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Comparison of International Fire Safety Standards with U.S. Requirements

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14. ABSTRACT
The Volpe National Transportation Systems Center compared and contrasted U.S. fire safety regulations and standards on rolling stock with the European Union, Japan, and China. The major areas of study were fire safety analysis, materials performance standards, toxicity performance standards, fire detection and suppression, as well as particular elements of international fire safety standards and regulations that might be valuable and worthy of analysis by the U.S. The varying international regulatory approaches give insight as to ways in which the U.S. might augment its own regulations and standards as well as demonstrate the ways in which international rolling stock might be acquired and found suitable on U.S. railways.

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Railroad, international, regulations, standards, fire safety, vehicle, rolling stock, fire

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

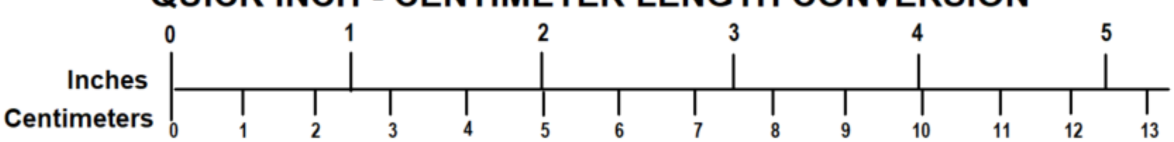
VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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The cover photo, taken by Robert Dorer, depicts a commuter train and is property of the Volpe Photo Library.

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Executive Summary

From August 2020 through January 2021, the Federal Railroad Administration sponsored the Volpe National Transportation Systems Center (Volpe Center) to compare U.S. fire safety regulations pertaining to rolling stock found in both the Title 49 Code of Federal Regulations (CFR) as well as industry standards (e.g., the National Fire Protection Association, American Society of Testing Materials, and American Public Transportation Association) and their counterparts in the European Union, Japan and China.

In emphasizing the differences in the international approach to fire safety as well as general risk-assumption philosophy, this report can be used to assist in further investigation and decision-making in improving fire safety for rolling stock in the U.S.

Fire safety analysis in the U.S., as described in 49 CFR Section 238.103, is unique and does not have a counterpart in international regulations or standards. It also presents a different outlook on risk management since the railroad has to determine and prove to FRA the extent to which a railcar meets the required safety standards for that railroad, as opposed to some larger approving body setting standards for all railroads. The materials performance standards and toxicity performance standards for the U.S., Japan, and China are similarly categorized and tested; the European Union's standards are the most robust and comprehensive.

Fire detection and suppression standards are qualitatively addressed in either an industrial or Federal standard, though the European Union is slightly more specific in determining the requirements of various detection and fixed suppression systems. Additionally, this report addresses some international fire safety standards that could be incorporated into U.S. standards and regulations. For instance, the Japanese technical standard that addresses rail safety includes a highly regulated inspection protocol and checklist, which provides a lower risk of fire ignition onboard passenger railcars and will be examined further in this report. Of particular use from the European standards are electrical fire safety, electrical arc barrier, and containment of flammable liquid and gas specifications. Inclusion of these types of requirements in U.S. standards and regulations may reduce the likelihood of a fire ignition or propagation and would make it easier for railroads to demonstrate effective hazard mitigation.

1. Introduction

From May 2020 until January 2021, the Federal Railroad Administration's (FRA) Office of Research, Development and Technology tasked the Volpe National Transportation Systems Center (Volpe Center) with researching and comparing the standards, tests and regulations for passenger rolling stock fire safety and toxicity requirements. This research reviews fire safety standards from the U.S., the European Union, Japan and China.

1.1 Background

Principally among safety measures that must be considered in design or acceptance of railway rolling stock is fire safety. Major railcar fires in the U.S. have been infrequent, though costly, and include Gibson, CA (1983), Bourbonnais, IL (1888), Miriam, NV (2011), and Valhalla, NY (2015) (Kennedy IV, B., 2017). Significant increases in fire safety standards over the years have developed among the international regulatory bodies, meaning that railcars are designed with different fire safety targets, and can vary significantly from one country to another.

1.2 Objectives

The objective of this report is to provide a comparison of railway technical regulations from a fire-safety perspective across national boundaries. The approaches and organization of fire-safety regulations differ considerably internationally, and it is advantageous to analyze the ways in which U.S. regulations and standards can be made more robust and comprehensive. Understanding these regulations also offers the foundation of analysis of technology used on railcars internationally, and their potential for use on U.S. railroads.

1.3 Overall Approach

The regulations and standards for various aspects of fire safety are compared and contrasted between the U.S., the European Union, Japan, and China. It is not the intent of this report to compare each small variation in regulation, nor analyze specific testing methods and performance criteria for equivalency, but rather provide an overview for the reader of the major differences in safety philosophy, approach, and methods.

1.4 Scope

This report compares and contrasts the rolling stock design and equipment regulations in the U.S., the European Union, Japan, and China. It covers both standards that are mandated by the respective State governing body as well as related industrial standards, and focuses on the following aspects of railroad operations:

- Passenger rail car material testing and performance criteria
- Passenger rail hazard analyses
- Fire detection and suppression
- Toxicity testing and performance criteria
- Other subject areas relative to fire safety

1.5 Organization of the Report

Section 1 – Addresses the objective of this research, defines the intended scope, and presents an outline for organizing the information found within this report

Section 2 – A review given by using the U.S. Fire Safety Analysis Procedures of the primary fire safety methodology used in the U.S

Section 3 – Compares the various methods of cataloguing materials, testing methods, and minimum/maximum requirements for various testing methods before a material may be used in a passenger train

Section 4 – Compares the various standards and requirements regarding fire detection and suppression within passenger rail vehicles, and provides considerations that may be made in the U.S. standards

Section 5 – Compares the methods of testing for toxic chemicals of materials during exposure to heat or flame, and examines the differences between the regulatory standards

Section 6 – Examines unique topic areas of focus within non-American regulations and standards. These areas of focus might be considered for incorporation into U.S. standards and regulations.

Section 7 – Summarizes the findings in this report and makes recommendations as to next steps forward

2. U.S. Fire Safety Analysis Procedure

Title 49 Code of Federal Regulations (CFR) Part 238 contains the fire safety regulations for passenger rail equipment. In addition to several material performance standards, a unique feature of the U.S. fire safety requirements is that railroads conduct a fire safety analysis for railcars, to be based on a formal hazard analysis methodology such as the Department of Defense Standard Practice for System Safety (MIL-STD 882) (Title 49 CFR Part 238). This requirement is described in the CFR but is supplemented in detail by industrial standards such as the National Fire Protection Association, the American Society of Testing Materials, and the American Public Transportation Association.

2.1 U.S. Fire Safety Analysis Requirements by Law

The fire safety analysis is typically divided into four parts: determination of design requirements, assessment of vehicle fire performance, evaluation of specific fire scenarios, and evaluation of suitability of design. 49 CFR § 238.103(c) and Appendix D require a fire safety analysis for newly-procured passenger cars and existing passenger rail cars, respectively. In procuring new passenger cars and locomotives, it is the railroad's responsibility to ensure that "fire safety considerations and features in the design of this equipment reduce the risk of personal injury caused by fire to an acceptable level in its operating environment using a formal safety methodology…" (Title 49 CFR Part 238).

The major elements of the analysis are:

- Identification, analysis and prioritization of fire hazards inherent in the design of the equipment
- Documentation of steps executed to design the equipment and select materials which help provide sufficient fire resistance and reasonably ensure adequate time to detect a fire and safely evacuate all persons onboard
- Address ventilation issues as they might affect a fire spread
- Identify any train components that have a risk of initiating a fire and require overheat protection
- Identify needs for fire or smoke detection systems
- Identify need for fire extinguisher, which references is made to 49 CFR § 239.101, which requires each passenger car to have at least one portable fire extinguisher
- Identify needs for a fixed, automatic fire-suppression system in any unoccupied train compartment that contains fire hazardous material/equipment
- Explain how safety issues are resolved in the design of the equipment and selection of materials to reduce risk of each fire hazard
- Describe the analysis and testing necessary in the design of the equipment and selection of materials to reduce the risk of each fire hazard

49 CFR § 238.103 has similar requirements for evaluation of existing passenger cars. Any existing passenger car is assigned a category of design and operation environment (to be

discussed later in this report in Section 2.2.3) and evaluated regarding potential hazards from a fire-safety point of view.

2.2 U.S. Fire Safety Analysis Guidance in Industrial Standards

A number of industrial standards document methods for performing a fire safety analysis. The railroads use a fire safety analysis to determine the suitability of a vehicle according to the risk that the railroad is willing to assume. The following is a discussion of these methods.

2.2.1 U.S. Fire Safety Analysis as Described in NFPA 130

The National Fire Protection Association Document 130: Standard for Fixed Guideway and Passenger Rail Systems (NFPA 130) presents an "Engineering Analysis Option" (National Fire Protection Association, 2020) as a method for meeting fire safety goals and objectives. Annex E defines the four major steps of the analysis and the major components of each step are described in the following Table 1.

Table 1: NFPA 130 Major Steps of Engineering Analysis

Step	Functions
Step 1: Define vehicle performance objectives and design	(A) Clearly define fire performance objectives (B) Determine the geometry of the vehicle (C) Include other design parameters that might have an impact on a possible fire, such as an enclosed trainway operating environment, material controls (such as insulation, non-flammable coatings), fire detection and suppression, or other system procedures
Step 2: Calculate vehicle fire performance	(A) Determine minimum acceptable performance criteria based on the vehicle design (B) Establish standard design fires (C) Use predictive calculation and/or model calculations, to determine the fire performance of the proposed design for a range of design fires (D) Create a fire performance graph that demonstrates the results of predictive calculations and/or models in part (C)

Step	Functions
Step 3: Evaluate specific fire scenarios	(A) Examine relevant fire incident experience with same/similar applications (B) Identify the likely role/involvement of application contents in fire (C) Ask which fires are most common/likely? Most challenging? (D) Quantify the burning behavior for chosen fire scenarios from available fire test data or appropriate small-and-large-scale tests
Step 4: Evaluate suitability of vehicle design	(A) Estimate through expert judgement, regulatory guidance, and when needed, complementary small-and-large-scale tests of the effects of unknowns not accounted for in the fire performance graphs (B) Establish the sensitivity of the fire performance graph to known inputs (C) Set appropriate design margins (D) Determine the acceptability of the design

An example fire performance graph, suggested in part (D) of step 2, is included in Figure 1.

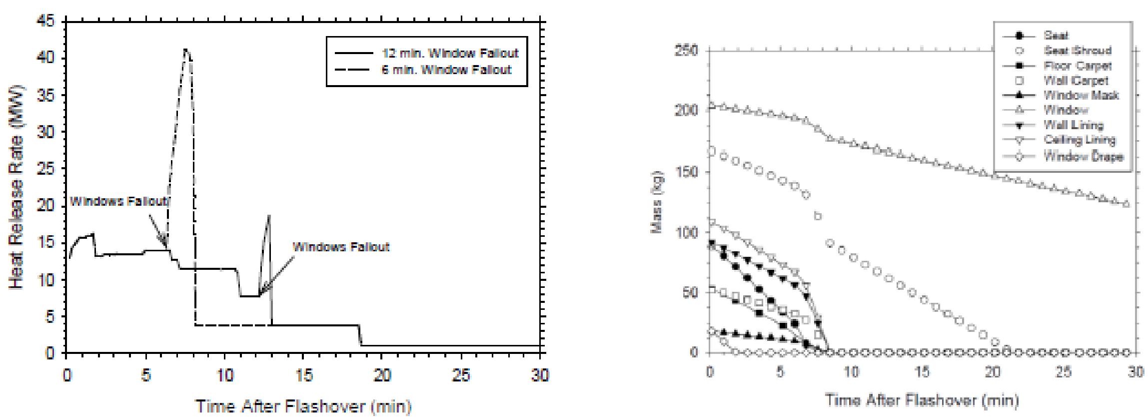

Figure 1: An Example Fire Performance Graph Showing Heat Release Rate vs Time (Lattimer & McKinnon, 2016)

2.2.2 U.S. Fire Safety Analysis as Described in ASTM E2061-20

NFPA 130 references several other documents that provide guidance regarding safety analyses, principally among them the American Society for Testing and Materials (ASTM) E2061: Fire Hazard Assessment of Rail Transportation Vehicles. Below is an outline of the same four general steps as NFPA 130, and adds descriptive detail.

Step 1: Define Vehicle Performance Objectives and Design

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. This is achieved if the calculations made in subsequent steps can demonstrate a shorter evacuation time than the time it would take for a fire to create untenable conditions. Tenability may be determined by the developer of the fire hazard.

The secondary fire safety objective is to prevent flashover in the vehicle (i.e., a condition in which every combustible surface exposed to heat rapidly catches fire), and a third fire safety objective may be to ensure a safe working environment for emergency personnel.

Step 2: Calculate Vehicle Fire Performance

ASTM E2061 requires using the numerical values of materials testing data for vehicle fire performance calculations. It also advises that the design specifications in this section must address and include all the relevant design features and products that are incorporated in the design of the vehicle. Appendix X5 of E2061 lists several test methods that can be applied to generate appropriate data for use in calculation of fire performance, to include specific materials testing methods and full-scale test methods. Included in this appendix are:

- Seating materials and composites exposed to radiant heat: ASTM E1474
- Individual materials in component products, floor covering materials, as well as all panel materials: ASTM E1354
- All wallcovering systems: ASTM E1740
- Wire and cable products: ASTM D6113

Appendix X5 of ASTM E2061 recommends the evaluator to use these data to calculate the heat released by each material and composites of materials, and then compare those results with the estimations of the minimum heat release required for flashover.

These materials testing methods are different and separate from the standards put forth by FRA in 49 CFR § 238.103, and expanded upon in NFPA 130, discussed in Section 3.1.

Step 3: Evaluate Specific Fire Scenarios

Step 3 requires specific fire scenarios to be compared against the fire performance data that have been produced in the previous step. ASTM E2061 describes a number of specific fire scenarios that may be evaluated:

1. Fire scenario 1 originates within the transportation vehicle
    - Fire scenario 1a) begins with an incendiary ignition involving the use of accelerants and prior damage that exposes the fillings of the upholstered seats

- Fire scenario 1b) begins with a trash fire under a seat assembly and spreads to that seat assembly
- Fire scenario 1c) begins with a fire associated to cooking if cooking equipment is used onboard
- Fire scenario 1d) begins with a small open-flame ignition of bedding in an unoccupied bed in a vehicle where overnight sleeping occurs
- Fire scenario 1e) begins with a small trash fire in an unoccupied cargo vehicle, or cargo storage space
- Fire scenario 1f) begins with the assumption that a crash occurred and the vehicle has overturned. This alters the geometry of the vehicle and manners in which heat will be released and flame spreads.

2. Fire scenario 2 originates outside of the transportation vehicle
    - Fire scenario 2a) begins with ignition of a fuel spill following a collision in which there are survivors
    - Fire Scenario 2b) begins with an electrical fire in a tunnel
    - Fire Scenario 2c) begins with a trash fire outside of the vehicle. This is a more likely scenario than the two previous though considered to be less severe.

ASTM E2061 additionally includes some assumptions for consideration when evaluating fire performance and evaluates specific fire scenarios. Some assumptions to consider, and relevant regulations are:

- Numbers and abilities of disabled persons, as provisioned by the Americans with Disabilities Act
- Age distribution of the occupants. Ridership data should be used to incorporate these assumptions
- Assumptions regarding alcohol or drug impairment. ASTM E2061 suggests a conservative assumption that 10 percent of adult occupants are impaired by alcohol.
- If the rail vehicles provide sleeping accommodations, it should be assumed that the maximum number of passengers are sleeping at the time of fire ignition.

Step 4: Evaluate Suitability of Vehicle Design

This final step is to evaluate whether the vehicle built to the design will meet each of the objectives in step 1 for each of the specified fire scenarios in step 3. It is advised that the fire hazard assessment procedure be confirmed by peer review.

At the end of the document, ASTM E2061 includes a number of annexes which provide more detailed methods of executing fire safety calculations:

- Annex X5, as discussed previously, lists the recommended methods for generating appropriate data or use in calculations for step 2
- Annex X6 describes calculation methods for estimating time to untenability

- Annex X7 describes calculation methods for estimating flashover potential
- Annex X8 provides statistics on fires in rail transportation
- Annex X9 provides a sample calculation using the FPETOOL software, which is a computerized package of relatively simple engineering equations and models to estimate fire hazard and response (Nelson, H. E., 1990).

2.2.3 U.S. Fire Safety Analysis for Existing Passenger Vehicles from the American Public Transportation Association

In 2001, the American Public Transportation Association (APTA) released *Recommended Practice for Fire Safety Analysis of Existing Passenger Rail Equipment* (APTA PR-PS-RP-005-00) as a method of guidance for addressing the requirements of 49 CFR § 283.103 (d) (American Public Transportation Association, 2000). Although 49 CFR § 238.103(d) stipulates that all fire safety analyses for existing passenger cars and locomotives should have been completed by July 2001, the APTA recommended practice still provides useful information for completing any fire safety analysis and gives insights as to the salient features of each step.

The APTA recommended practice breaks the fire safety analysis into 12 steps, though these steps generally follow the procedures outlined in both NFPA 130 and ASTM E2061:

Step 1: Compile, as accurately as possible, a historic record of equipment fire incidents on your railroad. If necessary, you may use operating histories of other railroads that operate similar equipment in similar fire safety environments.

The APTA recommended practice includes several recommended sources that included:

- FRA Accident/Incident Database
- Federal Transit Administration safety management information statistics annual reports
- National Fire Protection Association database
- Maintenance records of individual passenger railroads
- Annex B of the APTA recommended practice, which includes sources from the Federal Transit Administration

Step 2: Implement a program to keep complete and accurate fire incident records and establish reliable methods to retrieve and review such data.

At a minimum, this APTA practice recommends that fire incident records include the date, location, time, equipment type, type and location of ignition source, type and quantity of material involved, method of extinguishment, repairs made, and number of deaths and injuries.

Step 3: Take an inventory, from a fire safety features point-of-view, of each type (design) of equipment used in passenger service. Determine the number of particular equipment design categories that the railroad operates.

The "design categories" in this step refer to the equipment onboard and geometry of the vehicle that would have an effect on fire safety. Some of these features include, but are not limited to:

- The type and amount of construction materials
- Number, size, type, and location of doors

- Car length, levels, and purposes
- Compliance with the Association of American Railroads (AAR) S-580 *Standards for Locomotive Crashworthiness Requirements*
- Ventilation system control
- Fire detection/suppression systems, including fire extinguishers as required by 49 CFR Part 239
- Floor design/construction for fire delay, distance between emergency exits
- Number and width of stairways
- Number, size, and location of emergency exits
- Emergency light and signage levels/duration
- Low-level exit path marking system
- Location and type of trash receptacles

Step 4: Determine the number and characteristics of significantly different fire safety operating environments present on the railroad.

The "operation environment" categories refer principally to the environment through with the vehicle will be traveling. Operational environment categories are determined by the size and type of tunnels, number and type of grade crossings, potential exposure to hazardous material, electric power lines, third rail, catenary, proximity to pipelines, shared rail line and right of way usage, adjacent rail line/highway usage, proximity to emergency responders, and other significant hazards posed by the operating environment.

Step 5: Determine the number of categories of equipment and service in operation on the railroad.

The railroad takes the design categories from step 3 and operational categories from step 4 to determine the number of aggregate categories of equipment and service.

Steps 1–5 might be considered the "preparation work" for the actual fire hazard analysis, which begins with step 6. The fire hazard analysis itself uses the data in step 1, as well as the categories determined in step 5 as derived from steps 3 and 4 as a starting point to identify ignition source hazards, assess their severity, and identify countermeasures to determine the risks involved. It is important to note that a separate fire hazard analysis must be done for each category of equipment determined in step 5.

Step 6: Develop a list of significant ignition source hazards for each category of equipment and service.

Ignition source hazards may include, but are not limited to, traction motors, the electrical junction box (or "group box" in the APTA recommended practice) power dissipation resistor, reactors, pantograph (catenary), current collector and third rail, transformer, braking system, electrical system, heating/air (i.e., heating, ventilation, and air conditioning [HVAC]), oil and hydraulic fluid leaks, fuel, food service equipment, trash fires, vandalism, baggage, or hazardous materials from freight trains or motor carrier operations.

Step 7: Assess the hazard severity and the impact of existing fire safety design features and other countermeasures for each category of equipment and service.

Hazard severity of various ignition sources will be assigned a numerical value of 1–4 based on the following conditions:

1. Catastrophic: Fire involving loss of life or serious injury, usually due to the impossibility of evacuation and/or lack of smoke control. Example: "Crash and burn" in which passengers are trapped in burning cars or major fire in a tunnel where smoke cannot be controlled. The difference between serious and catastrophic is likely to be ease of evacuation, smoke control in tunnels, and emergency response time.
2. Serious: Fire that may cause lost time injuries (i.e., any injuries or incidents resulting a disability or missing work) or hospitalization. Evacuation required. Evacuation is possible in time to avoid fatalities. May involve significant property loss, such as an entire car or locomotive. Examples: major under-car, interior car fire, or external fuel fed fire from which timely evacuation is possible. The key to this category is that evacuation is possible in time to avoid fatalities, although the fire is serious.
3. Significant: Limited fires that do not cause lost time injuries or hospitalization. Evacuation of vehicles may occur but is not required for life safety. Example: Rectifier panel fire or other fire that may be large or smoky but goes out when the power is removed. Under-car fires in this category will not penetrate the floor. Interior fires will be limited in extent, such as a duct heater fire that may produce smoke inside the car but goes out due to a fusible link opening. Fire department response will usually be needed for significant fires. Most grease fires and running gear fires will be in this category.
4. Negligible: Small fires that do not cause any injuries or evacuation. Examples may include traction motor lead connection burns open, small trash fires that burn out quickly, or third rail shoe beam fires.

The design features assessed in step 3 can often mitigate the hazards identified, and, after consideration of these design features, might allow for adjustment of the hazard severity rating. Figure 2 shows Annex D from the APTA recommended practice provides a template for identifying the potential ignition sources as well as the hazard severities.

CATEGORY OF EQUIPMENT ____________________

SERVICE OPERATING ENVIRONMENT ____________________ Route ______

CAR Coach, Cab car (circle one) Model/type ______________ Builder _____________ Year ______

TYPE Single, Multi-level, Gallery (circle one) POWER Diesel, Catenary, Third Rail (circle one)

SYSTEM 1. Traction Motor ANALYST ________________________ DATE __________

POTENTIAL IGNITION SOURCE	HAZARD SEVERITY	*EVALUATION FACTORS*			REVISED HAZARD SEVERITY
		Fire location interior/exterior	Train location tunnel/other	Fire safety features/ countermeasures	

Figure 2: APTA Sample Fire Hazard Analysis Worksheet (American Public Transportation Association, 2000)

After consideration of design features, for any hazard that is still assigned a category of 1, 2, or 3, the fire risk should be assessed by determining the likelihood and consequences of those hazards in the following steps.

Step 8: Identify fire scenarios that could result in personal injury to passengers and crewmembers

Using data from Hathaway & Flores (1980), this step generates a list of likely fire scenarios that will be assigned a "risk rating" in later steps. A fire scenario is defined as "the sequence of events resulting from a fire hazard in a specific environment on a specific type of equipment" (American Public Transportation Association, 2000). An example of a fire scenario might be a fire caused by throwing a lighted match into a wastebasket as an act of vandalism. From this scenario, variations may be considered such as the timeliness of detection by a crewmember or installed fire detector, and ability to suppress the fire with or without evacuation. The data from sources such as Hathaway & Flores (1980) should aid in determining whether various fire scenarios are actually likely to occur to identify the scenarios that are most realistic or frequent. Many of these scenarios might be deemed unlikely to occur or mitigated by fire-safety design to a degree which will not require further analysis.

Step 9: Estimate the frequency of occurrence and the consequence of fire scenarios/incidents resulting from ignition source hazards not resolved in Step 8. Use these

estimates to determine the priority of remedial action for remaining category 1, 2 and 3 hazards. Repeat the process for each category of equipment.

The fire safety analysis process employs the concept of "acceptable risk," which is a key principle of the procedure. A fire risk rating is assigned to any particular scenario using a risk index that consists of the "severity" categories determined from step 7, and the "probability" categories are determined as follows:

- Frequent
  - More than two occurrences per year or one occurrence per $6 * 10^6$ vehicle miles
- Probable
  - More than one occurrence per 3 years or $3.6 * 10^7$ vehicle miles, but less than two occurrences/year or one per $6 * 10^6$ vehicle miles
- Occasional
  - More than one occurrence per 15 years or $2 * 10^8$ vehicle miles, but less than one occurrence per 3 years or $3.6 * 10^7$ vehicle miles
- Remote
  - More than one occurrence per 75 years or 10^9 vehicle miles, but less than one occurrence per 16 years or $2 * 10^8$ vehicle miles
- Improbable
  - Less than one occurrence per 75 years or 10^9 vehicle miles

Each fire scenario, in combination with the "severity" and "probability" categories can be assigned a risk rating using any of the following four categories:

- Unacceptable: Poses an immediate threat to personal safety. Correct or control immediately.
- Acceptable short-term: May pose a threat to personal safety. Formulate corrective action plans and implement on a priority basis. Action to resolve must be completed.
- Acceptable with management review: Deemed acceptable or unavoidable risk after review by person(s) with appropriate authority. Formal documentation of acceptance and sign-off necessary with documentation of risk analysis process completed. Nevertheless, correct the risk scenario if feasible.
- Acceptable: Not deemed to be a risk. Documentation needs to be provided.

Figure 3 shows this is to be done using the risk index matrix.

RISK INDEX MATRIX					
	Severity				
		Catastrophic 1	Serious 2	Significant 3	Negligible 4
Probability	Frequent 1	1	1	1	3
	Probable 2	1	1	2	3
	Occasional 3	1	2	2	4
	Remote 4	2	2	3	4
	Improbable 5	3	3	3	4

Figure 3: Risk Index Matrix Derived from Probability and Severity Categories (American Public Transportation Association, 2000)

Step 10: Develop and execute a fire safety remedial action plan if any fire safety hazard for any category of equipment and service has an unacceptable fire risk rating for the selected fire scenarios.

For any fire scenario that has a risk index of 1, 2, or 3, the following should be executed:

- Identify the strategy and specific countermeasure(s) to be used to resolve each unacceptable hazard
- Identify the resources necessary to implement the plan
- Schedule the implementation of the plan
- Assign responsibility for implementation of the plan
- Describe how progress against the plan will be tracked and monitored
- Describe how the effectiveness of the strategy and countermeasure will be checked

Step 11: Apply hazard mitigation strategies to fire hazards that pose unacceptable risks in terms of the unacceptable likelihood of the selected fire scenario and re-evaluate.

Typical hazard mitigation strategies include:

- Eliminate/decrease sources of combustion
- Slow fire/smoke spread/propagation by material selection
- Improve probability of early detection

- Increase amount of tenable evacuation time through design features such as floor endurance, fire suppression systems, etc.
- Provide additional necessary passenger and crewmember evacuation time through emergency preparedness plan implementation
    - Special attention to tunnel and elevated operations
- Decrease emergency response time
- Improve emergency response capability

At this point in the fire safety analysis, the fire risks should have been appropriately mitigated such that the railroad has deemed the risks to be acceptable.

Step 12: Monitor, track and update the fire safety remedial action plan.

Moving forward, the railroad should develop a process that allows for monitoring and tracking progress made toward the completion of the remedial action plan developed in step 10. If the schedule slips or the actions taken prove to be ineffective, the railroad should keep the plan current to accurately reflect the status of the fire risk reduction effort.

2.3 Discussion

The fire safety analysis for passenger rail rolling stock is unique to the U.S. in a few ways, and does not seem to exist as a manner of certifying railcar safety in the European Union, Japan, or China. The four steps of the analysis (i.e., defining the vehicle performance objectives, calculating vehicle fire performance, evaluating specific fire scenarios, and evaluating suitability of vehicle design) provide an overall analysis of the vehicle in a comprehensive manner. The U.S. fire safety analysis highlights an important emphasis on the autonomy of the railroads themselves. By completing their own fire safety analysis, the railroads are afforded more flexibility of design acceptance in a manner that is appropriate with their specific needs. The fire safety framework described in this section gives an overview of the U.S. approach, which will be helpful as context to understand international applications in comparison.

3. Passenger Rail Car Material Testing and Performance Criteria

The U.S., European Union, Japan and China all require the materials used in railcars to meet certain criteria via specified testing mechanisms. These criteria serve to limit the development of fire and prevent its spread so that passenger safety is maintained. Additionally, the materials standards aim to prevent flashover of the vehicle so as to preserve equipment to whatever extent possible.

3.1 U.S. Material Standards

49 CFR § 238.103(a) requires that materials used in construction of a passenger car or cab of a locomotive meet the test criteria in Appendix B of that section. Additionally, 49 CFR § 238.103(b) requires that materials be tested by an independent laboratory and that railroads must keep certification records of representative samples of combustible materials that are used in the cab and passenger cars.

Appendix B makes use of several different test methods, among which include:

- ASTM E 662-01: Standard Test Method for Specific Optical Density of Smoke Generated by Solid Materials (American Society of Testing Materials, 2019).

  This test method determines the specific optical density of smoke generated by solid materials. The test specimens are exposed to an electrically heated radiant-energy source with an irradiance level of $2.2 \frac{Btu}{s \cdot ft^2}$ for the non-flaming condition of the test. Alternately, a specimen is exposed to a six-tube burner that applies a row of equidistant flamelets across the lower edge of the specimen. In either case, a light beam is passed through the system to measure the variance in light transmission through the smoke.

  The results are expressed in terms of specific optical density, D_s such that

  $D_s = G\left[\log\left(\frac{100}{T}\right) + F\right]$, where

  $G = \frac{Volume}{exposed\ area \times length\ of\ the\ light\ path}$

  $T =$ Percent light transmittance as read from the light-sensing instrument

  F, a filter-factor that may or may not be used.

  ASTM E 662, the principal measure of smoke accumulation per Appendix B, is used for every category of passenger rail equipment.

- ASTM E 162: Standard Test Method for Surface Flammability of Materials Using a Radiant Heat Energy Source

  This method tests for flame spread on a vertically mounted specimen. The specimen is tilted at 30 degrees with the bottom of the sample facing away from the radiant panel. The results are expressed in terms of the radiant panel index such that

  $I_s = F_s \times Q$, where

  I_s is the radiant panel index

F_s is the "Flame Spread Factor," a measurement of the progress of the flame along the specimen
Q is the "Heat Evolution Factor," a measurement of the temperature difference achieved by the specimen via thermocouple with respect to the ambient temperature.

- ASTM E 3675: Standard Test Method for Surface Flammability of Flexible Cellular Materials Using a Radiant Heat Energy Source

  This test method also measures I_s, the radiant panel index, but is used with cellular foams such as cushions, mattresses, and flexible cellular foams used in armrests and seat padding.

- 14 CFR 25 Appendix F, Part I (Vertical Test)

  This is a test for self-extinguishment for interior ceiling panels, interior wall panels, partitions, galley structures among other items. After exposure to a Bunsen or Tirrill burner, the average burn length may not exceed 6 inches and the average flame time after removal of the ignition source may not exceed 15 seconds. Drippings from the test specimen may not continue to flame for more than an average of 3 seconds after falling. This is used in 49 CFR § 238.103 Appendix B for fabrics such as seat upholstery, mattress ticking and covers, curtains, draperies, wall coverings and window shades.

- ASTM E 119: Fire Tests of Building Construction and Materials

  This test method is designed to evaluate the structural integrity and fire resistance to masonry units and composite structural assemblies. The specimen is given a "Pass" or "Fail" rating based on a number of conditions. This test is used in 49 CFR § 238.103 Appendix B for structural components in the railcar.

NFPA 130 has a set of test procedures and minimum performance requirements that are quite similar to that of 49 CFR § 238.103 Appendix B, though they have added a category for "wire and cable," which are subject to UL 1685/FT4, a test of smoke release rate and total smoke released for wired cables.

3.2 European Materials Standards

European Standards (EN) 45545: Railway Applications – Fire Protection on Railway Vehicles, supports the essential requirements set forth by the European Commission and the European Free Trade Association in European Union Directive 2008/57/EC, which articulates procedures and practices for ensuring that railcars meet mutual safety standards within the European Union. EN 45545 Part 1 outlines Operation Categories and Design Categories that determine Hazard Levels are used in all subsequent parts of EN 45545 in determination of design requirements, including materials performance criteria.

3.2.1 Operation Categories, Design Categories, Hazard Levels

All railcars can be assigned one of four operation categories as follows:

- Operation Category 1: Vehicles for operation on infrastructure where railway vehicles may be stopped with minimum delay, and where a safe area can always be reached immediately.

- Operation Category 2: Vehicles for operation on underground sections, tunnels and/or elevated structures, with side evacuation available and where there are stations or rescue stations that offer a place of safety to passengers, reachable within a short running time.
- Operation Category 3: Vehicles for operation on underground sections, tunnels and/or elevated structures, with side evacuation available and where there are stations or rescue stations that offer a place of safety to passengers, reachable within a long running time.
- Operation Category 4: Vehicles for operation on underground sections, tunnels and/or elevated structures, without side evacuation available and where there are stations or rescue stations that offer a place of safety to passengers, reachable within a short running time.

Table 2 defines the "Running Time" in each category, along with the assumed minimum average speed.

Table 2: Operation Categories for European Union Rolling Stock

Operation Category (OC)	Running Time	Minimum Average Speed
OC 1	Vehicles may stop with minimum delay	Not applicable.
OC 2	4 minutes	80 km/h
OC 3	15 minutes	80 km/h
OC 4	4 minutes	No requirement

EN 45545 part 1 contains an Annex B, with more guidance on designation of OCs. The annex makes use of quantities such as tunnel length (OC 1 for tunnels no greater than 1 kilometer in length, or OC 2 for tunnels greater than 1 kilometer but less than 5 kilometers), or the availability of side evacuation.

All railcars can also be assigned one of four Design Categories:

- A: Vehicles forming part of an automatic train having no emergency trained staff on board
- D: Double-decked vehicles
- S: Sleeping and couchette vehicles
- N: All other vehicles (standard vehicles)

Table 3 shows every vehicle as assigned an Operation Category and Design Category, which is then ultimately used to assign one of three Hazard Levels (HL).

Table 3: Hazard Levels for European Rolling Stock

Operation Category	Design Category			
	N	A	D	S
1	HL1	HL1	HL1	HL2
2	HL2	HL2	HL2	HL2
3	HL2	HL2	HL2	HL3
4	HL3	HL3	HL3	HL3

3.2.2 European Union Requirement Sets and Listed Products

The materials tests required by the EN standard are by far the most extensive among the examined standards. EN 45545 Part 2 includes a table of 26 "Requirement Sets," each of which contains a battery of tests to be applied, with minimum or maximum performance criteria designated by Hazard Level.

Table 4 shows an example of a requirement set. Any component of the rolling stock is assigned one requirement set, which lists the test methods used, the parameters tested, and then the performance criteria given by HL. In Table 4, requirement set "R15" is the set of tests applied to electrical cables used on the interior of the carbody.

Table 4: Requirement Set "R15" for Tested Materials

Test method ref.	Parameter and unit	Maximum or minimum	HL1	HL2	HL3
T09.1 EN 60332-1-2	Unburned length (mm)	Minimum	Burned part ≤ 540 and unburned part > 50	Burned part ≤ 540 and unburned part > 50	Burned part ≤ 540 and unburned part > 50
T09.02 EN 60332-3-24 (for d≥ 12 mm)	M	Maximum	2.5	2.5	2.5

Test method ref.	Parameter and unit	Maximum or minimum	HL1	HL2	HL3
T09.03 EN 50305 (6 mm < d < 12 mm)	M	Maximum	2.5	2.5	2.5
T09.04 EN 50305 (for d ≤ 6 mm)	M	Maximum	1.5	1.5	1.5
T13 EN 61034-2	Transmission %	Minimum	25	50	70
T15 EN 50305	ITC dimensionless	Maximum	10	10	6

Each Requirement Set may be assigned to one or more Listed Products. For instance, R15 from the table above is assigned to Listed Product group "EL1A," which is "Cables for interior." The "Listed Products" section is quite thorough and is comprised of five main categories: interiors, exterior located products, furniture, electro-technical equipment, and mechanical equipment. More than one listed product could be assigned to the same Requirement Set, as shown in the excerpt of one product from the electro-technical section, and one product from the mechanical equipment section shown in Table 5.

Table 5: Excerpt of Product Number and Requirement Set

Product Number	Name	Details	Requirement
EL7A	Choke and coils – Interior	Chokes for supply line filtering, coils for air cooled transformers,	R22

Product Number	Name	Details	Requirement
		including spacers and air guiding plates	
M2	Hoses – Interior	Pipes and hoses for fuel, oils, hydraulics, pneumatics, water and drainage	R22

The parameters used among these test properties are:

- Oxygen Index, typically expressed as a percentage of oxygen
- Critical Flux at Extinguishment, expressed as $\frac{kW}{m^2}$
- Maximum Average Rate of Heat Emission, expressed as $\frac{kW}{m^2}$
- Critical Heat Flux, expressed as $\frac{kW}{m^2}$
- 30 second flame application, which tests whether a flame spreads to the length of 150 millimeters
- After burn time, expressed in seconds
- Determination of flash and fire points – Cleveland open cup method (i.e., a commonly used flash and fire point test method) expressed in °C (American Society for Testing and Materials, 2018).
- Optical density, which is a dimensionless measurement.
- Cumulative value of specific optical densities, which is a dimensionless measurement.
- Conventional Index of Toxicity, which is a dimensionless measurement.
- Height of Charred zone, which is reported in length (meters)
- Optical density D_s, which is a dimensionless measurement

3.3 Japanese Materials Standards

Ministry of Land, Infrastructure, and Tourism (MLIT) (2006) presented fire safety standards divided into three parts: Rolling Stock Fire Prevention, Fire Alarm, and Function of Devices at Power Failure. Though it is possible that additional standards beyond the Technical Regulatory Standards (TRS) are applied to Japanese passenger rail fire safety, it was not apparent in the research conducted. The scope of Japanese rail fire safety was therefore limited to the TRS.

3.3.1 Test Methods

The TRS uses two fire tests to establish performance criteria:

1. Test Method I, for Non-Metallic Materials for Use on Railways: A specimen size of 257 mm × 182 mm (10.11 inches × 7.17 inches) is inserted into a holder such that it makes a

45° angle with the ground, with the bottom of the specimen further away from a 0.5 mL fuel container. The fuel container (absolute ethanol) is lit and allowed to burn until the fuel runs out. Figure 4 shows a diagram.

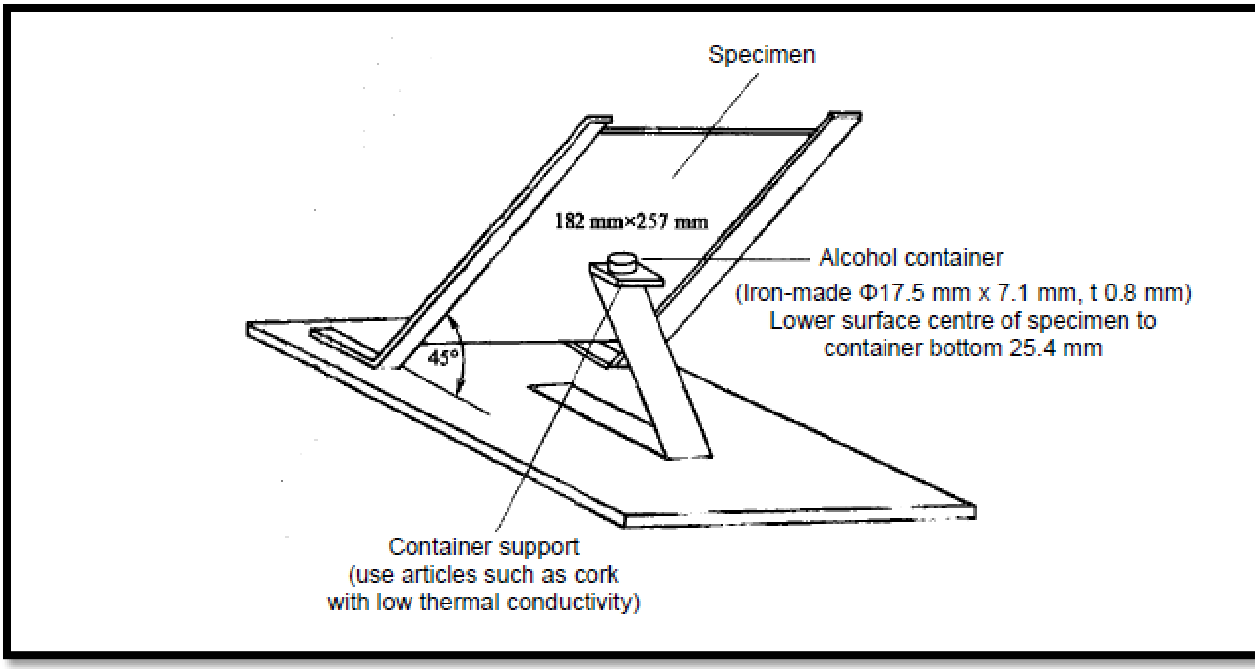

Figure 4: Test Method 1 for Non-Metallic Materials for use on railways (Ministry of Land, Infrastructure and Tourism, 2006)

The combustion is divided into two time periods: during ethanol combustion and after combustion. The following table is used to determine characterizations such as "Nonflammable/Incombustible," "High Flame Retardancy," and "Flame Retardancy" and is codified in Figure 4.

Grade	During ethanol combustion				After ethanol combustion			
	Catch fire	Flame	Smoke	Fire	Residual flame	Afterglow	Carbonization	Deformation
Nonflammable	None	None	Rare	-	-	-	Color changing below 100 mm	Surface deformation below 100 mm
High flame retardancy	None	None	Less	-	-	-	Not reach upper end of specimen	Deformation below 150 mm
	Yes	Yes	Less	Weak	None	None	Below 30 mm	
Flame retardancy	Yes	Yes	General	Flame not exceeding upper end of specimen	None	None	It may reach to upper end of specimen	Deformation reaches edge, local burning through
Note: The size of carbonization and deformation is represented by the length.								

Figure 5: Flame Resistance Characterizations (Ministry of Land, Infrastructure and Tourism, 2006)

2. Test Method II for Non-Metallic Materials for Use on Railways is the International Standards Organization (ISO) test 5660-1:2002 and uses a fairly common cone-calorimeter method (Ministry of Land, Infrastructure and Tourism, 2006). A square test specimen of dimensions 100 mm × 100 mm with a thickness up to 50 mm is exposed to a radiant heat flux of $50 \frac{kW}{m^2}$ for 10 minutes, shown here in Figure 5.

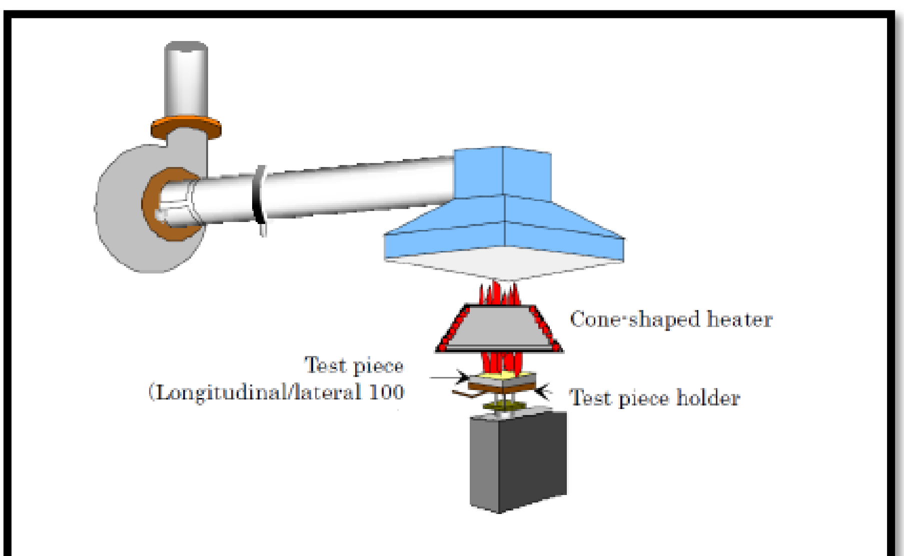

Figure 6: Test Method 2 for Non-Metallic Materials for Use on Railways (Ministry of Land, Infrastructure and Tourism, 2006)

Test Method II is used to report the overall heat value, ignition time, and maximum heating speed using the following information in Table 6.

Table 6: Overheat Values for Test Method II

Overall heat value (Megajoules per meter squared) $(\frac{MJ}{m^2})$	Ignition Time (seconds)	Maximum heating speed (Kilowatts per meter squared) $(\frac{kW}{m^2})$
≤ 8		300 or less
$8 < x < 30$	> 60	

Overall heat value is given in megajoules per squared meter $(\frac{MJ}{m^2})$, and the maximum heating speed is a standard heat-flux given in kilowatts per squared meter $(\frac{kW}{m^2})$.

If a material meets either of these two combinations of overheat value, ignition time, or maximum heating speed then it is designated as having "resistance to burning," which is used in subsequent materials performance ratings.

3.3.2 Materials Performance Criteria

The Japanese Ministerial Ordinance Article 83 requires that electric wires and cables should be capable of preventing fire caused by short-circuiting (called "electric confusion" in the Technical Regulatory Standard) and overheating of equipment among other reasons.

The TRS that addresses this ordinance for rolling stock fire prevention are largely qualitative, as shown in Table 7.

Table 7: TRS Fire Prevention Requirements

Category	Location/Use	Requirement
Wiring	Items near to or connected to equipment for which there is the danger of arcs or heat being generated	Cover with extremely flame retardant material including incombustible material, hereinafter the same
	Other than above	Cover with flame retardant material (including extremely flame retardant material and incombustible material, hereinafter the same). However, this does not apply to items for which there is no danger of mixed or contact
Electrical Equipment	Equipment for which there is the risk of arcs or heat being generated	Shall isolate from floors, walls, etc. and as necessary provide insulation and incombustible heat-resistant plates between them.
Rolling stock with internal combustion engines		The engine shall be isolated from floors, walls, etc., and as necessary provide incombustible heat-resistant plates between them.
		Shall reinforce the heat insulation between the smoke stack of the exhaust pipe and the carbody. (This means a structure for stopping burning to the carbody even if flame leakage due to wear, etc., of the smoke stack of the exhaust pipe, etc.; it means a structure such as providing an incombustible heat-resistant plate.)

Additionally, the TRS has materials standards that compare well with those in Appendix B of CFR 49 § 238.103. The parts of a railcar are categorized as roof, external sheeting, passenger room, heat and noise insulation, floor, underfloor equipment box, seat, window shades, and gangway bellows. The requirements are notably qualitative in nature. This is detailed in Table 8.

Table 8: TRS Materials Performance Standards (Ministry of Land, Infrastructure and Tourism, 2006)

Part		General Passenger Cars	Subways, Passenger Cars and Shinkansen (excluding MAGLEV railways)
Roof	Roof	Metal or equal-to-or-better than the combustibility of metal	
	Rooftop Surface	Shall be covered with a flame retardant insulating material (limited to passenger trains that travel on sections of track with an electric overhead contact line) (Not applicable to extremely high voltage contact lines)	
	Equipment and hardware mounted on the roof	Insulated from the car body or shall be covered with a flame retardant insulated material (limited to passenger trains that travel on sections of track with an electric overhead contact line) (Not applicable to extremely high voltage contact lines)	
External Sheeting	End Section	Flame Retardant. Shall be incombustible material for the surface paint	
	Other than end section	Shall be incombustible or surface shall be covered with incombustible material. Shall be incombustible material for the surface paint	Incombustible. Shall be incombustible material for the surface paint
Passenger Room	Ceiling	Shall be incombustible or surface shall be covered with incombustible material. Shall be incombustible material for the surface paint	Incombustible. Shall be incombustible material for the surface paint
	Inside Panel	Shall be incombustible or surface shall be covered with incombustible	Incombustible. Shall be incombustible material for the surface paint

3.4 Chinese Materials Standards

The Railway Industry Standard of The People's Republic of China TB/T 3138-2018: Technical Specification of Flame Retardant Materials for Railway Locomotive and Vehicle, as well as TB/T 3237: Flame Retardant Technical Specification of Decorating Materials for Multiple Unit Train contains the Chinese materials standards. In general, TB/T 3138 refers to structural components of the railcar (e.g., walls, ceiling etc.) whereas TB/T 3237 refers to the materials that cover these structural components (e.g., flooring, carpeting, cloths, etc.).

3.4.1 Test Methods – TB/T 3138

Almost every item in TB/T 3138-2018 is tested according to three test methods.

GB/T 2406.2: Plastics – Determination of Burning Behavior by Oxygen Index – Part 2: Ambient-Temperature Test

This test is used for plastic bars or sheets up to 10.5 mm thick and is used for determining the oxygen index of a material. A test specimen is held vertically in a chamber and is exposed to an oxygen/nitrogen gas mixture. The upper end of the test specimen is ignited, and the burning behavior is observed. Figure 6 shows the diagram.

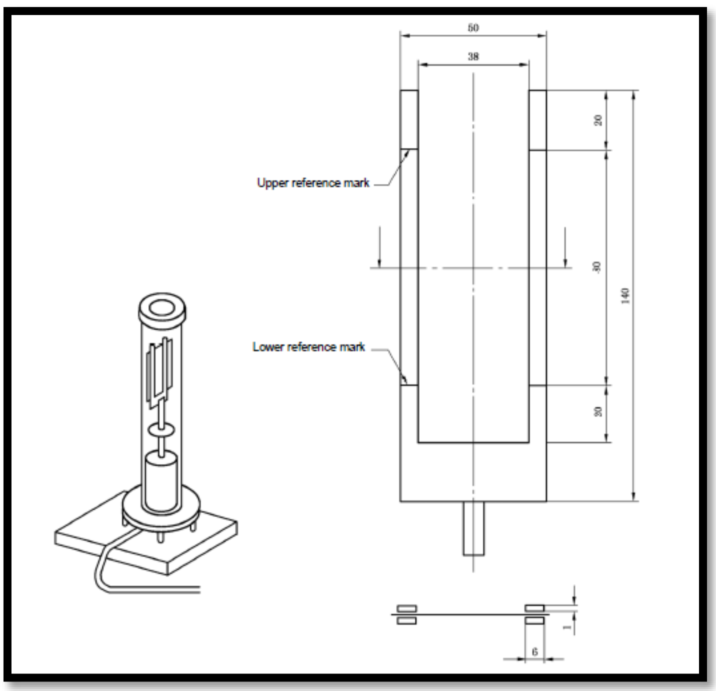

Figure 7: Oxygen Index Testing Apparatus (Chinese Standard, 2009)

The oxygen index, OI, is expressed as a percentage by volume from the formula

$OI = cf + kd$, where

cf is the final value of the oxygen concentration, in volume percent.

d is the interval, in volume percent between oxygen concentration levels used.

k is a normalization factor which is determined from the results of multiple iterations of the test, and a table included in GB/T 2406.2. "k," when multiplied by "d" in the equation above gives units of percentage.

GB/T 8323.2: Plastic – Smoke Generation – Part 2: Determination of Optical Density by a Single-Chamber Test

In this test, specimens of the product are mounted horizontally within a chamber and exposed to thermal radiation fluencies at both $25\frac{kW}{m^2}$ and $50\frac{kW}{m^2}$. Six specimens are tested at each irradiance level in a manner similar to the U.S. ASTM E662 method used in 49 CFR § 238.103 Appendix B. Optical density is measured using a photometric system that measures light transmission as smoke accumulates.

Results are expressed as optical density $D_{s,maximum} = 132 \log_{10}\left(\frac{100}{T_{\text{minimum}}}\right)$ where

$T_{minimum}$ is the minimum percentage light transmission.

Flame Retardancy Level Test (45 degree angle burning test)

This test is the same as Test Method I in the Japanese TRS, and is described in Appendix A of TB/T 3138. The standard dictates certain laboratory conditions that the Japanese TRS does not, including specification of ambient temperature, humidity level, and conditioning requirements such as temperature (23 °C $\pm$ 2 °C) and a "constant mass" condition where the weight of the specimen is measured twice in a 24-hour period and shown to differ by less than 1 percent.

3.4.2 Materials Performance Criteria – TB/T 3138

For the material items that are tested according to the previous three mentioned tests, items are grouped into the following categories:

- Products with horizontal surface facing down
- Vertical surface products
- Products with horizontal surface facing up
- Internal skeleton structure
- High polymer materials used for thermal insulation
- Packaging materials for thermal insulation
- Covering materials used for seats and sleepers
- Foam materials used for seats, sleepers etc.
- Air conditioning ducts

Additionally, in special circumstances the following tests are slight modifications of those more commonly used:

- "Nonflammability" test for inorganic materials used for thermal insulation (e.g., glass wool board, mineral wool, rock wool etc.), as well as general rubber materials

- "After-washing oxygen index" test and "after-washing 45 degree angle burning" test for curtain materials
- Specifications for wire and cable

3.4.3 Testing Requirements – TB/T 3237

TB/T 3237 tests three major parameters for decorating material: oxygen index and flammability (i.e., both a measure of how quickly flame spreads), smoke density, and toxic gas indicators. The latter of these will be discussed further in Section 5.4.

Oxygen and Flammability Requirements

Oxygen index is tested according to GB/T 2406, which was discussed previously. "Flammability Grades" are attributed using the International Union of Railways Standards (UIC) 564-2: Regulations Relating to Fire Protection and Firefighting Measures in Passenger Carrying Railway Vehicles or Assimilated Vehicles Used on International Services. The oxygen and flammability requirements according to these tests are reproduced in Table 9. Flammability Grades "A" and "B" are qualitative descriptors from UIC 562-2 that mean "Material With Very Good Fire-Resistance" and "Material With Acceptable Fire-Resistance," respectively (International Association of Railway Standards, 1991). TBT 3237 prefers for materials from flammability grade "A" to be used, but allows the materials with flammability grade "B" to be used if agreed upon by the producer and the purchaser.

Table 9: Oxygen Index and Flammability of Decorating Materials (Chinese Standard, 2008)

Material		Oxygen index %	Flammability Grade
Roof plates, finishing materials and their sealing and connecting materials	Plates, finishing materials	≥ 35	A
	Sealing and connecting materials	≥ 30	A, B
Side plates, wall plates, finishing materials and their sealing and connecting materials	Side plates, wall plates, finishing materials	≥ 32	A
	Sealing and connecting materials	≥ 30	A B
Materials constituting doors		≥ 32	A, B
Curtains, blinds		≥ 30	A, B
Lampshades		≥ 32	A, B
Seat, sleeper	Non-metallic frames	≥ 35	A
	Covering cloth	32	A
	Elastic mats	≥ 28	A, B
Floor, carpets and their connecting materials	Floor, carpets	≥ 30	A, B
	Connecting materials	≥ 28	
Non-metallic materials constituting luggage racks		≥ 32	A
Plates, finishing materials and their sealing materials for toilets	Plates, finishing materials	≥ 35	A
	Sealing materials	≥ 30	A, B
Anti-corrosion sealed noise reduction materials	Damping paint used in trains	≥ 32	A
	Sealing materials of doors and windows	≥ 28	A, B
Anti-cold materials	Polymer materials	≥ 32	A, B
	Inorganic materials	≥ 45	A
Inner walls and their connecting and sealing materials for air conditioners and piping		≥ 32	A
Other accessories[a]		Consistent with the requirements of the parts they are applied	
[a] In the choice of materials, it shall be preferred to use materials with the flammability grade of A. If agreed by the purchaser and the producer, it may also use materials with the flammability grade of B.			

Further, TB/T 3237 has smoke density requirements, which can be tested according to GB/T 8323 (described above in (Chinese Standard, 2008)), reproduced in Table 10.

Table 10: Smoke Density Indicators of Decorating Materials

Combustion Method	$D_{S1.5}$	D_{S4}
Not ignited	≤ 100	≤ 200
Ignited	≤ 100	≤ 200

3.5 Discussion

The U.S., Japan, and China all make use of dividing the railcar components into broad categories and then typically use two smoke-emission and flame/heat-spread tests to assess the fire performance of materials. China and Japan use an identical test (45° angle test) for testing flame/heat spread, and exploration of this test might prove beneficial in facilitating purchase and/or fire safety analysis of foreign railcars by American railroads. In addition, China includes requirements for flammability, oxygen index and smoke density for decorating materials. Both China and Japan categorize their materials standards in slightly different ways than Appendix B in 49 CFR 238.103, but the tests all cover the same basic metrics of flame spread, heat spread, and smoke density. The European Union has the most comprehensive and in-depth fire performance testing methods regarding the components of a railcar classification, the types of tests that are applied, and the multiple performance standards applied according to hazard levels. Despite having the most extensive safety testing requirements of those studied, it is not immediately clear the extent to which European-made railcars would conform to U.S. fire performance standards. 49 CFR 238.103(a) allows for alternative standards to be used as long as they are "issued or recognized by an expert consensus organization after special approval of FRA under § 238.21" (Title 49 CFR Part 238). Therefore, further analysis that thoroughly compares the European Union, Japanese, and Chinese tests to the 49 CFR Part 238(a) tests used in the U.S. is recommended. For example, a case study involving a railcar from Japan, China or Europe, along with its materials testing information and records, could be assessed for the extent to which those testing criteria translate well to American materials testing criteria. This likely will be easiest to execute for Japan and China, as the materials categories and testing methods are much more similar to that of the U.S. This further research may demonstrate a need for additional materials testing requirements in the United States, or international testing criteria that does not meet U.S. requirements.

4. Fire Detection and Suppression

Rolling stock uses fire detection and suppression to mitigate the spread of fire and extend the egress time for passengers by notifying of a fire event as soon as possible. Typically fire detection systems come in the form of fixed smoke alarms. Fire suppression systems can be either fixed, such as an automatic water mist system, or portable, such as a fire extinguisher.

4.1 U.S. Fire Detection and Suppression

The determinations to be made in a fire safety analysis for procurement of new railcars in 49 CFR 283.103 states, “whether any occupied or unoccupied space requires a portable fire extinguisher and, if so, the proper type and size of the fire extinguisher for each location.” Additionally, the CFR states that 49 CFR § 239.101 requires a minimum of one portable fire extinguisher for each passenger car (Title 49 CFR Part 238).

Apart from what may be included in a railroad’s fire safety analysis, NFPA 130 specifies the U.S. fire detection and suppression standards in the following instances:

- Chapter 8 section 8.9 requires the battery installation area to be provided with a heat, smoke, or other fire detection system as appropriate for the environment in which it will operate. It also stipulates that all heater elements must incorporate protective devices for failures of ventilation, failure of temperature controls or overheating, and short circuit overloads in supply wiring.
- Annex E mentions fire detection and suppression systems as possible mechanisms for reducing fire risk.

Generally, the U.S. requirements for fire detection and suppression in CFR 49 and NFPA 130 are non-prescriptive and subjective.

4.2 European Union Fire Detection and Suppression

In EN 45545-6, the European Union sets several standards in terms of placement of fire detection and fire suppression devices, though it typically does not designate the type or capabilities of the detection devices.

4.2.1 Fire Detection and Selective Shutdown

The European Union makes use of the operation and design categories outlined in EN 45545-1 to specify location requirements of fire detection devices, documented in EN 45545-6, and reproduced in Table 11.

Table 11: European Union Selective Shutdown Measures

Design Category	Operation Category	Passenger areas	Corridors	Toilets	Staff areas	Cooking or catering	Combustion engines	Technical cabinets containing traction equipment	Other technical cabinet	Luggage compartments
N and D	1	Nr	Nr	Nr	Nr	Nr	X	Nr	Nr	X
	2	Nr	Nr	X[e]	X[c]	X[c]	X	X	Nr	X
	3	X[ce]	Nr	X[e]	X[c]	X[c]	X	X	Nr	X
	4	X[ce]	Nr	X[e]	X	X	X	X	Nr	X
S and DS	1	X[c]	X	X[a]	X	X	X	X	X[b]	X
	2	X[c]	X	X[a]	X	X	X	X	X[b]	X
	3	X[c]	X	X[a]	X	X	X	X	X[b]	X
	4	X[c]	X	X[a]	X	X	X	X	X[b]	X
A	1	Nr	Nr	Nr	Nr	Nr	X	X	Nr	X
	2	Nr	Nr	X	Nr	Nr	X	X	Nr	X
	3	X[c]	Nr	X	Nr	Nr	X	X	X[b]	X
	4	X[c]	Nr	X	Nr	Nr	X	X	X[b]	X

Where,

- "X" indicates requirement
- "Nr" indicates no requirement
- "a" indicates an exception for toilets inside a sleeper compartment
- "b" indicates exceptions for where there is no electrical traction equipment in the technical cabinet, or if the technical cabinet complies with the materials performance standards or design standards listed elsewhere in EN 45545
- "c" indicates exceptions for vehicles that do not apply to the standard of EN 45545
- "d" indicates exceptions for vehicles which have motors located inside the body shell in a technical compartment
- "e" indicates "recommended"

EN 45545-6 also details actions to be taken in response to an automatic fire alarm in the form of selective shut-down of power. It is divided into primary and secondary level requirements. The primary requirements are for areas where the fire is being detected, and secondary requirements are for areas that may exacerbate the hazard arising from the fire. The selective shutdown of energy has three aims: to avoid the supply of additional energy to the fire (primary), to avoid collateral fire problems from surrounding personnel and/or equipment (secondary), and to facilitate firefighting. The primary level requirements for selective shutdown of energy are shown in Figure 7.

	Operation category	Passenger area/ staff area HVAC unit	Combustion engines	Technical cabinets containing traction equipment	Other technical cabinets
Design Categories N and D	1	nr	X	nr	nr
	2	nr	X	X	nr
	3	X	X	X	nr
	4	X	X	X	nr
Design Categories S and DS	1	X	X	X	nr
	2	X	X	X	nr
	3	X	X	X	nr
	4	X	X	X	nr
Design Category A	1	nr	X	X	nr
	2	nr	X	X	nr
	3	X	X	X	X [a]
	4	X	X	X	X

X indicates requirement

nr indicates no requirement

[a] There are no requirements if no electrical traction equipment is placed in the technical cabinet, and if the technical cabinet complies with one of the following conditions:

— the technical cabinet content is compliant to EN 45545-2,

— the technical cabinet is contained in a manner compliant to EN 45545-3.

Figure 8: Primary-Level Shutdown Requirements (European Standard, 2013)

Secondary shutdown of energy supply requirements do not vary by operation category, and include ventilation, as to limit the spread of fire, and photoelectric activated fire barrier doors, which run the risk of opening when it would be safer for them to remain closed.

4.2.2 Fire Suppression

EN 45545-6 designates areas that require "fixed firefighting" equipment as shown in Figure 8.

	Operation category	Combustion engines	Technical cabinets containing traction equipment
Design Categories N and D	1	nr	nr
	2	nr	nr
	3	X	X
	4	X	X
Design Categories S and DS	1	nr	nr
	2	nr	nr
	3	X	X
	4	X	X
Design Category A	1	nr	nr
	2	nr	nr
	3	X	X
	4	X	X
X indicates requirement nr indicates no requirement			

Figure 9: Fixed Firefighting Fire Suppression Requirements (European Standard, 2013)

The standard does not specify what kind of fixed firefighting equipment must be installed. However, it does state that systems that discharge hazardous extinguishing media should be fitted on a timer and with appropriate alarms so that passengers have time to evacuate so as not to be harmed by the extinguishing media (European Standard, 2013) (Part 6, section 5.4.5).

Additionally, fire extinguishers are placed according to the following rules:

- An extinguisher should be within 15 meters of any place in a passenger or staff area.
- There should be an extinguisher within 6 meters from the end of a railcar set.
- If a passenger or staff compartment is longer than 6 meters, it should be equipped with an additional extinguisher.
- Each driver's cab needs to have an extinguisher.
- In vehicles with design categories "S" and "DS," there should be a fire extinguisher at each end of the vehicle in the passenger area outside the sleeping compartments.
- In cooking areas, an additional fire extinguisher should be provided. If there is fat or oil based frying that takes place, a fire blanket should also be provided.

4.3 Japanese Fire Detection and Suppression

The extent of fire detection standards in Japan is quite limited. The Ministerial Ordinance article 84 says, "Sleeping cars shall be equipped with fire alarms that are automatically triggered in case of fire." The TRS that addresses this Ministerial Ordinance declares, "Fire alarms shall be provided in sleeping cars and rolling stock with *tatami* (sleeping bed) mats," as well as, "Fire alarms shall have a sensor that automatically detects the occurrence of fire through the use of heat or smoke resulting from fire."

4.3.1 Function of Devices at Power Failure

While EN 45545 stipulates devices that should be shut down in the event of a fire, the Japanese TRS offers a list of devices that need to remain functional for 30 minutes in the event of loss of the main power due to a fire, reproduced in Table 12.

Table 12: Function of Devices at Power Failure

Item	Device
Power generation system, etc.	Device that indicates when the temperature of the exhaust pipe has become abnormally overheated
Brake Devices	When electric circuits are used for brake operation
Passenger Room Construction	Ventilation for Rolling Stock Provided with forced-air ventilation (when appropriate to ([1] in table in item 2 of [Basic Items] of AMS relating to article 73)
	Lighting devices or auxiliary lighting devices
Construction of entrance/exits for getting on and off of passengers	Automatic door closing device functions
	Door open indicator lamps for entrance/exits for getting on and off of passengers
	Indicator of location and operating method of the door opening device (limited to when this device is provided on the inside of the rolling stock) that enables doors to be opened manually in case of emergency
Construction of emergency exits	Indicator of location and operating method for emergency exits
	Door open indicator lamps for emergency exits
Crew Room Facilities	Aspect facilities for onboard signal equipment
	Train stop device in case of driver's abnormality
	Cut-out switch for onboard facilities, devices indicating operating status of automatic train stop device, automatic control device and automatic train operation device
	Device indicating door-opening/closing status of emergency exit
	Door closed confirmation device for entrance/exit for getting on and off of passengers
Devices attached to rolling stock	Sign Device
	Whistle
	Communication device
	Public address device
	Lamps that light on for indicating the functions of the emergency alarm device/emergency stop device, the location and operating method indicators, and lamps that light on when the emergency alarm device/emergency stop device are operated
	Rear marker lights
Other facilities	Operating condition recording device

4.4 Chinese Fire Detection and Suppression

The Chinese standard on fire detection and suppression is also fairly brief. TB/T 2640 Chapter 5 "Design of fire extinguishing device" requires the following qualities of a fire extinguisher:

- Portable fire extinguishers shall be painted red. The method of use shall be painted on the fire extinguisher.
- The Portable fire extinguisher shall be placed on a bracket that is easy to take off and the place nearest to the location where a fire may occur.
- At least two portable fire extinguishers complying with relevant provisions shall be installed in each compartment of passenger train.

4.5 Discussion

The U.S. NFPA 130 and ASTM standards incorporate fire detection and suppression into the consideration of design features used in the fire safety analysis, but there are very few specified requirements beyond that. Like the materials performance standards, the European Union also has the most comprehensive requirements for fire detection and suppression. Japan also has a regulated list of devices that need to function for an appropriate amount of time using auxiliary battery power in the case of power loss due to fire. These varying detection and suppression requirements are outlined in Table 13. Although U.S. fire detection and suppression requirements will principally depend on the results of a fire safety analysis, the international requirements may be worth considering, and could be useful as reference to railroads completing a fire safety analysis.

Table 13: Summary of Fire Detection and Suppression Standards and Regulations

Region	Standard/Regulation	Detection	Suppression
U.S.	49 CFR 283.103	Incorporated into Fire Safety Analysis	Incorporated into Fire Safety Analysis
	49 CFR 39.101		At minimum one portable fire extinguisher for each location
	NFPA 130 Annex Chapter 8		Battery installation area needs heat and smoke detection systems, along with protective devices for ventilation failures or short circuit failures.
European Union	EN 45545-6	Various fire detection requirements, dependent upon vehicle areal/location according to hazard levels outlined in EN 45545-1.	Various fixed fire suppression requirements, dependent upon vehicle areal/location. Also includes selective fire suppression shutdown procedures in case of fire detection.
Japan	Japanese TRS	"Sleeping cars shall be equipped with fire alarms that are automatically triggered in case of fire"	Selective shutdown of devices in event of a fire.
China	TB/T 2640 Chapter 5	N/A	Portable Fire Extinguishers shall be painted Red. Placed on bracket that is easily removable. Two portable fire extinguishers in each compartment of a passenger train.

5. Toxicity Testing and Performance Criteria

In addition to setting performance standards for fire spread, heat spread and smoke accumulation, it is also worth considering material toxicity testing and performance to make fire safety testing more comprehensive.

5.1 US Toxicity Testing and Performance Criteria

The 49 CFR 238.103 does not contain materials toxicity testing requirements. NFPA 130 and ASTM E2061 both suggest considering toxicity and smoke as part of a risk assessment in a fire hazard analysis. In particular NFPA 130 gives some informational guidance on evaluating toxicity and tenable environments in an enclosed trainway or station. However, neither the regulations nor the industrial standards give guidance for testing toxicity performance of materials on rolling stock.

5.2 European Union Toxicity Testing and Performance Criteria

EN 45545-2 Annex C describes the testing methods for determination of toxic gases from railway products. The gases CO_2, CO, HF, HCl, HBr, HCN, SO_2, and NO_x need to be analyzed, using a metric known as Conventional Toxicity Index (CIT) and is calculated from two terms:

$$CIT = [Precursor\ Term] \times [Summation\ Term]$$

The "precursor term" is a normalization factor which means that CIT is a dimensionless number. The "summation term" is produced from the ratios of the observed emission level to the reference level of the gas, tabulated in Table 14.

Table 14: Reference Levels of Hazardous Gasses

Gas component	Reference concentration [mg/m³]
CO_2	72 000
CO	1 380
HBr	99
HCl	75
HCN	55
HF	25
NO_x	38
SO_2	262

CIT can be calculated from a smoke chamber area-based test, for larger products such as interior walls, floor covering, etc. or a mass-based test for smaller items such as mechanical components.

5.3 Japanese Toxicity Testing and Performance Criteria

The TRS do not provide specifications for toxicity testing.

5.4 Chinese Toxicity Testing and Performance Criteria

Chinese toxicity standards exist in TB/T 3237, which is the same document that contains its oxygen index, flammability, and smoke density requirements. Toxic gas analysis is executed using the same method specified in GB/T 8323, which is also the same as its U.S. counterpart ASTM 662 (Chinese Standard, 2010). This can be done in conjunction with the smoke density test. Toxic gas indicators and their concentration thresholds are shown in Table 15, and are the same gasses that are tested in the European EN 45545-2.

Table 15: Toxic Gas Indicators After Combustion for Decorating Materials

Gas Type	Concentration $(\frac{mg}{m^3})$	Concentration (parts per million)
CO	< 4,000	< 3,500
CO_2	< 90,000	< 50,000
HF	< 82	< 100
HBr	< 330	< 100
HCl	< 150	< 100
NO_x (in NO_2)	< 190	< 100
SO_2	< 260	< 100
HCN	< 110	< 100

5.5 Discussion

China and the European Union were the only two nations that require significant toxicity performance testing among those reviewed. U.S. standards rely on the fire hazard analysis to address toxicity concerns without prescribed tests or performance criteria. An analysis requirement of toxicity ratings of the materials tested in Appendix B of 49 CFR 238.103 could be useful for fire safety hazard analysis that are conducted on U.S. railroads.

6. Other Areas of Fire Safety Interest

In addition to material performance, fire detection and suppression, and toxicity testing, the standards in the U.S. and abroad include other topic areas that have implications for passenger rail fire safety. Among them are electrical fire safety, fire safety design and equipment arrangement, presence of flammable liquids and gases, and inspection protocols. Many of these requirements are featured in a particular standard and may not have a counterpart in other international standards.

6.1 Electrical Fire Safety

Most standards relating specifically to electrical fire safety are mentioned in NFPA 130 and have equivalent specifications in non-U.S. Standards.

6.1.1 Clearance and Creepage

Electrical safety standards may include requirements for clearance and creepage, both of which refer to shortest allowable distances between mechanisms (e.g., wires and conductors) that conduct electricity. Clearance refers to the distance in the air between two electrical components, while creepage refers to the distances along an insulating surface such as a wall or floor. Clearance also takes into account small air gaps between surfaces, where electrical air resistance is low.

United States

NFPA 130 requires circuits and cabling to be designed with clearance and creepage distance between voltage potentials and carbody ground as appropriate. Clearance is the shortest distance through air between two high-voltage conductors, while creepage is the shortest measured distance along an insulating surface material (typically the floor/ground). For voltage potentials up to 2,000 volts, the clearance distance between potentials and the ground need to comply with the formula

$$Clearance\ [mm] = 3.175 + (.0127 \times nominal\ voltage)$$

Creepage distances follow a similar formula

$$Clearance\ [mm] = 3.175 + (.047625 \times nominal\ voltage)$$

European Union

EN 45545-5 offers multiple methods for protecting circuits from the effects of electrical arcing, among them being clearance and creepage distances as described in European Standard (2017). Minimum clearances are based on rated impulse voltage (U_{ni}) and varying pollution degrees (PD), for which NFPA does not account. An example of clearance and creepage designations are shown in Table 16 and Table 17.

Table 16: EN 50124-1 Minimum Clearances In Air (in mm) Based on Rated Impulse Voltage, U_{ni}

U_{ni}(KV)	PD1	PD2	PD3	PD3A	PD4	PD4A	PD4B
6	5.5				10	18	20
8	8				14	21	23
10	11				18	23	26
12	14				22	27	30

Table 17: EN 50124-1 Minimum Creepage Distances Based on Rated Insulation Voltage, U_{Nm}

U_{NM} (V)	PD1	PD2
	Material Groups 1,2,3a,3b	Material Groups 1,2,3a
Up to 50	0.025	0.04
63	0.04	0.063
80	0.063	0.1

Japan

The Japanese TRS does not offer any information regarding clearance and creepage distance.

China

The Chinese TB/T 2640 does not offer any information regarding clearance and creepage distance.

6.1.2 Arc Splash and Fire Barrier

Arc barriers contain electrical arcs and offer protection against incandescent metal particles (sparks) from making and/or breaking high power electrical contacts.

United States

NFPA 130 mentions in Chapter 8, section 8.3.2, a few requirements for shields or separations that are lined with insulating material for arcing devices, particularly for electric equipment operating at greater than 300 V and its related wiring. No specifics on material type or size of arc barriers are given.

European Union

The European Union divides arc barriers into two types:

- Arc barrier type “A” for electrical arcs of short duration, resulting from the normal operation of high power equipment
- Arc barrier type “B” for instances of failure of high power equipment

Each barrier type is given a material property requirement in EN 45545-2. Additionally, EN 45545-3 has a section dedicated entirely to fire barriers, which carry requirements in common with the aforementioned arc barriers, with the addition of three fire-resistance requirements:

- Integrity: related to cracks or openings in the barrier, and sustained flaming on the unexposed side of the barrier (Marked "E" in the table below under "requirements")
- Insulation: the degree to which heat is transmitted to the unexposed surface of the barrier (Marked "I" in the table below under "requirements")
- Radiation: the degree to which heat is radiated from the barrier (Marked "W" in Table 18 under "requirements")

The "E," "I," and "W" designations are assigned using tests from EN 13501-2: "Fire classification of construction products and building elements." For instance, a designation of "E15" means that the integrity is maintained for 15 minutes according to the testing procedures contained in EN 13501-2.

Table 18 reproduced a portion of the requirements for where these fire barriers are to be placed.

Table 18: Fire Barrier Location Requirements

No.	Fire origin	Protected location	Remarks	Operation Category	Requirements
1	Underfloor technical cabinet containing electrical high power supply or traction circuits other than brake resistors	Passenger and staff area including driver's cab	Tested in accordance with EN 1364-2	1, 2 and 4	E15
			Requirements are defined from underfloor to top of the floor covering.	3	E15; I15
6	Passenger area	Driver's cab	Fire barriers are tested in accordance with EN 1364-1 (Walls) The full cross-section shall be tested with all elements positioned as they would be present in an actual railway vehicle	1 and 2	No Requirements
				4	E10
				3	E15; I15
7	Inside the luggage container	Outside the luggage container	Tested in accordance with EN 1364-1 (walls)	1 to 4	E15

Japan

The TRS is fairly sparse in giving arc barrier guidance on rolling stock. Brief mentions are made that require protective measures for electric devices that generate heat or electrical arcs.

China

The Chinese GB/T does not offer any arc barrier guidance.

6.2 Fire Safety Design/Equipment Arrangement

6.2.1 United States

In sections 8.3.1 and 8.3.2, NFPA 130 has a section titled "Vehicle Arrangement" which gives some qualitative design principles for rolling stock. These include:

- Isolating equipment posing an ignition threat from combustible materials in the passenger and crew compartments
- Isolating equipment (other than dining equipment) operating on voltage greater than 300 V from passenger and crew compartments
- Designing vehicles powered by overhead contact (catenary) in such a way that prevents arc penetration, ignition, and fire spread on the roof assembly

6.2.2 European Union

EN 45545 Part 4 is entirely devoted to fire safety requirements for rolling stock design, which are largely qualitative. EN 45545 Part 4 Annex A recommends preventative measures such as minimizing the risk of a fire starting by minimizing the accumulation of combustible products (e.g., newspaper, litter, dust, etc.). It is also recommended that appropriate ventilation systems are installed for combustible products that are near high-temperature equipment, as well as protective devices around such high-temperature equipment.

EN 45545-4 also addresses, in qualitative terms, the catering and cooking areas, luggage storage inside passenger areas, visibility in passenger areas, litter bins, ash trays, refuse containers, and monitors/televisions. This is generally qualitative in nature and does not differ from guidance in the NFPA 130. It is worth noting that any non-cooking surface must remain below 60 °C so as not to harm passengers and train personnel.

6.2.3 Japan

The Japanese TRS does not offer any information regarding design from a fire-safety perspective.

6.2.4 China

The Chinese TB/T 2640: Structural design for fire protection of passenger trains addresses many of the same design features as NFPA 130 and EN 45545-4. Like EN 45545-4, it requires that the temperature of non-cooking surfaces not exceed 60 °C. Beyond this, the design specifications are qualitative and largely resemble that of NFPA 130 and EN 45545-4.

6.3 Flammable Liquid and Gas

Neither the CFR nor NFPA 130 addresses the safe storage of flammable gasses or liquids onboard rolling stock. The EN 45545 Part 7 is dedicated to addressing these issues.

6.3.1 EN 45545-7: Fire safety requirement for flammable liquid and flammable gas installations:

Tanks for Flammable Liquids

Tanks for flammable liquids have standard thickness requirements according to Table 19.

Table 19: Tanks for Flammable Liquids Requirements (European Standard, 2013)

Volume	Steel	Aluminum
$\leq 2{,}000\ dm^3$	2.0 mm	3.0 mm
$> 2{,}000\ dm^3$	3.0 mm	4.0 mm

The tanks need to be designed so that the liquids cannot do any of the following:

- Come into contact with rotating machinery
- Be drawn into any device via suction such as ventilators and coolers
- Come into contact with heated components or electrical devices that might produce a spark
- Penetrate into layers of thermal or acoustic insulation material

Tanks should also not be filled to more than 90 percent of their nominal volume. The contained flammable liquid should be clearly labeled and have danger signs as appropriate.

Liquid Petroleum Gas

Additionally, EN 45545-7 gives storage standards for liquefied petroleum gas (LPG) installations for catering purposes. LPG needs to have specific danger signs that give flammability warnings and prohibit naked flames or smoking, which look like the images in Figure 10 and Figure 11.

Figure 10: Flammability/Naked Flames Warning (European Standard, 2013)

Figure 11: Flammability/Naked Flames Warning (European Standard, 2013)

Gas Distribution Requirements

Pressure regulators are required for gas distribution systems. Gas pipes that penetrate floors, pass through a partition, or are longer than 3 meters must have a stress relieving component such as an expansion-bend or coil.

6.4 Japanese Inspection Protocol

A unique component of Japanese rail vehicle safety is a highly regular and systematic inspection requirement for rolling stock and its components. The Ministerial Ordinance Article 90 requires that a "pertinent cycle, item and method of periodic inspection for facilities and rolling stock shall be determined according to their type, structure and usage in advance." The Japanese TRS addresses this in a Public Notice on Periodic Inspection of Facilities and Rolling Stock, Article 5. An example of the periods of inspection are shown in Table 20.

Table 20: Periodic Inspection of Japanese Rolling Stock

Kind of Rolling Stock		Period: Inspection of Condition and Function	Period: Inspection of Important and Critical Parts	Period: Overall Inspection
Locomotive, Passenger Car and Freight Car	Electric car of Trackless Rolling Stock	1 month	1 year	3 years
	Steam Locomotive	40 days	1 year	4 years
	Freight Car	3 months	2 years and 6 months	5 years
	Rolling stock of suspended railways, straddle type monorail, and guided railway	3 months	3 years (except for the first inspection of newly manufacture rolling stock which shall be within 4 years upon commencement of its usage)	6 years (except for the first inspection of newly manufactured rolling stock which shall be within 7 years upon commencement of its usage)
	Internal Combustion Locomotive and Internal Combustion Railcar	3 months	4 years, or the period of traveled mileage of the rolling stock being not exceeding 500 thousand kilometers (or 250 kilometers if the rolling stock is equipped with internal combustion engine with pre-combustion chambers or with transmission having dry clutch), of which shorter period is selected	8 years
	Other rolling stock of the railway other than Shinkansen	3 months	4 years, or the period of traveled mileage of the rolling stock not exceeding 600 thousand kilometers, of which shorter period is selected.	8 years
	Passenger car of Shinkansen (excluding superconducting magnetic levitation railways)	30 days or the period of traveled mileage of the rolling stock not to exceed 30 thousand kilometers, of which shorter period is selected	1 year and 6 months (except for the first inspection of newly manufactured rolling stock which shall be within 2 years and 6 months upon commencement of its useage), or the period of traveled mileage not to exceed 600 thousand kilometers (or 450 thousand kilometers if the rolling stock is equipped with traction circuit having control system by way of tap changer), whichever is shorter	3 years (except for the first inspection of newly manufactured rolling stock which shall be within 4 years upon commencement of its useage), or the period of traveled mileage not to exceed 1200 thousand kilometers (or 900 thousand kilometers if the rolling stock is equipped with traction circuit having control system by way of tap changer), whichever is shorter
	Shinkansen (superconducting magnetic levitation railways)	30 days	1 year	2 years
	Freight car of Shinkansen	90 days	2 years and 6 months	5 years
	Other type of Shinkansen car	90 days	3 years, or the period of traveled mileage not to exceed 250 thousand kilometers, of whichever is shorter	6 years

6.5 Discussion

There are some valuable safety mechanisms that can be gleaned from international standards and regulations for consideration in the U.S. Of particular value from the European Union are the arc splash and fire barrier standards offered in EN 45545-3, as well as the flammable gas and liquid standards in EN 45545-2. The arc splash and fire barrier standards offered would allow railroads in the U.S. to more accurately demonstrate an appropriate amount of hazard mitigation in the fire safety analysis, and the flammable gas and liquid standards would reduce the likelihood of ignition resulting in a major fire event. The Japanese use a highly regular inspection protocol that has the potential to enhance safety and the reliability of U.S. railways (i.e., if included in the standards and regulations) by reducing the likelihood of an electrical fire or combustion incident through proper tracking and maintenance of such equipment.

7. Conclusion

This study compared the U.S. fire safety standards and regulations to Europe, Japan, and China to ascertain ways in which U.S. fire safety might be more robust and thorough. The fire hazard analysis is unique to the U.S. and, though comprehensive, leaves much of the responsibility of risk assumption on the railroads themselves, and favors the railroad's own autonomy. This is in contrast to, for example, the European Union's goal of achieving interoperability between railways. The European Union's more prescriptive approach offers less autonomy to the individual railroads by requiring that all rolling stock achieve certain standards, but has the benefit of ensuring that railcars are safe to travel across borders among the European Union member states.

The materials standards in the U.S. employ broad categories for the railcar components and make use of two main materials tests in a similar manner to Japan and China, whereas the European Union has the most thorough material performance testing procedures. The U.S. currently does not have toxicity testing and performance criteria, and should continue to explore the possibility of incorporating such standards into its material performance standards. The U.S., European Union, Japan, and China all require fire detection and suppression in one form or another aboard rolling stock, though the European Union has specified most clearly the areas in which it is required. Though it is not prescribed in industrial standards such as NFPA 130 and ASTM E2061, this is certainly recommended as a way of reducing risk in a fire safety analysis.

There are also some unique fire safety procedures that would be valuable to the U.S., such as specifications for flammability and gas storage, which is found in the European Union standards, as well as inspection protocol and schedule, which has proven useful in Japan. Many of these fire safety procedures may be useful to enhance U.S. fire safety above current levels.

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Abbreviations and Acronyms

ACRONYMS	EXPLANATION
APTA	American Public Transportation Association
ASTM	American Society for Testing Materials
AAR	Association of American Railroads
CFR	Code of Federal Regulations
CIT	Conventional Toxicity Index
EN	European Norm (Standard)
FRA	Federal Railroad Administration
HL	Hazard Level
HVAC	Heating, Ventilation, and Air Conditioning
ISO	International Standards Organization
UIC	International Union of Railways Standards
LPG	Liquefied Petroleum Gas
MLIT	Ministry of Land, Infrastructure, Tourism
NFPA	National Fire Protection Association
OC	Operation Category
PD	Pollution Degrees
TRS	Technical Regulatory Standards (on Japanese Railways)