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Guide for Fire Hazard Assessment of Rail Transportation Vehicles[1]

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INTRODUCTION

The traditional approach to codes and standards is the specification of individual fire-test-response requirements for each material, component, or product that is found in a given environment and is deemed important to maintain satisfactory levels of fire safety. This practice has been in place for so long that it gives a significant level of comfort; manufacturers know what is required to comply with the specifications and specifiers simply apply the requirements. The implicit assumptions are not stated, but they are that the use of the prescribed requirements ensures an adequate level of safety. There is no need to impose any change on those manufacturers who supply safe systems meeting existing prescriptive requirements; however, as new materials, components, and products are developed, manufacturers, designers, and specifiers often desire the flexibility to choose how overall safety requirements are to be met. It is the responsibility of developers of alternative approaches to state explicitly the assumptions being made which result in a design having an equivalent level of safety. One way to generate explicit and valid assumptions is to use a performance-based approach, based on test methods that provide data in engineering units, suitable for use in fire safety engineering calculations, as this guide provides.

This fire hazard assessment guide focuses on rail transportation vehicles. Such a fire hazard assessment requires developing all crucial fire scenarios that must be considered and consideration of the effect of all contents and designs within the rail transportation vehicle, which will potentially affect the resulting fire hazard. The intention of this guide is that rail transportation vehicles be designed either by meeting all the requirements of the traditional prescriptive approach or by conducting a fire hazard assessment, that needs to provide adequate margins of error, in which a level of safety is obtained that is equal to or greater than the level of safety resulting from the traditional approach.

1. Scope

1.1 This is a guide to developing fire hazard assessments for rail transportation vehicles. It has been written to assist professionals, including fire safety engineers, who wish to prepare fire hazard assessments of rail transportation vehicles, including assessments for possible use in the design of such vehicles.

1.1.1 Potential users of this guide include professionals, who may assist manufacturers of materials, components, or products for use in rail transportation vehicles, manufacturers of the actual rail transportation vehicles, designers of such rail transportation vehicles, or specification writers.

1.2 Hazard assessment is a process resulting in the development of an estimation of the potential severity of the fires that can develop under defined scenarios, once defined incidents have occurred. Hazard assessment does not address the likelihood of a fire occurring. Hazard assessment is based on the premise that an ignition has occurred, consistent with a specified scenario, and that potential outcomes of the scenario can be reliably estimated.

1.3 This guide cannot be used for regulation. It is not in itself a fire hazard assessment but only a guide for developing a fire hazard assessment. Moreover, it does not give instructions on acceptance criteria or recommendations, which only can come from a specifier or an authority having jurisdiction.

1.3.1 Selective use of parts of the methodology in this guide and of individual fire-test-response characteristics from Table X1 does not satisfy the fire safety objectives of this guide or of the table. This guide shall be used in its entirety to develop a fire hazard assessment for rail transportation vehicles or to aid in the design of such vehicles.

1.4 This guide includes and applies accepted and clearly defined fire safety engineering techniques and methods whose applications are consistent with both existing, traditional prescriptive codes and standards and performance based fire codes and standards under development throughout the world.

1.5 This guide is intended, among other things, to be of

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assistance to personnel addressing issues associated with the following areas.

1.5.1 Design and specification of rail transportation vehicles.

1.5.2 Fabrication of rail transportation vehicles.

1.5.3 Supply of assemblies, subassemblies, and component materials, for use in rail transportation vehicles.

1.5.4 Operation of rail transportation vehicles.

1.5.5 Provision of a safe environment for all occupants of a rail transportation vehicle.

1.6 This guide is intended among other things, to provide assistance in mitigating potential damage from fires in rail transportation vehicles; thus, it provides recommended methods to accomplish this overall objective. Such methods could include changes to the materials, components, products, assemblies, or systems involved in the construction of the rail transportation vehicle or changes in the design features of the vehicle, including the number and location of automatically activated fire safety devices present (see 4.4.4 for further details).

1.7 The techniques used in this guide can be used for help in assessing the comparative fire hazard of particular products, assemblies, or systems intended for use in rail transportation vehicles. This is accomplished by providing standard bases for quantifying levels of fire safety associated with particular design choices made.

1.8 Consistent with 1.2, this guide provides designers, rail transportation vehicle builders, and operators with methods to estimate whether particular rail passenger designs provide an equal or greater level of fire safety when compared to designs developed based on the traditional applicable fire-test-response characteristic approaches currently widely used in this industry. Such approaches are typically based on the traditional guidelines of the Federal Railroad Administration (FRA) and recommended practices of the Federal Transit Administration (FTA). The performance-based methods provided will differ from commonly used material or product specifications and selection processes and from prescriptive selection processes, traditionally used in common rail transportation vehicle design methodologies.

1.9 The techniques provided in this guide are based on specific assumptions in terms of rail transportation vehicle designs and fire scenarios. These techniques can be used to provide a quantitative measure of the fire hazards from a specified set of fire conditions, involving specific materials, products, or assemblies. Such an assessment cannot be relied upon to predict the hazard of actual fires, which involve conditions other than those assumed in the analysis.

1.10 In terms of design and construction and consistent with the statements in 1.2, this guide provides the means for estimating fire hazards associated with the design and construction features of a given rail transportation vehicle, and acknowledging that such fire hazards may be affected by the anticipated use pattern of the vehicle. Characteristics of the vehicle analyzed must include specific designs, fabrication techniques, and materials of construction for the actual use intended. The predicted fire hazard will depend upon specific design and construction assumptions made and will not apply to vehicle designs based on other assumptions.

1.11 This guide can be used to analyze the estimated fire performance of the vehicle specified under defined specific fire scenarios. Under such scenarios, incidents will begin either inside or outside a vehicle, and ignition sources can involve vehicle equipment as well as other sources. The fire scenarios to be used are described in detail in Section 9.

1.12 The techniques provided in this guide do not address vehicle performance under fire scenarios other than those that are defined as part of the fire hazard assessment made. For example, fires with more severe initiating conditions than those assumed in an analysis may pose more severe fire hazard than that calculated using the techniques provided in this guide. For this reason severe conditions must be considered as part of an array of fire scenarios. In addition, the assessment techniques provided in this guide do not necessarily predict the hazard of actual fires which involve conditions other than those assumed in the analyses made (see Section 9), especially in cases where a more severe fire challenge than the ones assumed occurs.

1.13 This guide is to be used to predict or provide a quantitative measure of the fire hazard from a specified set of fire conditions involving specific materials, products, or assemblies. This assessment does not necessarily predict the hazard of actual fires, which involve conditions other than those assumed in the analysis.

NOTE 1—While 1.13 is the standard caveat described in section F2.2.2.2 of the Form and Style for ASTM Standards manual for fire hazard assessment standards, this guide is a guide and cannot be used to provide quantitative measures.

2. Referenced Documents

2.1 *ASTM Standards:*

C 542 Specification for Lock-Strip Gaskets[2]

C 1166 Test Method for Flame Propagation of Dense and Cellular Elastomeric Gaskets and Accessories[2]

D 123 Terminology Relating to Textiles[3]

D 2724 Test Methods for Bonded, Fused and Laminated Apparel Fabrics[3]

D 3675 Test Method for Surface Flammability of Flexible Cellular Materials Using a Radiant Heat Energy Source[4]

D 5424 Test Method for Smoke Obscuration of Insulating Materials Contained in Electrical or Optical Fiber Cables When Burning in a Vertical Cable Tray Configuration[5]

D 5537 Test Method for Heat Release, Flame Spread and Mass Loss Testing of Insulating Materials Contained in Electrical or Optical Fiber Cables When Burning in a Vertical Cable Tray Configuration[5]

D 6113 Test Method for Using a Cone Calorimeter to Determine Fire-Test-Response Characteristics of Insulating Materials Contained in Electrical or Optical Fiber Cables[4]

E 119 Test Methods for Fire Tests of Building Construction and Materials[2]

E 162 Test Method for Surface Flammability of Materials

[2] *Annual Book of ASTM Standards*, Vol 04.07.
[3] *Annual Book of ASTM Standards*, Vol 07.01
[4] *Annual Book of ASTM Standards*, Vol 08.02.
[5] *Annual Book of ASTM Standards*, Vol 10.02.

Using a Radiant Heat Energy Source[2]
E 176 Terminology of Fire Standards[2]
E 603 Guide for Room Fire Experiments[2]
E 648 Test Method for Critical Radiant Flux of Floor-Covering Systems Using a Radiant Heat Energy Source[2]
E 662 Test Method for Specific Optical Density of Smoke Generated by Solid Materials[2]
E 906 Test Method for Heat and Visible Smoke Release Rates for Materials and Products[2]
E 1321 Test Method for Determining Material Ignition and Flame Spread Properties[2]
E 1354 Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter[2]
E 1355 Guide for Evaluating the Predictive Capability of Fire Models[2]
E 1472 Guide for Documenting Computer Software for Fire Models[2]
E 1474 Test Method for Determining the Heat Release Rate of Upholstered Furniture and Mattress Components or Composites Using a Bench Scale Oxygen Consumption Calorimeter[2]
E 1537 Test Method for Fire Testing of Seating Upholstered Furniture[2]
E 1546 Guide for the Development of Fire-Hazard-Assessment Standards[2]
E 1590 Test Method for Fire Testing of Mattresses[2]
E 1591 Guide for Data for Fire Models[2]
E 1623 Test Method for Determination of Fire and Thermal Parameters of Materials, Products, and Systems Using an Intermediate Scale Calorimeter (ICAL)[2]
E 1740 Test Method for Determining the Heat Release Rate and Other Fire-Test-Resistance Characteristics of Wallcovering Composites Using a Cone Calorimeter[2]

2.2 *NFPA Standards:*[6]
NFPA 70 National Electrical Code
NFPA 130 Standard for Fixed Guideway Transit Systems
NFPA 262 Standard Method of Test for Flame Travel and Smoke of Wires and Cables for Use in Air-Handling Spaces
NFPA 265 Standard Methods of Fire Tests for Evaluating Room Fire Growth Contribution of Textile Wall Coverings
NFPA 901 Uniform Coding for Fire Protection

2.3 *ISO Standards:*[7]
ISO Guide 52: Glossary of Fire Terms and Definitions
ISO 4880: Burning Behaviour of Textiles and Textile Products
ISO 9705: Full Scale Room Fire Test for Surface Products

2.4 *Federal Aviation Administration Standards:*[8]
FAR 25.1359: Federal Aviation Administration 60° Bunsen Burner Test for Electric Wire
FAR 25.853 (a): Federal Aviation Administration Vertical Bunsen Burner Test
FAR 25.853 (c): Federal Aviation Administration Oil Burner Test for Seat Cushions

2.5 *Other Federal Standards:*[9]
Americans with Disabilities Act
FED STD 191A Textile Test Method 5830

2.6 *Underwriters Laboratories Standards:*[10]
UL 1581: Reference Standard for Electrical Wires, Cables, and Flexible Cords, 1080 (VW-1 (Vertical Wire) Flame Test)
UL 1581: Reference Standard for Electrical Wires, Cables, and Flexible Cords, 1160 Vertical Tray Flame Test
UL 1685: Standard Vertical Tray Fire Propagation and Smoke Release Test for Electrical and Optical Fiber Cables
UL 1975: Standard Fire Tests for Foamed Plastics Used for Decorative Purposes

2.7 *Canadian Standards Association Standards:*[11]
CSA Standard C22.2 No. 3, Test Methods for Electrical Wires and Cables, Vertical Flame Test—Cables in Cable Trays/FT4

2.8 *Institute of Electrical and Electronic Engineers Standards:*[12]
IEEE Standard 383, Standard for Type Tests of Class 1E Electric Cables, Field Splices, and Connections for Nuclear Power Generating Stations

3. Terminology

3.1 *Definitions*— For terms related to fire used in this guide, refer to Terminology E 176 and ISO Guide 52. In case of conflict, the terminology in Terminology E 176 shall prevail. For terms relating to textiles used in this guide, refer to Terminology D 123 or to ISO 4880. In case of conflict, the terminology in Terminology D 123 shall prevail.

3.1.1 *fire-characteristic profile*, *n*—array of fire-test-response characteristics, all measured using tests relevant to the same fire scenario, for a material, product, or assembly to address, collectively, the corresponding fire hazard.

3.1.1.1 *Discussion*—This array of fire-test response characteristics is a set of data relevant to the assessment of fire hazard in a particular fire scenario. In other words, all the fire tests used would have a demonstrated validity for the fire scenario in question, for example, by having comparable fire intensities. The fire-characteristic profile is intended as a collective guide to the potential fire hazard from a material, product, or assembly involved in a fire that could be represented by the laboratory test conditions.

3.1.2 *fire hazard*, *n*—the potential for harm associated with fire.

[6] Available from the National Fire Protection Association (NFPA), 1 Batterymarch Park, Quincy, MA, 02269–9101.

[7] Available from International Standardization Organization, P.O. Box 56, CH-1211; Geneva 20, Switzerland or from the American National Standards Institute, 11 West 42nd Street, New York, NY 10046.

[8] Available from the Federal Aviation Administration, Technical Center, Atlantic City International Airport, Atlantic City, NJ 08405.

[9] Available from General Services Administration, Specifications Activity, Printed Materials Supply Division, Building 197, Naval Weapons Plant, Washington, DC 20407.

[10] Available from Underwriters Laboratories, Inc., 333 Pfingsten Rd., Northbrook, IL 60062.

[11] Available from the Canadian Standards Associations, 178 Rexdale Blvd., Rexdale, Ontario, Canada M9W 1R3.

[12] Available from the Institute of Electrical and Electronic Engineers, Inc., 345 East 47th Street, New York, NY 10017.

3.1.2.1 *Discussion*—A fire may pose one or more types of hazard to people, animals, or property. These hazards are associated with the environment and with a number of fire-test-response characteristics of materials, products, or assemblies including but not limited to ease of ignition, flame spread, rate of heat release, smoke generation and obscuration, toxicity of combustion products, and ease of extinguishment (see Terminology E 176).

3.1.3 *fire performance*, *n*—response of a material, product, or assembly in a specific fire, other than in a fire test involving controlled conditions (different from fire-test-response characteristics, q.v.)

3.1.3.1 *Discussion*—The ASTM policy on fire standards distinguishes between the response of materials, products, or assemblies to heat and flame "under controlled conditions," which is fire-test-response characteristic, and "under actual fire conditions," which is fire performance. Fire performance depends on the occasion or environment and may not be measurable. In view of the limited availability of fire-performance data, the response to one or more fire tests, approximately recognized as representing end-use conditions, is generally used as a predictor of the fire performance of a material, product, or assembly (see Terminology E 176).

3.1.4 *fire scenario*, *n*—a detailed description of conditions, including environmental, of one or more of the steps from before ignition to the completion of combustion in an actual fire, or in a full-scale simulation.

3.1.4.1 *Discussion*—The conditions describing a fire scenario, or a group of fire scenarios, are those required for the testing, analysis, or assessment that is of interest. Typically, they are those conditions that can create significant variation in the results. The degree of detail necessary will depend upon the intended use of the fire scenario. Environmental conditions may be included in a scenario definition but are not required in all cases. Fire scenarios often define conditions in the early steps of a fire while allowing analysis to calculate conditions in later steps (see Terminology E 176).

3.1.5 *flashover*, *n*—the rapid transition to a state of total surface involvement in a fire of combustible materials within an enclosure.

3.1.5.1 *Discussion*—Flashover occurs when the surface temperatures of an enclosure and its contents rise, producing combustible gases and vapors, and the enclosure heat flux becomes sufficient to heat these gases and vapors to their ignition temperatures. Flashover commonly occurs when the upper layer temperature reaches 600°C or when the radiant heat flux at the floor reaches 20 kW/m^2 (see Terminology E 176).

3.1.6 *smoke*, *n*—the airborne solid and liquid particulates and gases evolved when a material undergoes pyrolysis or combustion (see Terminology E 176).

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *heat release rate*, *n*—the calorific energy released per unit time by the combustion of a material under specified test conditions.

3.2.2 *product*, *n*—material, component, or complete end-use product, in use in fixed guideway transportation vehicles.

4. Significance and Use

4.1 This guide is intended for use by those undertaking the development of fire hazard assessments for rail transportation vehicles and products contained within rail transportation vehicles.

4.2 This guide provides information on an approach to develop a fire hazard assessment, but fixed procedures are not established. Any limitations in the availability of data, of appropriate test procedures, of adequate fire models, or in the advancement of scientific knowledge, will place significant constraints upon the procedure for the assessment of fire hazard.

4.3 A fire hazard assessment developed following this guide must specify all steps required to determine fire hazard measures for which safety thresholds or pass/fail criteria can be meaningfully set by responsible authorities. It is preferred that such exercises have input from various sources.

4.4 A fire hazard assessment developed as a result of using this guide should be able to assess a new product being considered for use in a certain rail transportation vehicle and reach one of the conclusions listed in 4.4.1-4.4.4 through 4.4.5.

4.4.1 The new product is safer, in terms of predicted fire performance, than the one in established use. In this case, the new product is desirable, from the point of view of fire safety.

4.4.2 There is no difference between the predicted fire safety of the new product and of the one in established use. In this case, use of the new product provides neither advantage nor disadvantage, from the point of view of fire safety.

4.4.3 The new product is less safe, in terms of predicted fire performance, than the one in established use. In this case, a direct substitution of products would provide a lower level of safety and the new product would be undesirable, and should not be used, from the point of view of fire safety, without other compensatory changes being made.

4.4.3.1 A new product that is less safe, in terms of predicted fire performance, can nevertheless be made acceptable if, and only if, it is part of a complete, comprehensive, fire safety design for the rail transportation vehicle. Such redesign of the vehicle should include other features such as use of an alternative layout or increased use of automatic fire protection systems, that demonstrably produce the same or better safety for the complete design. In such cases, a more in-depth fire hazard assessment would have to be conducted to ensure that the entire design achieves the safety goals, and the new product would be acceptable only as part of the larger, approved design.

4.4.4 The new product could offer some safety advantages and some safety disadvantages over the item in established use. An example of such an outcome could be increased smoke obscuration with decreased heat release. In such cases, a more in-depth fire hazard assessment would have to be conducted to ensure that the advantages outweigh the disadvantages, and the resulting overall level of safety is no less than that provided by the traditional approach (see Table X1 and Appendix X1).

4.5 Following the analysis described in 4.4, a fire hazard assessment developed following this guide would reach a conclusion regarding the desirability of the new product studied. It is essential for the results of the assessment to lead to a design that is at least as safe as the one being replaced.

5. Procedure

5.1 The procedure for conducting a fire hazard assessment on a product in a rail transportation vehicle is given in Section 7, for the fire safety objectives, see Section 6. Conducting these procedures requires applying the design considerations in Section 8; for the scenarios considered, see Section 9; and, under the additional assumptions presented, see Section 10. Appendix X1 and Appendix X3 provide a list of test methods from which the test methods to be used should be chosen (see also X2.3). Some appropriate calculation methods are listed in Appendix X4 and Appendix X5.

5.2 The final step in a fire hazard assessment procedure should be the development of a detailed procedure to ensure consistent quality control over time.[13] In the absence of prescriptive small-scale tests that dictate the minimum fire-test response characteristics required for each material, component, or product, alternative means should be described so that the fire safety of the rail transportation vehicle can be ensured without having to conduct full rail transportation vehicle burn tests.

6. Fire Safety Objectives

6.1 The primary fire safety objective is to ensure the safe (unharmed) evacuation of all occupants of a rail transportation vehicle in the event of a fire.

6.1.1 This is achieved if the time required, in the event of a fire, to evacuate the vehicle is less than the time for the fire to create untenable conditions, preferably for the fire not to create conditions that cause harm to people, whenever possible, in the passenger compartment. The evacuation time includes the time required for the occupants to reach, or be transported, to a safe location and notification time.

6.1.2 The time to untenability shall be the shortest time until untenable conditions are created for any occupant starting at any location within the vehicle or along the evacuation path.

6.1.3 If the fire scenario involves a vehicular accident, then the assessment shall assume evacuation is achieved through rescue by emergency personnel. The fire hazard assessment needs to recognize that the accident may take place in an area (or at a time) when such rescue is difficult. Examples of conditions of difficult access are tunnels, bridges, remote locations, and unfavorable weather.

6.1.4 Tenability is assessed on the basis of fire effects on the occupants, including both direct effects, such as heat, toxic gases, or oxygen deprivation, and indirect effects, such as reduced visibility due to smoke obscuration. A tenable environment, therefore, will prevent loss of life and reduce the likelihood of harm, including nonfatal injury to individuals.

6.1.4.1 Levels of tenability should be set by the developer of the fire hazard assessment generated from using this guide or by the specific.

NOTE 2—Investigations of the tenability in a fire scenario have shown the maximum temperatures which human beings can withstand **(1-3)**,[14] the maximum convected heat humans can tolerate **(4)**, the heat flux required to blister or burn skin **(5-8)**, the restrictions to escape imposed by smoke obscuration **(9, 10)**, the effects of the primary toxic gases **(11-16)**, the overall effects of smoke toxicity **(17-20)** and various ways to combine one or more of these effects **(4, 21 and 22)**.

6.1.4.2 If no levels of tenability are chosen, the default tenability criteria should be the values specified in the documentation for HAZARD **(21, 22)**.

6.2 A secondary fire safety objective is to prevent flashover inside the rail transportation vehicle.

6.3 The user shall consider inclusion of a third fire safety objective, which is to maintain a safe working environment for safety personnel, including fire fighters.

7. Steps in Conducting a Fire Hazard Assessment

7.1 Fire hazard assessment begins by choosing fire safety objective(s) to be achieved. This step is described in Section 6.

7.2 Fire hazard assessment requires specification of the design to be assessed, in a form that permits the fire safety performance of the design to be tested and modeled. This step is described in Section 8.

7.3 Fire hazard assessment requires specification of the fire scenarios for which a design must meet the fire safety objectives. This step is described in Section 9.

7.4 Fire hazard assessment requires specification of any additional assumptions, such as conditions of the environment, in the assessment. This step is described in Section 10.

7.5 Fire hazard assessment finds a specified design to be acceptable if, under the specified assumptions, a vehicle built to the design will meet each of the objectives for each of the specified fire scenarios.

7.6 It is the intention of this standard to maintain or exceed the levels of fire safety in rail transportation vehicles associated with the traditional applicable fire-test-response characteristic requirements for rail transportation systems, including the recommendations from the Federal Transit Administration and the guidelines from the Federal Railroad Administration, while providing an alternative method of assessing designs to achieve equivalent safety. Appendix X6 **(23, 24)** illustrates the level of safety achieved in 1990–1991.

7.6.1 Fire hazard assessment requires the use of testing and calculation methods to determine whether the objectives will be met by a specified design for a specified fire scenario, under the specified assumptions. The calculations to be performed are described in Section 9, and the selection and qualifying of calculation methods for the assessment are described in Section 10.

7.7 For the fire hazard assessment procedure to be valid, it is necessary that the calculation methods and the fire-test-response characteristics used produce valid estimates of success or failure in achievement of the fire safety objectives, given the specified fire scenario(s).

7.7.1 It is advisable for the validity of the fire hazard assessment procedure to be confirmed by peer review.

7.8 One way in which acceptable levels of safety would be achieved is through a design that complies with the applicable fire-test-response characteristic requirements for rail transportation systems, including the traditional recommendations from the Federal Railroad Administration in 1989 **(25)**, or those in

[13] One way to ensure consistent quality control is by listing materials, components, products, or assemblies.

[14] The boldface numbers in parentheses refer to the list of references at the end of this standard.

NFPA 130. If a rail transportation vehicle is designed fully with materials, components, and products meeting those requirements or recommendations, that vehicle would not traditionally need to be subjected to the fire hazard assessment procedure described here.

7.8.1 A complete listing of the fire-test-response characteristics of a design, together with the corresponding Federal Railroad Administration recommendations for those characteristics (see Table X1 and Appendix X1), would constitute an acceptable design.

7.9 The recommendations cited in 7.8 should be used to set specific values in the fire safety objectives and in other qualified elements of the fire hazard assessment in any instance where those values are not specified by this guide. This should be done so as not to compromise the fire safety levels reflected in the statistics of fire incidents shown in Appendix X6. Any values or other assumptions specified by the user must be set explicitly and conservatively, that is, providing greater safety, with an explicitly stated rationale for the specific values or assumptions.

8. Use of Design Specifications in Calculations for Estimates of Fire Hazard

8.1 The issue of design of products or entire rail transportation vehicles can have significant impact on fire safety. Design specifications can be used as input into the calculation methods of a fire hazard assessment; however, for design specifications to be useful, they cannot be expressed in vague terms but must be expressed as either numerical values or as other instructions, for example, equations compatible with the fire hazard assessment calculation method used.

8.1.1 Once expressed as numerical or other specific values, design specifications are a source for input variables for fire hazard assessment. For example, design specifications will include specification of the materials or components to be used in the vehicle compartment linings, including ceilings, walls, and floors. The calculations required to assess whether flashover will be prevented in the vehicle (an objective specified in 6.2) will require heat absorption parameters for the compartment linings. These heat absorption parameters will not be identical to the design specifications for the compartment lining materials but will be derivable from these specifications by reference to data from established test methods. Because this guide does not specify the models as calculation methods to be used, it follows that it cannot list the input variables that will be required or the appropriate procedures to use in deriving those input variables from design specifications.

8.1.2 A fire hazard assessment is an evaluation of a complete design that addresses certain fire safety objectives; therefore, the design specifications used must address and include all relevant products and design features used, including those specified by conventional prescriptive practices. A fire hazard assessment of a retrofit, rebuild, or repair cannot be limited to the parts of the design being changed. Rather, a fire hazard assessment of a retrofit carried out according to the practices presented in this guide must address the resulting car, including contents, in its entirety.

8.1.3 This guide does not address minor changes to vehicles designed using components or materials that are defined originally by property lists, such as those described in 7.8. In such cases, the techniques presented in this guide will have less applicability and may present fewer, if any, economic benefits than continuing the use of the lists described in 7.8.

8.2 In connection with this guide, the term "design" refers both to the general arrangement of the vehicle (for example, size, location of doors and windows, the nature of emergency exits, the number and configuration of levels and compartments) and to the materials, components, and products used to fabricate the vehicle. The development of such designs often involves decisions that include tradeoffs and ad-hoc benefit analyses and is a traditional approach.

8.2.1 An example of such a decision are trade-offs considered between using traditional glazing materials, which are not combustible but have high mass and low impact resistance. The use of these materials may compromise passenger and staff security, due to the hazard of projectiles. An alternative, to address hazards posed by projectiles to noncombustible, but friable, glazing is the use of more impact resistant materials, which are combustible.

NOTE 3—The use of plastic glazing materials with high impact resistance is a common practice in the transportation industry and has been since the 1970s.

8.3 Design specifications for materials, components, and products will include fire-test-performance characteristics. Appendix X1 and Appendix X3 provide a list of test methods from which the test methods to be used should be chosen. Alternative test methods are contained in Table X1 **(26)** and Appendix X1, and they generate fire-test-response characteristics, albeit ones that cannot be used for fire safety engineering calculations.

8.3.1 The test methods referenced include, but are not limited to, those required to measure the fire-test-response characteristics included in recommendations or requirements of NFPA 130, the Federal Railroad Administration (FRA) **(25)** AMTRAK **(27)**, and the Federal Transit Administration (FTA) **(28)**. A new FRA rule was issued in 1999, which incorporated the majority of the earlier FRA guidelines **(29)**.

8.3.1.1 The choice of any test method is nonmandatory, and the developer of a fire hazard assessment will need to provide evidence of its validity for use in testing of rail transportation system components or composites (see also 7.7.1).

8.3.2 The test methods referenced in Appendix X3 have been designed to yield results in fire safety engineering units, which are appropriate for fire hazard assessment, and measure heat release rate, which has been demonstrated to be an essential component of fire hazard assessment **(30, 31)**.

8.3.3 It is likely that design specifications of any finished product with different component materials will not be available normally (from the suppliers of the individual materials or components that go into them) in a form suitable for application of fire hazard assessment. Manufacturers of such products normally cannot be expected to have developed data on characteristics that are not part of existing sets of requirements or recommendations for their products. Similarly, suppliers of individual materials cannot be expected to identify or provide materials, components, or products, based exclusively on the kinds of design specifications required for fire hazard assessment; therefore, suppliers of such products may require the translation of the performance specifications into conventional specifications for the individual materials. A prescriptive approach to achieve fire safety objectives should always exist as an alternative. In the case of rail transportation vehicles, such an approach would be through use of the traditional methods as exemplified by the recommendations in Table X1 and Appendix X1. The hazard assessment approach becomes an option available to those manufacturers who prefer to seek alternative means of achieving acceptable levels of fire safety inside rail transportation vehicles.

9. Fire Scenarios

9.1 Fire Scenario 1 is a fire that originates within the rail transportation vehicle.

9.1.1 Fire Scenario 1a, specified as the highest-challenge likely scenario of this type, begins as an incendiary ignition involving the use of accelerants and prior damage exposing the fillings of the two upholstered seats nearest the point of ignition. Fire begins while the vehicle is in motion between stations, at the maximum distance from any station (see also Appendix X2).

9.1.2 Fire Scenario 1b, specified as one of the most common scenarios, is a trash fire that begins under a seat assembly and spreads to that seat assembly, in a passenger compartment.

9.1.3 If cooking is permitted on any passenger vehicle, an additional fire scenario, to be called Scenario 1c, also must be assessed. Fire Scenario 1c is a cooking fire originating at the cooking equipment and involving initial ignition of cooking fuel, if equipment is gas-fueled, or cooking oil, if equipment is not gas-fueled. Fire begins while the vehicle is in motion between stations, at the maximum distance from any station.

9.1.4 If there are one or more vehicles provided for overnight sleeping, fire scenario 1d also must be assessed, where Fire Scenario 1d is a small open-flame ignition of bedding in an unoccupied bed in a vehicle, with other beds occupied by sleeping people. Fire begins while the vehicle is in motion between stations, at the maximum distance between stations.

9.1.5 If there are one or more vehicles provided for cargo (or cargo storage space is provided within a passenger vehicle), Fire Scenario 1e also must be assessed, where Fire Scenario 1e consists of small open-flame ignition of a combustible, for example trash, in a fully-filled cargo vehicle. The assumed fuel load shall be the maximum allowed, including the highest quality of hazardous materials possible under the planned operating procedures. Openings connecting the cargo vehicle to an assumed adjacent passenger vehicle shall be assumed to be open to the maximum degree permitted by the design.

9.1.6 If the rail transportation vehicle overturns and then catches on fire, it is possible that different considerations apply as a function of the way the vehicle ends up. If it remains in its normal orientation, the earlier scenarios apply, but if it falls on its side or if it turns around completely, to end up upside down, they represent different scenarios. In both cases, fire begins while the vehicle is stationary between stations, at the maximum distance between stations.

9.2 Fire Scenario 2 is a fire that originates outside the rail transportation vehicle, penetrates the rail transportation vehicle, and endangers the evacuation route from the vehicle through the spread of flames or smoke into the evacuation route.

9.2.1 Fire Scenario 2a, specified as the highest-challenge likely scenario of this type, begins with ignition of a fuel spill following a collision with survivors. Fire begins in a tunnel, where the vehicle has stopped due to the collision, at a point maximally distant from any egress to the outside. Evacuation is to a place of safe refuge.

9.2.2 If the vehicles are individually electrically powered, Fire Scenario 2b must be assessed, where Fire Scenario 2b is an electrical fire that causes the vehicle to stop in a tunnel, at a point maximally distant from any egress to the outside. The interruption of electrical power also affects operation of the vehicle doors, in accordance with the vehicle's design. The point of origin is assumed to be whatever point in the electrical system will lead to the fastest spread of smoke and toxic gases to the vehicle interior.

9.3 The specification of fire scenarios included in this section assumes that other fire scenarios either are less severe, and therefore, will lead to achievement of fire safety objectives if the design achieves the objectives for the specified fire scenarios, or are sufficiently unlikely that they need not be considered as part of the overall fire hazard assessment, although they may be considered individually.

9.3.1 The fire scenarios that are appropriate for a certain rail system may not be adequate for a different rail system. Additional or different fire scenarios may be needed in certain cases.

10. Additional Assumptions

10.1 Occupancy of the rail transportation vehicle and any other relevant occupiable spaces, such as the platform to which occupants may move to evacuate, shall be set for analysis purposes so as to pose the greatest challenge to the fire safety objectives. A logical assumption would be occupancy to capacity and a mix of occupants of different abilities, where some will have various physical or mental disabilities, and capabilities, for example, some will be assumed to be impaired by alcohol, or drugs, or by age-related limitations.

10.1.1 Assumptions regarding numbers and abilities of disabled persons shall incorporate relevant provisions of the Americans with Disabilities Act.[9]

10.1.2 Assumptions regarding age distributions of the occupants shall reflect data on age patterns among users of the rail system. Assumptions regarding the capabilities of older or younger occupants shall reflect patterns in the general population, or known applications to the specific rail transportation scenario chosen, if they differ, and shall be documented as to sources of data.

10.1.3 Assumptions regarding alcohol or drug impairment among occupants shall be documented as to source data and shall be based on patterns in the general population, weighted to reflect the age and economic distribution of users of the rail system. If such data are not available, conservatively assume that 10 % of adult occupants are impaired by alcohol.

10.1.4 If the rail vehicles provide sleeping accommodations, assume that fire occurs when the maximum number of occupants will be sleeping. If there are no data available to determine the maximum fraction of people sleeping, assume all passengers are sleeping.

11. Required Calculations

11.1 The fire hazard assessment involves using one or more calculation procedures to determine whether the fire safety objectives in Section 6 will be met if the design specified in Section 8 experiences each of the fires of the scenarios specified in Section 9, and given the additional assumptions specified in Section 10.

11.1.1 This guide does not assign a specific choice of calculation procedure just as it does not assign a specific test method. It simply gives guidance on the types of procedures available and on the required output to generate a valid fire hazard assessment.

11.1.2 Use Guide E 1546 when developing the procedure.

11.1.3 Use NFPA 901 if needed for overall coding of materials or products.

11.2 Because the fire safety objectives are all stated in terms of specified fire effects by location and time, the fire hazard assessment calculation procedures must support the calculations in 11.2.1-11.2.5.

11.2.1 Translate the fire scenario specifications into a description of the fire in its initial stages, as a function of time in the initially involved space. The fire-test-response characteristics of the materials, components, or products initially involved that should be considered for such a description are rate of heat release, rate of mass loss, total heat release (if burned to completion, or cumulative heat release to end of burning otherwise), flame spread, cumulative full-scale smoke obscuration and toxic potency of the products of combustion released. A thorough analysis of the actual rail transportation vehicle fire scenario should result in a final decision on the properties required for the fire hazard assessment. If the product under consideration is a structural component, assess also its fire endurance.

11.2.2 Assess and evaluate the vehicle design specifications to develop and describe foreseeable characteristics of the fuel load environment near the initial fire. Use these and the time-based description of the initial fire as a function of time to calculate the spread of fire to secondary items and the ignition of those secondary items.

11.2.3 For each space, or potential fire compartment, calculate the timing of major fire events, including the onset of flashover, as well as, fire spread from one space to an adjacent space, whether through barriers or not, particularly from outside a rail vehicle to inside the vehicle. The calculation of fire spread from one space to another will require measurement of barrier fire resistance characteristics.

11.2.4 For each potentially exposed occupant, calculate the time to reach safe refuge and compare it to the calculated time until exposure to an unacceptable potential for harm (hazard). The former requires calculation of occupant alerting response, travel speed, and other behavior. For occupants requiring rescue, calculations will need to estimate the size, capabilities, and arrival time of fire department or other rescue personnel. The latter can be calculated as time to exposure to an untenable cumulative dose of fire effects or conservatively calculated as time to first exposure to unacceptably hazardous fire conditions. Calculations will be required for the area of fire origin, any occupied spaces, and any spaces that are part of escape or rescue routes.

11.2.5 When making the calculations described in 11.2.3 and 11.2.4, incorporate the activation and effects of any fire protection systems, including automatic or manual fire suppression, detection, and smoke control systems. Consider that, once a collision has occurred, electrically-controlled detection and protection systems may be damaged.

11.3 For the fire safety objective of preventing flashover, flashover shall be calculated as occurring when the radiative heat flux at the center of the floor reaches 20 kW/m^2. Other fire characteristics that are sometimes used as indicators of flashover, such as an upper layer temperature of 600°C, can be used in the calculations but are not to be used to assess achievement of the objective.

12. Selection and Qualification of Fire Hazard Calculation Methods

12.1 Because no applicable calculation methods have been adopted as ASTM standards, the choice of calculation methods is nonmandatory and must include written evidence of the validity of the method for this purpose. Use Guide E 1355 in order to evaluate the predictive capability of the fire model used. Guide E 1591 provides guidelines on how to obtain the appropriate input data, in particular material properties, that are needed for fire modeling. Guide E 1472 illustrates the type of documentation required for fire models to be satisfactory.

12.2 The user must provide guidance on safety factors needed to offset the uncertainties and biases associated with the method or with the data used by the method. Any valid calculation method is valid only for certain applications and within the limits of its own uncertainties and biases and the uncertainties of its source data; therefore, the evidence of validity required in 10.1 will provide the basis for specifying safety factors.

12.3 See Appendix X4 and Appendix X5 for candidate calculation methods.

12.4 Under the provisions in 7.8, a design fully complying with the existing requirements or recommendations based on fire-test-response characteristics is deemed to satisfy the fire hazard assessment. This is equivalent to stating that a fire-characteristic profile for the design is deemed to satisfy the fire hazard assessment if it satisfies the fire-test-response characteristic limits in Table X1 and Appendix X1. This does not constitute acceptance of the fire-characteristic profile in general as a simplification of the fire hazard assessment procedure. Any use of the fire-characteristic profile other than this specific application must be shown to be valid.

APPENDIXES

(Nonmandatory Information)

X1. EXAMPLE OF FIRE-TEST-RESPONSE CHARACTERISTICS RECOMMENDATIONS

X1.1 *Notes to Table X1.1 as set out by the Federal Railroad Administration* ***(25)****:*

X1.1.1 *Test Methods D 3675 and E 162*—Materials tested for surface flammability should not exhibit any flaming running or flaming dripping; window and light diffuser panels need not meet the running or dripping requirement.

X1.1.2 *Cushions, Mattresses, Seat Upholstery, Mattress Ticking, and Covers, Curtains*—The surface flammability and smoke emission characteristics of a material should be demonstrated to be permanent by washing, if appropriate, according to FED STD 191-A Textile Test Method 5830.[15]

X1.1.3 *Seat Upholstery, Mattress Ticking, Covers, and Curtains*—The surface flammability and smoke emission characteristics of a material should be demonstrated to be permanent by dry-cleaning, if appropriate, according to Test Methods D 2774. Materials that cannot be washed or dry-cleaned should be so labeled and should meet the applicable performance criteria after being cleaned as recommended by the manufacturer.

X1.1.4 *Window Panels*— For double window glazing, only the interior glazing should meet the material recommendations specified herein; the exterior need not meet those recommendations.

X1.1.5 *Test Method E 662*—Test Method E 662 maximum test limits for smoke emission (specific optical density) should be measured in either the flaming mode or the nonflaming mode, depending on which mode generates the most smoke.

X1.1.6 *Test Methods E 119*—Structural flooring assemblies should meet the performance criteria during a nominal test period determined by the transit property. The nominal test period should be twice the maximum expected period of time, under normal circumstances, for a vehicle to come to a complete, safe stop from maximum speed, plus the time necessary to evacuate all passengers from a vehicle to a safe area. The nominal time period should not be less than 15 min. Only one specimen need be tested. A proportional reduction may be made in dimensions of the specimen provided that it represents a true test of its ability to perform as a barrier against undercar fires. Penetrations (ducts, etc.) should be designed against acting as passageways for fire and smoke.

[15] The American Association of Textile Chemists and Colorists (AATCC, P.O. Box 12215, Research Triangle Park, NC, 27709) has issued the Standard Laboratory Practice for Home Laundering Fabrics prior to Flammability Testing, to Differentiate Between Durable and Nondurable Finishes (May 1, 1991). Although no AATCC formal equivalent standard exists, the practice mentioned is likely to be useful as a replacement to the Federal Test Method, since the Federal standards are in the process of being withdrawn.

TABLE X1.1 U.S. Flammability and Smoke Emission Recommendations for Passenger Rail Vehicles (22)

		Flammability		Smoke Emission	
Category	Function of Material	Test Procedure	Performance Criteria	Test Procedure	Performance Criteria
Passenger seats, sleeping, and dining car components	Cushions, mattresses	ASTM D 3675	$I_s \leq 25$	ASTM E 662	$D_s(1.5) \leq 100$: $D_s(4.0) \leq 175^A$
	Seat Frames, mattress frames	ASTM E 162	$I_s \leq 35$	ASTM E 662	$D_s(1.5) \leq 100$; $D_s(4.0) \leq 200$
	Seat and toilet shroud, food trays	ASTM E 162	$I_s \leq 35$	ASTM E 662	$D_s(1.5) \leq 100$; $D_s(4.0) \leq 200$
	Seat upholstery, mattress ticking and covers, curtains	FAR 25.853 (a) (Vertical burner)	Flame time ≤ 10 s Burn length ≤ 6 in	ASTM E 662	$D_s(4.0) \leq 250$ coated $D_s(4.0) \leq 200$ uncoated
Panels	Wall, ceiling, partition, tables and shelves, windscreen, HVAC ducting	ASTM E 162	$1_s \leq 35$	ASTM E 662	$D_s(1.5) \leq 100$; $D_s(4.0) \leq 200$
		ASTM E 119	as appropriate^B	ASTM E 662	
	Window, light diffuser	ASTM E 162	$I_s \leq 100$	ASTM E 662	
Flooring	Structural	ASTM E 119	nominal evacuation time, at least 15 min	ASTM E 662	$D_s(1.5) \leq 100$; $D_s(4.0) \leq 200$
	Covering	ASTM E 648	C.R.F. ≥ 5 kW/m^{2D,E}	ASTM E 662	
		ASTM E 162^C	$I_s \leq 25$	ASTM E 662	
Insulation	Thermal, acoustic	ASTM E 162	$I_s \leq 25$	ASTM E 662	$D_s(4.0) \leq 100$
Elastomers	Window gaskets, door nosing, diaphragms, roof mat	ASTM C 542	Pass	ASTM E 662	$D_s(1.5) \leq 100$; $D_s(4.0) \leq 200$
Exterior plastic components	End cap roof housings	ASTM E 162	$I_s \leq 35$	ASTM E 662	$D_s(1.5) \leq 100$; $D_s(4.0) \leq 200$
Component box covers	Interior, exterior boxes	ASTM E 162	$I_s \leq 35$	ASTM E 662	$D_s(1.5) \leq 100$; $D_s(4.0) \leq 200$

^{A}NFPA 130 and FTA requirement is D_s (1.5) ≤ 100; D_s (4.0) ≤ 200
^{B}Test criteria for floors or criteria appropriate to the physical locations and magnitude of the major ignition, energy, or fuel loading sources, may be used.
^{C}NFPA 130 only.
^{D}Amtrak requirement is C.R.F. ≥ 6 kW/m^2
^{E}Amtrak requirement is I_s ≤ 35.

X1.1.7 *Floor Coverings*— Floor coverings should be tested in accordance with Test Method E 648 with its padding, if the padding is used in actual installation.

X1.1.8 *Seat or Mattress Frames*—Arm rests, if foamed plastic, are tested as cushions, and, if hard material, are tested as a seat back shroud.

X1.1.9 *Cushions and Mattresses*—Testing is performed without upholstery.

X1.1.10 *Wall and Ceiling Panels, Floor Coverings*—Carpeting on walls and ceilings are to be considered wall and ceiling panel materials, respectively.

X1.1.11 *Elastomers*— The fire test method in Specification C 542 is Test Method C 1166.

X1.2 Table X1.1 shows all of the materials and products addressed by the Federal Railroad Administration, and indicates the traditional approach to fire-test-response characteristic requirements for rail transportation systems.

X1.3 NFPA 130 requires that wiring materials and installations in fixed guideway transit systems, other than for traction power, conform to the requirements of NFPA 70, the National Electrical Code. It also requires that wire and cable constructions intended for use in operating vital train circuits and power circuits to emergency fans and lights pass the flame propagating criteria of IEEE 383. AMTRAK also has issued separate specifications for wire and cable **(32)**.

X1.3.1 IEEE 383 is substantially similar to the flame spread portion of Protocol A of Test Method D 5537. It is a vertical cable tray flame propagation test, with a 2.4-m (8-ft) long test sample.

X1.3.2 The National Electrical Code states that cables that meet a more severe fire test can be appropriately used in applications where a less severe test is required (see X3.12.7 for the applicable test methods).

X1.3.3 In comparison, the Federal Aviation Administration requires electric wire insulation to meet requirements based on a 60° angle test method [FAR 25.1359]. Average extinguishing time not to exceed 30 s; average drip extinguishing time not to exceed 3 s; average burn length not to exceed 76-mm (3-in.), and the wire shall not break during the test.

X2. PHYSICAL CHANGES OCCURRING IN MATERIALS, COMPONENTS AND PRODUCTS AFTER MANUFACTURE

X2.1 Some materials, components, and products may be exposed to the effects of accidental or intentional disfiguration, so that the exposed surface is different from the one intended to be exposed when it is offered for sale.

X2.2 The exposure to a flame source of inner layers of various products has been shown, in some cases, to result in different fire performance.

X2.3 The standard test methods referenced in this guide do not address changes to protective layers due to wear, tear, or abuse, which potentially affect the fire-test-response characteristics of the item. Such changes would have to be addressed by tests specifically intended for such purposes.

X2.4 If the user of a particular test method chooses to expose one or more of the inner layers during testing, the mode in which the inner layer was exposed should be described in detail.

X2.5 The user of this guide should consider anticipated conditions of use of any material, component, or product to ensure that the performance characteristics do not deteriorate beyond acceptable levels.[16]

[16] It should be noted that changes caused by aging, wear and tear, willful or accidental damage, and inconsistency in the manufacturing process, for example practices which do not ensure retention of assembly fire properties, are examples of ways in which the fire performance characteristics of a material, component, product, or assembly can vary in service.

X3. RECOMMENDED METHODS FOR GENERATING APPROPRIATE DATA FOR USE IN CALCULATIONS

X3.1 Use Test Method E 1474 to expose composites of seat materials to radiant heat, at an incident heat flux of 35 kW/m^2. Test Method E 1474 is an applications method of the cone calorimeter, while Test Method E 1354 addresses the mounting for upholstered furniture and mattress composites.

X3.2 Use Test Method E 1354 to expose individual materials in component products to radiant heat, at an incident heat flux of 35 kW/m^2.

X3.3 Use Test Method E 1354 to expose all panel materials, in a construction representative of that in which they are installed in the rail transportation vehicle, to radiant heat, at an incident heat flux of 35 kW/m^2.

X3.4 Use Test Method E 1740 to expose all wallcovering systems, in a construction representative of that in which they are installed in the rail transportation vehicle, to radiant heat, at an incident heat flux of 35 kW/m ^{2}. Test Method E 1740 is an applications method of the cone calorimeter, while Test Method E 1354, addresses the mounting method for wallcovering systems.

X3.5 Use Test Method E 1354 to expose the floor covering materials, in a manner representative of the way they are installed in the rail transportation vehicle, to radiant heat, at an incident heat flux of 25 kW/m^2. The rationale for testing floor coverings at a lower incident flux level than other fuel sources is that it has been shown that floor covering systems are not exposed to very high heat fluxes until after the compartment has reached flashover (heat flux to the floor of 20 kW/m^2), by which time they have no further contribution to the probability of reaching flashover.

X3.6 Use Test Method D 6113 to expose all wire and cable products used in the rail transportation vehicle, to radiant heat, at an incident heat flux of 40 kW/m^2. Test Method D 6113 is an applications method of the cone calorimeter, Test Method E 1354 addresses the mounting method for electrical and optical fiber cables. The incident heat flux was chosen because of the extensive amount of information available on testing cables and cable materials at that incident heat flux **(33, 34)**. If a specific incident heat flux is found to be suitable for a particular application, it shall be used instead of using an incident heat flux of 40 kW/m^2.

X3.7 In X3.1-X3.6, exposure to radiant heat using Test Method E 906 is an acceptable alternative, provided a valid correspondence of heat release results between the test methods has been demonstrated in advance. Other test methods also are acceptable, provided it has been demonstrated validly that the fire-test-response characteristics resulting from them are equivalent to cone calorimeter heat release rate data for the specific purpose of performing a fire hazard assessment.

X3.8 Use Test Method E 1623 for assessment of materials, components, products, or assemblies which require a somewhat larger scale of testing, primarily because of the effects of joints or other edge effects. Use an incident heat flux relevant to the product under consideration, in its location within the rail transportation vehicle.

X3.9 Calculate the heat released by each material and by each composite of materials.

X3.10 Compare the results obtained with the estimations of the minimum heat release for flashover, to ensure that no material, and no composite of materials, is used in quantities large enough that its potential for heat release is such that it is capable of yielding flashover conditions, or creating an untenable environment, on its own.

X3.11 Compare too the results obtained with estimation for tenability values for smoke obscuration or smoke toxicity (see 6.1.4.1).

X3.12 *Full-Scale Test Methods*:

X3.12.1 Properly conducted fire tests involving a complete rail transportation vehicle, and which determine all relevant fire properties, containing all the composites and components present in an actual vehicle will be sufficient to carry out this fire hazard assessment; however, such testing is not practical as a normal procedure. It may be desirable, therefore, to carry out properly validated full-scale tests on individual products, or on specially designed portions of rail transportation compartments, as a more general practice.

X3.12.2 There are few standardized examples of full-scale fire tests of individual products.

X3.12.3 Test Method E 1537 (upholstered furniture, 19 kW exposure) and Test Method E 1590 (mattresses, 18 kW exposure) are deemed to be adequate procedures for testing individual items of upholstered furniture or mattresses for purposes of fire hazard assessment in some public occupancies; however, such individual stand-alone (not fixed in place) items are not those normally present in rail transportation vehicles. The applicability of the test methods to rail transportation vehicles has not been validated, and they are probably not sufficiently representative of the situation, and may require some modifications for better applicability (see also X3.12.4).

X3.12.4 The use of alternative ignition sources (by varying the location, the gas flow intensity or the exposure time) for Test Method E 1537 or Test Method E 1590 may be a means of addressing some very high challenge fire scenarios, potentially present in rail transportation vehicles. Examples of more powerful ignition sources that could be used include a 50 kW gas burner **(35)** or the oil burner used for aircraft seat cushions [FAR 25.853 (c)], but the measurements should involve the same fire properties as in Test Method E 1537 or Test Method E 1590.

X3.12.4.1 The FAA oil burner test [FAR 25.853 (c)] is used for aircraft seat cushions, but in its current form, it is a pass-fail test and cannot be used for fire safety engineering calculations; however, the exposure conditions of the oil burner test itself can be used as an alternative ignition source for evaluating rail transportation vehicle seats, and that would better address a higher challenge fire scenario than the exposure conditions of the burner from Test Method E 1537.

X3.12.5 In fire scenarios intended to reflect willful (vandalism) or accidental damage of the initially fabricated seat (or mattress) assembly, before fire ignition, one example of such damage may be a knife cut 6 in. long and 1 in. deep in the middle of an actual seat (or mattress) assembly. Other examples also may be used. Bench-scale representations of the proposed damage should take into account test method sample size.

X3.12.6 NFPA 265 or ISO 9705 are means of testing wall or ceiling linings in a standardized room for their contribution to compartment fire development. This can be used to test room surface finishes. ISO 9705 lists several ways in which the test method is conducted. NFPA 265 differs from the usual way of conducting ISO 9705 lists several ways in which the test method is conducted. NFPA 265 differs from the usual way of conducting ISO 9705 in the following three ways: the ignition source is 40 kW (for 5 minutes), and then 150 kW (for 10 minutes), while in ISO 9705 it is 100 kW (for 10 minutes) and 300 kW (for 10 minutes); the ceiling is covered in ISO 9705, but not in NFPA 265; and, that the positioning of the ignition burner is somewhat different.

X3.12.6.1 Most combustible wall linings are likely to reach flashover when tested according to ISO 9705; however, the test results are likely still to produce useful information. This can be used to test products that occupy large interior areas of the rail transportation vehicle.

X3.12.7 Use Test Methods D 5424 and D 5537 (20 kW exposure) for testing wire and cable products used in the rail transportation vehicle for heat release, smoke release, mass loss, and flame spread. Examples of acceptance criteria for flame travel distance (or flame spread) and smoke obscuration are given in UL 1685 and in the National Electrical Code.

X3.12.7.1 The National Electrical Code uses several cable fire test methods for approval purposes.

X3.12.7.2 The single vertical wire test, UL 1581-1080, is used where minimal fire retardance of individual conductors is required.

X3.12.7.3 The bunched cables vertical tray tests, UL 1581-1160 and CSA FT4, are used for tray cable and general purpose cables where flame spread (and heat release) needs to be controlled. Test Methods D 5424 and D 5537 assess vertical flame spread of cables in the same way as UL 1581-1160 (when using Protocol A) or as CSA FT4 (when using Protocol B). They also assess heat release and smoke release for the same cable.

X3.12.7.4 The vertical cable tray tests listed are not of identical severity. Protocol B of Test Method D 5537 or D 5424 (CSFA FT4) is somewhat more severe than Protocol A (UL 1581-1160), but cables meeting either requirement are accepted for the same application in the National Electrical Code.

X3.12.7.5 The plenum cable test, NFPA 262, is required for assessing flame travel distance and smoke obscuration of wires and cables installed in ducts, plenums, and other spaces used for environmental air, which are to be listed as suitable for use as plenum cables and as having adequate fire resistant and low smoke producing characteristics.

X3.12.7.6 Limited smoke is defined in the National Electrical Code on the basis of the UL 1685 vertical cable tray test.

X3.12.8 UL 1975 is an example of a full-scale furniture calorimeter test of an individual product, in this case foam displays. The exact same technology (testing of the individual finished product in a furniture calorimeter) could be used for full-scale tests of several other individual products.

X3.12.9 If nonstandardized full-scale tests are being designed, use Guide E 603 to develop a realistic representation of the rail transportation vehicle under consideration and for guidance on full-scale testing.

X3.12.10 Use an ignition source realistic for the fire scenario investigated, and applicable to as large as possible a variety of potential fire scenarios, to ignite one of the potential products. The applicability of the ignition source must be explicitly addressed. When designing the ignition source to be used, the fuel load and items carried by passengers also must be considered.

X3.13 When using full-scale test methods carry out measurements of heat release rates, smoke obscuration, mass loss rates, and carbon monoxide and carbon dioxide emissions, during the test. If the fire hazard estimation procedure requires measurements of other gaseous combustion products, such as hydrogen chloride or hydrogen cyanide, measure those products as well. If no combustion products other than carbon oxides are measured, explain the rationale for not conducting such measurements for major combustion gases.

X3.14 When using full-scale test methods, also compare the results obtained with the estimations of the minimum heat release for flashover, to ensure that no product, or combination of products, is used in such a way that its potential for heat release is such that it is capable of yielding flashover conditions, or creating an untenable environment, on its own.

X3.15 Measurements of physical dimensions of rail transportation vehicles (with particular emphasis on their interior) have been made in NFPA 130, as well as in work by Braun **(36)** and by Peacock and Braun **(37)**, all of which also contain a number of measurements of fire properties.

X4. CALCULATION METHODS FOR ESTIMATING TIME TO UNTENABILITY

X4.1 Use a room fire growth model to estimate the development of potentially incapacitating conditions in a rail transportation vehicle, as a function of time, for Fire Scenario 1, in which the fire begins in the vehicle.

X4.1.1 In a recent survey **(38)**, 36 actively supported fire models were identified. Of these, 20 predict the fire generated environment (mainly temperature) and 19 predict smoke movement in some way. Six calculate fire growth rate, nine predict fire endurance, four address detector or sprinkler response, and two calculate evacuation times. The computer models now available vary considerably in scope, complexity, and purpose.

X4.1.2 The simplest ones are “room filling” models, such as the Available Safe Egress Time (ASET) model **(39)**, which run quickly on almost any computer, and provide adequate estimates of a few parameters of interest for a fire in a single compartment.

X4.1.3 Special purpose models can provide a single function. For example, COMPF2 **(40)** calculates post-flashover room temperature and LAVENT **(41)** includes the interaction of ceiling jets with fusible links in a room containing ceiling vents and draft curtains. Very detailed models like the HARVARD 5 code **(42)** or FIRST **(43)** predict the burning behavior of multiple items in a room, along with the time-dependent conditions therein.

X4.1.4 In addition to the single-room models mentioned above, there are a smaller number of multiroom models, which have been developed. These include the BRI transport model **(44)**, the HARVARD 6 code **(45)**, (which is a multiroom version of HARVARD 5) **(42)**, FAST **(46–47)**, CCFM **(48)** and the CFAST model **(49)**.

X4.1.5 None of the cited models has been adopted as an ASTM standard or demonstrated as valid for application to rail transportation systems. As part of the preparation of written evidence of validity required for any calculation methods selected for use, the user may find some existing detailed reviews useful. It is essential to consider the shortcomings of these models.

X4.1.5.1 Reports by Mitler **(50)**, Jones **(51)**, and Janssens **(52)** have reviewed the underlying physical concepts in several of the fire models in detail.

X4.1.5.2 The fire models fall into two categories: those that start with the principles of conservation of mass, momentum, and energy; and, the curve fits to particular experiments or series of experiments, used in order to develop the relationship among some parameters. In both cases, errors arise in those instances where a mathematical short cut is taken, a simplifying assumption is made, or something important is not well enough understood to include.

X4.2 To operate any room fire growth model, it will be necessary to estimate the time to secondary ignition of each of the major combustible items in the vehicle **(53)**.

X4.3 In calculating times, as required to assess the primary or secondary fire safety objective, absolute time values are not required and are less useful than accurate estimations of the relative size of the time for hazard development and the time for evacuation.

X5. CALCULATION METHODS FOR ESTIMATING FLASHOVER POTENTIAL

X5.1 A secondary objective is to prevent flashover. This objective can be achieved by the use of a room fire model, such as the ones described in Appendix X4. Alternatively, it is possible to estimate whether flashover will occur by means of a calculation approach. The shortcomings of these calculation methods should be considered.

X5.2 A variety of calculation approaches have been developed to predict the minimum rate of heat release required to achieve flashover in a certain compartment. Some of these models or calculation methods may apply to specific scenarios that do not involve contents, and then they would be inappropriate for use. Estimations of flashover in compartment fires via a model involve the use of certain input fire curves, and the output from the rail transportation vehicle furnishings or contents then would become a part of that input fire curve.

X5.2.1 Direct estimations, by simple calculations, have been proposed by Babrauskas and Krasny **(54)**, Thomas **(55)** and Quintiere **(56)**, based simply on geometrical characteristics of the compartment. These expressions are a first approximation, but they will vary depending on the materials used for construction and for lining the various surfaces.

X5.3 The first two of those approaches permit the calculation of a range of values of heat release rate sufficient to cause flashover in a compartment with a floor area not to exceed 500 m^2. The equations are optimized for surfaces made from gypsum wallboard, concrete or thermally similar materials, on walls, floors and ceilings (preferably with the same type of material on all surfaces). These equations have been validated for heat release rates in the range of 0.5 to 1.0 MW. The most commonly used one is that by Thomas, Eq X5.1:

$$Q = 7.8 * 10^{-3} * A_T + 0.758 * m \qquad (X5.1)$$

where:
Q = the rate of heat release (MW),
E = the energy released per kg of air consumed (E=3.00) MJ/kg),
A_T = the total compartment area: walls, floor and ceiling (in m^2), and the maximum air flow (kg/s) into the compartment following flashover.

X5.4 The air flow rate in equation (1) can be estimated by Eq X5.2:

$$m = 0.5\, A \sqrt{h} \qquad (X5.2)$$

where:
A = the area of the ventilation opening (in m^2), and
h = the height of the ventilation opening (in m).

X5.5 The approach by Quintiere **(56)** is less limited in the choice of interior surface materials, but is more complex, because it includes thermal properties of the compartment surfaces.

X5.6 Two empirical relative approaches also have been proposed by Ostman and Nussbaum **(57)** and Hirschler **(58, 59)**.

X5.7 The Ostman-Nussbaum **(57)** relationship was designed to predict time to flashover from room wall lining materials in the ISO 9705 test, at 100 and 300 kW input, and materials lining three walls and the ceiling. It uses input data from Test Method E 1354, at incident heat fluxes of 25 and 50 kW/m^2, and has been validated with test data on wall lining materials **(60)**.

X5.8 The Hirschler empirical approach **(58, 59)** is a first order approximation for relative time to flashover in a room-corner fire scenario and uses input data from Test Method E 1354, at an incident flux, which is relevant to the fire scenario in question. Recent work has shown the simultaneous application of this method to room-corner and an aircraft interior **(61)**.

X5.9 The other three approaches to be mentioned are fire models where heat release rates in the compartment are estimated from wall lining test result data in a small scale test **(52)**.

X5.10 The OSU model by Smith and Satija **(62)** uses as its input data obtained from the OSU small scale heat release calorimeter (Test Method E 906), in a model has been validated properly with wood materials, but not with some other wall linings. No work on its development has been conducted since 1990.

X5.11 The EUREFIC method, by Wickström and Göransson, **(60, 63)** predicts time to flashover of wall linings in the ISO 9705 test method (with lining material covering three walls and the ceiling and using successive ignition sources of 100 and 300 kW), as a function of time using results obtained with the cone calorimeter (Test Method E 1354) at an incident heat flux of 50 kW/m^2. The model is a reasonably simple empirical approach, based on three major assumptions: there is no direct relationship between the burning area growth rate and the heat release rate; the burning area growth rate is directly proportional to the ease of ignition, in other words it is inversely proportional to the time to ignition in the cone calorimeter, and the history of the heat release rate per unit area at each location is the same in full-scale (cone calorimeter).

X5.12 The Lund model, by Karlsson and Magnusson **(64-66)** represents a fire scenario similar to that in the EUREFIC model, except that the walls only are lined with the material being investigated in ISO 9705, instead of walls and ceiling. Furthermore, it requires input from the lateral ignition and spread of flame test (LIFT) apparatus (Test Method E 1321), as well as from the cone calorimeter (Test Method E 1354). Third, it predicts a large number of room fire test variables, rather than simply heat release rate and time to flashover. The model assumes that the total heat release rate comes from five sources: the gas burner, the vertical wall area behind the burner flame, a horizontal strip of material at the ceiling/wall intersection corresponding to the vertical height of the ceiling jet, the wall material in the upper layer, after flame spread has started and the wall linings burning below the hot gas layer.

X5.13 Any one of the eight approaches can be used to estimate, at least on a relative basis, the energy required for flashover of a rail transportation vehicle. This total should be compared with the sum of the heat release rates measured or estimated for all items proposed as rail transportation vehicle contents. If the former exceeds the latter, the analysis indicates that flashover is not likely to occur. Report the method used.

X5.14 The combination of fire models and equations contained in FPETOOL **(67)** can be employed to calculate upper layer compartment temperatures, by using fire growth curves with quadratic growth, as well as flashover heat release rate requirements, using the approach by Thomas **(55)**.

X6. STATISTICS ON FIRES IN MASS TRANSPORTATION

X6.1 Table X6.1 contains some statistics of fire incidents, injuries and fatalities, according to statistics by U.S. Department of Transportation (Federal Transit Administration) for 1990 and 1991 (excluding intercity trains) **(23, 24)**. Table X6.2 contains FTA fire statistics for the years 1992 through 1997 and data on fire fatalities and fire injuries for 1997 **(72)**. Table X6.3 contains NFPA average annual statistics for the years 1991 to 1995 for all rail transportation **(73)**. Table X6.4 contains NFPA average annual statistics for fires in rail passenger and diner cars for the years 1988 through 1997 **(74)**. The statistics should not be averaged to obtain overall yearly average representative data, but should be analyzed as representing an adequately low number of fire fatalities for some recent years.

X6.2 Accidental fatalities in railroad accidents have been steady for a few years: 1165 in 1987, 1279 in 1993, and 1114 in 1995 **(69)**. The fraction of fire fatalities is unknown, but the fraction of fires compared to other accidents was close to 3 % during the mid 1970's **(37)**.

TABLE X6.1 FTA Statistics of Fire Incidents in Rail Transportation (1990–1991) (23, 24)

	1990	1991
Commuter Rail Fires	1226	695
Light Rail Fires	72	96
Rapid Rail Fires	4217	5124
Total Rail Fires	5515	5915
Commuter Rail Fire Fatalities	0	0
Light Rail Fire Fatalities	0	0
Rapid Rail Fire Fatalities	2	0
Total Rail Fire Fatalities	2	0
Commuter Rail Fire Injuries	583	12
Light Rail Fire Injuries	0	1
Rapid Rail Fire Injuries	438	160
Total Rail Fire Injuries	1021	173
Commuter Rail Fire Miles (millions)	204.2	205.3
Light Rail Miles (millions)	24.1	27.3
Rapid Rail Miles (millions)	528.6	521.8
Total Rail Miles (millions)	756.9	754.4
Commuter Rail Passengers (millions)	319.4	307.3
Light Rail Passengers (millions)	174.0	183.6
Rapid Rail Passengers (millions)	2252.5	2123.2
Total Rail Passengers (millions)	2745.9	2614.1

TABLE X6.2 FTA Statistics of Fire Incidents in Rail Transportation (1992–1997)[A] (72)

	1992	1993	1994	1995	1996	1997
Commuter Rail Fires	527	540	715	544	503	602
Light Rail Fires	101	75	67	50	106	83
Rapid Rail Fires	5068	4452	4117	3201	3154	3253
Total Rail Fires	5696	5067	4899	3795	3763	3938
Total Fire Fatalities	0	0	0	2	0	0
Commuter Rail Fire Injuries	13	25	49	28	36	31
Light Rail Fire Injuries	0	0	3	238	3	3
Rapid Rail Fire Injuries	365	172	310	0	78	99
Total Rail Fire Injuries	378	197	362	266	117	133

[A] Note that Table X6.3 indicates that there were multiple rail fire fatalities and multiple rail fire injuries in the years 1992 to 1996. Note also that data reported by FTA does not include Amtrak fire-related accident/incident information; including the 8 fire fatalities from the 1996 MARC/Amtrak collision and fire.

TABLE X6.3 NFPA Statistics of Fires in Overall Rail Transportation (1991–95, and 1992–96) (73, 74)

Annual Average Fires in Transportation 1991–95; 1992–96				
	Fires 91–95	% 91–95	Fires 92–96	% 92–96
Passenger Road	308,760	85.9	298,570	72.9
Freight road transport	39,990	11.1	38,050	9.3
Heavy equipment	6,070	1.7	5,870	1.4
Special	2,040	0.6	2,000	0.5
Water transport	1,820	0.5	1,670	0.4
Rail Transport	700	0.2	630	0.2
Air Transport	240	0.1	230	0.1
Total Transport Vehicles	359,620		409,750	
Annual Average Fires in Rail Transportation 1991–95; 1992–96				
		% 91–95	Fires 92–96	% 92–96
Freight cars		36	230	36
Locomotive		25	160	26
Equipment		9	50	8
Passenger		8	50	8
Other		22	130	22
Causes of Fires in Rail Transportation 1991–95; 1992–96				
		%	Fires 92–96	% 92–96
Incendiary		20	130	21
Non-incendiary		80	500	79
Material First Ignited in Fires in Rail Transportation 1991–95; 1992–96				
		% 91–95	Fires 92–96	% 92–96
Fuel		17	110	17
Electrical Wire		11	70	11
Trash		8	60	9
Upholstery		3		2
Unclassified		16		15
Other		45		46
Average Annual Fire Fatalities and Fire Injuries in Rail Transportation 1991–95; 1992–96				
	Fatalities 91–95	Injuries 91–95	Fatalities 92–96	Injuries 92–96
Overall	1	12	4	11

TABLE X6.4 NFPA Statistics of Fires in Rail Transportation Passenger and Diner Cars (1988–97) (75)

Annual Average Rail Passenger & Diner Car Data 1988–97		
		Number
Fires		71
Fire Fatalities		2
Fire Injuries		4
Annual Average Causes of Rail Passenger & Diner Car Fires 1988–97		
	Fires	%
Incendiary	12	12
Non-incendiary	59	88
Annual Average Material First Ignited in Rail Passenger & Diner Car Fires 1988–97		
	Fires	%
Fuel	12	16
Electrical Wire	13	18
Trash	1	1
Upholstery	7	11
Unclassified	5	7
Other	33	47

X7. EXAMPLE CALCULATION

X7.1 Table X7.1 and Table X7.2 contain cone calorimeter data for rail transportation vehicle materials **(33, 37, 68-71)**.

X7.2 One of the methods that can be employed to calculate upper layer room temperatures is the fire model contained in the FPETOOL software **(67)**. In that fire model, a moderate fire is defined as one where the growth is governed by a constant $\alpha = 11.72 \times 10^{-3}$ kJ/s ^{3} and a fast fire is defined as one where the growth is governed by a constant $\alpha = 46.88 \times 10^{-3}$ kJs^3. Using a fast fire curve, and a BART-type rail transportation vehicle **(36)**, flashover is reached after 9 minutes, while the moderate fire does not reach flashover in 15 minutes. The analyses were conducted using resilient flooring. In order to see the sensitivity of the analysis, alternate ones were conducted using wood flooring and concrete flooring of similar thickness. Slightly different upper layer temperatures were obtained for the various flooring types, representing the thermal response characteristics of the flooring material.

X7.3 The FP-PVC2 and PO1-PO3 cables from Table X7.1 were used to investigate their relative effectiveness, which respectively have, excellent and borderline-failing fire performance in the vertical cable tray test). Application of a different fire model within the same FPETOOL software can be made using specially-constructed fire curves. In the first curve it is assumed that only a few lengths of cable were present (some 40

TABLE X7.1 Cone Calorimeter Test Data for Some Materials Used in Rail Transportation Vehicle[A](33, 37, 69-71)

Material	Flux [kW/m^2]	Pk RHR [kW/m^2]	Tm Pk [s]	Av RHR 3 [kW/m^2]	THR [MJ/m^2]	EHC [MJ/kg]	T_{ig}[s]	Av SEA [m^2/kg]	Pk SEA [m^2/kg]	Thickness [mm]
Low smoke polychloroprene foam **(37)**	25	27	634		12	NA	NA	NA		25?[B]
Vinyl chloride acrylic copolymers window mask **(37)**	25	200	99		2	NA	90	NA		25?[B]
Acrylic wall covering	25	410								25?[B]
Nylon floor covering with underlayment **(37)**	25	350	228		21	NA	117	NA		25?[B]
CMHR Upholst. Foam A **(69)**	35	26	5	12	3	5	5	12		27
CMHR Upholst. Foam 2 **(69)**	35	20	25	11	3	3	4	139		27
CMHR Upholst. Foam B **(70)**	35			31						50?[B]
CMHR Upholst. Foam C **(70)**	35			34						50?[B]
Neoprene Uph. Foam **(71)**	35			32						50?[B]
Wire and Cable										
PVC1-PVC2 Cable **(33)**	40	189		56	54	11	113	387		10
PVC1-PO1 Cable **(33)**	40	163		77	88	19	59	261		10
FP-PVC2 Cable **(33)**	40	132		46	46	12	72	654		10
PO2-PO1 **(33)**	40	282		52	77	24	62	272		10
PO1-PO3 **(33)**	40	398		52	124	26	114	303		

[A] The materials chosen from reference **(71)** are high performance foams potentially used in rail. The designation CMHR in this table is not restricted to polyurethane foam but reflects an advanced degree of improved fire performance. Foams were tested at 50-mm thickness (except the graphite foam tested at 25-mm); other materials were tested at use thickness. The cable material data from **(33)** were obtained from testing communications cables of various chemical compositions (insulation and jacket), of which the first four meet the flame spread, heat and smoke requirements from UL 1685 in Test Method D 5424, a test method which is somewhat similar to the AMTRAK Specifications for High Performance Wire and Cable Spec 323-1990 **(31)** and the last one does not meet them (PO1-PO3). Abbreviations: PO: polyolefin, halogen-free; PVC: poly(vinyl chloride-based); FP: fluoropolymer. Property abbreviations: Flux: incident heat flux; Pk RHR: maximum rate of heat release; Tm Pk: time to Pk RHR: Av RHR 3: 3 min average rate of heat release; THR: total heat released; EHC: effective heat of combustion; T_{ig}: time to ignition; Av SEA: average specific extinction area; Pk SEA: peak specific extinction area.

[B] ?: Symbol indicates that the thickness used for testing is likely to be that indicated.

TABLE X7.2 Cone Calorimeter NIST Test Data for Some Additional Materials Used in Rail Transportation Vehicles at 50 kW/m^2 (68)

Material[A]	Pk RHR[B] [kW/m^2]	Tm Pk[B] [s]	THR[B] [MJ/m^2]	Av RHR 3[B] [kW/m^2]	Av MLR[B] [g/s m^2]	EHC[B] [MJ/kg]	T_{ig} [B] [s]	Av SEA[B] [m^{2}kg]	Pk SEA[B] [m^2/kg]	Thickness [mm]
Individual Seat/Mattress Materials										
CMHR upholstery foam	77	25	15.7	32	3.17	9.7	14	18	211	50
Graphite upoholstery foam[C]	99	8	8.5	43	2.42	17.5	5	48	457	26
Upholstery interliner	25	13	0.9	5	0.94	18.5	5	421	2388	1
Wood/nylon upholstery fabric	423	20	6.2	31	9.42	16.7	11	225	418	1
PVC upholstery cover fabric	359	13	6.0	29	16.51	11.9	7	782	1040	1
Mattress ticking	14	10	0.2	1	0.51	12.5	5	38		1
Polychloroprene elastomer seat support diaphragm	295	53	24.2	114	9.83	12.5	32	1219	1779	1
FR cotton muslin seat support diaphragm	193	12	2.5	12	4.89	9.7	7	494	1346	1
PVC/acrylic seat shroud	107	353	43.5	484	9.20	11.9	29	552	1427	2
Armrest pad foam, coach seat	659	168	121.5	431	12.23	20.1	17	643	1128	7
Polychloroprene elastomer seat footrest cover	190	98	34.8	125	10.32	11.4	26	689	1401	4
Polychloroprene seat track cover	267	40	62.5	207	15.95	12.8	18	1011	1246	15
Individual Interior Finish Materials										
Wall finish wool carpet	655	95	76.7	394	15.67	29.6	30	509	857	1
Wall finish wool fabric	745	35	18.8	91	2.68	19.2	21	209	464	2
Polycarbonate space divider	272	153	246.9	208	7.66	21.1	108	787	1958	13
Wall material FRP/PVC	122	40	21.9	101	10.94	11.4	22	627	1328	2
Wall panel FRP	612	57	62.9	140	8.33	13.5	54	578	925	4
Individual Glazing Materials										
Polycarbonate window glazing	329	208	137.2	263	13.13	21.7	91	857	1141	6
FRP window mask	398	68	22.4	111	15.07	10.0	45	586	718	2
Individual Fabrics										
Door privacy curtain window drapery fabric	308	22	5.3	27	12.25	14.5	13	381	475	1
Polyester drapery fabric	175	30	5.4	28	4.35	12.7	21	757	1091	1
Blanket, wool fabric	168	15	1.9	8	2.16	7.2	11	561	2443	3
Blanket, modacrylic fabric	18	25	0.4	2	1.35	10.7	17	. . .	. . .	3
Floor carpet, nylon	245	72	17.8	97	9.01	17.0	10	245	771	4
Other Individual Materials										
Rubber mat, styrene butadiene	281	95	83.1	173	3.09	29.3	32	943	1610	20
Table, phenolic-wood laminate	249	55	188.9	132	9.00	11.0	45	48	222	29
Air duct, polychloroprene	143	53	13.5	71	2.71	32.4	30	736	1077	1
Pipe wrap, insulation foam	93	10	7.0	38	4.22	14.3	7	689	1190	13
Window gasketing, polychloroprene elastomer	208	305	196.6	165	2.60	37.4	33	714	1409	15
Door gasketing, polychloroprene elastomer	207	275	263.5	175	2.70	49.6	38	731	1474	15
Composite Systems										
Seat cover with CMHR foam, interliner and wool/nylon cover	268	15	8.9	46	4.92	11.3	12	318	847	51
Seat cover with CMHR foam, interliner and PVC cover	269	30	10.7	51	8.64	10.3	7	319	596	51
Mattress: CMHR foam interliner, and ticking	174	10	11.7	53	5.07	10.1	7	30	144	51
Bed pad: CMHR foam and ticking	143	10	7.8	42	5.47	10.2	7	31	130	39
Pillow: cotton fabric and polyester filler	341	58	19.6	108	14.74	19.3	24	563	656	51

[A]The materials were all tested at use thickness.

[B]Property abbreviations: Flux: incident heat flux; Pk RHR: maximum rate of heat release; Tm Pk: time to Pk RHR; Av RHR 3: 3 min average rate of heat release; THR: total heat released; EHC: effective heat of combustion; T_{ig}: time to ignition; Av SEA: average specific extinction area; Pk SEA: peak specific extinction area.

[C]This material does not comply fully with all the recommendations in Table X1.1.

kg). In that case, the better performing cable causes virtually no problem (peak heat release rate: < 30 kW). On the other hand the poorer cable (peak heat release rate > 200 kW) causes a row of seats to ignite and release enough heat to ignite the next row, and so on; however, the overall fire is still much slower than a moderate fire curve. In reality, however, there are approximately 500–1000 kg of cable in a rail transportation vehicle, so that changing to the poorer fire performing cable would decrease safety considerably and should not be not be done unless it is accompanied by a number of other compensatory fire safety measures.

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