition sources.[6] The use of such plastic materials, as opposed to materials that do not meet any fire test, as the materials and products used in engine compartments of passenger road vehicles would likely decrease heat release rate properties.

Δ Table A.11.1.2 Cone Calorimeter Data for Car and Van Instrument Panel Materials at Heat Flux Indicated [5–7]

Material	t_{ig} (sec)	$PHRR_a$ (kW/m²)	THR_a (MJ/m²)	FPI (sec m²/kW)	$HRR_{180\ sec}$ (kW/m²)	$HRR_{a,\ avg}$ (kW/m²)	$H_{c,\ eff}$ (MJ/kg)	SEA (m²/kg)	Mass Loss (%)	TSR_a	$PSRR_a$ (1/sec)
At 25 kW/m²											
# 1	82	565	103	0.15	494	397	27.6				
# 2	154	230	107	0.67	124	111	21.2	839	75.5	4211	13.6
# 3	72	384	91	0.19	313	206	35.3	1342	85.0	4572	20.5
# 4	103	649	110	0.16	470	414	31.6	1053	94.0	3037	23.0
# 5	64	344	95	0.18	305	104	30.5	477	75.5	1202	6.1
# 6	53	363	150	0.15	280	125	39.5	783	67.5	2986	7.8
# 7 Dash up	37	253	136	0.15	163	105	25.3	766	73.9	3685	20
# 7 Dash down	65	393	135	0.16	217	103	26.2	777	77.9	3965	18.3
# 7 Dash frame up	97	668	80	0.15	441	487	28.4	1234	96.8	3500	28.9
# 7 Dash frame down	91	702	82	0.13	444	402	28.9	1201	96.7	3398	29.2
# 8	38	219	179	0.17	156	—	25.9	948	79.5	6573	4.0
# 9 Dash	162	672	95.1	0.24	435	—	27.2	926	78.5	3248	6.3
# 9 Upper dash cover	154	508	91	0.30	326	—	25.7	833	77.9	2970	5.3
At 40 kW/m²											
# 1	26	645	127	0.04	575	465	27.5				
# 2	26	214	115	0.12	161	125	20.6	808	84.7	4101	13.5
# 3	36	469	93	0.08	364	276	26.3	1332	86.0	4319	24.7
# 4	28	666	74	0.04	400	417	27.9	1121	95.0	2930	26.9
# 8	16	275	185	0.06	189	—	25.5	1067	90.8	7764	
# 9 Dash	64	613	102	0.10	464	—	26.2	847	89.0	3324	7.7
# 9 Upper dash cover	44	590	108	0.08	419	—	25.9	774	89.3	3254	6.7

Δ Table A.11.1.3 Cone Calorimeter Fire Test Data for Vehicle Seating Materials [5–7]

	Units	Seat	Foam 1	Fabric 1		Units	Seat a	Seat b	Foam	Fabric
At 25 kW/m²										
$PHRR_a$	kW/m²	259	283	345	$PHRR_a$	kW/m²	296	321	418	162
T_{ig}	Sec	23	6	35	t_{ig}	sec	15	37	3	42
THR_a	MJ/m²	31	12	8	THR_a	MJ/m²	128	24	69	10
FPI	sec m²/kW	0.09	0.02	0.103	FPI	sec m²/kW	0.05	0.114	0.006	0.262
$Hc_{,\ eff}$	MJ/kg	20.9	23.6	20.1	SEA	m²/kg	365	536	375	543
HRR_a, avg	kW/m²	58	175	187	Mass loss	%	83.2	65.2	90.4	76.8
HRR_{180} sec	kW/m²	119	65	41	TTE	sec	1117	363	271	131
At 40 kW/m²										
$PHRR_a$	kW/m²		337	435	$H_{c,\ eff}$	MJ/kg	19.8	19.3	25.6	16.6
t_{ig}	MJ/m²		2	18	$HRR_{a,avg}$	kW/m²	145	69	252	103
THR_a	sec m²/kW		14	9	$HHR_{180\ sec}$	kW/m²	201	113	306	53
FPI	MJ/kg		0.006	0.041	Smoke factor	MW/m²	449	156	233	34
$H_{c,\ eff}$	kW/m²		23.4	20.5	TSR_a	—	2208	554	993	296
$HRR_{a,\ avg}$	kW/m²		237	218	$PSRR_a$	1/sec	10.2	9.7	6.8	6.5
$HRR_{180\ sec}$	kW/m²		73	46	MLR_{avg}	g/sec	0.068	0.031	0.088	0.058

	t_{ig} (sec)	$PHRR_a$ (kW/m²)	THR_a (MJ/m²)	FPI (sec m²/kW)	$HRR_{180\ sec}$ (kW/m²)	Mass Loss (g/percent)	$H_{c,\ eff}$ (MJ/kg)
At 25 kW/m²							
Seat fabric	16	213	16.9	0.075	94	9.2/82.4	16.2
At 40 kW/m²							
Seat fabric	8	315	19.6	0.025	109	9.6/82.6	18.1

Δ Table A.11.1.4 Cone Calorimeter Data for Selected Vehicle Floor Covering Materials at Heat Flux Indicated Selected [5–7]

Material	t_{ig} (sec)	$PHRR_a$ (kW/m²)	THR_a (MJ/m²)	FPI (sec m²/kW)	$HRR_{180\ sec}$ (kW/m²)	$HRR_{a,\ avg}$ (kW/m²)	$H_{c,\ eff}$ (MJ/kg)	SEA (m²/kg)	Mass Loss (%)	TSR_a	$PSRR_a$ (1/sec)
At 25 kW/m²											
# 1	60	373	49	0.16	257	235	26.7	558	61	1024	10.0
# 2	103	349	48	0.30	220	80	30.6	647	37	874	8.5
# 3	59	205	99	0.29	173	80	27.6	526	46	1846	4.1
# 4	31	167	56	0.18	114	—	17.4	264	67	846	1.1
At 40 kW/m²											
# 1	41	450	51	0.09	268	261	26.4	515	61	993	11.0
# 4	16	195	71	0.08	140	—	20.2	348	70.3	1235	1.5

Δ Table A.11.1.5 Cone Calorimeter Data for Car or Van Headliner Materials at Heat Flux Indicated [5–7]

Material	t_{ig} (sec)	$PHRR_a$ (kW/m²)	THR_a (MJ/m²)	FPI (sec m²/kW)	$HRR_{180\ sec}$ (kW/m²)	$HRR_{a,\ avg}$ (kW/m²)	$H_{c,\ eff}$ (MJ/kg)	SEA (m²/kg)	Mass Loss (%)	TSR_a	$PSRR_a$ (1/sec)
At 25 kW/m²											
# 1	65	202	61	0.33	136	122	12.3	96	78	341	4.8
# 2	9	298	6	0.03	31	131	28.2	254	13	51	2.7
# 3	17	217	4	0.08	22	—	5.0	62	55	52	—
# 4	12	360	14	0.03	80	—	24.2	722	69	432	3.7
# 5 Cover	13	205	—	0.07	21	127	12.2	—	—	—	—
# 5 Backing	8	107	—	0.07	31	64	11.3	—	—	—	—
# 5 System	12	206	—	0.06	64	123	11.3	—	—	—	—
At 40 kW/m²											
# 1	28	307	64	0.09	187	162	12.4	95	78	337	6.7
# 3	5	277	5	0.02	15	—	23.8	250	15	50	1.6
# 4	5	388	16	0.01	89	—	25.9	579	68	357	2.7
# 5 Cover	7	219	—	0.03	21	130	11.6	—	—	—	—
# 5 Backing	3	126	—	0.02	29	84	11.6	—	—	—	—

Note: Materials 1 through 4 were vinyl materials with a foam backing. Material 5 had a vinyl cover and a felt backing.

Δ Table A.11.1.6 Cone Calorimeter Data for Selected Car or Van Interior Trim Materials at Heat Flux Indicated [5–7]

Material	t_{ig} (sec)	$PHRR_a$ (kW/m²)	THR_a (MJ/m²)	FPI (sec m²/kW)	$HRR_{180\ sec}$ (kW/m²)	$HRR_{a,\ avg}$ (kW/m²)	$H_{c,\ eff}$ (MJ/kg)	SEA (m²/kg)	Mass Loss (%)	TSR_a	$PSRR_a$ (1/sec)
At 25 kW/m²											
# 1	30	357	63	0.08	175	111	15.7	155	84	502	9.6
# 2 Fabric — Foam	10	254	15	0.04	76	107	16.2	793	69	614	15.8
# 3	65	468	88	0.14	382	183	28.3	1394	93	4316	23.1
# 4	59	483	93	0.12	297	91	33.7	462	83	1259	7.9
# 5	41	480	75	0.08	274	67	20.7	278	85	870	8.7
# 6	95	391	42	0.24	184	—	46.1	254	32	243	0.5
At 40 kW/m²											
# 1	11	315	56	0.04	174	103	15.9	174	86	496	7.9
# 6	37	623	63	0.06	268	—	33.3	273	66	516	0.9

A.11.2.1.2 See also A.11.1.8.2.

A.11.2.3.2 One project investigated 13 collision-related fires and showed that fire originating in the engine compartment reached the passenger compartment in less than 8 minutes and occasionally in as little as 2 minutes to 4 minutes. [8]

In a different study, three full-scale fire tests where a fire was initiated near the bulkhead in passenger vans showed that, once ignited, the combustible dash and HVAC components and the headliner cause fire growth and propagation inside the passenger compartment. In each case, the fire resulted in untenable conditions in the passenger compartment after a few minutes. These tests indicate that temperatures in the passenger compartment were in excess of 800°C (1472°F) within 3 minutes to 6 minutes. [7, 9] The details of the fire test conditions are as follows.

In the first full-scale fire test, a shallow pan of gasoline (50 mL, 1.7 liquid oz) and gasoline-soaked crumpled newspaper were placed on the passenger side of the floor under the dash of a passenger van and ignited. The van was not collision-damaged, and the driver- and passenger-side door windows were rolled down three-quarters of the way. Flames emerged from the HVAC vent on the face of the dash on the passenger side at 2 minutes after ignition of the gasoline. The passenger compartment was fully involved at 4 minutes after ignition of the gasoline.

In the second full-scale fire test, a passenger van was modified to simulate a front-end collision. Modifications to the van included removing the front windshield, removing the rear side windows, displacing the roof forward so the headliner was directly above the dash, displacing the dash upward in the center, and placing the engine cover 152 mm (6 in.) back from the dash. A 25.4 mm (1 in.) propane flame was positioned in the area of the engine cover under the dash on the passenger-side floor area. At 1 minute, 56 seconds after ignition, fire was observed on the dash. Flames from the dash impinged on and ignited the headliner at 2 minutes, 17 seconds. The front of the van was fully involved at 2 minutes, 40 seconds after ignition, and fire emerged from the rear side windows at 3 minutes, 3 seconds after ignition.

The third full-scale fire test was performed with a passenger van modified to simulate a front-end collision. The ignition source, location of the ignition source, and modifications to the van test were the same as described above for the second test. Fire was observed emerging from the passenger-side dash HVAC vents and in the area of the engine cover at 2 minutes after ignition. Flames from the dash impinged on and ignited the headliner at 4 minutes, 20 seconds. The passenger compartment of the van was fully involved at 5 minutes, 10 seconds after ignition.

In another pair of full-scale passenger road vehicle burn tests, the time to reach untenable conditions within the passenger compartment was not substantially increased when fire-retarded materials were used within the bulkhead as compared to the control test in which the test vehicle did not contain fire-retarded materials. In fact, the quantity of toxic gases, including CO and HCN, within the passenger compartment was an order of magnitude higher in the vehicle that contained flame-retarded materials. [10–12]

A.11.2.4 A full-scale fire test was conducted at Factory Mutual (FM), where an engine compartment fire propagated into the passenger compartment through the HVAC housing. A fire was initiated in the engine compartment of a front-end collision-damaged passenger road vehicle. The full-scale test was performed in 1997 by FM as part of the Fire Initiation and Propagation Tests for General Motors. [4, 13] The 55 km/hr impact with a steel pole caused damage to the bumper and hood, displaced the engine and transmission rearward, broke the HVAC modules, cracked the windshield, and caused punctures and openings in the bulkhead and floor pan. No fuel leaks occurred as a result of the impact, but transmission fluid, oil, and brake fluid were pooled under the engine compartment, and the hood lining was sprayed with a coolant–water mixture prior to the full-scale fire test. A 4.2 kW propane-fueled burner was placed in the vicinity of the collision-damaged upper and lower HVAC module at the rear right side of the engine compartment. The propane to the burner was turned off after 2 minutes. Flames from the burner ignited the engine and transmission wire harnesses or an HVAC hose or both. The fire spread to involve the HVAC module housing (talc-filled polypropylene). Molten plastic from the housing fell, accumulated on the exhaust manifold heat shield, and self-extinguished. Fire spread laterally along the bulkhead and into the air inlet area at the base of the windshield at 3 minutes, 30 seconds after ignition of the burner. Temperatures at the windshield were 600°C (1112°F) at 4 minutes after ignition. Fire also spread forward in the engine compartment. Flames propagated into the passenger compartment through the HVAC module and the windshield simultaneously at 11 minutes after ignition and emerged through the defroster outlet of the instrument panel at 15 minutes, 32 seconds. The cracked windshield failed, and hot pieces of the windshield fell and burned but did not establish a propagating fire on top of the dash. The fire was manually extinguished at 16 minutes after ignition before the fire in the passenger compartment could spread. Post-test examination of the engine compartment and passenger compartment showed that the HVAC module and other plastic dash components were largely consumed.

A.11.2.5.2 Details about two full-scale fire tests conducted at FM Global with the fire originating in the engine compartment of collision-damaged vehicles are as follows.

In one test, a passenger minivan was first subjected to a movable-barrier crash test. [14] The impact was at the front driver-side corner of the vehicle. The windshield was broken but otherwise intact, while the driver-side door window was shattered as a result of the impact. Approximately 5 minutes after impact, a fire started in the engine compartment in the vicinity of the battery and power distribution center. This fire was manually extinguished. For the full-scale fire test, a 1.2 kW nichrome wire igniter was positioned between the battery housing and the power distribution center. Observation of fire inside the engine compartment in the area of the battery was considered as the start of the test. Flames propagated into the passenger compartment through the windshield and HVAC-related openings in the bulkhead. At 4 minutes after sustained combustion in the engine compartment, fire from the engine compartment melted the polymer in the broken windshield, and flaming pieces of windshield fell into and ignited materials in the passenger compartment on the dash, seat, and floor. The headliner was ignited as a result of the fire penetrating the windshield and the windshield failing at 10 minutes to 11 minutes after sustained combustion in the engine compartment. Fire propagated inside the passenger compartment from the front of the minivan to the rear. Flashover conditions inside the passenger compartment occurred prior to manual extinguishment of the fire at 11 minutes after the start of the test.

In another test, a movable barrier struck the front driver's side of the vehicle. [15] Power steering fluid was released during the impact and was ignited by the hot exhaust manifold. This engine compartment fire was extinguished. An engine compartment fire was initiated using an aerosol spray of power steering fluid and a propane torch. The fire impinged on and ignited methanol vapors inside the broken windshield wiper fluid reservoir. The burning vapors inside the windshield wiper reservoir ignited the plastic reservoir container in 4 minutes to 6 minutes after ignition of the vapors. The fire spread to other nearby combustible materials in the engine compartment. After 22 minutes, the fire in the engine compartment impinged on the broken windshield. Burning pieces of the windshield fell into the passenger compartment and ignited the seat cushion, center console, and steering wheel at 26 minutes after ignition of the vapors inside the windshield wiper reservoir. The fire was manually extinguished at 27 minutes after ignition of vapors inside the windshield wiper reservoir.

A.11.2.7.4.1 The type of fire exposures likely to originate in the engine compartment will generally involve relatively small amounts of flammable and combustible liquids. Thus, the fire exposure curve in ASTM E119 is considered more appropriate for this type of fire than that in ASTM E1529 or UL 1709, as the latter address a hydrocarbon fuel fire, which is what would be expected to be generated from a fuel leak from the fuel tank. Also see A.10.2 for further information on these test methods.

A.11.2.7.6 NFPA 257 is a test for assessing fire protection ratings of glazing materials. See A.10.2 for further information on this test method.

A.11.3.5.1 NFPA 260 is a fire test for individual components that assesses the smoldering fire performance of materials. See A.10.2 for further information on this test method.

A.11.3.5.2 ASTM D2859 is a fire test to assess the ignitability and flammability of horizontally mounted textile materials when exposed to an ignition source (a methenamine pill) under controlled laboratory conditions. NFPA 253 and ASTM E648 are fire tests suitable for assessing the critical radiant flux of horizontally mounted textile materials exposed to a flaming ignition source, in a graded radiant heat energy environment in a test chamber. See A.10.2 for further information on these test methods.

A.11.4.1 Full-scale fire tests on collision-damaged vehicles were conducted by General Motors for NHTSA/Department of Transportation. Two of the fire initiation and propagation tests involved a pool fire of gasoline under the vehicle. The gasoline pool fires penetrated into the passenger compartments in under 4 minutes.

In one test, a movable barrier struck the rear end of a passenger vehicle. [16] The impact caused seam openings in the wheel house and a gap at the bottom of the driver's door. The fuel tank was not compromised during the impact, and no leaks occurred. A subsequent test was conducted to simulate a fuel leak. The simulated fuel leak delivered a total of 4 L (1.05 gal) of gasoline discharged at a rate of 515 cm^3/min (8.16 gal/hr), forming a pool under the vehicle. The gasoline pool was ignited with a propane torch. The fire concentrated at the rear of the vehicle. Fire penetrated into the passenger compartment through an open seam in the left rear wheel house, the gap at the bottom of the driver-side door, and a floor pan drain hole under the vehicle. The flames penetrated the open seam in the left rear wheel house at 10 seconds to 20 seconds after ignition of the pool and ignited the passenger seat, trim, and carpet. The fire in the passenger compartment impinged on and ignited the headliner at 30 seconds after the pool was ignited. Flames spread from the rear of the passenger compartment to the front of the passenger compartment along the headliner at 180 seconds to 190 seconds after ignition. The vehicle fire was manually extinguished at 210 seconds after the start of the test.

A second test involved igniting a pool of gasoline under the rear cargo area of a collision-damaged sport utility vehicle. [17] Before the fire test, a movable barrier struck the left rear driver's side at 84.4 km/hr (52.4 mph). The impact caused a number of seam openings and gaps and upward displacement in the area of the left side rear of the vehicle and broke the left and right side rear window panes and the lift gate window. The fuel tank and system did not leak as a result of the impact. A subsequent test was conducted to simulate a fuel leak. A total of 4 L (1.05 gal) of gasoline was discharged at a rate of 750 cm^3/min (11.9 gal/hr) near the rear inboard corner of the fuel tank under the vehicle, which formed a pool. The pool was ignited with a propane torch. Flames from the gasoline pool first penetrated to the passenger compartment through seam openings and gaps at 120 seconds after ignition of the pool. Fire also penetrated into the passenger compartment through the broken rear glass panes and lift gate window. Fire in the cargo area impinged on and ignited the headliner panel at 150 seconds after ignition. The spare and rear left tires both failed and ruptured in less than 160 seconds. The fire was manually extinguished at 170 seconds.

A.11.4.5.2.1 The fire exposure curve in ASTM E1529 or UL 1709 is considered more appropriate for potential fire from a fuel leak than that in ASTM E119 or UL 263. The test method in ASTM E1529 and UL 1709 addresses a hydrocarbon fuel fire, which is what would be the expected result from spills due to ruptures in the fuel tank. See A.10.2 for further information on these test methods.

A.12.3.6 See A.10.2.

Annex B Fire Retardants

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

B.1 Fire retardants have been used in a number of applications and consumer products for many years. Most commercial fire-retardant (FR) products have acceptable physical and fire properties when formulated and specified correctly. The principal benefits of fire retardants are reduced risk from fire, reduced property loss, and reduced loss of life and injury. In some instances, improved fire performance can be achieved by use of inherently fire-safe polymeric materials such as some natural fibers, textiles for protective clothing such as para- and meta-aramids (Nomex, Kevlar, and Twaron), fluorine-based polymers, polysulfones, PBI, Basofil, Visil, carbon fibers, etc. Other approaches to improving fire safety of flammable polymers and materials include the addition of fire-retardant chemicals and/or by use of other additives such as inorganic fillers and nanotechnology. Polymers with acceptable fire performance and physical properties are currently available for numerous end-use markets such as electronic devices, appliances, automotive, cables and furnishings, including upholstered furniture and mattresses.

B.2 The use of materials with improved fire properties has been extensively studied, and these materials have been shown to provide societal benefits. In 1988, NBS compared the fire performance of five end-use products that were both FR and non-FR. The goals of the project were to examine FR products and determine whether the FR additives effected a trade off between decreased burning and increased emission of toxic gases species, and whether there was a net safety benefit from the use of fire retardants. Improved fire performance of the FR products was demonstrated by an average escape time that was more than 15-fold greater in room burn tests with the FR products, the amount of the FR system consumed was less than half the loss of the non-FR systems, FR products evaluated yielded approximately one-quarter of the heat release rate than obtained from non-FR products, production of CO for the FR tests was about one-half of that obtained from non-FR systems, and the production of smoke was not significantly different.

B.3 There have been some FR systems commercialized over the years that have been shown to have negative properties, and those FR additives have been withdrawn from the market. For example, TRIS, a commercial product intended for treating textile fibers used in clothing applications, was taken off the market. Other materials, in screening tests, have been shown to have negative properties but have never been commercialized, such as trimethylolpropane phosphate (TMPP). More recently penta- and octa-diphenyl oxides or ethers have been banned from use in the United States and in Europe. The main concern for these chemicals was that they had been shown to be bio-accumulative, as well as potentially having other deleterious properties.

B.4 A study by the National Academy of Sciences (NAS), performed under contract to the Consumer Product Safety Commission (CPSC), examined 16 fire retardants that could be potentially used for upholstered furniture and other textile application. The NAS findings were that eight chemicals — hexabromocylclododecane, decabromobiphenyloxide, aluminum trihydrate, magnesium hydroxide, zinc borate, ammonium polyphosphates, THPC, and phosphonic acid, 3-hydroxylmethyl-3-oxlypropyl dimethyl ester — had no hazard or risk associated with their use. The other eight chemicals evaluated — antimony trioxide, calcium and zinc molybdates, sodium antimonite, organic phosphonates, tris monochloropropyl phosphates, tris 1,3 trichloropropyl 2 phosphate, aromatic phosphate plasticizers, and chlorinated paraffins — were found to have insufficient toxicological data to make a determination related to hazard or risk.

B.5 A study by Stevens examined the toxicology of common fire retardants used in consumer products and found that in general the fire retardants do not pose any significant threats to human life and the environment (Stevens, et al. 1999). Further, bromine recovery and recycling of FR-treated materials are possible. (Tange, et al. 2004)

B.6 Recently, SP in Sweden has developed Life Cycle Assessments (LCA) that have been used to evaluate the costs and societal benefits for fire-treated plastic television enclosures and fire-retardant upholstered furniture. (Andersson, et al. 2004; Simonsen, et al., 2006; Blundell, et al., 2003). A cost/benefit analysis was part of the life cycle assessment and SP examined additional costs, if any, during production, use, transport, destruction, and fires of television cabinets and upholstered furniture. The SP studies utilized multiple scenarios, and each one concluded that the societal benefits of using fire retardants to improve the level of fire performance in a television set and in upholstered furniture far outweighed the potential societal costs associated with increased use of fire retardants. The effects on the environment of FR upholstered furniture is lower because fewer fires would result in lower emissions in comparison to fires involving non-FR upholstered furniture.

B.7 FR formulations exist for polymers commonly used in automobile applications such polyethylene, polypropylene, ABS, polystyrene, polyurethane, and rubber. In fact, several of the plastics currently used in automobile applications already contain certain levels of flame retardants. The release and exposure of fire retardants used in upholstered furniture, including FR foams for automotive foam, were studied and included tests designed to simulate release as a result of environmental aging and wear (Drohmann, et al., 2003).

B.8 Fire statistics have demonstrated that there has been a reduction of death and injuries from the use of improved-fire-performance materials such as upholstered furniture; electric cables; mattress, wall, and ceiling linings; clothing; aircraft interior materials, and televisions.

Annex C Informational References

C.1 Referenced Publications. The documents or portions thereof listed in this annex are referenced within the informational sections of this guide and are not advisory in nature unless also listed in Chapter 2 for other reasons.

C.1.1 NFPA Publications. National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02169-7471.

NFPA *101*®, *Life Safety Code*®, 2024 edition.

NFPA 220, *Standard on Types of Building Construction*, 2024 edition.

NFPA 253, *Standard Method of Test for Critical Radiant Flux of Floor Covering Systems Using a Radiant Heat Energy Source*, 2023 edition.