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Rationale for Recommended Fire Safety Practices for Rail Transit Materials Selection

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Final Report

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16. Abstract

Recent trends in the design and construction of rail rapid transit (RRT) and light rail transit (LRT) vehicles have resulted in the increased use of non-metallic materials such as plastics and elastomers for transit vehicle components. In many instances, these materials are more flammable than the materials they replace thereby increasing the fire threat in the transit vehicle. Millions of passengers, as well as transit property personnel, are exposed daily to this increased fire threat. This fire threat can be reduced or limited by using flammability and smoke emission performance criteria in the selection of materials for rail transit vehicle construction.

This document presents the rationale for Recommended Fire Safety Practices for Rail Transit Materials Selection.

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PREFACE

The United States urban mass transit systems move millions of passengers daily and thus are key factors in meeting the transportation needs of this country. Because of rising fuel costs and population growth, service is expanding and ridership is growing. Increasingly strong, lightweight, modern materials are being introduced in the construction of mass transit vehicles. Some of these materials are more flammable than those previously used and may significantly increase the fire hazard of these vehicles to transit riders. The Urban Mass Transportation Administration (UMTA) has developed Recommended Fire Safety Practices for selecting materials used in the construction or retrofit of rapid rail and light rail transit vehicles. This report presents the rationale for these Recommended Fire Safety Practices.

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METRIC CONVERSION FACTORS

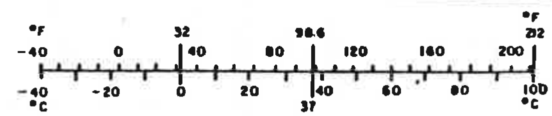
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13 10 286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. INTRODUCTION

1.1 BACKGROUND

A recent study,[1] sponsored by the Urban Mass Transportation Administration (UMTA), indicated that fire and smoke incidents represent between one and five percent of all rail incidents. Although the occurrence of severe transit fires is rare, the potential for fire is always present, and once ignition occurs and a fire spreads, life threatening situations may develop.

Recent trends in the design and contruction of rail rapid transit (RRT) and light rail transit (LRT) vehicles have resulted in the increased use of nonmetallic materials such as plastics and elastomers for transit vehicle components. These materials may be more flammable than the materials they replace. The potenial fire threat can be reduced or limited through the use of flammability and smoke emission performance criteria in the selection of materials for transit vehicle construction or retrofit.

In 1973, the Urban Mass Transportation Administration, as part of its mission to improve mass transportation, initiated an effort to evaluate and improve fire safety in transit vehicles. In 1974, the "Guidelines for Flammability and Smoke Emission Specifications" of materials used in transit vehicles (Guidelines) were developed by the Transportation Systems Center (TSC) for UMTA. Since that time, these Guidelines have undergone periodic review and updating. A slightly modified version of the Guidelines has been proposed for adoption as Recommended Fire Safety Practices for Rail Transit Materials Selection and appeared as such in the Federal Register, November 26, 1982. Application of these recommendations will be advised for all transit vehicles purchased with UMTA funding assistance.

This document presents the rationale for the selection of the Recommended Fire Safety Practices for Rail Transit Materials Selection. Detailed flammability and smoke emission performance criteria are contained in the Appendix.

1.2 OBJECTIVE OF RECOMMENDED FIRE SAFETY PRACTICES FOR RAIL TRANSIT MATERIALS SELECTION

The overall objective of the Recommended Fire Safety Practices is the limitation of the fire threat in transit vehicles by means commensurate with the state-of-the-art of materials technology. The following four basic goals are addressed:

1) Increased Resistance to Ignition;

2) Decreased Flame Spread Rates;

3) Decreased Smoke Emission;

4) Increased Time for Egress.

The selection of materials whose characteristics further these basic goals will serve to limit the fire threat from nonmetallic materials and will be the initial step in reducing or limiting the overall fire threat in transit vehicles.

2. DEVELOPMENT OF RECOMMENDED FIRE SAFETY PRACTICES FOR RAIL TRANSIT MATERIALS SELECTION

A fire safety practice for rail transit materials selection directed toward limiting the fire threat in transit vehicles may take two different forms.

1) specification of the actual materials to be used as in a design standard, or

2) recommendation of performance criteria for the selection of materials.

A design standard for transit vehicle materials selection would tend to freeze the materials technology at the present design standard and would not facilitate any improvement in materials technology. Furthermore, the United States Government does not endorse products of manufacturers and, consequently, does not use a materials design standard which specifies the names of commercial materials. A performance recommendation is a more suitable method of dealing with the materials fire threat because it will provide flexibility in both materials selection and design. Furthermore, performance criteria, by allowing discretion in the selection of materials, present more opportunity for price competition among manufacturers of materials that meet the recommended criteria. Consequently, the Recommended Fire Safety Practices are based on performance criteria.

The two major elements of a performance criteria are:

1) selection of the test method to be used, and

2) establishment of acceptance limits for each of the test methods.

Sections 3 and 4, respectively, identify and discuss the test method selection and the establishment of acceptable performance limits for the materials used in the following transit vehicle component applications:

- Seating
  - Cushion
  - Frame
  - Shroud
  - Upholstery
  - Hard Molded Seat
- Panels
  - Ceiling
  - HVAC Ducting
  - Light Diffuser
  - Partition
  - Wall
  - Window
  - Windscreen
- Flooring
  - Covering
  - Structural
- Insulation
  - Acoustical
  - Thermal
- Miscellaneous
  - Component Box Covers
  - Elastomers
  - Exterior Shell.

Electrical insulation, although not included in the present Recommended Fire Safety Practices, is recognized as a potential fire hazard. Initial studies of electrical insulation flammability and smoke emission characteristics has been conducted and the results are presented in references 2 and 3. The results of two additional studies are being assessed prior to determining the feasibility of developing Recommended Fire Safety Practices for electrical insulation materials.

3. TEST METHOD SELECTION

3.1 TEST SELECTION CRITERIA

There are many materials flammability and smoke emission test methods available for use in the development of performance criteria. These test methods have been developed by consensus, standards organizations, independent commercial laboratories, military services, and other government and industrial organizations. In selecting the test methods on which to base the performance criteria, the following selection criteria were employed:

- The test method should be a standardized method which provides a quantitative measure of the desired response by addressing the four basic goals identified in Section 1.2.
- The test method should provide a realistic simulation of the exposure conditions and environment of possible fire scenarios.
- The test method should be directed at evaluating the individual component materials rather than the assembly of materials (e.g., evaluate seat cushion, seat frame, and seat upholstery individually rather than as an entire seat assembly). Testing of assemblies can become complex and costly, whereas the testing of individual compoents is more straightforward. Furthermore, the component supplier may verify the adequacy of his own products without having to be concerned or involved with other suppliers and products in the assembly chain.
- The test method should provide repeatable results from test to test and from laboratory to laboratory.
- The test method should be relatively low cost, not requiring large amounts of material or time.

- The number of test methods used should be kept to a minimum.

The above selection criteria are not presented in any particular order and are not all of equal importance.

Individual tests are required for flammability and smoke emission characteristics because of the variety of materials used in transit vehicles and the inability to find a suitable universal test to provide both the desired flammability and smoke characteristics.

The basic nonmetallic materials used in transit vehicles may be categorized as follows:

1) sheet plastics in seating, walls, ceiling, ducting, windows;
2) insulation materials for acoustic and thermal insulation;
3) fabrics in upholstery seating and on walls;
4) foam in seating;
5) floor covering, i.e., carpeting, tile;
6) structural flooring;
7) miscellaneous applications such as elastomers on door edges and window gaskets, etc.

The following sections discuss the flammability and smoke emission tests that were chosen based on the selection criteria and the types of materials and applications presented above.

3.2 SELECTION OF FLAMMABILITY TEST METHODS

The categories of transit vehicle materials presented above represent different material types (i.e., foam, fabric,sheet plastic, etc.) and, as such, are best evaluated by flammability tests directed toward assessing that specific material type. The materials flammability test methods are presented in Table 3-1 and discussed below.

3.2.1 Sheet and Insulation Materials

The test method selected for these materials is the ASTM E-162: "Surface Flammability of Materials using a Radiant Heat Energy Source." This test method, developed at the National Bureau of Standards, provides a laboratory test procedure for measuring and comparing the surface flammability of materials when exposed to a prescribed level of radiant heat. The test method has been widely used by the materials community and is also used in building codes and military standards. It has proven to be repeatable and provides an indication of comparative flame spread rates and the heat emission of various materials.

The test employs a 6 by 18 inch test specimen representative, where possible, of the thickness of the material as installed (up to one inch). The test specimen is inclined 30 degrees to a vertically mounted radiant panel with a controlled heat flux equivalent to that of a blackbody of the same dimensions operating at a temperature of 670°C. Ignition is initiated at the upper edge of the test specimen with a pilot flame, and observations are made of the progress of the flame front down the specimen surface, as well as the temperature rise measured by thermocouples located in a stack above the test specimen. The test duration is 15 minutes or until a sustained flame front has propagated down the entire specimen length, whichever time period is less. The Flame Spread Index (I_s) is computed as the product of the Flame-Spread Factor (F_s), a function of flame propagation

TABLE 3-1. MATERIAL CATEGORIES AND SELECTED TEST METHODS FOR FLAMMABILITY

MATERIAL CATEGORY	TEST METHOD
Sheet Materials	ASTM* E-162-Surface Flammability of Materials Using Radiant Heat Energy Source
Insulation Materials (Except Foams)	ASTM E-162 - Surface Flammability of Materials Using Radiant Heat Energy Source
Fabrics	Federal Aviation Administration FAR-25.853 - Vertical Burn Test
Foams	ASTM D-3675 - Surface Flammability of Flexible Cellular Materials Using a Radiant Heat Energy Source
Floor Covering	NFPA**253 - Flooring Radiant Panel Test
Structural Flooring	ASTM E-119 - Fire Tests of Building Construction and Materials
Elastomers	ASTM C-542 - Specification for Gaskets

*American Society for Testing and Materials
**National Fire Protection Association

versus time, and the heat evolution (Q), or $I_s=F_sQ$. The flame spread index values obtained by this method are calibrated to asbestos cement board ($I_s=0$) and red oak ($I_s=100$). The test apparatus is relatively compact and easy to use.

3.2.2 Fabrics

The test method selected for fabrics is the Federal Aviation Administration (FAA) FAR 25.853: "Vertical Burn Test." This test method, adopted by the FAA for the materials used in the compartment interiors of aircraft, is basically the same as Federal Test Method Standard No. 191A, Method 5903, "Flame Resistance of Cloth; Vertical," approved by the General Services Administration, and ASTM F-501, "Aerospace Materials Response to Flame with Vertical Test Specimen."

The FAR 25.853 test is conducted in a draft-free cabinet as described in Federal Test Method Standard 191A, Method 5903. The test specimens are 2 inches (51 mm.) wide and 12 inches (306 mm.) long, and are supported vertically in a U-type holder, with the small dimensions exposed to the flame. A 1 to 1½ inch high bunsen burner flame is applied to the fabric for 12 seconds. Flame time after burner removal, burn length, and flaming time of drippings, if any, are recorded. This test method is quite simple and may be conducted on a laboratory bench.

3.2.3 Foams

The test method selected for foams is the ASTM D-3675, "Surface Flammability of Flexible Cellular Materials Using a Radiant Heat Energy Source." This is a new test method recently adopted by the ASTM and derived from the ASTM E-162 test. The voluntary UMTA materials Guidelines initially specified the ASTM E-162 for foam materials.

The test apparatus for ASTM D-3675 is identical to that of ASTM E-162. Additional provisions require that the specimen have a thickness of 1.0 inch. The report must indicate whether the material under test tends to exhibit rapid running or dripping of flaming material. The flame spread index is computed in the same manner as in the E-162 test, except that observations of "flashing" are treated somewhat differently.

3.2.4 Floor Covering

The test method selected for floor covering is the NFPA Test 253: "Flooring Radiant Panel Test." This test method is identical to ASTM E-648, "Critical Radiant Flux of Floor Covering Systems using a Radiant Heat Energy Source." In 1973, the National Bureau of Standards prepared a draft of the Flooring Radiant Panel Test and it has since been adopted by the NFPA (1978) and ASTM (1978).

The test consists of a horizontally mounted 20 by 100 cm floor covering specimen which is exposed to radiant energy from an air-gas fueled radiant panel mounted above the specimen and inclined at a 30 degree angle. A pilot burner is used to initiate the test by open flame ignition of the specimen. The test continues until flaming of the sample ceases. The distance burned to extinguishment (point at which burning ceases) is converted to watts/cm^2 from a calibrated flux profile graph and the result is reported as a Critical Radiant Flux (watts/cm^2). This value represents the minimum heat flux necessary to sustain flame propagation on the surface of the flooring. A flooring specimen with a CRF value of 1.1 watts/cm^2 is more resistant to ignition than flooring with a CRF values of 0.1 watt/cm^2. As in the ASTM E-162, the test apparatus is relatively compact and easy to use.

3.2.5 Structural Flooring

The test method selected for the structural flooring is the ASTM E-119, "Fire Tests of Building Construction and Materials." This test method is identical to NFPA Test 251, "Fire Tests-Building Construction and Materials" and Underwriters' Laboratory Test 263. The ASTM adopted the E-119 test in 1918 and it was then known as the C-19 standard. As applied in the performance criteria, the test measures the fire endurance or resistance of the vehicle floor to the passage of fire.

In this test, a floor specimen of a representative floor size is heated by exposure to the standard E-119 time-temperature curve. The time-temperature curve of the E-119 has been essentially unchanged over the years and closely resembles the time-temperature curves used by most other countries. The test specimen is prepared and weight loaded so that the flooring simulates in-service conditions. The test is successful if the specimen sustains the predetermined weight load, without passage of flame or gases hot enough to ignite cotton waste. Also, transmission of heat through the specimen shall not be such as to raise the temperature of its unexposed surface more than 250°F (139°C) above the initial temperature. The test duration is determined by the time necessary to evacuate the vehicle, with a minimum test duration of 15 minutes. The conduct of this test procedure is quite involved and requires a sizeable test apparatus. This test is necessary as most transit vehicle fires originate under the vehicle and the floor is the principal barrier preventing the fire from entering the occupant compartment. Fires which initiate under the vehicle may pose the greatest threat because they can go undetected until they are well developed. Containing the fire under the vehicle and preventing its propagation into the occupant compartment, thus allows increased time for the vehicle occupants to be evacuated to safety.

3.2.6 Elastomers

The test method selected for elastomers is the ASTM C-542, "Standard Specification for Lock Strip Gaskets." This test method, initially published by the ASTM in 1965, prescribes a series of tests to determine the physical properties, including flammability, of elastomic materials. Elastomers are commonly used in transit vehicle component applications such as door edge guards, window gaskets, expansion joints, etc.

The test consists of an 18 inch (460 mm) long specimen suspended over a bunsen burner which remains burning in place for the duration of the 15 minute test. The specimen is considered acceptable if, after removal of the burner, there is no flame propagation or progressive glow in the sample. The specimen is not acceptable if the flame has propagated through the length of the specimen, and if the specimen has been nearly or completely consumed. This test is similar in nature to the FAR 25.853 except that the specimen is exposed to the burner for 15 minutes instead of 12 seconds as in the FAR 25.853. This 15 minute exposure is considered reasonable as several of the elastomeric components in transit vehicles, such as the door edge guards, may also serve as a barrier to the entrance of fire into the occupant compartments.

3.3 SELECTION OF SMOKE EMISSION TEST METHOD

Because the flammability tests in Section 3.2 do not provide for determining the smoke evolution of the test specimen, a test specifically designed for determining the smoke evolution through visual observation was selected. Decreased smoke emission is desirable because one of the hazards of smoke is that it obstructs vision. The occupant has a higher probability of escaping from a burning vehicle if the exit locations are not obscured. Also, a firefighter can better control and extinguish fires if visibility remains adequate. Because of this concern for visibility, the test method selected was the NFPA 258, "Standard Test Method for Measuring the Smoke Generated by Solid Materials." This test method is also known as the National Bureau of Standards Smoke Density Chamber and the ASTM E-662, "Specific Optical Density of Smoke Generated by Solid Materials." The National Bureau of Standards originally developed this test method. It has been used by the materials community for well over ten years.

The test is conducted in an 18 cubic foot chamber (3 ft by 3 ft by 2 ft). A 3 inch square test specimen is placed in the chamber that is supported vertically and exposed to heat under either flaming or nonflaming conditions. For each specimen, the combustion-generated smoke accumulates within the chamber and the reduction of light transmission during the test is reported in terms of the optical density of the smoke. Optical density is the measurement of the concentration of smoke particulates. By limiting smoke emission, a degree of limitation of toxic gaseous products is also achieved. Toxicity standards have not yet been established for transit application, because at this time, the available test methodologies are not fully acceptable to the technical community.

4. ESTABLISHMENT OF MATERIALS ACCEPTANCE LIMITS

With the flammability and smoke emission test methods for each of the material types selected, the next task is that of establishing the acceptance criteria for accepting or rejecting a material. There are two basic ways for determining the material acceptance limits for the tests specified in Section 3:

1) the acceptance limits are determined by a series of factors which are predefined and therefore result in the required acceptance limit being defined in an objective manner; or

2) the acceptance limits are determined in a subjective manner.

For structural flooring, the acceptance limits are determined objectively because the test method provides a direct measurement of the time period that the floor serves as a suitable fire barrier. For elastomers, the acceptance limits are also determined objectively according to time measurement.

The following section will discuss the subjective criteria used for establishing of acceptance limits for the other materials tests. The recommended test methods and the criteria for each component application are given in the Appendix.

4.1 GENERAL CRITERIA

The following general criteria were established for guidance in determining acceptance limits for the specified materials flammability and smoke emission tests:

- The acceptance limits should insure that a selection of materials is available to meet the design requirements of the individual transit properties (e.g., foam seat cushions versus hard non-cushion seats).

- The acceptance limits should consider the four basic goals of Section 1.2 and provide criteria commensurate with the state-of-the-art of materials.
- The acceptance limits should be consistent for the different non-metallic materials found in a transit vehicle and not allow the presence of unnecessary fire hazards (e.g., polyurethane seats with an ASTM E-162 Flame Spread Index (I_s) of 300 in a vehicle with an I_s of ≤ 35 for all other materials).
- The acceptance limits for materials flammability and smoke emission should not conflict with other materials requirements, i.e., crashworthiness, impact resistance, etc.
- The acceptance limits used successfully in comparable materials applications by other industry and government organizations should be considered for possible transit vehicle application.

4.2 ACCEPTANCE LIMITS FOR FLAMMABILITY TESTS

Each of the above criteria was considered in the development of the acceptance limits, in order to determine adequate and reasonable Recommended Fire Safety Practices. The soundness of this approach is demonstrated by the voluntary acceptance of the transit industry, of the recommendations originally introduced in the form of Guidelines. Materials which do not ignite readily and which permit only limited flame propagation in tests such as the ASTM E-162 test have performed satisfactorily in large-scale mock-up fire tests[4,5] and in actual use. A Flame Spread Index (I_s) of < 35 provides generally good behavior; an I_s of > 150 provides generally poor behavior.

The following sections present the materials test acceptance limits by category of vehicle component application rather than materials type as in Section 3. This approach is taken to simplify the application of the component performance criteria within the recommendations. The selection of flammability acceptance limits is influenced by the smoke emission acceptance limits which are discussed in Section 4.3. This section is devoted solely to a discussion of the flammability acceptance limits.

4.2.1 Seating

Contained in the seating category are seat cushion, seat frame and seat shroud, and seat upholstery.

4.2.1.1 Seat Cushions - In vehicles where seat cushions are used (presently 30 percent of the RRT fleet), the seat cushions may represent the largest single source of combustible material in the occupant compartment. At the present time, there are four types of materials used or proposed for seat cushions: polyurethane foam, foamed latex (styrene/butadiene rubber or SBR), polyimide foam, and neoprene foam. The experience with each is as follows:

Polyurethane Foam. This has been a very commonly used material with excellent physical properties except for flammability. Even the fire-retardant versions, although somewhat more difficult to ignite than the non-fire retardant types, burn with a high rate of heat release. The destructive fires which have occurred in BART vehicles and numerous buses have been attributed to its use.

Foamed Latex (SBR). This type of foam has also been fairly commonly used as a seat cushion. It is more flammable than polyurethane form, and was considered principally responsible for the destruction of four vehicles by fire in the Toronto subway in 1976.

Polyimide Foam. This type of foam is relatively new and has excellent flammability characteristics. The ASTM D-3675 Flame Spread Index is 1, and smoke emission by NFPA 258 is also 1. Although it is a very promising material, production problems have delayed its commercial appearance.

Neoprene Foam. This foam has been on the market for a number of years and is now produced by at least three manufacturers. Its Flame Spread Index by ASTM D-3675 is less than 10. After considerable testing by several transit properties, including the Washington Area Metropolitan Transit Authority, (WMATA), Toronto Transit Commission, and Bay Area Rapid Transit (BART), it has become their material of choice for seat cushions.

The selection of an I_s of 25 or less for seat cushions in RRT and LRT vehicles eliminates the use of materials which could provide an unacceptable degree of fire hazard. Cushions represent a relatively large portion of the vehicle interior furnishing materials. A review of the TSC Computerized Materials Data Bank revealed that there were no seat cushion materials listed as having an I_s in the range of 25 to 100. Hence, an I_s of 25 is a reasonable cutoff limit for seat cushions. It is interesting to note that other organizations use a similar test method and that the U.S. Navy in its Mil-Std. 1623, "Cushioning and Mattresses," (similiar to ASTM D-3675) requires an I_s of 10 or less.

A seat cushion performance criterion requiring an I_s of 25 or less allows the use of materials which are within the present state-of-the-art and will provide a suitable selection of materials suppliers.

4.2.1.2 Seat Frame and Seat Shroud - As the seat frame and seat shroud recommendations each require the same acceptance criterion of an I_s of 35 or less when tested in accordance with the ASTM E-162 test method, they will be discussed together. The frame and shroud (seat back) may be constructed of metallic or nonmetallic materials, both of which are presently used in the transit fleet. Although an I_s of 25 or less as in the seat cushion recommendation

(Section 4.2.2.1) is preferred, a review of the TSC Materials Data Bank indicated that an I_s of 35 or less was necessary to provide a suitable selection of materials. Few of these component materials are found in the I_s range of 35 to 50. The frame or shroud is manufactured from many of the same resins used for other vehicle components.

4.2.1.3 Seat Upholstery - The seating upholstery is used primarily to cover the seat cushion and may be a plain fabric or a coated or noncoated vinyl material. The performance criteria utilize the FAR 25.853 test procedure presented in Section 3.2.2. These criteria require that the maximum after-flame time not exceed 10 seconds and the specimen burn length not exceed 6 inches. Furthermore, any flaming running, or flaming dripping is not permitted since these conditions could serve as ignition sources to propagate a fire. These criteria are considered reasonable because particular types of upholstery materials are not eliminated from consideration. The TSC Materials Data Bank, moreover contains in excess of 25 materials which meet these limits. From a comparative standpoint, the acceptance limits of the two materials standards from which this recommendation is drawn are the following:

1) Federal Test Method Standard 191A, Method 5903 allows a maximum after-flame time of 2 seconds, a maximum char length of 3 inches. No mention is made of flaming drippings.

2) The FAR 25.853 Standard allows a 15 second flame time after removal of the flame, and an average burn length not exceeding 8 inches. Drippings may not continue to burn for more than an average of 5 seconds.

4.2.2 Panels

Within the category of panels are: heating, ventilation and air conditioning (HVAC) ducting; window and light diffuser glazing; and all wall panels, ceiling panels, partitions, and windscreens. With the exception of the HVAC ducting and the window and light diffuser glazing, all of the panels have the same flammability criteria.

4.2.2.1 Panels and Partitions - All wall panels, ceiling panels, partitions, and windscreens are required by the criterion to have an I_s of 35 or less when tested in accordance with the ASTM E-162 test method. Selection of an I_s of 35 or less provides for a good selection of materials and is consistent with the state-of-the-art of these materials and other materials in the vehicle. The TSC Materials Data Bank contains at least 30 wall and ceiling panel materials which meet the acceptance level. Moreover, the panel materials in the I_s range of 35 to 65 generally have unacceptable smoke emission characteristics. The present selection of available materials which meet the acceptance limit indicates that the criterion is not unreasonable.

4.2.2.2 HVAC Ducting - The specification for heating, ventilation, and air conditioning (HVAC) ducting also specifies an I_s of 35 or less when tested in accordance with the ASTM E-162 Test method.

4.2.2.3 Window and Light Diffuser Glazing - This acceptance limit recommends that all window and light diffuser glazing have an I_s of 100 or less. This I_s is not consistent with the I_s of 35 or less required for all other sheet and panel materials but is necessary to allow for window and light diffuser glazing materials other than glass. About 97 percent of the vehicles in the current RRT fleet contain laminated safety sheet glass which meets the criterion.[6] However, an alternative to glass is necessary in order to provide the transit properties with a material that is more resistant to vandalism.

There are two types of clear plastic sheet which are available for use as glazing. One of these is polymethylmethacrylate (PMMA), commonly referred to as "acrylic" (Lucite, Plexiglas and Acrivue). The other is polycarbonate (Lexan and Tuffak). The ASTM E-162 Radiant Panel Test performed on these two types of material shows a Flame Spread Index (I_s) for polycarbonate of between 70 and 90. The I_s for acrylic window sheets is in excess of 300. Furthermore, a series of actual fires in vehicles and buildings has demonstrated that acrylic sheets tend to propagate fire. Polycarbonate, on the other hand, tends to self-extinguish.

4.2.3 Floor Covering

The criterion for floor covering requires that the carpet or tile be tested in accordance with the NFPA 253, "Flooring Radiant Panel Test," and have a minimum critical radiant flux (CRF) value of 0.5 watts/cm^2 or greater. This acceptance limit is the minimum radiant heat necessary to sustain flame propagation on the surface of the floor covering. The higher the CRF, the more stringent the requirement. A variety of carpets, some nylons, and other floor covering materials, such as wool carpet and vinyl tile, meet this acceptance limit. A standard wool carpet tested without a pad has a CRF of 1.2 watt/cm^2, well above the 0.5 watts/cm^2 required by the acceptance limit. In the most recent vehicle procurements by BART, WMATA, and the Metropolitan Atlanta Rapid Transit Authority, when carpeting was specified, wool floor carpeting was selected for the vehicles.[7]

The performance criterion requires testing with or without the underlayment (carpet pad) depending on whether or not it will be used. This is because the underlayment will affect the CRF and can result in an acceptable carpet being unacceptable with a particular type of underlayment. In many instances, an underlayment is not used.

4.2.4 Thermal and Acoustical Insulation

The recommendations utilize the ASTM E-162 test procedure presented in Section 3.2.1 for the thermal and acoustical insulation criteria and require an I_s of 25 or less. An I_s of 25, instead of an I_s of 35 as required in wall and ceiling panels, is possible because of the ready availability of insulation materials, such as fiberglass and rock wool, which meet these test limits, and because of widespread use in the transit and building trades.

4.2.5 Miscellaneous

Many of the materials used in the manufacture of a vehicle's external shell and the component box covers are also used in interior panels and other components and as such, should already meet the panel criteria. Hence, the recommendations for the exterior shell and component box covers are in line with the other components. The material availability should pose no problem.

4.3 ACCEPTANCE LIMITS FOR SMOKE EMISSION

The Recommended Fire Safety Practices for Rail Transit Materials Selection utilize NFPA Test 258, "Standard Test Method for Measuring the Smoke Generated by Solid Materials," as the sole measure for the smoke emission characteristics of the materials. In this test method, the smoke characteristics of a material are presented in terms of the specific optical density (D_s), a dimensionless value that represents smoke density (visual observation). Establishment of acceptance limits for smoke characteristics considers not only the basic goals of Section 1.2 and the selection criteria of Section 4.1, but also the trade-off necessary between a material's flammability and smoke emission characteristics. A material with acceptable flammability characteristics may have poor smoke characteristics or vice versa. The main factors considered in determining how to accomplish this trade-off are the establishment of meaningful smoke emission limits for the transit vehicle environment and the determination of the smoke characteristics of the materials which meet the flammability limits. Meaningful smoke emission limits are those that achieve that basic goal of providing increased time for the occupants to evacuate the vehicle. A decrease in smoke emission results in a decrease in the smoke density (visual observation) in the vehicle and a subsequent increase in the available egress time from the vehicle.

Past experience has shown that materials which generate only limited quantities of smoke at a limited rate according to the NFPA 258 test perform satisfactorily in large-scale tests[4,5] and in actual experience; i.e., they do not rapidly create untenable smoke conditions and thus allow increased time for escape.

In determining the acceptable smoke density limits, the specific smoke density (D_s) value was chosen. The D_s is the specific optical density at the particular time selected for measurement of the smoke density. The establishment of acceptance limits using the D_s at 1.5 and 4.0 minutes, although arbitrary, can be related to the time necessary to evacuate a vehicle. This concern for the ability to evacuate a vehicle is most important. In the performance criterion, a D_s of 100 or less at 1.5 minutes into the test translates into a light transmittance of 17.5 percent and a D_s of 200 or less at 4.0 minutes into the test translates into a light transmittance of 3 percent. A D_s any higher than 200 is meaningless as the visibility within the compartment is totally obscured.

The D_s limits of 100 and 200 at 1.5 and 4.0 minutes, respectively, were derived from the smoke criteria proposed by the Federal Aviation Administration. They apply to all of the vehicle materials applications with the exception of upholstery, HVAC ducting, thermal and acoustical insulation, elastomers, structural flooring and floor covering. The following paragraphs discuss the smoke emission limits of the exceptions cited above.

Upholstery

The smoke emission acceptance limit for uncoated upholstery materials is a D_s of 100 or less at 4.0 minutes into the test. For coated materials it was necessary to increase the smoke limits to a D_s of 250 or less at 4.0 minutes. Only five materials which meet this criterion could be identified in the Materials Data Bank. Moreover, the other available coated materials contained D_s values in excess of 500.

HVAC Ducting

The smoke emission limits of a D_s of 100 or less at 4.0 minutes were chosen solely on the basis of the availability of materials which meet this limit. This more restrictive smoke emission acceptance limit is important, because should the ducting, which conveys air from outside the vehicle to the occupant compartment begin to burn, the smoke from the ducting would be forced into the vehicle. As this air is propelled by a fan, the vehicle could quickly fill with smoke and hinder evacuation.

Insulation

The good quality and availability of thermal and acoustical insulation materials made possible a D_s limit of 100 or less at 4.0 minutes.

Elastomers, Flooring, Floor Covering

Elastomers that meet the ASTM C-542 flammability standard have not, at present, been formulated to have low smoke emission properties. Therefore, no acceptance limit for smoke emission has been specified. Because of a similar problem with flooring and floor covering no smoke emission limit is specified for those components.

5. CONCLUSION

The Recommended Fire Safety Practices for Rail Transit Material Selection are considered reasonable and could, if applied, serve as the initial step in minimizing the fire threat in RRT and LRT vehicles. This conclusion has been partially substantiated by a series of full-scale fire tests recently conducted by the Bay Area Rapid Transit District (BARTD).[4,5] For these full-scale tests, a portion of a retired BARTD vehicle was refurbished with several materials designed to achieve the four basic goals of the Recommended Fire Safety Practices presented in Section 1.2. This vehicle was then fire tested with several ignition sources designed to be representative of the in-service transit vehicle environment. The refurbished vehicle did achieve the goals of the Recommended Fire Safety Practices in that the fire did not propagate from the local area or origin and the materials present (seat cushions, liner, wall panel, carpeting, insulation) did not contribute significantly to the fire in any of the tests. Furthermore, the visibility in the vehicle was such that an occupant could evacuate the vehicle.

It is recognized that the most obvious means of quantifiably measuring the total effectiveness (validation) of the Recommended Fire Safety Practices in their entirety, is through a series of full-scale vehicle/fire tests. Such full-scale tests are believed to be more appropriate when additional fire safety performance criteria are identified to fully address the fire threat in transit vehicles.

6. REFERENCES

1. W.T. Hathaway and A.L. Flores, "Identification of the Fire Threat in Urban Transit Vehicles," U.S. Department of Transportation, Transportation Systems Center, Report No. UMTA-MA-06-0051-80-1, June 1980.

2. L.E. Meyer, et al., "Electrical Insulation Fire Characteristics Volume I: Flammability Tests," Boeing Commerical Airplane Company, Report No. UMTA-MA-06-0025-79-1, I, March 1979, (NTIS PB-294 840/4WT).

3. Charles R. Crane, et al., "Electrical Insulation Fire Characteristics, Volume II: Toxicity," Boeing Commercial Airplane Company, Report No. UMTA-MA-06-0025-79-2, II, March 1979.

4. BART Transit Vehicle Full Scale Test, Final Report, McDonnell Douglas Corp., February 1981, Report No. MDCJ4670.

5. C.E. Jenkins and M.K. duPlessis, "BART Vehicle Fire-Hardening Program," San Francisco Bay Area Rapid Transit District, March 2, 1981.

6. W.T. Hathaway and A.L. Flores, "Assessment of the Benefits and Costs Associated with the Adoption of Recommended Fire Safety Practices for Materials Selection," U.S. Department of Transportation, Transportation Systems Center, Report No. UMTA-MA-06-0098-81-3, September 1981.

7. Roster of North American Rapid Transit Cars, 1945-76, American Public Transit Association, Report No. UMTA-DC-06-0121-77-1, January 1977.

APPENDIX A

RECOMMENDED FIRE SAFETY PRACTICES FOR RAIL TRANSIT MATERIALS SELECTION

SCOPE

The Recommended Fire Safety Practices for Rail Transit Materials Selection are directed at improving the vehicle interior materials selection practices for the procurement of new vehicles and the retrofit of existing RRT and LRT vehicles. Adoption of these recommended fire safety practices will help to minimize the fire threat in transit vehicles and, thereby, reduce the injuries and damage resulting from vehicle fires.

APPLICATION

This document provides recommended fire safety practices for testing the flammability and smoke emission characteristics of materials used in the construction of RRT and LRT vehicles.

DEFINITION OF TERMS

1. Critical Radiant Flux (CRF) as defined in NFPA 253 is a measure of the behavior of horizontally-mounted floor covering systems exposed to a flaming ignition source in a graded radiant heat energy environment in a test chamber.

2. Flame spread index (I_s) as defined in ASTM E-162 is a factor derived from the rate of progress of the flame front (F_s) and the rate of heat liberation by the material under test (Q), such that $I_s = F_s Q$.

3. Specific optical density (D_s) as defined in NFPA 258 is the optical density measured over unit path length within a chamber of unit volume, produced from a specimen of unit surface area, that is irradiated by a heat flux of 2.5 watts/cm^2 for a specified period of time.

4. Surface flammability denotes the rate at which flames will travel along surfaces.

5. Flaming running denotes continuous flaming material leaving the site of material burning or material installation.

6. Flaming dripping denotes periodic dripping of flaming material from the site of material burning or material installation.

7. Light rail transit (LRT) vehicle means a streetcar-type transit vehicle railway operated on city streets, semi-private rights-of-way, or exclusive private rights-of-way.

8. Rail-rapid transit (RRT) vehicle means a subway-type transit vehicle railway operated on exclusive private rights-of-way with high-level platform stations.

RECOMMENDED TEST PROCEDURES AND PERFORMANCE CRITERIA

(a) The materials used in RRT and LRT vehicles should be tested according to the procedures and performance criteria set forth in Table A-1.

(b) Transit properties shall require certification that combustible materials to be used in the construction of vehicles have been tested by a recognized testing laboratory, and that the results are within the recommended limits.

(c) Although, at present, there are no Recommended Fire Safety Practices for electrical insulation materials, information pertinent to the selection and specification of electrical insulation for use in transit fire environments are contained in the following UMTA reports:

   1. Electrical Insulation Fire Characteristics, Volume I, Flammability Tests, December, 1978.

   2. Electrical Insulation Fire Characteristics, Volume II, Toxicity, December, 1978.

TABLE A-1. RECOMMENDATIONS FOR TESTING THE FLAMMABILITY AND SMOKE EMISSION CHARACTERISTICS OF TRANSIT VEHICLE MATERIALS

Category	Function of Material	Test Procedure	Performance Criteria
Seating	Cushion[1;2;5]*	ASTM D-3675	$I_s \le 25$
		NFPA 258	$D_s(1.5) \le 100$; $D_s(4.0) \le 200$
	Frame[1;5]	ASTM E-162	$I_s \le 35$
		NFPA 258	$D_s(1.5) \le 100$; $D_s(4.0) \le 200$
	Shroud[1;5]	ASTM E-162	$I_s \le 35$
		NFPA 258	$D_s(1.5) \le 100$; $D_s(4.0) \le 200$
	Upholstery[1;2;3;5]	FAR 25.853	Flame Time $\le$ 10 sec; burn length $\le$ 6 inch
		NFPA 258	$D_s(4.0) \le 250$ coated $D_s(4.0) \le 100$ uncoated
Panels	Wall[1;5]	ASTM E-162	$I_s \le 35$
		NFPA 258	$D_s(1.5) \le 100$; $D_s(4.0) \le 200$
	Ceiling[1;5]	ASTM E-162	$I_s \le 35$
		NFPA 258	$D_s(1.5) \le 100$; $D_s(4.0) \le 200$
	Partition[1;5]	ASTM E-162	$I_s \le 35$
		NFPA 258	$D_s(1.5) \le 100$; $D_s(4.0) \le 200$
	Windscreen[1;5]	ASTM E-162	$I_s \le 35$
		NFPA 258	$D_s(1.5) \le 100$; $D_s(4.0) \le 200$
	HVAC Ducting[1;5]	ASTM E-162	$I_s \le 35$
		NFPA 258	$D_s(4.0) \le 100$
	Window[4;5]	ASTM E-162	$I_s \le 100$
		NFPA 258	$D_s(1.5) \le 100$; $D_s(4.0) \le 200$
	Light Diffuser[5]	ASTM E-162	$I_s \le 100$
		NFPA 258	$D_s(1.5) \le 100$; $D_s(4.0) \le 200$
Flooring	Structural[6]	ASTM E-119	Pass
	Covering[7]	NFPA 253	C.R.F. $\ge 0.5 w/cm^2$
Insulation	Thermal[1;2;5]	ASTM E-162	$I_s \le 25$
		NFPA 258	$D_s(4.0) \le 100$
	Acoustic[1;2;5]	ASTM E-162	$I_s \le 25$
		NFPA 258	$D_s(4.0) \le 100$
	Elastomers[1]	ASTM C-542	Pass
Miscellaneous	Exterior Shell[1;5]	ASTM E-162	$I_s \le 35$
		NFPA 258	$D_s(1.5) \le 100$; $D_s(4.0) \le 200$
	Component Box covers[1;5]	ASTM E-162	$I_s \le 35$
		NFPA 258	$D_s(1.5) \le 100$; $D_s(4.0) \le 200$

*Refers to Notes on Table A-1.

TABLE A-1. RECOMMENDATIONS FOR TESTING THE FLAMMABILITY AND SMOKE EMISSION CHARACTERISTICS OF TRANSIT VEHICLE MATERIALS (Cont.)

NOTES:

1. Materials tested for surface flammability must not exhibit any flaming running, or flaming dripping.

2. The surface flammability and smoke emission characteristics shall be demonstrated to be permanent by washing, if appropriate, according to FED-STD-191A Textile Test Method 5830.

3. The surface flammability and smoke emission characteristics shall be demonstrated to be permanent by dry-cleaning, if appropriate, according to AATCC-86. Materials that cannot be washed or dry cleaned must so be labeled and meet the applicable performance criteria after being cleaned as recommended by the manufacturer.

4. For double window glazing, only the interior glazing must meet the materials requirements specified herein.

5. NFPA-258 maximum test limits for smoke emission (specific optical density) should be measured in either the flaming or non-flaming mode, depending on which mode generates the most smoke.

6. Structural flooring assemblies shall meet the performance criteria during a nominal test period determined by the transit property. The nominal test period shall 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 test period should not be less than 15 minutes. Only one specimen need be tested.

7. Carpeting shall be tested in accordance with NFPA-253 with its padding, if the padding is used in actual installation.

REFERENCED FIRE STANDARDS

The sources of test procedures listed in Table A-1 are as follows:

(1) Leaching Resistance of Cloth, FED-STD-191A-Textile Test Method 5830

Available from:

General Services Administration
Specifications Division, Building 197
Washington Navy Yard, Washington, DC 20407

(2) Federal Aviation Administration Vertical Burn Test, FAR-25.853

Available from:

Superintendent of Documents
U.S. Government Printing Office
Washington, DC 20402

(3) American Society for Testing Materials (ASTM)

(a) Specification for Gaskets, ASTM C-542

(b) Surface Flammability of Flexible Cellular Materials Using a Radiant Heat Energy Source, ASTM D-3675

(c) Fire Tests of Building Construction and Materials, ASTM E-119

(d) Surface Flammability of Materials Using a Radiant Heat Energy Source, ASTM E-162

Available from:

American Society for Testing and Materials
1916 Race Street
Philadelphia, PA 19103

(4) National Fire Protection Association (NFPA)

(a) Flooring Radiant Panel Test, NFPA-253

(b) Smoke Generated by Solid Materials, NFPA-258

Available from:

National Fire Protection Association
Batterymarch Park
Quincy, MA 02269

(5) American Association of Textile Chemists and Colorists Test (AATCC-86)

Available from:

American Association of Textile Chemists and Colorists
P.O. Box 12215
Research Triangle Park
North Carolina 27709

(6) Proposed Guidelines for Flammability and Smoke Emission Specifications

Available from:

Urban Mass Transportation Administration
Office of Safety and Product Qualification
UTD-50
400 7th Street, S.W.
Washington, DC 20590

(7) Electrical Insulation Fire Characteristics, Volume I, Flammability Tests, UMTA-MA-06-0025-79-1, PB-294 840/4WT,

Electrical Insulation Fire Characteristics, Volume II: Toxicity, UMTA-MA-06-0025-79-2, PB-294 841/2WT

Available from:

The National Technical Information Service
Springfield VA 22161

In all instances the most recent issue of the document or the revision in effect at the time of request should be employed in the evaluation of the materials specified herein.