Recommended Fire Safety Practices for Rail Transit Materials Selection

Project No. DC-26-5243-00

Prepared for the
U.S. Department of Transportation
Federal Transit Administration
Office of Safety and Security
Technical Assistance Program

Submitted by the
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Table of Contents

Executive Summary

Mass transit agencies are under constant economic pressure, yet efficiently and safely move tens of millions of people daily. Not many fires occur in mass transit, but if they do, the ramifications are great: even a single significant fire involving mass transit can destroy costly infrastructure and undermine riders' confidence, in addition to endangering many lives. From the start, the challenge was formidable: take mass transit fire safety to the next level, without adding to cost.

In early 2007, the National Association of State Fire Marshals (NASFM) entered into a Grant Agreement (Project No. DC-26-5243-00) with the Federal Transit Administration (FTA) to address the fire safety factor of the fire performance of the materials and products used in the construction of the interiors of railcars and buses. The project comprised research into the adequacy of existing railcar and bus fire safety standards and an investigation of potential improvements in test methods and criteria.

To achieve the goals of the Grant Agreement, NASFM formed a Technical Advisory Committee consisting of emergency responders, mass transit experts and scientists. The Committee conducted most of its work by email and met in May 2008 to review

NASFM retained the highly regarded materials experts from Underwriters Laboratories to conduct flammability research for this project. NASFM and UL leveraged FTA-funded research already completed by the National Institute of Standards and Technology, and related work supported by General Electric Plastics (now SABIC Innovative Plastics). The research conducted by UL for this project focused most strongly on preventing fires from occurring in the first place, and keeping fires small if they do occur, so that the results are easier to manage.

The work was reviewed at two critical points by NASFM's Science Advisory Committee (SAC). The SAC consists of well-respected scientists, engineers and statisticians from government, academia and private industry who volunteer to serve for NASFM. Guidance issued by the SAC over the years for use by State Fire Marshals and others cover topics such as wearing apparel flammability, fire test laboratory accreditation and smoke alarm technology. The flammability of vehicles is a longtime concern and interest of the SAC, and several of its members have conducted research into this topic.

The enclosed documents, which provide details, are summarized here:

- The UL research indicates that existing bench-scale tests do not predict real-world fire performance of materials available for use in the interiors of rail cars and buses. However, other well-known and commonly used fire testing methods may be used to select materials able to withstand typical mass transit fire ignition sources. This avoids additional testing expense for materials producers.

- The existing requirements for the flammability and smoke emission characteristics of materials used in passenger cars and locomotive cabs (outlined in 49 CFR Ch. II, Part

238 App. B, 10-1-07 Edition) do not address the toxic effects of burning mass transit interior materials. The best practices recommended by NASFM address these issues in two ways. Fewer, slower developing fires will generate less smoke and toxic gases, thereby allowing more time for passengers and crew to evacuate safely. The recommended best practices also include a toxicity test that is already widely accepted by large mass transit organizations in North America. The inclusion of this best practice should be regarded as an interim measure, since international work is nearing completion on improved smoke toxicity testing methods, which should be reviewed for appropriateness to this application in the future.

- The recommended best practices will have minimal and perhaps no cost impact. Any number of commercially available materials produced by multiple suppliers and used in mass transit vehicles already satisfy these best practices. The best practices will exclude a few inappropriately flammable materials that are currently permitted – and, perhaps more important, will prevent the entrance into the market of poorly performing materials in the future.

To facilitate FTA's adoption process, the recommended best practices have been written as amendments to your existing best practices. Phase I of this project has come to a successful conclusion at a time when far greater federal investment in mass transportation seems probable.

TAB I:
PROPOSED FIRE SAFETY BEST PRACTICES FOR RAIL TRANSIT MATERIALS SELECTION

Summary of “Best Practices” recommendation

The motivation behind the development of NASFM’s Best Practices recommendation was to achieve a marked improvement in the fire safety criteria for materials used in rail transit interiors without having to invent new tests or specify combinations of tests that are not already used in the United States. Another motivator was a sensitivity to not add costs to whatever Best Practices would be specified.

The recommended Best Practices can be summarized in the following manner:

> For wall and ceiling panels, partitions, shelves, opaque windscreens, end caps, roof housings, and HVAC ducting, add criteria of Avg. HRR@180 seconds ≤ 120 kW/sq. m. and Max HRR ≤ 140 kW/sq. m. These numbers are derived from the ASTM E1354-99 @ 50 kW/m^2 applied heat flux with a retainer frame. For all applications requiring smoke density testing (ASTM E662), the BSS 7239 smoke toxicity test is also required.

It is important to note that these recommendations represent an upgrading of guidelines that are currently in place. All existing DOT/FRA/NFPA criteria are still intact for these applications. The currently specified test methods for these applications have been used for two decades: ASTM E162 attempts to limit flame propagation, while ASTM E662 attempts to limit smoke optical density. This combination of criteria has been successful in limiting – but not eliminating – materials prone to rapid fire growth and spread.

The Best Practices recommendations take two tracks: limiting flame propagation and flashover, and limiting smoke toxicity. The explanation and rationale for these recommendations is explained below and in the documents that follow.

Limiting flame propagation and flashover

The addition of ASTM E1354-99, Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter (also known as the Cone Calorimeter test), with the specified criteria for average and peak heat release, is intended to limit flame propagation and flashover. It represents a new small-scale guideline based on the results of the large-scale testing performed by Underwriters Laboratories for this project. UL’s research, which demonstrated the flashover potential of some materials that otherwise met existing criteria, also showed that specific smaller-scale tests could track larger-scale results. (Note that ASTM E1354 is essentially identical to the ISO 5660-1 Cone Calorimeter test referred to in the UL report, with the exception that the ISO standard does not address smoke production.)

The research has shown correlations between the ASTM E1354 tests and the large-scale NFPA 286 (Standard Methods of Fire Tests for Evaluating Contribution of Wall and Ceiling Interior Finish to Room Fire Growth, also known as the Room Corner Test). A forced ranking of tested materials shows that the combination of 1) Avg. HRR@180 seconds $<$ 120 kW/sq. m., and 2) Max HRR $<$ 140 kW/sq. m. will separate materials that caused a flashover in the large-scale NFPA 286 room corner burn test from materials that did not cause flashover. The one “borderline” material remains so in both tests.

Therefore, the addition of ASTM E1354 requirements represents a true data-driven upgrade to existing requirements, since it would eliminate the possibility that once-failing materials would be used.

Even though ASTM E1354 represents an additional test in this context, it will fit almost seamlessly into the existing requirements for several reasons. First, E1354 is an established test that is already referenced in the FRA regulations as a requirement for small parts unable to be tested in E162, and it is used in new regulations from the European Union (EU). Additionally, because this test, without specific pass/fail limits, is frequently requested by Original Equipment Manufacturers (OEMs), suppliers already regularly perform it. Therefore, adding the E1354 test to current Best Practices represents a low testing cost burden for suppliers. Moreover, fiberglass reinforced plastic (FRP), the most prevalent plastic used in the walls and ceilings of U.S. trains, can pass the proposed new requirement; therefore, no new material inventions are required.

The time elements used in the proposed criteria for ASTM E1354 are based on existing time elements for trains and aircraft. The underlying assumptions are the following:

- Aircraft, with trained personnel and specific time targets for evacuations, have the need and ability to evacuate faster in case of an emergency involving fire, and

- Many trains, without the expert personnel, have potentially longer evacuation times after the start of a fire, but potentially less evacuation time than would be expected for a building.

Therefore, it seems appropriate that more emphasis be put upon early fire development in aircraft, while a longer time element be used in trains. Current testing seems to reflect this emphasis. For example, a 5-minute duration is used in the OSU heat release test for aircraft large parts and a 15-minute duration is used in the current flame/heat release test (ASTM E162) for trains.

In the recommended Best Practices, limits are put on the maximum heat release rate (HRR) and a time-based Heat Release average. The time (180 seconds, or 3 minutes) correlates to other time-based measurements used in trains (smoke density at 1.5 and 4 minutes) and is 50% longer than the time-based total for aircraft (FAA uses a 2-minute total number in the OSU heat release test). Also, the maximum HRR limit proposed for trains is over the course of the test, again longer than the “5 minute maximum” time used by FAA in the aircraft OSU Heat Release test.

Limiting smoke toxicity

The prevailing thought for including a smoke toxicity test in these proposed Best Practices is to limit concentrations of specific smoke by-products that, if not leading to outright death, would lead to incapacitation, rendering the victim incapable of escape on his/her own. If smoke density is a concern, then it seems logical that smoke toxicity also would be of concern; moreover, not all by-products of combustion are “seen” in optical measurements. Therefore, the BSS 7239 Test Method for Toxic Gas Generation by Materials on Combustion is the recommended Best Practices test for limiting smoke toxicity for all materials that currently require the ASTM E662 smoke density test.

The BSS 7239 test uses the ASTM E662 smoke test, which as mentioned is already an FRA requirement for these materials, and the BSS 7239 test does not interfere with E662 requirements. Maximum parts per million (ppm) levels are set for specific gases (HCN, CO, NO/NO2, SO2, HF and HCL), and other gases could be added. Many U.S. train authorities, along with railcar OEMs such as Bombardier, currently use either BSS 7239 or a similar smoke toxicity test. Also, smoke toxicity requirements are used in European train regulations and at North American and EU aircraft OEMs. Therefore, toxicity testing is not a “new” concept for these materials.

It should be noted that BSS 7239 was chosen over the toxicity requirement in the EU Norm 45545-2 for the following reasons:

- As previously noted, BSS 7239 or a similar test is currently used by many U.S. train authorities and car manufacturers, while there are no examples of 45545-2 being used in U.S. rail.

- Many independent North American laboratories are capable of conducting BSS 7239 at reasonable cost, so the addition of this test represents a low testing cost burden for suppliers.

- BSS 7239 uses a reaction-to-fire test (E662) that is already required, so there is no "new" fire test that needs to be performed. The 45545-2 test uses a different setup of E662 (higher flux, different sample orientation), thus effectively introducing a new test.

- Because BSS 7239 is already in widespread current use, there are known results against this test for many products used in U.S. rail, while the data set for U.S. North American rail materials tested to the 45545-2 test is much smaller – primarily because it is used only for products that “overlap” U.S. and EU rail.

It should be noted that other toxicity tests - such as ASTM E1678 - would have at least the same drawbacks as 45545-2, with some being more extreme (different test, small data set for U.S. rail materials).

The BSS 7239 does not necessarily address all toxicity concerns. For example, due to the nature of its individual component pass/fail criteria, it does not address cumulative effects of different gases. There may also be an opportunity to modify the procedure to increase accuracy and repeatability, or to add more gas components for analysis. Therefore, this is an area that could be recommended for further study. A short-term effort might be a BSS 7239 procedure review to see if improvements can be made. A longer-term effort could be a focused study to substitute a consensus-based toxicity standard that addresses more concerns.

NASFM hopes that any new “Best Practices” put forth by FTA could be flexible enough to incorporate new information and new test methods for toxicity that are in the process of being developed and researched, such as the test currently working its way through the ISO process, if they are determined to be superior to the currently recommended test.

Proposed Best Practices for Train Interiors by Technical Advisory Committee of NASFM

Current FRA (& Doc 90 & NFPA130) Requirements for Walls and Ceilings

Test Method	Output	Attempts to Limit…
ASTM - E162	**Flame Spread Index & Flaming Drips**	**Flame propagation**
ASTM - E662	**Smoke Developed at 1.5 and 4 min**	**Smoke Optical Density (not toxicity)**

Combination Has Been Used for 2 Decades. Success In Limiting (but Not Eliminating) Materials Prone To Rapid Fire Growth and Spread

UL Fire Testing and Research

Demonstrated Flashover Potential of Some Materials Which Otherwise Met Existing Criteria

Showed Specific Smaller Scale Tests Could Track Larger Scale Results

Rate of Heat Release Test (Cone Calorimeter - ASTM E1354) Provides Valuable Predictive Data For Room Scale Test

Buildings, Trains, Aircraft

Escape Time ↑

Buildings
- 15 minutes is time used in Room-Corner test

Trains
- ?? , but reasonable to assume between buildings and aircraft

Aircraft
- 2 minutes for total evacuation

Flashover Threat ↑

Aircraft
- Measures Heat Release to reduce likelihood

Trains
- No real measurement or “transfer function”

Buildings
- Measures Flashover in Room Scale Test

Best Practice “Thought Process”...
Aircraft>Train>Building

Strategy for New Set of Criteria

Item	Benefit
Keep Existing Tests	**True upgrade - eliminate possibility of once-failing materials being used**
Focus on gaps/new concerns	**Avoids trying to “perfect” E162/E662**
Utilize Large Scale Results	**Line-of-Sight to Real World**
No New Test To Be Invented	**Test House Capability**
Use Tests That Are Performed Routinely	**Lower Cost Burden**
Know That Some Existing Materials Pass	**No Inventions, Sole Source, or unrealistically difficult test**

Minimize Uncertainties and Focus on
The Large-Scale UL Test Results

Proposed Best Practices for Walls and Ceilings

	Test Method	Output	Attempts to Limit…
KEEP	ASTM - E162	Flame Spread Index & Flaming Drips	Flame propagation
	ASTM - E662	Smoke Developed at 1.5 and 4 min	Smoke Optical Density (not toxicity)
ADD	ASTM – E1354	Heat Release- Peak, Average (3 min)	Flame propagation & Flashover
	BSS 7239, After E662	Concentrations of Specific Combustion By-Products	Smoke Toxicity

Two Additional Tests Are Not "New" and Not Always Additional

ASTM E1354 – Cone Calorimeter

Currently found in FRA

- Requirements for small parts unable to be tested in E162
- Used in Fire Hazard Analysis of railcars
- Frequently requested by OEM's
- Tested at the 50 kW/sq. m input level

Used in new EU Regulations

- Tested at the 50 kW/sq. m input level

Similar Set of Requirements in Aircraft, Using OSU Calorimeter

- Maximum Peak Heat Release Rate
- Maximum Total Heat Release (2 min)

Material Suppliers Very Frequently Asked for this Data, Without Specific Pass/Fail Limits

BSS 7239 – Smoke Toxicity*

*** - UL Study used EU method, not BSS7239**

Uses E662 Smoke Test

- Gasses collected / analyzed after 4 min. Does not interfere with E662 requirements.
- Sets maximum ppm on specific gasses (HCN, CO, NOx, So2, HF, HCl)
- Can be modified to add other gasses to the list

Currently Requested by many Train OEM's and Authorities

- Alternate is very similar - SMP800C, by Bombardier

Used Globally in Aircraft

- Airbus uses exact same methodology, but sets slightly different gas limits
- Bombardier SMP800C used in Bombardier aircraft.

New EU Regulations Has Smoke Toxicity Requirements

- Different analysis, using different smoke density method with E662 chamber.

Smoke Test Already Needed, Toxic Gas Analysis Often Requested

ASTM E1354 – Specific Addition

Function of Material	**Why**	**What**
- Wall and ceiling panels, partitions, shelves, opaque windscreens, end caps, roof housings - HVAC Ducting	- Larger parts representative of UL Large Scale test - Potential for flame spread	Avg. HRR @ 180 ≤ 120 kW/sq. m Max HRR ≤ 140 kW/sq. m

- 180 Sec. Average emphasizes early fire growth limits, using a time consistent with train smoke limits (1.5 and 4 min. measurements) and is 50% longer than the time-based total for aircraft (2 min total in OSU)

- Maximum HRR is over course of test – longer than the "5 minute maximum" used in aircraft.

- 50 kW/sq. m input level consistent with real-scale testing of rail vehicles. (Rick Peacock best to talk to this)

Data Driven Addition, Based on Large Scale Testing

BSS 7239 – Specific Addition

Function of Material	**Why**	**What**
All that require the ASTM E662-01 smoke density test	- If smoke density is a concern, smoke toxicity seems a logical concern - Not all by-products of combustion are “seen” in optical measurements	Pass BSS 7239: HCN $\leq$ 150 ppm CO $\leq$ 3500 ppm NO/NO2 $\leq$ 100 ppm SO2 $\leq$ 100 ppm HF $\leq$ 200 ppm HCL $\leq$ 500 ppm

A “Translation” of a Current Best Practice

Specific Changes to “The Table and Footnotes”

Refer to Handout “Proposed Guidelines Rolled Into Existing FRA Requirements”

Changes are specific and fit well with table / footnote approach

Deletions occur only where large parts are taken out of one functional category, to be added as their own functional category

Footnote 18 added for clarification

Effect on Materials Called Out on Pg. 3, “Proposed Guidelines To Be Used With Existing FRA Requirements

Additional Information, Possible Further Study

Refer to 3-page Handout "Proposed Guidelines To Be Used With Existing FRA Requirements "

Appendix on Page 3 contains information on flame spread:

- Some correlation between flame spread distance, a calculated "rate" in LIFT apparatus and flashover in NFPA 286
- But, some materials performed well in 286 & had relatively high rates of spread or distance
- Can LIFT be used to determine a meaningful flame spread metric?

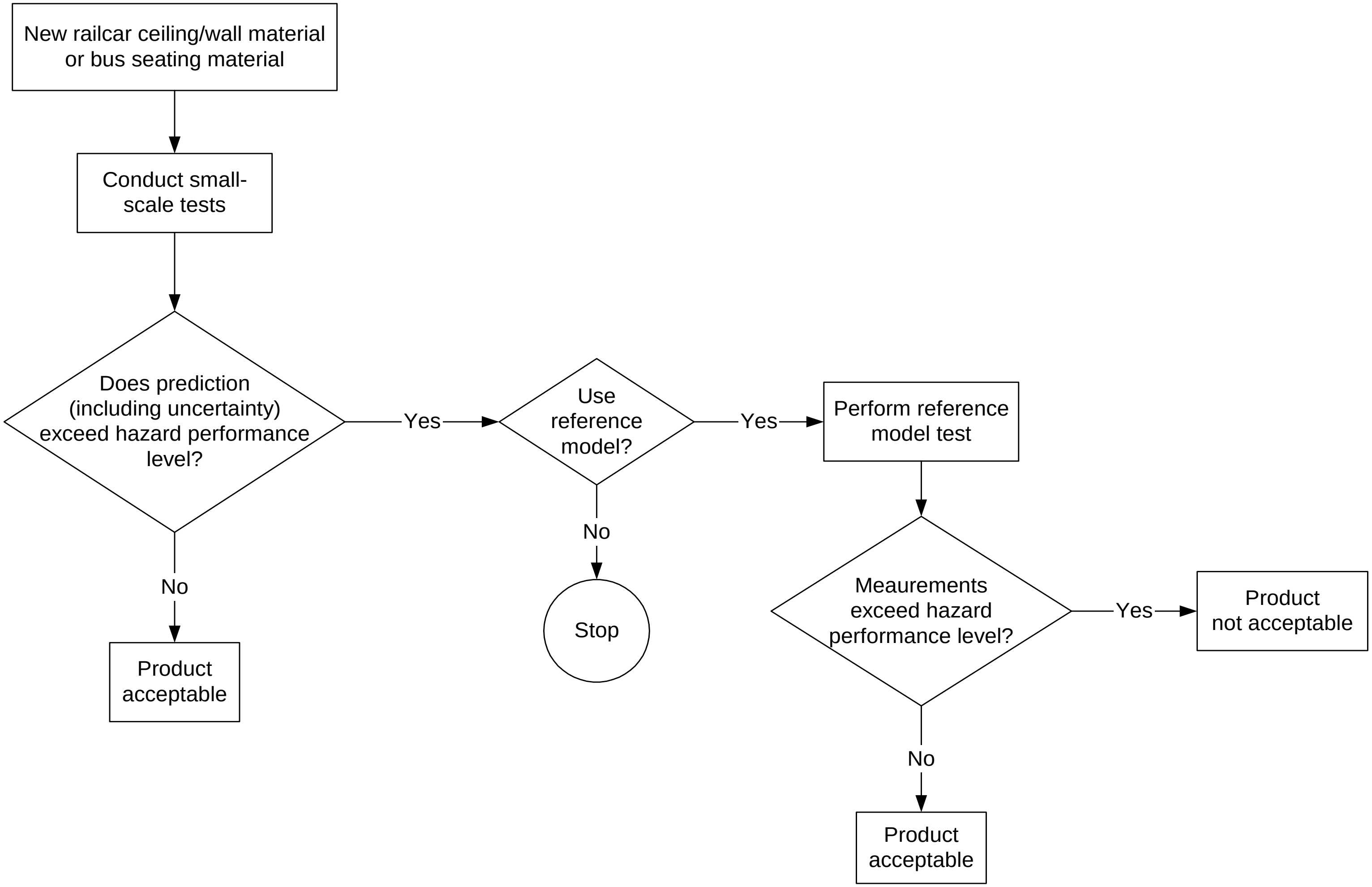
Smoke Toxicity - BSS 7239 Should be Seen as a Beginning

- Is there a test that realistically captures cumulative effects of gasses?
- Can gas analysis in large scale tests be correlated to smaller scale results?

Incorporate Large Scale Test?

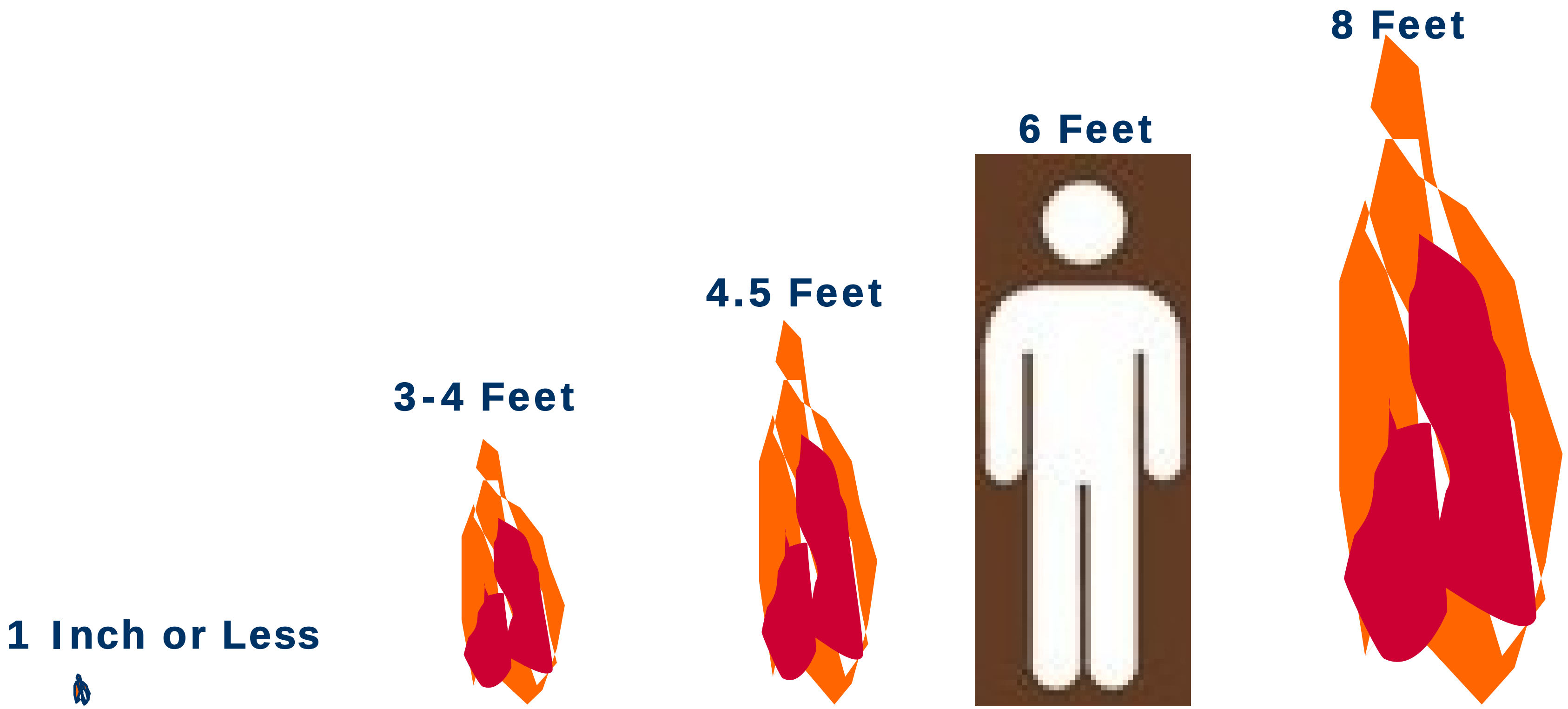
- See next slide from UL for example

Assessment of materials (Slide provided by UL, from the UL Study)



Flowchart illustrating the assessment of materials using fire performance metrics

Scale of Some Fire Tests



1 kW or less
- D635
- UL "V" Test
- Cig. Lighter

App 40 kW
- Waste paper basket
- 1st 5 min in NFPA 286

88 kW
- E84

App 160 kW
- Cushioned office chair
- 10 min in NFPA 286

Proposed Guidelines To Be Used With Existing FRA Requirements

Highlighted text in the table represents the new criteria

CATEGORY	FUNCTION OF MATERIAL	TEST METHOD	PERFORMANCE CRITERIA
Vehicle Components [1, 2, 3]	Wall and Ceiling Panels, partitions, shelves, opaque windscreens, end caps, roof housings	ASTM E 162-98	$I_s \leq 35$
		ASTM E 662-01	D_s (1.5) $\leq$ 100 D_s (4.0) $\leq$ 200
		ASTM E1354-99 - 50 kW/m^2 applied heat flux with a retainer frame	Avg. HRR@180 $\leq$ 120 kW/sq. m. Max HRR $\leq$ 140 kW/sq. m.
	HVAC ducting	ASTM E 162-98	$I_s \leq 35$
		ASTM E 662-01	D_s (4.0) $\leq$ 100
		ASTM E1354-99 - 50 kW/m^2 applied heat flux with a retainer frame	Avg. HRR@180 $\leq$ 120 kW/sq. m. Max HRR $\leq$ 140 kW/sq. m.
All	All that require the ASTM E 662-01 smoke density test	BSS 7239	HCN $\leq$ 150 ppm
			CO $\leq$ 3500 ppm
			NO/NO2 $\leq$ 100 ppm
			SO2 $\leq$ 100 ppm
			HF $\leq$ 200 ppm
			HCL $\leq$ 500 ppm

[1] Materials tested for E162-98 surface flammability shall not exhibit any flaming running or dripping.
[2] The ASTM E 662–01 maximum test limits for smoke emission (specific optical density) shall be measured in either the flaming or non-flaming mode, utilizing the mode which generates the most smoke.
[3] Carpeting used as a wall or ceiling covering shall be tested as a vehicle component.

Key Points	Benefit
- All existing DOT/FRA/NFPA criteria still intact for these applications	- Upgrading guidelines, not just change
- Data-driven E1354 pass/fail, based on large-scale testing	- New Small-scale guidelines tied to large scale performance
- FRP, most prevalent plastic, tested and can pass	- No new material inventions required
- Suppliers already regularly perform E1354 and Toxicity tests	- Low testing cost burden for suppliers
- E1354 referenced in FRA Regulations, and EU trains	- Established tests
- Toxicity referenced at OEM,s and many authorities	- Established tests

Technical Basis for Heat Release and Time Factors

Time

Time elements are based on existing time elements for trains and aircraft. The underlying assumptions are:
1) Aircraft, with trained personnel and specific time targets for evacuations, have the need and ability to evacuate faster in case of an emergency involving fire, and
2) Many trains, without the expert personnel, have potentially longer evacuation times after the start of a fire.

Therefore, it seems appropriate that more emphasis be put upon early fire development in aircraft, while a longer time element is used in trains. Current testing seems to reflect this emphasis. For example, a 5-minute duration is used in the heat release test (OSU) for aircraft large parts and a 15-minute duration is used in the current flame/heat release test (ASTM E162) for trains.

Limits are put on the maximum HRR and a time-based Heat Release average. The time (180 sec.) correlates to other time based measurements used in trains (smoke density @ 1.5 and 4 minutes) and is 50% longer than the time-based total for aircraft (FAA uses a 2 minute total number in the OSU). Also, the maximum HRR limit proposed for trains is over the course of the test, again longer than the “5 minute maximum” time used by FAA in the aircraft OSU Heat Release test.

Heat Release

The research has shown correlations between the ASTM E1354 tests and the large-scale NFPA 286 corner room burn test. A forced ranking of tested materials show that the combination of 1) Avg. HRR@180 ≤ 120 kW/sq. m., and 2) Max HRR ≤ 140 kW/sq. m. will separate materials which caused a flashover in NFPA 286 from materials that did not cause flashover. The one “borderline” material remains so in both tests.

Basis for Smoke Toxicity Requirement

Many US train authorities, along with railcar OEM’s such as Bombardier, currently use either the proposed test or a similar smoke toxicity test. Also, smoke toxicity requirements are used in European train regulations and at North American and EU aircraft OEM’s. The prevailing thought is to attempt to limit concentrations of specific smoke by-products that, if not leading to outright death, would lead to incapacitation, rendering the victim incapable of escape on his/her own.

The BSS 7239 was chosen over the toxicity requirement in the EU Norm 45545-2 for the following reasons:

BSS 7239	45545-2 Toxicity
This test or similar (SMP800-C) is currently used at many US train Authorities and car manufacturers.	No examples of 45545-2 being used in US Rail.
Many independent North American labs capable of doing this test at reasonable cost	Unknown.
Uses a reaction-to-fire test (E662) that is already required, there is no "new" fire test that needs to be performed	Uses a different set-up of E662 (higher flux, different sample orientation), thus introducing a new test.
Known results for many products used in US Rail	Data set for US North American Rail materials is much smaller – basically only for products that “overlap” US and EU rail.

Other toxicity tests - such as ASTM E1678 - would have at least the same drawbacks as 45545-2, with some being more extreme (different test, small data set for US rail materials).

Area for Further Study

The BSS 7239 does not necessarily address all toxicity concerns. For example, due to the nature of its individual component pass/fail criteria, it does not address cumulative effects of different gasses. There may also be an opportunity to modify the procedure to increase accuracy and repeatability, or to add more gas components for analysis. Therefore, this is an area that could be recommended for further study. A short-term effort might be a BSS 7239 procedure review to see if improvements can be made. A longer-term effort could be a focused study to substitute a consensus-based toxicity standard that addresses more concerns.

Impact on Current Materials Used in US Train Walls & Ceilings

Fail New Guidelines
Pass New Guidelines
Borderline

Plastic	Heat Flux (k/Wm2)	Peak RHR (kW/m2)	Av. RHR over 180 s (kW/m2)	NFPA 286 Flash-over?	Notes
					Smoke Toxicity

FRP is majority of plastic used in walls/ceilings of US trains.

Other Materials, Not Currently Used in US Train Walls & Ceilings

Resin	Heat Flux (k/Wm2)	Peak RHR (kW/m2)	Av. RHR over 180 s (kW/m2)	NFPA 286 Flash-over
				No
				Yes

Appendix A: **Flame Spread – Another Potential Area for Further Study**

Based on further analysis of data generated at UL, there were interesting correlations between flashover in NFPA 286 and flame spread distance and a "flame spread rate" seen in ISO 5658-2 (LIFT test). Although the correlation was not exact – some materials performed well in large scale tests, but had a relatively high rates of spread and/or distances, this highlighted an area of fire testing that might be a candidate for further study – flame spread rates. The current set of US requirements use a flame spread factor (Is from E162) that combines both an actual flame spread rate and a heat release number. There is no easily understood metric that captures a flame spread rate relevant to large-scale performance.

Proposed Guidelines Rolled Into Existing FRA Requirements

Table and Footnotes From 49 CFR Ch II (10-1-07 Edition), Part 238 App. B

Highlighted text represents changes

CATEGORY	FUNCTION OF MATERIAL	TEST METHOD	PERFORMANCE CRITERIA
Cushions, Mattresses	ALL [1, 2, 3, 4, 5, 6, 7, 8, 18]	ASTM D 3675-98	$I_s \le 25$
		ASTM E 662-01	D_s (1.5) $\le$ 100 D_s (4.0) $\le$ 175
Fabrics	Seat upholstery, mattress ticking and covers, curtains, draperies, wall coverings, and window shades [1, 2, 3, 6, 7, 8, 18]	14 CFR 25, Appendix F, Part I, (vertical test)	Flame time $\le$ 10 seconds Burn length $\le$ 6 inches
		ASTM E 662-01	D_s (4.0) $\le$ 200
Other Vehicle Components [9, 10, 11, 12]	Wall and ceiling panels, partitions, shelves, opaque windscreens, end caps, roof housings[1, 2, 18]	ASTM E 162-98	$I_s \le 35$
		ASTM E 662-01	D_s (1.5) $\le$ 100 D_s (4.0) $\le$ 200
		ASTM E1354-99 - 50 kW/m^2 applied heat flux with a retainer frame	Avg. HRR@180 $\le$ 120 kW/sq. m. Max HRR $\le$ 140 kW/sq. m.
	Seat and mattress frames, ~~wall and ceiling panels~~, seat and toilet shrouds, tray and other tables, ~~partitions, shelves, opaque windscreens, end caps, roof housings~~, and component boxes and covers [1, 2, 18]	ASTM E 162-98	$I_s \le 35$
		ASTM E 662-01	D_s (1.5) $\le$ 100 D_s (4.0) $\le$ 200
	Flexible cellular foams used in armrests and seat padding [1, 2, 4, 6, 18]	ASTM D 3675-98	$I_s \le 25$
		ASTM E 662-01	D_s (1.5) $\le$ 100 D_s (4.0) $\le$ 175
	Thermal and acoustic insulation [1, 2, 18]	ASTM E 162-98	$I_s \le 35$
		ASTM E 662-01	D_s (4.0) $\le$ 100
	HVAC Ducting [1, 2, 18]	ASTM E 162-98	$I_s \le 35$
		ASTM E 662-01	D_s (4.0) $\le$ 100
		ASTM E1354-99 - 50 kW/m^2 applied heat flux with a retainer frame	Avg. HRR@180 $\le$ 120 kW/sq. m. Max HRR $\le$ 140 kW/sq. m.
	Floor covering [12, 13, 18]	ASTM E 648-00	C.R.F. $\ge$ 5kW/m^2
		ASTM E 662-01	D_s (1.5) $\le$ 100 D_s (4.0) $\le$ 200
	Light diffusers, windows, and transparent plastic windscreens [2, 14, 18]	ASTM E 162-98	$I_s \le 100$
		ASTM E 662-01	D_s (1.5) $\le$ 100 D_s (4.0) $\le$ 200
Elastomers [1, 10, 11]	Window gaskets, door nosings, inter-car diaphragms, roof mats, and seat springs [18]	ASTM C 1166-00	Average flame propagation $\le$ 4 inches
		ASTM E 662-01	D_s (1.5) $\le$ 100 D_s (4.0) $\le$ 200
Structural Components [15]	Flooring [26], Other [17]	ASTM E119-00a	Pass
All [18]	All [18]	BSS 7239	HCN $\le$ 150 ppm
			CO $\le$ 3500 ppm
			NO/NO2 $\le$ 100 ppm
			SO2 $\le$ 100 ppm
			HF $\le$ 200 ppm
			HCL $\le$ 500 ppm

Notes:

[1] Materials tested for surface flammability shall not exhibit any flaming running or dripping.
[2] The ASTM E 662–01 maximum test limits for smoke emission (specific optical density) shall be measured in either the flaming or non-flaming mode, utilizing the mode which generates the most smoke.
[3] Testing of a complete seat assembly (including cushions, fabric layers, upholstery) according to ASTM E 1537–99 using the pass/fail criteria of Cal TB 133, and testing of a complete mattress assembly (including foam and ticking) according to ASTM 1590-01 using the pass/fail criteria of Cal TB 129 shall be permitted in lieu of the test methods prescribed herein, provided the assembly component units remain unchanged or new (replacement) assembly components possess equivalent fire performance properties to the original components tested. A fire hazard analysis must also be conducted that considers the operating environment within which the seat or mattress assembly will be used in relation to the risk of vandalism, puncture, cutting, or other acts which may expose the individual components of the assemblies to an ignition source. Notes 5, 6, 7, and 8 apply.
[4] Testing is performed without upholstery.
[5] The surface flammability and smoke emission characteristics shall be demonstrated to be permanent after dynamic testing according to ASTM D 3574–95, Test I2 (Dynamic Fatigue Test by the Roller Shear at Constant Force) or Test I3 (Dynamic Fatigue Test by Constant Force Pounding) both using Procedure B, except that the test samples be a minimum of 6 inches (154 mm) by 18 inches (457 mm) by the thickness of the material in its end use configuration, or multiples thereof. If test I3 is used, the size of the indentor described in paragraph 96.2 shall be modified to accommodate the specified test specimen.
[6] The surface flammability and smoke emission characteristics shall be demonstrated to be permanent by washing, if appropriate, according to FED–STD–191A Textile Test Method 5830.
[7] The surface flammability and smoke emission characteristics shall be demonstrated to be permanent by dry-cleaning, if appropriate, according to ASTM D 2724–87.
[8] Materials that cannot be washed or dry-cleaned shall be so labeled and shall meet the applicable performance criteria after being cleaned as recommended by the manufacturer.
[9] Signage is not required to meet any flammability or smoke emission performance criteria specified in this appendix.
[10] Materials used to fabricate miscellaneous, discontinuous small parts (such as knobs, rollers, fasteners, clips, grommets, and small electrical parts) that will not contribute materially to fire growth in end use configuration are exempt from flammability and smoke emission performance requirements, provided that the surface area of any individual small part is less than 16 square inches (100 cm^2) in end use configuration and an appropriate fire hazard analysis is conducted which addresses the location and quantity of the materials used, and the vulnerability of the materials to ignition and contribution to flame spread.
[11] If the surface area of any individual small part is less than 16 square inches (100cm^2) in end use configuration, materials used to fabricate such a part may be tested in accordance with ASTM E 1354–99, as an alternative to both (a) the ASTM E 162-98 flammability test procedure otherwise specified in the table, and (b) the ASTM E 662-01 smoke generation test procedure. Testing shall be at 50 kW/m^2 applied heat flux with a retainer frame. Materials tested in accordance with ASTM E 1354–99 shall meet the following performance criteria: average heat release rate of ($q^{//}$ 180) less than or equal to 100 kW/m^2, and average specific extinction area less than or equal to 500 m^2/kg over the same 180-second period.
[12] Carpeting used as a wall or ceiling covering shall be tested according to ASTM E 162-98 and ASTM E 662-01 and meet the respective criteria of Is less than or equal to 35 and Ds (1.5) less than or equal to 100 and Ds (4.0) less than or equal to 200. Notes 1 and 2 apply.
[13] Floor covering shall be tested with padding in accordance with ASTM E 648-00, if the padding is used in the actual installation.
[14] For double window glazing, only the interior glazing is required to meet the requirements specified herein. (The exterior glazing is not required to meet these requirements.)
[15] Penetrations (ducts, etc.) shall be designed against acting as passageways for fire and smoke and representative penetrations shall be included as part of test assemblies.
[16] A structural floor assembly separating the interior of a vehicle from its undercarriage shall meet the performance criteria during a nominal test period as determined by the railroad. The nominal test period must be twice the maximum expected time period under normal circumstances for a vehicle to stop completely and safely from its maximum operating speed, plus the time necessary to evacuate all the vehicle's occupants to a safe area. The nominal test period must not be less than 15 minutes. Only one specimen need be tested. A proportional reduction may be made in the dimensions of the specimen provided it serves to truly test the ability of the structural flooring assembly to perform as a barrier against under-vehicle fires. The fire resistance period required shall be consistent with the safe evacuation of a full load of passengers from the vehicle under worst-case conditions.
[17] Portions of the vehicle body which separate major ignition sources, energy sources, or sources of fuel-load from vehicle interiors, shall have sufficient fire endurance as determined by a fire hazard analysis acceptable to the railroad which addresses the location and quantity of the materials used, as well as vulnerability of the materials to ignition, flame spread, and smoke generation. These portions include equipment carrying portions of a vehicle's roof and the interior structure separating the levels of a bi-level car, but do not include a flooring assembly subject to Note 16. A railroad is not required to use the ASTM E 119-00a test method.
[18] When a Function of Material requires the ASTM E662-01 smoke density test, then the smoke toxicity test BSS7239 is also required.

amendment, any person may comment on the program or amendment.

(1) Each comment shall set forth specifically the basis upon which it is made, and contain a concise statement of the interest of the commenter in the proceeding.

(2) Three copies of each comment shall be submitted to the Associate Administrator for Safety, Federal Railroad Administration, 1120 Vermont Ave., Mail Stop 25, Washington, DC 20590.

(3) The commenter shall certify that a copy of the comment was served on the railroad.

(c) *Approval.* (1) Within 60 days of receipt of each initial inspection, testing, and maintenance program, FRA will conduct a formal review of the program. FRA will then notify the primary railroad contact person and the designated employee representatives in writing whether the inspection, testing, and maintenance program is approved and, if not approved, the specific points in which the program is deficient. If a program is not approved by FRA, the railroad shall amend its program to correct all deficiencies and resubmit its program with the required revisions not later than 45 days prior to commencing passenger operations.

(2) FRA will review each proposed amendment to the program within 45 days of receipt. FRA will then notify the primary railroad contact person and the designated employee representatives in writing whether the proposed amendment has been approved by FRA and, if not approved, the specific points in which the proposed amendment is deficient. The railroad shall correct any deficiencies and file the corrected amendment prior to implementing the amendment.

(3) Following initial approval of a program or amendment, FRA may reopen consideration of the program or amendment for cause stated.

Subpart G—Specific Safety Planning Requirements for Tier II Passenger Equipment

§ 238.601 Scope.

This subpart contains specific safety planning requirements for the operation of Tier II passenger equipment, procurement of Tier II passenger equipment, and the introduction or major upgrade of new technology in existing Tier II passenger equipment that affects a safety system on such equipment.

§ 238.603 Safety planning requirements.

(a) Prior to commencing revenue service operation of Tier II passenger equipment, each railroad shall prepare and execute a written plan for the safe operation of such equipment. The plan may be combined with any other plan required under this part. The plan shall be updated at least every 365 days. At a minimum, the plan shall describe the approaches and processes to:

(1) Identify all requirements necessary for the safe operation of the equipment in its operating environment;

(2) Identify all known or potential hazards to the safe operation of the equipment;

(3) Eliminate or reduce the risk posed by each hazard identified to an acceptable level using a formal safety methodology such as MIL-STD–882; and

(4) Impose operational limitations, as necessary, on the operation of the equipment if the equipment cannot meet safety requirements.

(b) For the procurement of Tier II passenger equipment, and for each major upgrade or introduction of new technology in existing Tier II passenger equipment that affects a safety system on such equipment, each railroad shall prepare and execute a written safety plan. The plan may be combined with any other plan required under this part. The plan shall describe the approaches and processes to:

(1) Identify all safety requirements governing the design of the passenger equipment and its supporting systems;

(2) Evaluate the total system, including hardware, software, testing, and support activities, to identify known or potential safety hazards over the life cycle of the equipment;

(3) Identify safety issues during design reviews;

(4) Eliminate or reduce the risk posed by each hazard identified to an acceptable level using a formal safety methodology such as MIL-STD-882;

(5) Monitor the progress in resolving safety issues, reducing hazards, and meeting safety requirements;

(6) Develop a program of testing or analysis, or both, to demonstrate that safety requirements have been met; and

(7) Impose operational limitations, as necessary, on the operation of the equipment if the equipment cannot meet safety requirements.

(c) Each railroad shall maintain sufficient documentation to demonstrate how the operation and design of its Tier II passenger equipment complies with safety requirements or, as appropriate, addresses safety requirements under paragraphs (a)(4) and (b)(7) of this section. Each railroad shall maintain sufficient documentation to track how safety issues are raised and resolved.

(d) Each railroad shall make available to FRA for inspection and copying upon request each safety plan required by this section and any documentation required pursuant to such plan.

[64 25660, May 12, 1999, as amended at 67 FR 19994, Apr. 23, 2002]

APPENDIX A TO PART 238—SCHEDULE OF CIVIL PENALTIES[1]

Section	Violation	Willful violation
SUBPART A—GENERAL		
238.15 Movement of power brake defects:		
(b) Improper movement from Class I or IA brake test	5,000	7,500
(c) Improper movement of en route defect	2,500	5,000
(2), (3) Insufficient tag or record	1,000	2,000
(4) Failure to determine percent operative brake	2,500	5,000
(d) Failure to follow operating restrictions	5,000	7,500
(e) Failure to follow restrictions for inoperative front or rear unit	2,500	5,000
238.17 Movement of other than power brake defects: [1]		
(c)(4), (5) Insufficient tag or record	1,000	2,000
(d) Failure to inspect or improper use of roller bearings	2,500	5,000
(e) Improper movement of defective safety appliances	(1)	
238.19 Reporting and tracking defective equipment:		
(a) Failure to have reporting or tracking system	7,500	11,000
(b) Failure to retain records	2,000	4,000
(c) Failure to make records available	1,000	2,000
(d) Failure to list power brake repair points	2,000	4,000
SUBPART B—SAFETY PLANNING AND GENERAL REQUIREMENTS		
238.103 Fire protection plan/fire safety:		
(a) Failure to use proper materials	5,000	7,500
(b) Improper certification	1,000	2,000
(c) Failure to consider fire safety on new equipment	5,000	7,500
(d) Failure to perform fire safety analysis	5,000	7,500
(e) Failure to develop, adopt or comply with procedures	5,000	7,500
238.105 Train electronic hardware and software safety:		
(a), (b), (c) Failure to develop and maintain hardware and software safety	7,500	11,000
(d) Failure to include required design features	5,000	7,500
(e) Failure to comply with hardware and software safety program	5,000	7,500
238.107 Inspection, testing, and maintenance plan:		
(b) Failure to develop plan	7,500	11,000
(b)(1)–(5) Failure of plan to address specific item	3,000	6,000
(d) Failure to conduct annual review	5,000	7,500
238.109 Training, qualification, and designation program:		
(a) Failure to develop or adopt program	7,500	11,000
(b)(1)–(4) Failure of plan to address specific item	3,000	6,000
(b)(5)–(12) Failure to comply with specific required provision of the program	5,000	7,500
(b)(13) Failure to maintain adequate records	2,500	5,000
238.111 Pre-revenue service acceptance testing plan:		
(a) Failure to properly test previously used equipment	7,500	11,000
(b)(1) Failure to develop plan	7,500	11,000
(b)(2) Failure to submit plan to FRA	5,000	7,500
(b)(3) Failure to comply with plan	5,000	7,500
(b)(4) Failure to document results of testing	5,000	7,500
(b)(5) Failure to correct safety deficiencies or impose operating limits	5,000	7,500
(b)(6) Failure to maintain records	3,000	6,000
(b)(7) Failure to obtain FRA approval	5,000	7,500
238.113 Emergency window exits	2,500	5,000
238.115 Emergency lighting	2,500	5,000
238.117 Protection against personal injury	2,500	5,000

Section	Violation	Willful violation
238.119 Rim-stamped straight plate wheels	2500	5,000
SUBPART C—SPECIFIC REQUIREMENTS FOR TIER I EQUIPMENT		
238.203 Static end strength	2,500	5,000
238.205 Anti-climbing mechanism	2,500	5,000
238.207 Link between coupling mechanism and car body	2,500	5,000
238.209 Forward-facing end structure of locomotives	2,500	5,000
238.211 Collision posts	2,500	5,000
238.213 Corner posts	2,500	5,000
238.215 Rollover strength	2,500	5,000
238.217 Side structure	2,500	5,000
238.219 Truck-to-car-body attachment	2,500	5,000
238.221 Glazing	2,500	5,000
238.223 Fuel tanks	2,500	5,000
238.225 Electrical System	2,500	5,000
238.227 Suspension system	2,500	5,000
238.229 Safety appliances—general:.		
(e) Failure to properly identify equipment (per car)	2,500	5,000
(g) Failure to adopt or comply with inspection plan	2,500	5,000
(h) Failure to use qualified person (per car)	2,500	5,000
(i) Failure to properly conduct initial or periodic inspection (per car)	2,500	5,000
(j) Failure to take proper remedial action (per car)	2,500	5,000
(k) Failure to maintain records (per car)	2,000	4,000
238.230 Safety appliances—new equipment:.		
(b)(2) Failure to identify welded appliance (per car)	2,500	5,000
(b)(3) Failure to receive approval for use (per car)	2,500	5,000
(c)(2) Failure to make proper repair (per car)	2,500	5,000
238.231 Brake System (a)–(g), (i)–(n)	2,500	5,000
(h)(1), (2) Hand or parking brake missing or inoperative	5,000	7,500
(h)(3) Hand or parking brake inspection or record (per car)	2,500	5,000
(h)(4) Hand or parking brake not applied to hold unattended equipment or prematurely released	5,000	7,500
238.233 Interior fittings and surfaces	2,500	7,500
238.235 Doors	2,500	5,000
238.237 Automated monitoring	2,500	5,000
SUBPART D—INSPECTION, TESTING, AND MAINTENANCE REQUIREMENTS FOR TIER I EQUIPMENT		
238.303 Exterior mechanical inspection of passenger equipment:		
(a)(1) Failure to perform mechanical inspection	[1]2,000	4,000
(a)(2) Failure to inspect secondary brake system	2,500	5,000
(b) Failure to perform inspection on car added to train	[1]2,000	4,000
(c) Failure to utilize properly qualified personnel	2,000	4,000
(e)(1) Products of combustion not released outside cab	2,500	5,000
(e)(2) Battery not vented or gassing excessively	2,500	5,000
(e)(3) Coupler not in proper condition	2,500	5,000
(e)(4) No device under drawbar pins or connection pins	2,500	5,000
(e)(5) Suspension system and spring rigging not in proper condition	2,500	5,000
(e)(6) Truck not in proper condition	2,500	5,000
(e)(7) Side bearing not in proper condition	2,500	5,000
(e)(8) Wheel not in proper condition:		
(i), (iv) Flat spot(s) and shelled spot(s):		
(A) One spot 2½″ or more but less than 3″ in length	2,500	5,000
(B) One spot 3″ or more in length	5,000	7,500
(C) Two adjoining spots each of which is 2″ or more in length but less than 2½″ in length	2,500	5,000
(D) Two adjoining spots each of which are at least 2″ in length, if either spot is 2½7″ or more in length	5,000	7,500
(ii) Gouge or chip in flange:		
(A) More than 1½″ but less than 1⅝″ in length; and more than ½″ but less than ⅝″ in width	2,500	5,000
(B) 1⅝″ or more in length and ⅝″ or more in width	5,000	7,500
(iii) Broken rim	5,000	7,500
(v) Seam in tread	2,500	5,000
(vi) Flange thickness of:	2,500	5,000
(A) ⅞″ or less but more than.		
(B) 13/16″ or less	5,000	7,500
(vii) Tread worn hollow	2,500	5,000
(viii) Flange height of:		
(A) 1½″ or greater but less than 1⅝″	2,500	5,000
(B) 1⅝″ or more	5,000	7,500
(ix) Rim thickness:		
(A) Less than 1″	2,500	5,000

Section	Violation	Willful violation
(B) 15⁄16″ or less	5,000	7,500
(x) Crack or break in flange, tread, rim, plate, or hub:		
(A) Crack of less than 1″	2,500	5,000
(B) Crack of 1″ or more	5,000	7,500
(C) Break	5,000	7,500
(xi) Loose wheel	5,000	7,500
(xii) Welded wheel	5,000	7,500
(e)(10) Improper grounding or insulation	5,000	7,500
(e)(11) Jumpers or cable connections not in proper condition	2,500	5,000
(e)(12) Door or cover plate not properly marked	2,500	5,000
(e)(13) Buffer plate not properly placed	2,500	5,000
(e)(14) Diaphragm not properly placed or aligned	2,500	5,000
(e)(15) Secondary braking system not in operating mode or contains known defect	2,500	5,000
(e)(16) Roller bearings:		
(i) Overheated	5,000	7,500
(ii) Cap screw loose or missing	2,500	5,000
(iii) Cap screw lock broken or missing	1,000	2,000
(iv) Seal loose, damaged, or leaks lubricant	2,500	5,000
(e)(17) Air compressor inoperative	2,500	5,000
(g) Record of inspection:		
(1), (4) Failure to maintain record of inspection	5,000	4,000
(2) Record contains insufficient information	1,000	2,000
238.305 Interior mechanical inspection of passenger cars:		
(a) Failure to perform inspection	[1] 1,000	2,000
(b) Failure to utilize properly qualified personnel	1,000	2,000
(c)(1) Failure to protect against personal injury	2,500	5,000
(c)(2) Floors not free of condition that creates hazard	2,500	5,000
(c)(3) Access to manual door release not in place	2,000	4,000
(c)(4) Emergency equipment not in place	1,000	2,000
(c)(5) Emergency brake valve not stenciled or marked	2,500	5,000
(c)(6) Door or cover plates not properly marked	2,500	5,000
(c)(7) Safety signage not in place or legible	1,000	2,000
(c)(8) Trap door unsafe or improperly secured	2,500	5,000
(c)(9) Vestibule steps not illuminated	2,000	4,000
(c)(10) Door not safely operate as intended	2,500	5,000
(c)(11) Seat broken, loose, or not properly attached	2,500	5,000
(e) Record of inspection:		
(1), (4) Failure to maintain record of inspection	2,000	4,000
(2) Record contains insufficient information	1,000	1,000
(f) Record of inspection:		
(1), (4) Failure to maintain record of inspection	2,000	4,000
(2) Record contains insufficient information	1,000	2,000
238.307 Periodic mechanical inspection of passenger cars and unpowered vehicles:		
(a) Failure to perform periodic mechanical inspection	[1] 2,500	5,000
(b) Failure to utilize properly qualified personnel	2,500	5,000
(c)(1) Seat or seat attachment broken or loose	2,500	5,000
(c)(2) Luggage rack broken or loose	2,500	5,000
(c)(3) Bed, bunks, or restraints broken or loose	2,500	5,000
(c)(4) Emergency window exit not properly operate	2,500	5,000
(c)(5) Emergency lighting not operational	2,500	5,000
(c)(6) Switches not in proper condition	2,500	5,000
(c)(7) Coupler not in proper condition	2,500	5,000
(c)(8) Truck not equipped with securing arrangement	2,500	5,000
(c)(9) Truck center casting cracked or broken	5,000	7,500
(c)(10) General conditions endangering crew, passengers	2,500	5,000
(c)(13) Hand or parking brake test not performed	2,500	5,000
(d)(1) Manual door release not operate as intended	2,500	5,000
(d)(2) Hand or parking brake inspection not performed	2,500	5,000
(e)(1) Failure to maintain record of inspection	2,000	4,000
(i)–(iv) Record contains insufficient information	1,000	2,000
(f)(1) Record of inspection:		
(i) Failure to maintain record of inspection	2,000	4,000
(ii) Record contains insufficient information	1,000	2,000
238.309 Periodic brake equipment maintenance:		
(b) Failure to perform on MU locomotive	2,500	5,000
(c) Failure to perform on conventional locomotive	2,500	5,000
(d) Failure to perform on passenger coaches or other unpowered vehicle	2,500	5,000
(e) Failure to perform on cab car	2,500	5,000
(f) Record of periodic maintenance:		
(1), (2) Failure to maintain record or stencil	2,000	4,000
238.311 Single car tests:		
(a) Failure to test in accord with required procedure	2,500	5,000
(b) Failure to utilize properly qualified personnel	2,500	5,000

Section	Violation	Willful violation
(c), (e) Failure to perform single car test	2,500	5,000
(f) Improper movement of car for testing	2,000	4,000
(g) Failure to test after repair or replacement of component	2,000	4,000
238.313 Class I brake test:		
(a) Failure to perform on commuter or short distance intercity passenger train	[1] 10,000	15,000
(b) Failure to perform on long-distance intercity passenger train	[1] 10,000	15,000
(c) Failure to perform on cars added to passenger train	[1] 5,000	7,500
(d) Failure to utilized properly qualified personnel	5,000	7,500
(f) Passenger train used from Class I brake test with less than 100% operative brakes	5,000	7,500
(g) Partial failure to perform inspection on a passenger train	5,000	7,500
(3) Failure to adjust piston travel (per car)	2,500	5,000
(h) Failure to maintain record	2,000	4,000
(j) Failure to perform additional Class I brake test	5,000	7,500
(j)(3) Failure to maintain record	2,000	4,000
238.315 Class IA brake test:		
(a) Failure to perform inspection	[1] 5,000	7,500
(d) Failure to utilize properly qualified personnel	2,500	5,000
(e) Passenger train used from Class IA brake test with improper percentage of operative brakes	5,000	7,500
(f) Partial failure to perform inspection on passenger train	2,500	5,000
238.317 Class II brake test:		
(a) Failure to perform inspection	[1] 2,500	5,000
(b) Failure to utilize properly qualified personnel	2,500	5,000
(c) Improper use of defective equipment from Class II brake test	2,500	5,000
238.319 Running brake tests:		
(a), (b) Failure to perform test	2,000	4,000
238.321 Out-of-service credit	1,000	2,000
SUBPART E—SPECIFIC REQUIREMENTS FOR TIER II PASSENGER EQUIPMENT		
238.403 Crash energy management	2,500	5,000
238.405 Longitudinal static compressive strength	2,500	5,000
238.407 Anti-climbing mechanism	2,500	5,000
238.409 Forward end structures of power car cabs:		
(a) Center collision post	2,500	5,000
(b) Side collision posts	2,500	5,000
(c) Corner posts	2,500	5,000
(d) Skin	2,500	5,000
238.411 Rear end structures of power car cabs:		
(a) Corner posts	2,500	5,000
(b) Collision posts	2,500	5,000
238.413 End structures of trailer cars	2,500	5,000
238.415 Rollover strength	2,500	5,000
238.417 Side loads	2,500	5,000
238.419 Truck-to-car-body and truck component attachment	2,500	5,000
238.421 Glazing:		
(b) End-facing exterior glazing	2,500	5,000
(c) Alternate glazing requirements	2,500	5,000
(d) Glazing securement	1,000	2,000
(e) Stenciling	2,500	5,000
238.423 Fuel tanks:		
(a) External fuel tanks	2,500	5,000
(b) Internal fuel tanks	2,500	5,000
238.425 Electrical system:		
(a) Circuit protection	2,500	5,000
(b) Main battery system	2,500	5,000
(c) Power dissipation resistors	2,500	5,000
(d) Electromagnetic interference and compatibility	2,500	5,000
238.427 Suspension system	2,500	5,000
238.429 Safety Appliances:		
(a) Couplers	5,000	7,500
(b) Hand/parking brakes	5,000	7,500
(d) Handrail and handhold missing	2,500	5,000
(d)(1)–(8) Handrail or handhold improper design	2,500	5,000
(e) Sill step missing	5,000	7,500
(e)(1)–(11) Sill step improper design	2,500	5,000
(g) Optional safety appliances	2,500	5,000
238.431 Brake system	2,500	5,000
238.433 Draft System	2,500	5,000
238.435 Interior fittings and surfaces	2,500	5,000
238.437 Emergency communication	2,500	5,000
238.439 Doors:		
(a) Exterior side doors	2,500	5,000
(b) Manual override feature	2,500	5,000

Section	Violation	Willful violation
(c) Notification to crew of door status	2,500	5,000
(d) Emergency back-up power	2,500	5,000
(f) End door kick-out panel or pop-out window	2,500	5,000
(g) Marking and instructions	[Reserved]	
238.441 Emergency roof hatch entrance location	2,500	5,000
238.443 Headlights	2,500	5,000
238.445 Automated monitoring	2,500	5,000
238.447 Train operator's controls and power car cab layout	2,500	5,000
SUBPART F—INSPECTION, TESTING, AND MAINTENANCE REQUIREMENTS FOR TIER II PASSENGER EQUIPMENT		
238.503 Inspection, testing, and maintenance requirements:		
(a) Failure to develop inspection, testing, and maintenance program or obtain FRA approval	10,000	15,000
(b) Failure to comply with provisions of the program	5,000	7,500
(c) Failure to ensure equipment free of conditions which endanger safety of crew, passengers, or equipment	2,500	5,000
(d) Specific safety inspections:		
(1)(i) Failure to perform Class I brake test or equivalent	10,000	15,000
(1)(ii) Partial failure to perform Class I brake test or equivalent	5,000	7,500
(2)(i) Failure to perform exterior mechanical inspection	[1] 2,000	4,000
(2)(ii) Failure to perform interior mechanical inspection	[1] 1,000	2,000
(g) Failure to perform scheduled maintenance as required in program	2,500	5,000
(h) Failure to comply with training, qualification and designation program	5,000	7,500
(i) Failure to develop or comply with standard procedures for performing inspection, tests, and maintenance	2,500	5,000
(j) Failure to conduct annual review	5,000	7,500
(k) Failure to establish or utilize quality control program	5,000	7,500
SUBPART G—SPECIFIC SAFETY PLANNING REQUIREMENTS FOR TIER II PASSENGER EQUIPMENT		
238.603 Safety plan:		
(a) Failure to develop safety operating plan	7,500	11,000
(b) Failure to develop procurement plan	7,500	11,000
(1)–(7) Failure to develop portion of plan	2,500	5,000
(c) Failure to maintain documentation	2,500	5,000

[1] A penalty may be assessed against an individual only for a willful violation Generally when two or more violations of these regulations are discovered with respect to a single unit of passenger equipment that is placed or continued in service by a railroad, the appropriate penalties set forth above are aggregated up to a maximum of $10,000 per day. However, failure to perform, with respect to a particular unit of passenger equipment, any of the inspections and tests required under subparts D and F of this part will be treated as a violation separate and distinct from, and in addition to, any substantive violative conditions found on that unit of passenger equipment. Moreover, the Administrator reserves the right to assess a penalty of up to $27,000 for any violation where circumstances warrant. *See* 49 CFR part 209, appendix A. Failure to observe any condition for movement of defective equipment set forth in §238.17 will deprive the railroad of the benefit of the movement-for-repair provision and make the railroad and any responsible individuals liable for penalty under the particular regulatory section(s) concerning the substantive defect(s) present on the unit of passenger equipment at the time of movement Failure to observe any condition for the movement of passenger equipment containing defective safety appliances, other than power brakes, set forth in §238.17(e) will deprive the railroad of the movement-for-repair provision and make the railroad and any responsible individuals liable for penalty under the particular regulatory section(s) contained in part 231 of this chapter or §238.429 concerning the substantive defective condition. The penalties listed for failure to perform the exterior and interior mechanical inspections and tests required under §238.303 and §238.305 may be assessed for each unit of passenger equipment contained in a train that is not properly inspected Whereas, the penalties listed for failure to perform the brake inspections and tests under §238.313 through §238.319 may be assessed for each train that is not properly inspected.

[64 FR 25660, May 12, 1999, as amended at 65 FR 41310, July 3, 2000; 67 FR 19994, Apr. 23, 2002]

EFFECTIVE DATE NOTE: At 72 FR 51198, Sept. 6, 2007, footnote 1 to appendix A to part 238 was amended by removing the numerical amount ''$10,000'' and adding in its place the numerical amount ''$16,000'', effective October 9, 2007.

APPENDIX B TO PART 238—TEST METHODS AND PERFORMANCE CRITERIA FOR THE FLAMMABILITY AND SMOKE EMISSION CHARACTERISTICS OF MATERIALS USED IN PASSENGER CARS AND LOCOMOTIVE CABS

This appendix contains the test methods and performance criteria for the flammability and smoke emission characteristics of materials used in passenger cars and locomotive cabs, in accordance with the requirements of §238.103.

(a) *Incorporation by reference.* Certain documents are incorporated by reference into this appendix with the approval of the Director of the Federal Register in accordance with 5 U.S.C. 552(a) and 1 CFR part 51. You may inspect a copy of each document during normal business hours at the Federal Railroad Administration, Docket Clerk, 1120

Vermont Ave., N.W., Suite 7000 or at the National Archives and Records Administration (NARA). For information on the availability of this material at NARA, call 202–741–6030, or go to: *http://www.archives.gov/federal_register/code_of_federal_regulations/ibr_locations.html*. The documents incorporated by reference into this appendix and the sources from which you may obtain these documents are listed below:

(1) American Society for Testing and Materials (ASTM), 100 Barr Harbor Dr., West Conshohocken, PA 19428–2959.

(i) ASTM C 1166–00, Standard Test Method for Flame Propagation of Dense and Cellular Elastomeric Gaskets and Accessories.

(ii) ASTM D 2724–87, Standard Test Methods for Bonded, Fused, and Laminated Apparel Fabrics.

(iii) ASTM D 3574–95, Standard Test Methods for Flexible Cellular Materials-Slab, Bonded, and Molded Urethane Foams.

(iv) ASTM D 3675–98, Standard Test Method for Surface Flammability of Flexible Cellular Materials Using a Radiant Heat Energy Source.

(v) ASTM E 119–00a, Standard Test Methods for Fire Tests of Building Construction and Materials.

(vi) ASTM E 162–98, Standard Test Method for Surface Flammability of Materials Using a Radiant Heat Energy Source.

(vii) ASTM E 648–00, Standard Test Method for Critical Radiant Flux of Floor-Covering Systems Using a Radiant Heat Energy Source.

(viii) ASTM E 662–01, Standard Test Method for Specific Optical Density of Smoke Generated by Solid Materials.

(ix) ASTM E 1354–99, Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter.

(x) ASTM E 1537–99, Standard Test Method for Fire Testing of Upholstered Furniture.

(xi) ASTM E 1590–01, Standard Test Method for Fire Testing of Mattresses.

(2) General Services Administration, Federal Supply Service, Specification Section, 470 E. L'Enfant Plaza, S.W., Suite 8100, Washington, D.C., 20407. FED-STD-191A-Textile Test Method 5830, Leaching Resistance of Cloth; Standard Method (July 20, 1978).

(3) State of California, Department of Consumer Affairs, Bureau of Home Furnishings and Thermal Insulation, 3485 Orange Grove Avenue, North Highlands, CA 95660–5595.

(i) California Technical Bulletin (Cal TB) 129, Flammability Test Procedure for Mattresses for Use in Public Buildings (October, 1992).

(ii) Cal TB 133, Flammability Test Procedure for Seating Furniture for Use in Public Occupancies (January, 1991).

(b) *Definitions.* As used in this appendix—

Average heat release rate ($\dot{q}''_{180}$) means, as defined in ASTM E 1354–99, the average heat release rate per unit area in the time period beginning at the time of ignition and ending 180 seconds later.

Critical radiant flux (C.R.F.) means, as defined in ASTM E 648–00, a measure of the behavior of horizontally-mounted floor covering systems exposed to a flaming ignition source in a graded radiant heat energy environment in a test chamber.

Flame spread index (I_s) means, as defined in ASTM E 162–98, a factor derived from the rate of progress of the flame front (F_s) and the rate of heat liberation by the material under test (Q), such that $I_s = F_s \times Q$.

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

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

Heat release rate means, as defined in ASTM E 1354–99, the heat evolved from a specimen per unit of time.

Specific extinction area (σ_f) means, as defined in ASTM E 1354–99, specific extinction area for smoke.

Specific optical density (D_s) means, as defined in ASTM E 662–01, the optical density measured over unit path length within a chamber of unit volume, produced from a specimen of unit surface area, that is irradiated by a heat flux of 2.5 watts/cm^2 for a specified period of time.

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

(c) *Required test methods and performance criteria.* The materials used in locomotive cabs and passenger cars shall be tested according to the methods and meet the performance criteria set forth in the following table and notes:

Test Procedures and Performance Criteria for the Flammability and Smoke Emission Characteristics of Materials Used in Passenger Cars and Locomotive Cabs

CATEGORY	FUNCTION OF MATERIAL	TEST METHOD	PERFORMANCE CRITERIA
Cushions, Mattresses	All [1,2,3,4,5,6,7,8]	ASTM D 3675-98	$I_s \le 25$
		ASTM E 662-01	$D_s(1.5) \le 100$ $D_s(4.0) \le 175$
Fabrics	Seat upholstery, mattress ticking and covers, curtains, draperies, wall coverings, and window shades [1,2,3,6,7,8]	14 CFR 25, Appendix F, Part I, (vertical test)	Flame time $\le$ 10 seconds Burn length $\le$ 6 inches
		ASTM E 662-01	$D_s(4.0) \le 200$
Other Vehicle Components [9,10,11,12]	Seat and mattress frames, wall and ceiling panels, seat and toilet shrouds, tray and other tables, partitions, shelves, opaque windscreens, end caps, roof housings, and component boxes and covers [1,2]	ASTM E 162-98	$I_s \le 35$
		ASTM E 662-01	$D_s(1.5) \le 100$ $D_s(4.0) \le 200$
	Flexible cellular foams used in armrests and seat padding [1,2,4,6]	ASTM D 3675-98	$I_s \le 25$
		ASTM E 662-01	$D_s(1.5) \le 100$ $D_s(4.0) \le 175$
	Thermal and acoustic insulation [1,2]	ASTM E 162-98	$I_s \le 25$
		ASTM E 662-01	$D_s(4.0) \le 100$
	HVAC ducting [1,2]	ASTM E 162-98	$I_s \le 35$
		ASTM E 662-01	$D_s(4.0) \le 100$
	Floor covering [12,13]	ASTM E 648-00	C.R.F. $\ge$ 5 kW/m^2
		ASTM E 662-01	$D_s(1.5) \le 100$ $D_s(4.0) \le 200$
	Light diffusers, windows and transparent plastic windscreens [2,14]	ASTM E 162-98	$I_s \le 100$
		ASTM E 662-01	$D_s(1.5) \le 100$ $D_s(4.0) \le 200$
Elastomers [1,10,11]	Window gaskets, door nosings, inter-car diaphragms, roof mats, and seat springs	ASTM C 1166-00	Average flame propagation $\le$ 4 inches
		ASTM E 662-01	$D_s(1.5) \le 100$ $D_s(4.0) \le 200$
Structural Components [15]	Flooring [16], Other [17]	ASTM E 119-00a	Pass

[1] Materials tested for surface flammability shall not exhibit any flaming running or dripping.

[2] The ASTM E 662 01 maximum test limits for smoke emission (specific optical density) shall be measured in either the flaming or

[1] Materials tested for surface flammability shall not exhibit any flaming running or dripping.

[2] The ASTM E 662–01 maximum test limits for smoke emission (specific optical density) shall be measured in either the flaming or

non-flaming mode, utilizing the mode which generates the most smoke.

[3] Testing of a complete seat assembly (including cushions, fabric layers, upholstery) according to ASTM E 1537–99 using the pass/fail criteria of Cal TB 133, and testing of a complete mattress assembly (including foam and ticking) according to ASTM E 1590–01 using the pass/fail criteria of Cal TB 129 shall be permitted in lieu of the test methods prescribed herein, provided the assembly component units remain unchanged or new (replacement) assembly components possess equivalent fire performance properties to the original components tested. A fire hazard analysis must also be conducted that considers the operating environment within which the seat or mattress assembly will be used in relation to the risk of vandalism, puncture, cutting, or other acts which may expose the individual components of the assemblies to an ignition source. Notes 5, 6, 7, and 8 apply.

[4] Testing is performed without upholstery.

[5] The surface flammability and smoke emission characteristics shall be demonstrated to be permanent after dynamic testing according to ASTM D 3574–95, Test I_2 (Dynamic Fatigue Test by the Roller Shear at Constant Force) or Test I_3 (Dynamic Fatigue Test by Constant Force Pounding) both using Procedure B, except that the test samples shall be a minimum of 6 inches (154 mm) by 18 inches (457 mm) by the thickness of the material in its end use configuration, or multiples thereof. If Test I_3 is used, the size of the indentor described in paragraph 96.2 shall be modified to accommodate the specified test specimen.

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

[7] The surface flammability and smoke emission characteristics shall be demonstrated to be permanent by dry-cleaning, if appropriate, according to ASTM D 2724–87.

[8] Materials that cannot be washed or dry-cleaned shall be so labeled and shall meet the applicable performance criteria after being cleaned as recommended by the manufacturer.

[9] Signage is not required to meet any flammability or smoke emission performance criteria specified in this Appendix.

[10] Materials used to fabricate miscellaneous, discontinuous small parts (such as knobs, rollers, fasteners, clips, grommets, and small electrical parts) that will not contribute materially to fire growth in end use configuration are exempt from flammability and smoke emission performance requirements, provided that the surface area of any individual small part is less than 16 square inches (100 cm^2) in end use configuration and an appropriate fire hazard analysis is conducted which addresses the location and quantity of the materials used, and the vulnerability of the materials to ignition and contribution to flame spread.

[11] If the surface area of any individual small part is less than 16 square inches (100 cm^2) in end use configuration, materials used to fabricate such a part may be tested in accordance with ASTM E 1354–99 as an alternative to both (a) the ASTM E 162–98 flammability test procedure, or the appropriate flammability test procedure otherwise specified in the table, and (b) the ASTM E 662–01 smoke generation test procedure. Testing shall be at 50 kW/m^2 applied heat flux with a retainer frame. Materials tested in accordance with ASTM E 1354–99 shall meet the following performance criteria: average heat release rate ($\dot{q}''_{180}$) less than or equal to 100 kW/m^2, and average specific extinction area (σ_f) less than or equal to 500 m^2/kg over the same 180-second period.

[12] Carpeting used as a wall or ceiling covering shall be tested according to ASTM E 162–98 and ASTM E 662–01 and meet the respective criteria of I_s less than or equal to 35 and D_s (1.5) less than or equal to 100 and D_s (4.0) less than or equal to 200. Notes 1 and 2 apply.

[13] Floor covering shall be tested with padding in accordance with ASTM E 648–00, if the padding is used in the actual installation.

[14] For double window glazing, only the interior glazing is required to meet the requirements specified herein. (The exterior glazing is not required to meet these requirements.)

[15] Penetrations (ducts, etc.) shall be designed against acting as passageways for fire and smoke and representative penetrations shall be included as part of test assemblies.

[16] A structural flooring assembly separating the interior of a vehicle from its undercarriage shall meet the performance criteria during a nominal test period as determined by the railroad. The nominal test period must be twice the maximum expected time period under normal circumstances for a vehicle to stop completely and safely from its maximum operating speed, plus the time necessary to evacuate all the vehicle's occupants to a safe area. The nominal test period must not be less than 15 minutes. Only one specimen need be tested. A proportional reduction may be made in the dimensions of the specimen provided it serves to truly test the ability of the structural flooring assembly to perform as a barrier against under-vehicle fires. The fire resistance period required shall be consistent with the safe evacuation of a full load of passengers from the vehicle under worst-case conditions.

[17] Portions of the vehicle body which separate major ignition sources, energy sources, or sources of fuel-load from vehicle interiors, shall have sufficient fire endurance as determined by a fire hazard analysis acceptable to

the railroad which addresses the location and quantity of the materials used, as well as vulnerability of the materials to ignition, flame spread, and smoke generation. These portions include equipment carrying portions of a vehicle's roof and the interior structure separating the levels of a bi-level car, but do not include a flooring assembly subject to Note 16. A railroad is not required to use the ASTM E 119–00a test method.

[67 FR 42910, June 25, 2002]

Appendix C to Part 238—Suspension System Safety Performance Standards

This appendix contains the minimum suspension system safety performance standards for Tier II passenger equipment as required by § 238.427. These requirements shall be the basis for evaluating suspension system safety performance until an industry standard acceptable to FRA is developed and approved under the procedures provided in § 238.21.

(a) Passenger equipment suspension systems shall be designed to limit the lateral and vertical forces and lateral to vertical (L/V) ratios, for the time duration required to travel five feet at any operating speed or over any class of track, under all operating conditions as determined by the railroad, as follows:

(1) The maximum single wheel lateral to vertical force (L/V) ratio shall not exceed Nadal's limit as follows:

$$\text{Wheel L/V} \le \frac{\tan(\delta) - \mu}{1 + \mu \tan(\delta)}$$

where:

δ=flange angle (deg).

μ=coefficient of friction of 0.5.

(2) The net axle lateral force shall not exceed 0.5 times the static vertical axle load.

(3) The vertical wheel/rail force shall not be less than or equal to 10 percent of the static vertical wheel load.

(4) The sum of the vertical wheel loads on one side of any truck shall not be less than or equal to 20 percent of the static vertical axle load. This shall include the effect of a crosswind allowance as specified by the railroad for the intended service.

(5) The maximum truck side L/V ratio shall not exceed 0.6.

(6) When stopped on track with a uniform 6-inch superelevation, vertical wheel loads, at all wheels, shall not be less than or equal to 60 percent of the nominal vertical wheel load on level track.

(b) For purposes of this appendix, wheel/rail force measurements shall be processed through a low pass filter having a cut-off frequency of 25 Hz.

Appendix D to Part 238—Requirements for External Fuel Tanks on Tier I Locomotives

The requirements contained in this appendix are intended to address the structural and puncture resistance properties of the locomotive fuel tank to reduce the risk of fuel spillage to acceptable levels under derailment and minor collision conditions.

(a) *Structural strength*—(1) *Load case 1—minor derailment*. The end plate of the fuel tank shall support a sudden loading of one-half the weight of the car body at a vertical acceleration of 2g, without exceeding the ultimate strength of the material. The load is assumed to be supported on one rail, within an eight inch band (plus or minus) at a point nominally above the head of the rail, on tangent track. Consideration should be given in the design of the fuel tank to maximize the vertical clearance between the top of the rail and the bottom of the fuel tank.

(2) *Load case 2—jackknifed locomotive*. The fuel tank shall support transversely at the center a sudden loading equivalent to one half the weight of the locomotive at a vertical acceleration of 2g, without exceeding the ultimate strength of the material. The load is assumed to be supported on one rail, distributed between the longitudinal center line and the edge of the tank bottom, with a rail head surface of two inches.

(3) *Load case 3—side impact*. In a side impact collision by an 80,000 pound Gross Vehicle Weight tractor/trailer at the longitudinal center of the fuel tank, the fuel tank shall withstand, without exceeding the ultimate strength, a 200,000 pound load (2.5g) distributed over an area of six inches by forty-eight inches (half the bumper area) at a height of thirty inches above the rail (standard DOT bumper height).

(4) *Load case 4—penetration resistance*. The minimum thickness of the sides, bottom sheet and end plates of the fuel tank shall be equivalent to a 5⁄16-inch steel plate with a 25,000 pounds-per-square-inch yield strength (where the thickness varies inversely with the square root of yield strength). The lower one third of the end plates shall have the equivalent penetration resistance by the above method of a 3⁄4-inch steel plate with a 25,000 pounds-per-square-inch yield strength. This may be accomplished by any combination of materials or other mechanical protection.

(b) *Sideswipe*. To minimize fuel tank damage during sideswipes (railroad vehicles and grade crossings), all drain plugs, clean-out ports, inspection covers, sight glasses, gauge openings, etc., must be flush with the tank surface or adequately protected to avoid catching foreign objects or breakage. All seams must be protected or flush to avoid catching foreign objects.

(c) *Spill controls.* Vents and fills shall be designed to avert spillage of fuel in the event of a roll over.

APPENDIX E TO PART 238—GENERAL PRINCIPLES OF RELIABILITY-BASED MAINTENANCE PROGRAMS

(a) Any maintenance program has the following four basic objectives:

(1) To ensure realization of the design level of safety and reliability of the equipment;

(2) To restore safety and reliability to their design levels when deterioration has occurred;

(3) To obtain the information necessary for design improvements of those items whose design reliability proves inadequate; and

(4) To accomplish these goals at a minimum total cost, including maintenance costs and the costs of residual failures.

(b) Reliability-based maintenance programs are based on the following general principles. A failure is an unsatisfactory condition. There are two types of failures: functional and potential. Functional failures are usually reported by operating crews. Conversely, maintenance crews usually discover potential failures. A potential failure is an identifiable physical condition, which indicates that a functional failure is imminent. The consequences of a functional failure determine the priority of a maintenance effort. These consequences fall into the following general categories:

(1) Safety consequences, involving possible loss of the equipment and its occupants;

(2) Operational consequences, which involve an indirect economic loss as well as the direct cost of repair;

(3) Non-operational consequences, which involve only the direct cost of repair; or

(4) Hidden failure consequences, which involve exposure to a possible multiple failure as a result of the undetected failure of a hidden function.

(c) In a reliability-based maintenance program, scheduled maintenance is required for any item whose loss of function or mode of failure could have safety consequences. If preventative tasks cannot reduce the risk of such failures to an acceptable level, the item requires redesign to alter its failure consequences. Scheduled maintenance is also required for any item whose functional failure will not be evident to the operating crew, and therefore reported for corrective action. In all other cases the consequences of failure are economic, and maintenance tasks directed at preventing such failures must be justified on economic grounds. All failure consequences, including economic consequences, are established by the design characteristics of the equipment and can be altered only by basic changes in the design. Safety consequences can, in nearly all cases, be reduced to economic consequences by the use of redundancy. Hidden functions can usually be made evident by instrumentation or other design features. The feasibility and cost effectiveness of scheduled maintenance depend on the inspectablility of the component, and the cost of corrective maintenance depends on its failure modes and design reliability.

(d) The design reliability of equipment or components will only be achieved with an effective maintenance program. This level of reliability is established by the design of each component and the manufacturing processes that produced it. Scheduled maintenance can ensure that design reliability of each component is achieved, but maintenance alone cannot yield a level of reliability beyond the design reliability.

(e) When a maintenance program is developed, it includes tasks that satisfy the criteria for both applicability and effectiveness. The applicability of a task is determined by the characteristics of the component or equipment to be maintained. The effectiveness is stated in terms of the consequences that the task is designed to prevent. The basics types of tasks that are performed by maintenance personnel are each applicable under a unique set of conditions. Tasks may be directed at preventing functional failures or preventing a failure event consisting of the sequential occurrence of two or more independent failures which may have consequences that would not be produced by any of the failures occurring separately. The task types include:

(1) Inspections of an item to find and correct any potential failures;

(2) Rework/remanufacture/overhaul of an item at or before some specified time or age limit;

(3) Discard of an item (or parts of it) at or before some specified life limit; and

(4) Failure finding inspections of a hidden-function item to find and correct functional failures that have already occurred but were not evident to the operating crew.

(b) Components or systems in a reliability-based maintenance program may be defined as simple or complex. A simple component or system is one that is subject to only one or a very few failure modes. This type of component or system frequently shows decreasing reliability with increasing operating age. An age/time limit may be used to reduce the overall failure rate of simple components or systems. Here, safe-life limits, fail-safe designs, or damage tolerance-based residual life calculations may be imposed on a single component or system to play a crucial role in controlling critical failures. Complex components or systems are ones whose functional failure may result from many different failure modes and show little or no decrease in overall reliability with increasing age unless there is a dominant failure mode. Therefore, age limits imposed on complex components or systems have little or no effect on their overall failure rates.

(g) When planning the maintenance of a component or system to protect the safety and operating capability of the equipment, a number of items must be considered in the reliability assessment process:

(1) The consequences of each type of functional failure;

(2) The visibility of a functional failure to the operating crew (evidence that a failure has occurred);

(3) The visibility of reduced resistance to failure (evidence that a failure is imminent);

(4) The age-reliability characteristics of each item;

(5) The economic tradeoff between the cost of scheduled maintenance and the benefits to be derived from it;

(6) A multiple failure, resulting from a sequence of independent failures, may have consequences that would not be caused by any one of the individual failures alone. These consequences are taken into account in the definition of the failure consequences for the first failure; and

(7) A default strategy governs decision making in the absence of full information or agreement. This strategy provides for conservative initial decisions, to be revised on the basis of information derived from operating experience.

(h) A successful reliability-based maintenance program must be dynamic. Any prior-to-service program is based on limited information. As such, the operating organization must be prepared to collect and respond to real data throughout the operating life of the equipment. Management of the ongoing maintenance program requires an organized information system for surveillance and analysis of the performance of each item under actual operating conditions. This information is needed to determine the refinements and modifications to be made in the initial maintenance program (including the adjustment of task intervals) and to determine the need for product improvement. The information derived from operating experience may be considered to have the following hierarchy of importance in the reliability-based maintenance program:

(1) Failures that could affect operating safety;

(2) Failures that have operational consequences;

(3) The failure modes of units removed as a result of failures;

(4) The general condition of unfailed parts in units that have failed; and

(5) The general condition of serviceable units inspected as samples.

(i) At the time an initial maintenance program is developed, information is usually available to determine the tasks necessary to protect safety and operating capability. However, the information required to determine optimum task intervals and the applicability of age or life limits can be obtained only from age or life exploration after the equipment enters service. With any new equipment there is always the possibility of unanticipated failure modes. The first occurrence of any serious unanticipated failure should immediately set into motion the following improvement cycle:

(1) An inspection task is developed to prevent recurrences while the item is being redesigned;

(2) The operating fleet is modified to incorporate the redesigned part; and

(3) After the modification has proved successful, the special inspection task is eliminated from the maintenance program.

(j) Component improvements based on identification of the actual reliability characteristics of each item through age or life exploration, is part of the normal development cycle of all complex equipment.

PART 239—PASSENGER TRAIN EMERGENCY PREPAREDNESS

Subpart A—General

Sec.

Subpart B—Specific Requirements

Subpart C—Review, Approval, and Retention of Emergency Preparedness Plans

Subpart D—Operational (Efficiency) Tests; Inspection of Records and Recordkeeping

AUTHORITY: 49 U.S.C. 20102–20103, 20105–20114, 20133, 21301, 21304, and 21311; 28 U.S.C. 2461, note; and 49 CFR 1.49(c), (g), (m).

TAB II:
RESEARCH BY UNDERWRITERS LABORATORIES

the standard in safety

Investigation of the fire performance of materials and products for use in U.S. railcar and bus applications

Presented to

FTA Technical Advisory Committee

May 6, 2008

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Jacob L. Borgerson, Ph.D.

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Overview

- Acknowledgements
- Motivation
- Summary of findings
- Project overview & objectives
- Background
- Hazard assessment methodology
- Fire performance data
- Data analysis
- Fire performance metrics
- Summary and conclusions
- Future work

Acknowledgements

- National Association of State Fire Marshals' (NASFM) Safe Energy and Transportation Task Force
- Federal Transit Administration (FTA) Technical Advisory Committee
- GE Advanced Materials Research Project on Railcar Materials

Motivation

- $25 million per year in direct property damage to passenger railcars and buses is caused by fires (Ahrens, 2005)
- 700 fire-related incidents occurred in the U.S. from 1999 to 2003 involving passenger railcars, causing an estimated 25 deaths and 335 injuries (Ahrens, 2005)
- 6 bus or school bus fires occur each day on average (Ahrens, 2006)
- Important to develop methods to aide in fire prevention and control of first items ignited

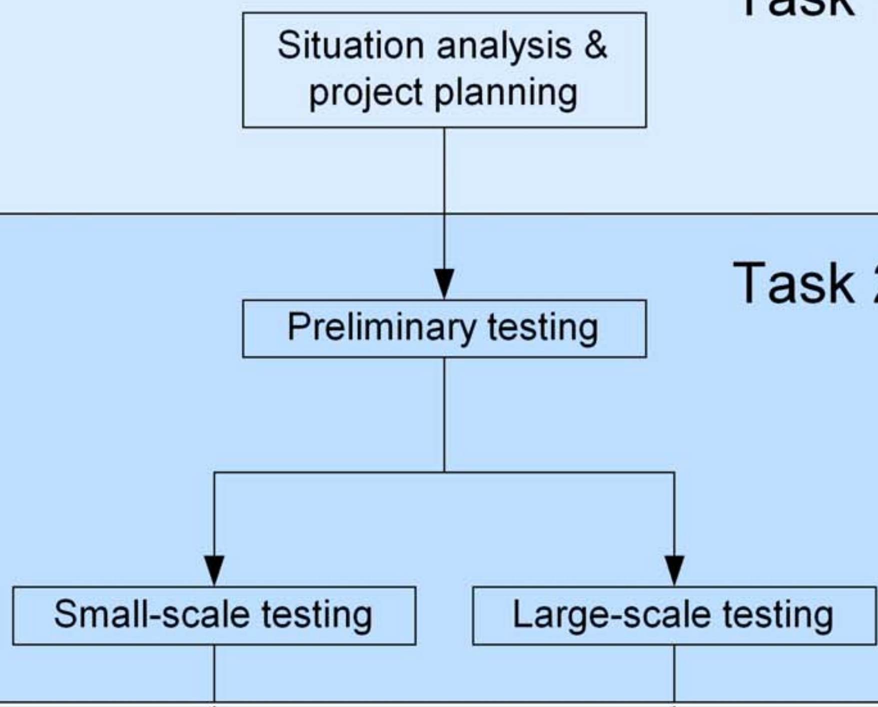
Summary of findings

- Considerable research conducted by NIST on fire performance of railcar materials/components
- CBUF research (Sundström, 1995) provides good reference for fire performance characteristics of furniture, which is applicable to bus and railcar seats
- More robust fire performance regulations for materials exist in other high risk environments (e.g. IMO, Building Codes, CAL TB 133)
- A risk/hazard-based approach can assist to develop an appropriate fire safety strategy
  - Define fire safety objectives
  - Identify reference test models for railcar and bus
  - Determine fire performance metrics and describe threshold hazard
  - Identify small-scale test methods that correlate to the reference model

Summary of findings

- Current U.S. railcar and bus standards are in need of re-examination
  - Commercial railcar wall and ceiling materials
    - Comply with FRA requirements using small-scale test methods
    - Some materials develop significant fire challenge in the reference test model considered in this investigation (i.e. NFPA 286 room corner test)
    - Results from EN methods provide better correlations to results from reference test model
  - Commercial bus seating materials
    - Comply with FMVSS 302 requirement
    - Some bus seat samples create a large fire source for secondary fire pathways in a bus when a larger ignition source is used

Project overview & objectives



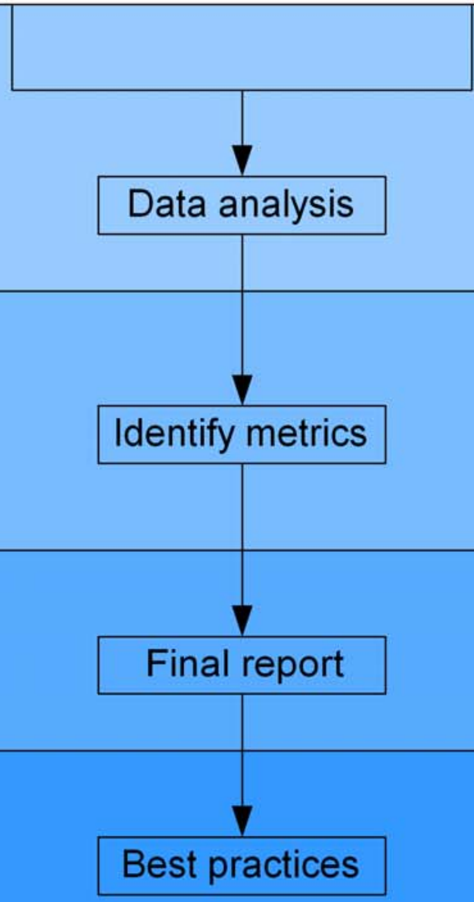
Task 1

- Provide necessary background on current regulations and previous research
- Formulate test plan including selection of test materials, test parameters, and test methods

Task 2

- Conduct preliminary cone calorimeter tests on test materials
- Perform small-scale tests to obtain fire performance metrics
- Perform large-scale tests to be used for validation of small-scale tests

Project overview & objectives



Task 3 - Use various analysis techniques to correlate small-scale data to large-scale results

Task 4 - Identify key performance metrics to classify fire growth and speed
- Validate metrics using results from large-scale experiments

Task 5 - Detail project in the form of a written report

Task 6 - Work with technical advisory panel to reach a consensus on best practices

Task 1: Situation analysis & project planning

- Background on railcars and buses
  - Fire incidents
  - Current regulations
  - Previous research
- Hazard assessment methodology
  - Fire safety objectives
  - Fire development stages
  - Fire protection strategy
  - Prevention in favor of mitigation
  - Scaling test results from small-scale to large-scale

Background

- Fire incidents involving railcars and buses
- Current U.S. and international regulations
- Literature review on previous research

Railcar fire incidents

Notable fire incidents involving passenger railcars

Date	Location	Description	Ignition source
Aug 25, 2007	Micro, North Carolina	Intercity train. Engine room fire. No injuries.	Engine
May 15, 2003	Ladhowal, India	Intercity train. Fire origin unknown. 39 dead. 15 seriously injured.	Unknown
Nov 6, 2002	Nancy, France	Intercity train. Hot plate igniting jacket. 12 dead.	Kitchenette hot plate
Feb 20, 2002	Cairo, Egypt	Intercity train. Propane gas cylinder explosion. 363 dead.	Propane gas cylinder
Nov 11, 2000	Kaprun, Austria	Commuter train. Overheating and ignition of electric heater. 155 dead.	Electric heater
June 23, 1982	Gibson, California	Intercity train. Cigarette discarded on a cushion. 2 dead. 2 seriously injured.	Cigarette
Jan 17, 1979	San Francisco, California	Commuter train. Short circuit started fire. 1 dead. 40 seriously injured.	Short circuit
Jul 6, 1978	Taunton, England	Intercity train. Electric heater ignited plastic bags and dirty linen. 12 dead. 15 seriously injured.	Electric heater

Bus fire incidents

Notable fire incidents involving passenger buses

Date	Location	Description	Ignition source
Aug 27, 2007	Lewisburg, Pennsylvania	Intercity bus. Engine fire. No injuries.	Engine
Oct 23, 2006	Panama City, Panama	Intercity bus. Engine overheated, igniting insulation. 18 dead. 25 seriously injured.	Engine
Sept 23, 2005	Wilmer, Texas	Intercity bus. Improper lubrication of wheel assembly, leading to excess friction and heat generation. 23 dead. 2 seriously injured.	Wheel assembly
Jan 29, 1991	Bellwood, Illinois	Commuter bus. High-voltage power line fell on a bus. 1 dead. 1 seriously injured.	Power line

U.S. vehicle fire problem

U.S. vehicle fire problem, by type of vehicle, 1999-2002 annual averages (Ahrens, 2005)

Vehicle Type	Fires		Civilian deaths		Civilian injuries		Direct Property Damage (in millions)	
Passenger road vehicle	243,830	(70%)	316	(64%)	1,099	(61%)	$796	(57%)
Freight road vehicle	26,060	(7%)	67	(13%)	210	(12%)	$209	(15%)
Industrial, agricultural, or construction vehicle	8,350	(2%)	8	(2%)	59	(3%)	$103	(7%)
Water vessel	1,490	(0%)	3	(1%)	58	(3%)	$24	(2%)
Rail transport vehicle	770	(0%)	6	(1%)	79	(4%)	$17	(1%)
Aircraft	230	(0%)	35	(7%)	19	(1%)	$12	(1%)
Other	68,850	(20%)	61	(12%)	278	(15%)	$240	(17%)

U.S. rail transport vehicle fires

U.S. rail transport vehicle fires, by factor contributing to ignition, 1999-2002 (Ahrens, 2005)

Factor contributing to ignition	Fires	Civilian deaths	Civilian injuries	Direct property damage
Mechanical failure or malfunction	27%	0%	0%	27%
Leak or break	13%	0%	33%	23%
Cutting/welding close to combustible material	8%	0%	0%	3%
Electrical failure or malfunction	8%	0%	0%	2%
Heat source close to combustible material	5%	0%	0%	2%
Short circuit arc	5%	0%	0%	1%
Worn out	4%	0%	0%	0%
Exposure fire	3%	0%	0%	32%
Backfire	2%	0%	0%	0%
Discarded material/product	2%	0%	0%	0%

U.S. bus and school bus fires

U.S. bus and school bus fires, by factor contributing to ignition, 1999-2003 (Ahrens, 2006)

Factor contributing to ignition	**Fires**	**Civilian deaths**	**Civilian injuries**	**Direct property damage**
Mechanical failure or malfunction	36%	100%	35%	35%
Leak or break	14%	0%	6%	15%
Short circuit arc	12%	0%	9%	5%
Electrical failure or malfunction	10%	0%	22%	13%
Worn out	5%	0%	0%	1%
Exposure fire	4%	0%	0%	7%
Backfire	3%	0%	0%	1%
Misuse of material/product	2%	0%	0%	1%
Flammable liquid/gas spilled	2%	0%	0%	3%

Current U.S. rail and bus regulations

U.S. fire performance requirements for rail and bus materials

Form of Transport	Application	Test procedure	Performance criteria	Organization
Rail	Ceiling & wall	ASTM E 162	Flame spread index $I_S \leq 35$	FRA, NFPA
Rail	Ceiling & wall	ASTM E 662	Specific optical density $D_S(1.5) \leq 100$, $D_S(4.0) \leq 200$	FRA, NFPA
Bus	Seating	FMVSS 302	Burn rate < 102 mm/min	NHTSA

Proposed EN rail regulations

EN fire performance requirements for rail materials (prEN 45545-1, 45545-2)

Application	Test procedure	Performance criteria	
Ceiling & wall	ISO 5658-2	Critical heat flux at extinguishment	
		HL1: CHF $\geq$ 23.9	HL2: CHF $\geq$ 23.9
		HL3: CHF $\geq$ 30.9	HL4: CHF $\geq$ 37.8
Ceiling & wall	ISO 5659-2	Specific optical density	
		HL1: $D_S(4.0) \leq 600$	HL2: $D_S(4.0) \leq 300$
		HL3: $D_S(4.0) \leq 300$	HL4: $D_S(4.0) \leq 150$
Ceiling & wall	ISO 5659-2	Valeur obscurcissement fumée in 4 min	
		HL1: VOF4 $\leq$ 1200	HL2: VOF4 $\leq$ 600
		HL3: VOF4 $\leq$ 600	HL4: VOF4 $\leq$ 300
Ceiling & wall	ISO 5659-2	Conventional index of toxicity at 8 min	
		HL1: CIT $\leq$ 1.2	HL2: CIT $\leq$ 0.9
		HL3: CIT $\leq$ 0.9	HL4: CIT $\leq$ 0.75
Ceiling & wall	ISO 5660-1	Max average rate of heat emission	
		HL1: -	HL2: MARHE $\leq$ 90
		HL3: MARHE $\leq$ 90	HL4: MARHE $\leq$ 60

**HL4 represents most dangerous operation/design category, HL1 represents safest category

Valeur Obscurcissement Fumée in 4 min

VOF4 is the area under the D_S versus time curve during the period t=0 to t=4; using trapezoidal rule with discrete time step of t=1 min (prEN 45545-2)

$$\text{VOF4} = \sum_{i=0}^{3} \frac{t\left(D_S(i) + D_S(i+1)\right)}{2}$$

D_S : Specific optical density

t : Time

Conventional Index of Toxicity

CIT is a dimensionless summation of relative amounts of gas components (prEN 45545-2)

$$\mathrm{CIT} = 0.0805\sum_{i=0}^{8}\frac{c_i}{C_i}$$

c_i : concentration of ith gas

C_i : Reference concentation of ith gas

Gas components		Reference concentration (mg/m^3)
CO_2	Carbon dioxide	72,000
CO	Carbon monoxide	1380
HF	Hydrogen flouride	25
HCl	Hydrogen chloride	75
HBr	Hydrogen bromide	99
HCN	Hydrogen cyanide	55
NO_2	Nitrogen dioxide	38
SO_2	Sulphur dioxide	262

Maximum Average Rate of Heat Emission

Average Rate of Heat Emission at time t is defined as the cumulative heat emission in the period t=0 to t=t divided by t (prEN 45545-2)

$$\mathrm{ARHE}(t_i) = \frac{\sum_{i=2}^{n}\left((t_i - t_{i-1}) \times \frac{(\dot{q}_i + \dot{q}_{i-1})}{2}\right)}{t_i - t_1}$$

$\dot{q}$: Heat release rate

t : Time

Maximum Average Rate of Heat Emission is then maximum value of the ARHE curve

$$\mathrm{MARHE} = \mathrm{ARHE}_{\mathrm{MAX}}$$

Previous railcar research

- In mid 70s, NIST became involved with fire safety for passenger rail transportation
  - Identified hazards for subway cars in Washington D.C. area (Braun, 1975)
  - Examined subway cars in San Francisco area (Braun, 1978)
  - Determined that primary hazards were seat assemblies and walls of car
- Later, a study was conducted on Amtrak passenger railcars (Peacock & Braun, 1984)
  - Performed small-scale, large-scale, and real-scale tests
  - Discovered geometry and material interaction are critical elements for fire performance of a system

Previous railcar research

- Recently NIST completed 3-phase study for FRA
  - Phase 1 evaluated various properties of railcar interior materials using cone calorimeter (Peacock & Braun, 1999)
  - Phase 2 used cone calorimeter data in conjunction with full-scale assembly results, to perform computer fire analysis (Peacock et al., 2002)
  - Phase 3 performed real-scale tests on a railcar to evaluate the ability that small-scale tests, large-scale tests, and computer modeling could predict fire behavior (Peacock et al., 2004)

Previous bus research

- In early 90s, NIST completed series of studies on school bus components (Braun et al., 1990)
  - Focused on seat assemblies
  - Conducted full-scale testing and computer modeling to determine time-to-untenable conditions
- In related work, the CBUF research program performed in-depth study on fire performance of upholstered furniture (Sundström, 1995)
- Compared to railcars, little research has been conducted on fire safety for passenger buses

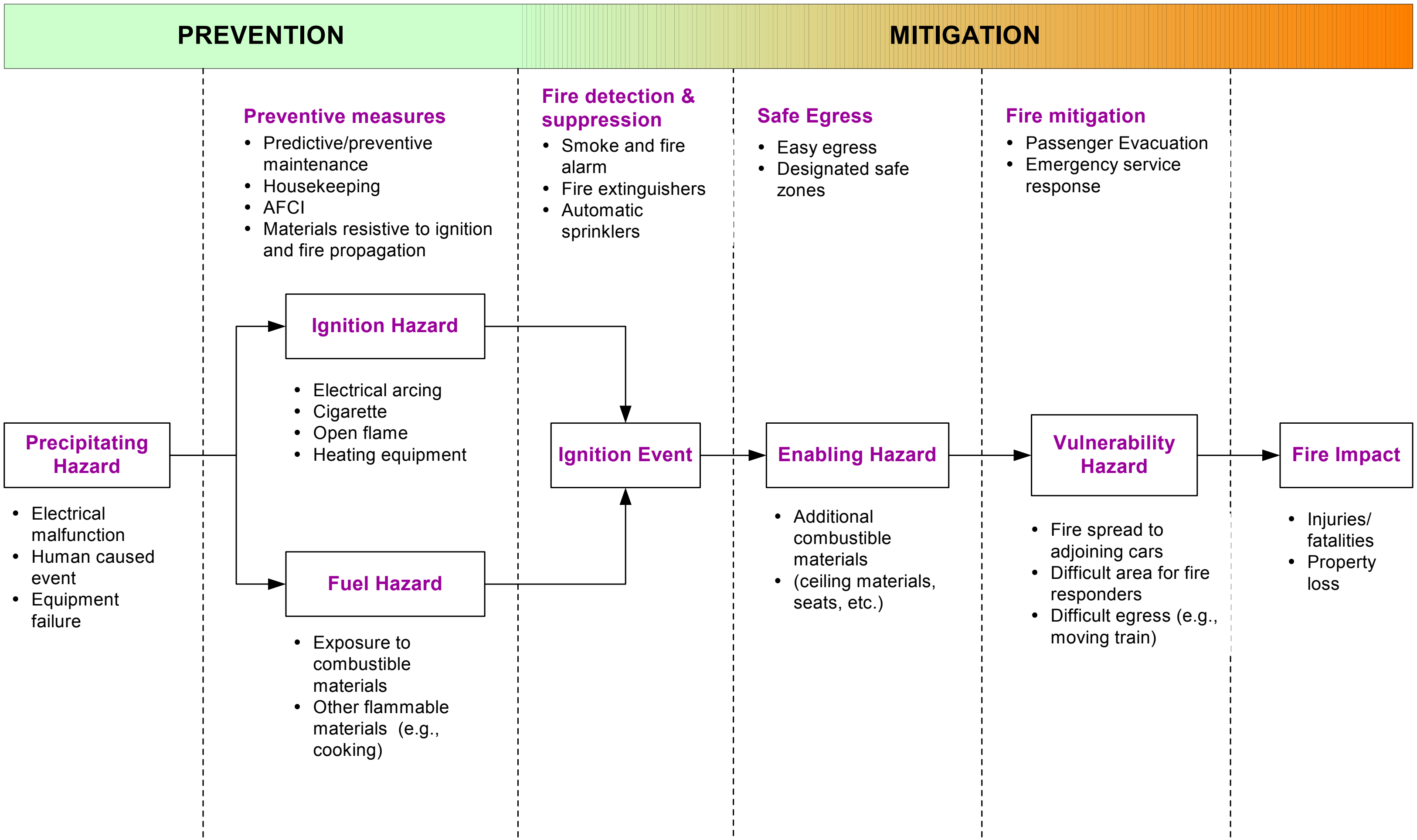
Hazard assessment methodology

- Fire safety objectives
- Fire development stages
- Fire protection strategy
- Prevention in favor of mitigation
- Scaling test results from small-scale to large-scale

Fire safety objectives

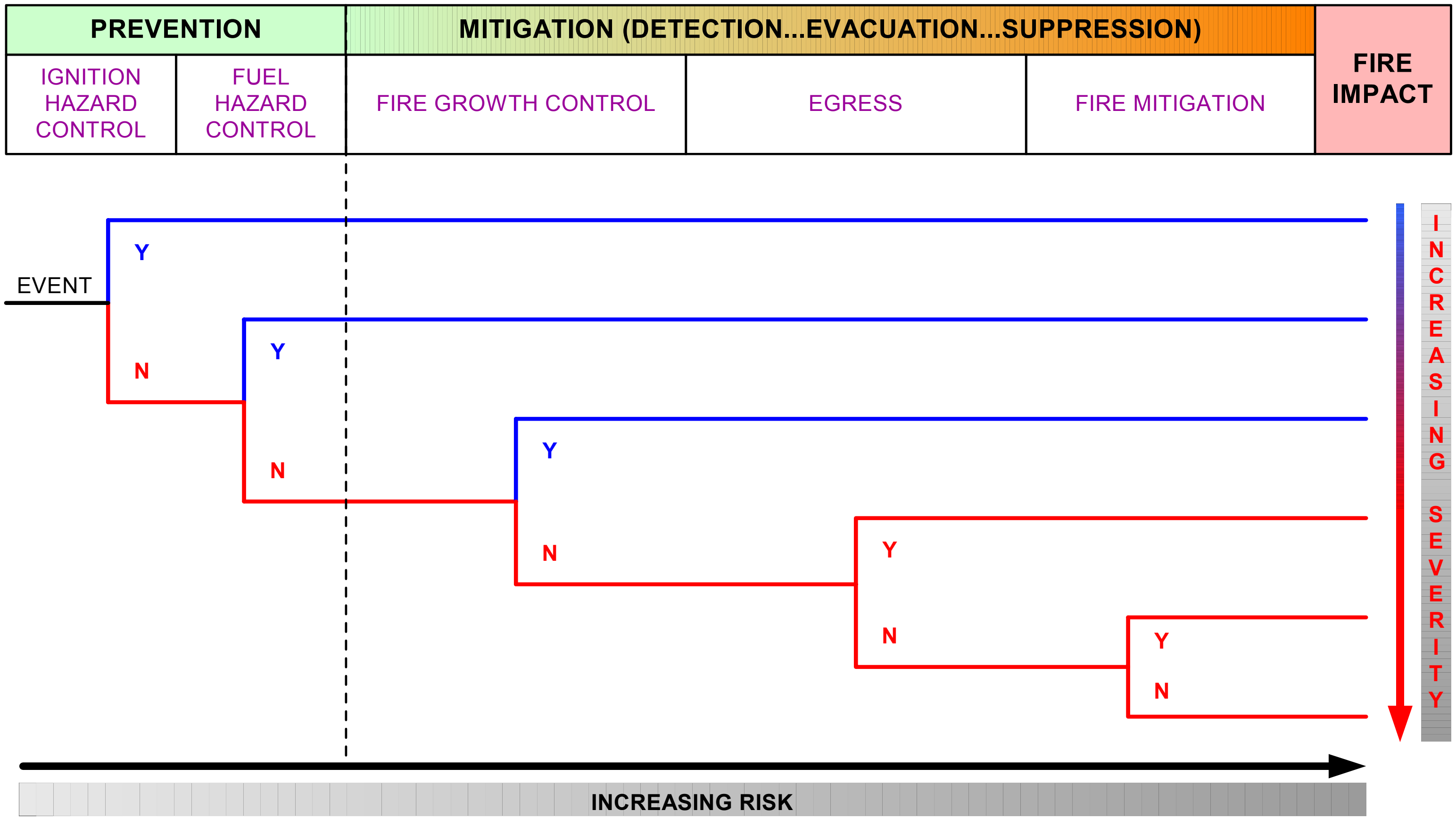
- Prevent ignition due to common ignition sources (e.g. small open flames, heating equipment)
- Limit fire growth and spread
  - Limit heat release
  - Limit smoke release
  - Limit toxic potential of evolved gases

Fire development stages



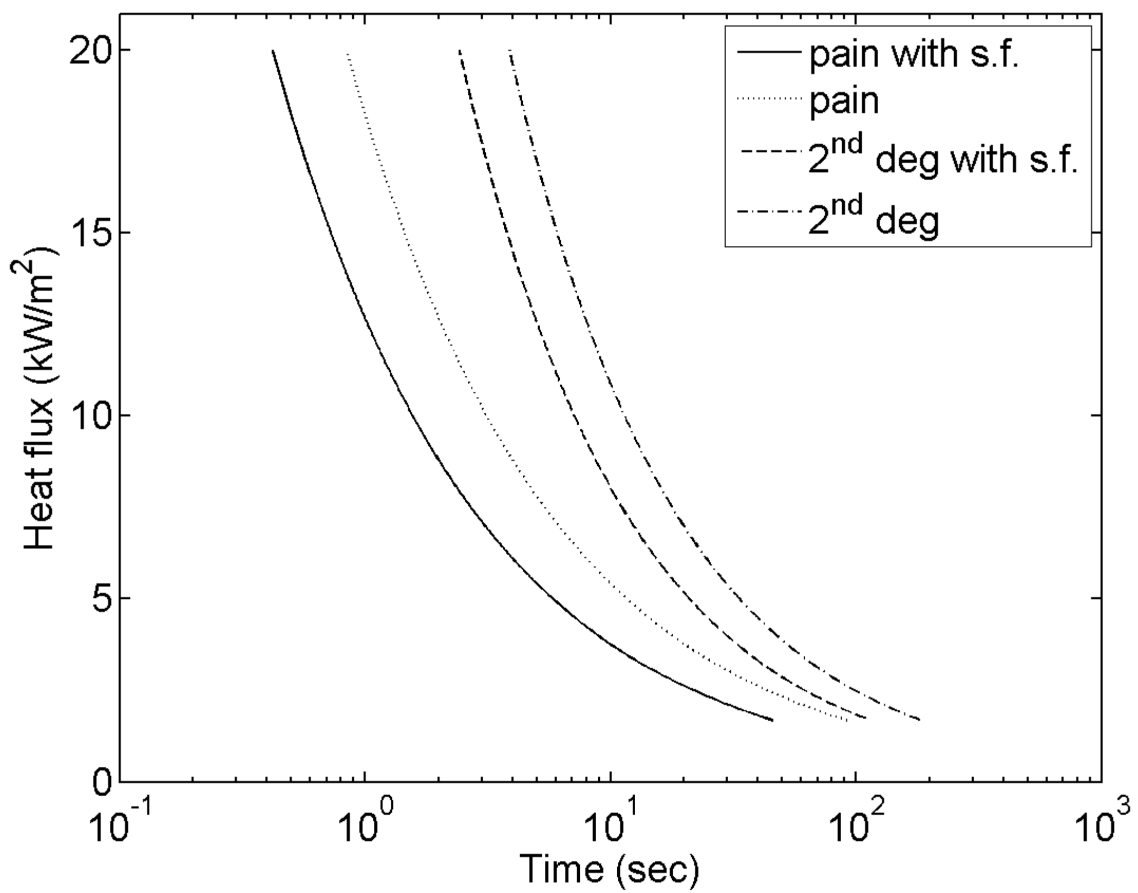
Stages of fire development within fire prevention and mitigation

Fire protection strategy



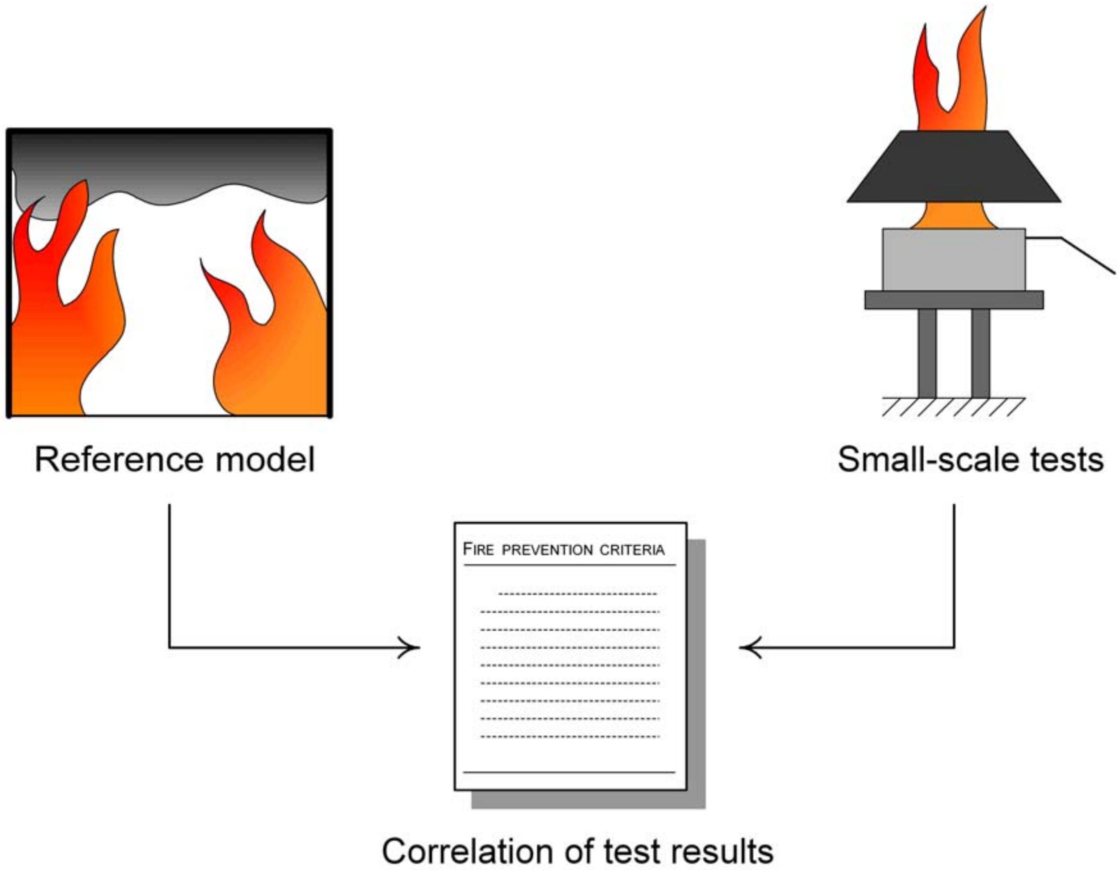
Event tree illustrating that as fire continues to develop, the overall risk and severity of the fire impact will increase

Prevention in favor of mitigation



Incident heat flux as a function of exposure time for limits on pain and second degree burns, with and without safety factors (s.f.) applied (Wieczorek & Dembsey, 2001)

Scaling test results from small- to large-scale



Hazard-based regulations through the scaling of small-scale test metrics to large-scale hazard parameters

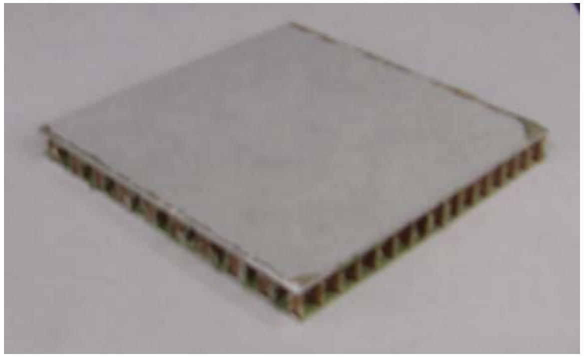
Task 2: Develop fire performance data

- Railcar performance data
  - ASTM E 162
  - ASTM E 662
  - ISO 5658-2
  - ISO 5659-2
  - ISO 5660-1
  - NFPA 286
- Bus performance data
  - FMVSS 302
  - ISO 5658-2
  - ISO 5660-1
  - ASTM E 1537

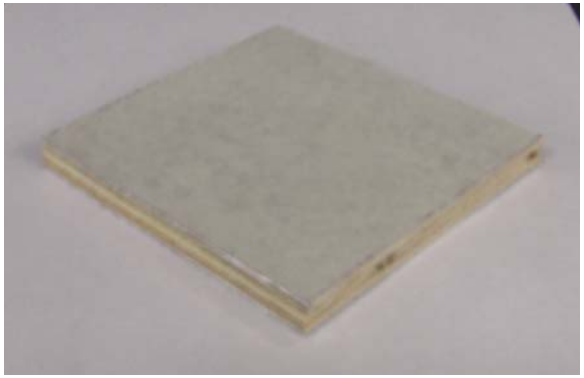
Railcar fire performance data

- Testing materials
- ASTM E 162
- ASTM E 662
- ISO 5658-2
- ISO 5659-2
- ISO 5660-1
- NFPA 286 (reference model)

Railcar test materials

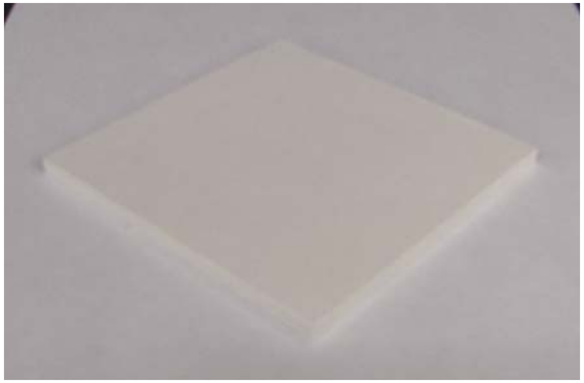


Nomex® rail panel



Plywood rail panel

Plywood



FRP

Railcar test materials used for railcar investigation (4'' square samples)

Railcar test materials

Test materials for railcar investigation

Material	**Description**	**Application**
Nomex® rail panel	Melaminium (melamine fused to aluminum) face, Nomex® honeycomb core (0.25" cell size), aluminum backer; panel thickness 0.375"	Ceiling and wall for intercity railcar
Plywood rail panel	Melaminium (melamine fused to aluminum) face, plywood core, aluminum backer; panel thickness 0.375"	Ceiling and wall for intercity railcar
FRP	Fiberglass-reinforced plastic (FRP); panel thickness 0.1875"	Fume hood liner for laboratory, ceiling and wall for clean room
Plywood	Plywood, C-D Exposure 1 (CDX); panel thickness 0.375"	Furniture, houses

ASTM E 162

Overview of apparatus without specimen

Detail of apparatus with specimen

Experimental arrangement for ASTM E 162, downward flame spread along inclined oriented sample

ASTM E 162

Summary of surface flammability results according to ASTM E 162 for railcar investigation

Material	Ignition time (min)	Flame spread index
Nomex® rail panel	2.8	3
Plywood rail panel	4.5	6
FRP	4.5	8
Plywood	1.1	141

**Results are an average of four trials

ASTM E 662

Overview of apparatus

Detail of apparatus

Experimental arrangement for ASTM E 662, density of smoke for vertically oriented sample (flaming and nonflaming exposure at 25 kW/m^2)

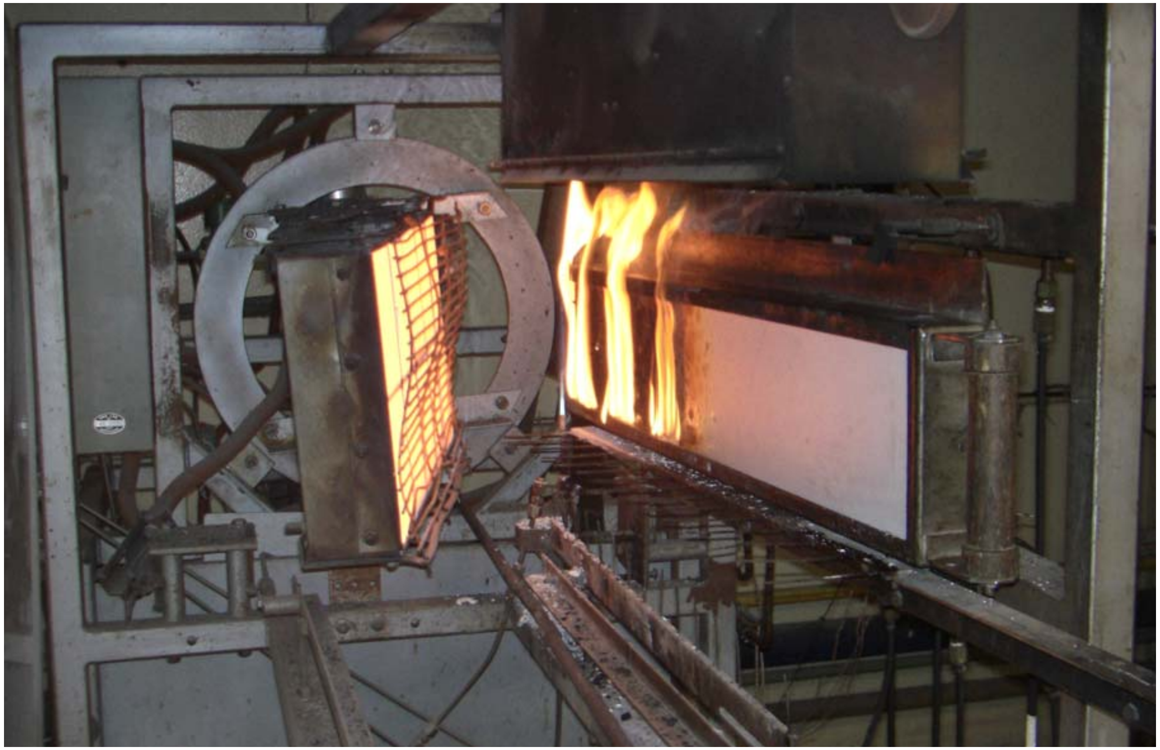
ASTM E 662

Summary of smoke density results according to ASTM E 662 for railcar investigation

Material	**Test Mode**	**Ignition time (min:sec)**	**D_S(1.5)**	**D_S(4.0)**
Nomex® rail panel	Flaming	3:37	4.1	90.2
	Non-flaming	DNI	0.1	13.3
Plywood rail panel	Flaming	DNI	0.4	54.9
	Non-flaming	DNI	0.0	0.0
FRP	Flaming	0:50	0.9	28.1
	Non-flaming	DNI	0.0	5.7
Plywood	Flaming	0:54	1.7	2.3
	Non-flaming	DNI	3.1	39.6

**Results are an average of three trials

ISO 5658-2



Experimental arrangement for ISO 5658-2, lateral flame spread along surface of vertically orientated sample

ISO 5658-2

Summary of surface flammability results according to ISO 5658-2 for railcar investigation

Material	Ignition time (min:sec)	Peak heat release rate (kW)	Critical heat flux at extinguishment (kW/m^2)	Maximum flame travel (mm)
Nomex® rail panel	0:34	1.8	22.0	367
Plywood rail panel	1:19	2.4	20.2	383
FRP	1:38	2.0	30.5	300
Plywood	0:08	4.6	2.9	733

**Results are an average of three trials

ISO 5659-2

Overview of apparatus

Detail of apparatus

Experimental arrangement for ISO 5659-2, density of smoke for horizontally oriented sample (nonflaming exposure at 50 kW/m^2)

ISO 5659-2

Summary of smoke generation results according to ISO 5659-2 for railcar investigation

Material	**Ignition time (min:sec)**	**D_S(4.0)**	**VOF4 (min)**	**CIT(8.0)**
Nomex® rail panel	3:09	172.8	306.1	0.44
Plywood rail panel	5:51	73.6	101.3	0.40
FRP	3:24	168.4	181.8	0.11
Plywood	0:39	99.5	229.6	0.18

**Results are an average of three trials

ISO 5660-1

Overview of apparatus

Detail of apparatus

Experimental arrangement for ISO 5660-1, combustibility for horizontally oriented sample (50 kW/m^2)

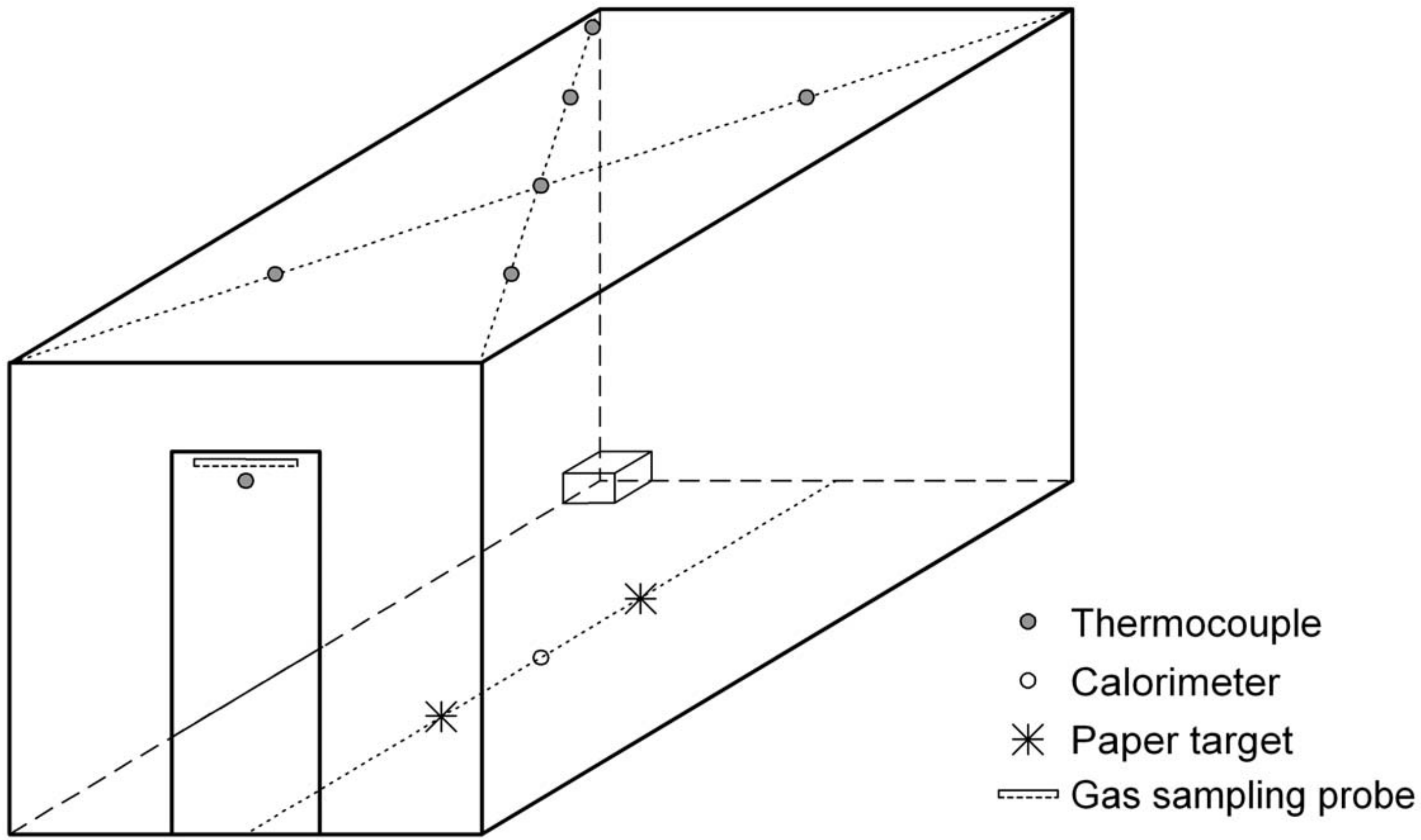
ISO 5660-1

Summary of test results according to ISO 5660-1 (50 kW/m^2) for railcar investigation

Material	**Ignition time (sec)**	**Peak heat release rate (kW/m^2)**	**Maximum average rate of heat emission (kW/m^2)**	**Peak smoke release rate (m^2/sec)**	**Extinction cross-sectional area (m^2/g)**
Nomex® rail panel	63	168	76	0.06	0.205
Plywood rail panel	107	201	107	0.02	0.014
FRP	166	137	86	0.05	0.311
Plywood	26	238	148	0.02	0.015

**Results are an average of three trials

NFPA 286 (reference model)



Experimental arrangement for NFPA 286 room corner test (reference model)

Nomex® rail panel

1 minute

2 minutes

4 minutes

6 minutes

Room corner test according to NFPA 286 for Nomex® rail panel

Plywood rail panel

1 minute

3 minutes

6 minutes

9 minutes

Room corner test according to NFPA 286 for plywood rail panel

Plywood

1 minute

2 minutes

3 minutes

5 minutes

Room corner test according to NFPA 286 for plywood

FRP

1 minute

5 minutes

10 minutes

14 minutes

Room corner test according to NFPA 286 for FRP

NFPA 286 (reference model)

Summary of room corner test results according to NFPA 286 for railcar investigation

Material	Peak heat release rate (kW)	Peak smoke release rate (m^2/sec)	Max floor heat flux (kW/m^2)	Max ceiling temp (ºC)	Flashover time (min:sec)	Termination time (min:sec)
Nomex® rail panel	1130	17.74	26.1	770	7:01	7:22
	1390	18.43	25.0	766	6:51	7:02
Plywood rail panel	1291	14.30	35.4	779	9:22	10:09
	1244	15.00	58.7	785	9:36	9:54
FRP	358	1.66	5.3	451	--	15:01
	443	2.68	8.4	532	--	15:02
Plywood	2520	11.66	25.7	755	5:17	5:37
	1764	9.49	26.2	756	5:17	5:31

Bus fire performance data

- Testing materials
- FMVSS 302
- ISO 5658-2
- ISO 5660-1
- ASTM E 1537 (reference model)

Bus seat assemblies

Vinyl & Kevlar®

Wool & Kevlar®

Polyester & foam

Wool & foam

Bus seat assemblies used for bus investigation

Bus test materials

Test materials for bus investigation

Material	Description	Application
Vinyl & Kevlar®	Vinyl cover with Kevlar® backing layer	Seating for city bus
Wool & Kevlar®	Wool fabric cover with Kevlar® backing layer	Seating for city bus
Polyester & foam	Polyester fabric cover with polyurethane foam insert	Seating for intercity coach
Wool & foam	Wool fabric cover with polyurethane foam insert	Seating for intercity coach

FMVSS 302

Experimental arrangement for FMVSS 302, flammability of a horizontally oriented sample

FMVSS 302

Summary of flammability test results according to FMVSS 302 for bus investigation

Material	Burn rate (mm/min)	Comments
Vinyl & Kevlar®	--	Self extinguished before timing could begin (i.e. 38 mm)
Wool & Kevlar®	--	Self extinguished before timing could begin (i.e. 38 mm)
Polyester	62	--
Wool	--	Did not ignite
Foam	71	--

**Results are an average of four trials

ISO 5658-2

Summary of surface flammability test results according to ISO 5658-2 for bus investigation

Material	Ignition time (sec)	Peak heat release rate (kW)	Critical flux at extinguishment (kW/m^2)	Maximum flame travel (mm)
Vinyl & Kevlar®	0:02	2.8	10.1	500
Wool & Kevlar®	0:02	2.9	23.7	350
Polyester & foam	0:02	5.7	2.7	750
Wool & foam	0:02	3.2	23.7	350

**Results are an average of three trials

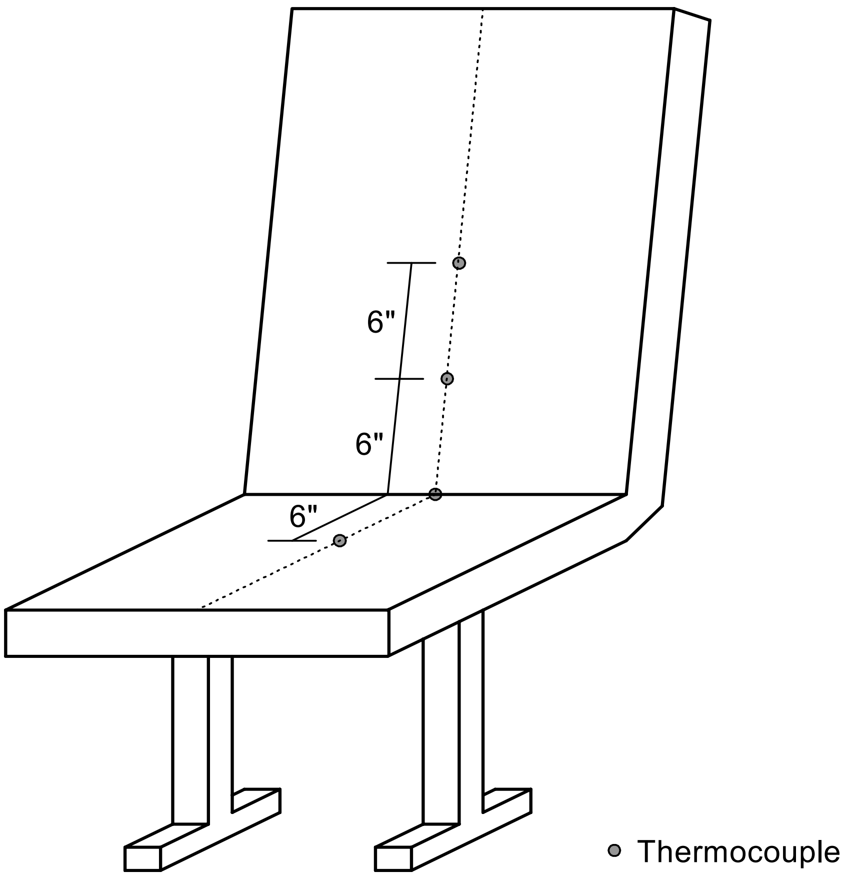
ISO 5660-1

Summary of test results according to ISO 5660-1 (35 kW/m^2) for bus investigation

Material	Ignition time (sec)	Peak heat release rate (kW/m^2)	Peak smoke release rate (m^2/sec)	Extinction cross-sectional area (m^2/g)
Vinyl & Kevlar®	11	172	0.12	0.500
Wool & Kevlar®	79	133	0.07	0.320
Polyester & foam	39	322	0.07	0.349
Wool & foam	76	113	0.04	0.082

**Results are an average of three trials

ASTM E 1537 (reference model)



Thermocouple placement on bus seat for ASTM E 1537

Vinyl & Kevlar®

20 sec

2 min 5 sec

16 min 30 sec

40 min

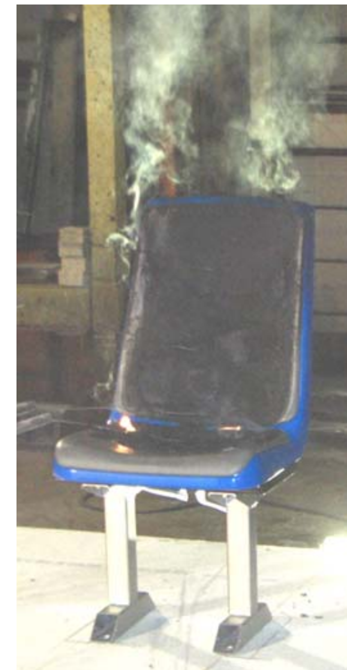
Bus seat test according to ASTM E 1537 for vinyl & Kevlar® showing significant damage

Vinyl & Kevlar®

10 sec

30 sec

1 min 25 sec



2 min 15 sec

Bus seat test according to ASTM E 1537 for vinyl & Kevlar® showing mild damage

Wool & Kevlar®

15 sec

40 sec

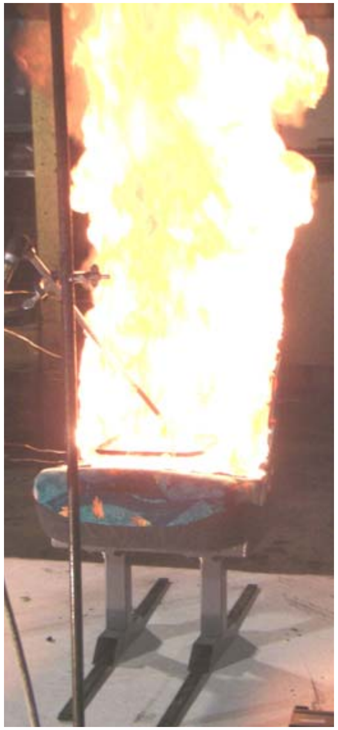
1 min 10 sec

2 min 20 sec

Bus seat test according to ASTM E 1537 for wool & Kevlar®

Polyester & foam

10 sec



1 min

3 min 30 sec

7 min

Bus seat test according to ASTM E 1537 for polyester & foam

Wool & foam

20 sec

1 min 10 sec

1 min 25 sec

5 min 30 sec

Bus seat test according to ASTM E 1537 for wool & foam

ASTM E 1537 (reference model)

Summary of bus chair results according to ASTM E 1537 for bus investigation

Material	Peak heat release rate (kW)	Peak smoke release rate (m^2/sec)	Max seat cushion temp (ºC)	Max back cushion temp (ºC)
Vinyl & Kevlar®	203	1.68	797	779
	74	1.70	839	843
	77	1.88	708	758
Wool & Kevlar®	27	0.04	595	686
	26	0.04	580	743
Polyester & foam	308	2.53	870	877
	308	2.92	855	880
Wool & foam	37	0.04	772	768
	38	0.04	637	788

Task 3: Data analysis

- Railcar data analysis
  - Comparison of railcar regulations and reference model (NFPA 286)
  - Heat release rate
  - Smoke release rate
  - Toxicity
- Bus data analysis
  - Comparison of bus regulations and reference model (ASTM E 1537)
  - Heat release rate

Railcar data analysis

- Comparison of railcar regulations and reference model (NFPA 286)
- Heat release rate
- Smoke release rate
- Toxicity

NFPA and FRA performance requirements

Comparison of NFPA and FRA requirements to reference model results

Material	ASTM E 162	NFPA 286
	$I_s \leq 35$	Flashover time (min:sec)
Nomex® rail panel	3	6:56
Plywood rail panel	6	9:29
FRP	8	--
Plywood	141	5:17

NFPA and FRA performance requirements

Comparison of NFPA and FRA requirements to reference model results

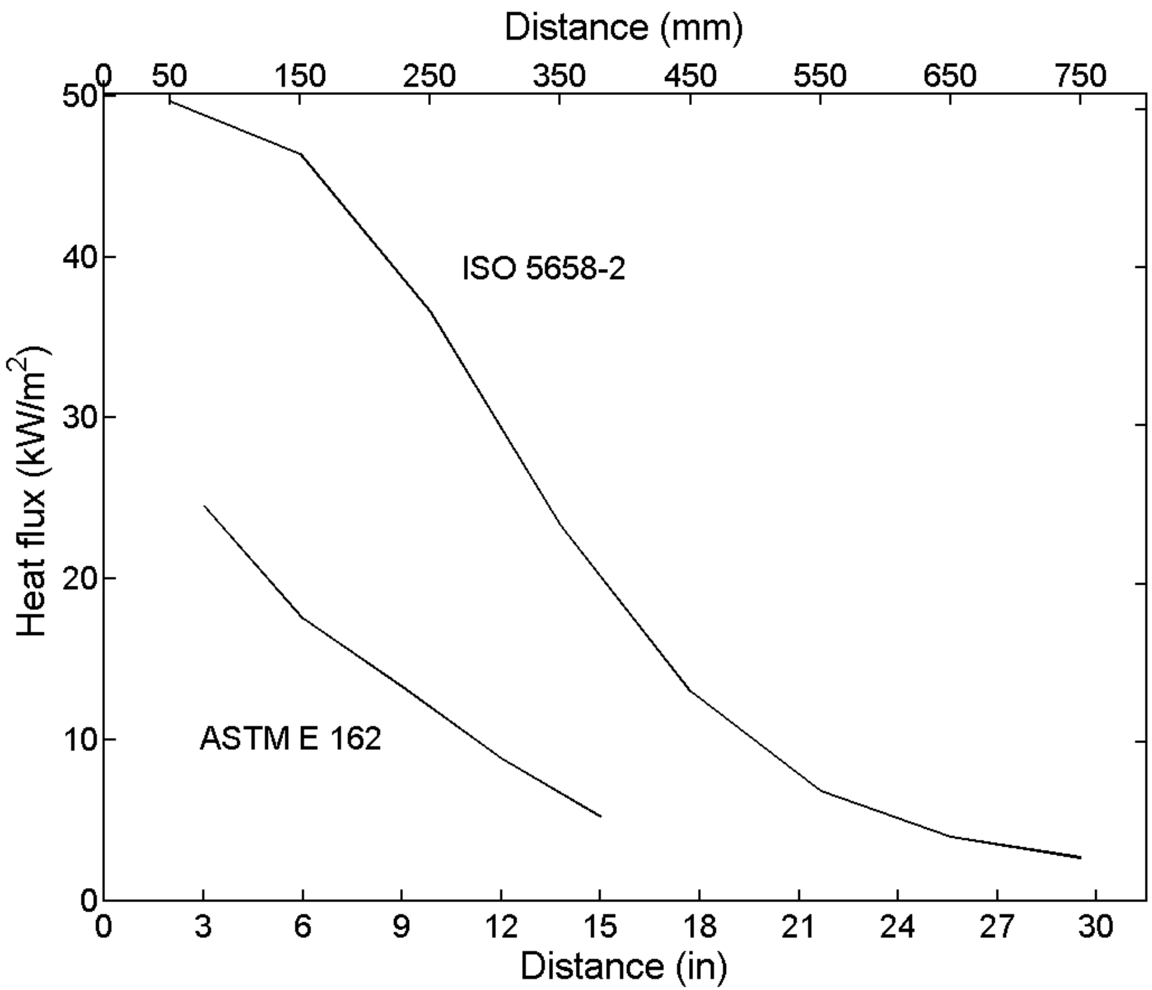
Material	ASTM E 662		NFPA 286		
	$D_S(1.5) \leq 100$	$D_S(4.0) \leq 200$	Peak SRR at 5 min (m^2/sec)	Total smoke at 5 min (m^2)	Peak SRR (m^2/sec)
Nomex® rail panel	4.1	90.2	0.15	23.20	18.09
Plywood rail panel	0.4	54.9	0.14	19.63	14.65
FRP	0.9	28.1	0.18	18.89	2.17
Plywood	3.1	39.6	0.18	18.73	10.58

EN performance requirements

Comparison of EN requirements to reference model results

Material	ISO 5658-2	NFPA 286
	CHF (kW/m^2)	Flashover time (min:sec)
Nomex® rail panel	22.0 --	6:56
Plywood rail panel	20.2 --	9:29
FRP	30.5 HL3	--
Plywood	2.9 --	5:17

ASTM E 162 versus ISO 5658-2



Comparison of heat flux distributions for ASTM E 162 and ISO 5658-2

EN performance requirements

Comparison of EN requirements to reference model results

Material	ISO 5659-2		NFPA 286		
	Ds(4.0)	VOF4 (min)	Peak SRR at 5 min (m^2/sec)	Total smoke at 5 min (m^2)	Peak SRR (m^2/sec)
Nomex® rail panel	172.8 HL3	306.1 HL3	0.15	23.20	18.09
Plywood rail panel	73.6 HL4	101.3 HL4	0.14	19.63	14.65
FRP	168.4 HL3	181.8 HL4	0.18	18.89	2.17
Plywood	99.5 HL4	229.6 HL4	0.18	18.73	10.58

EN performance requirements

Comparison of EN requirements to reference model results

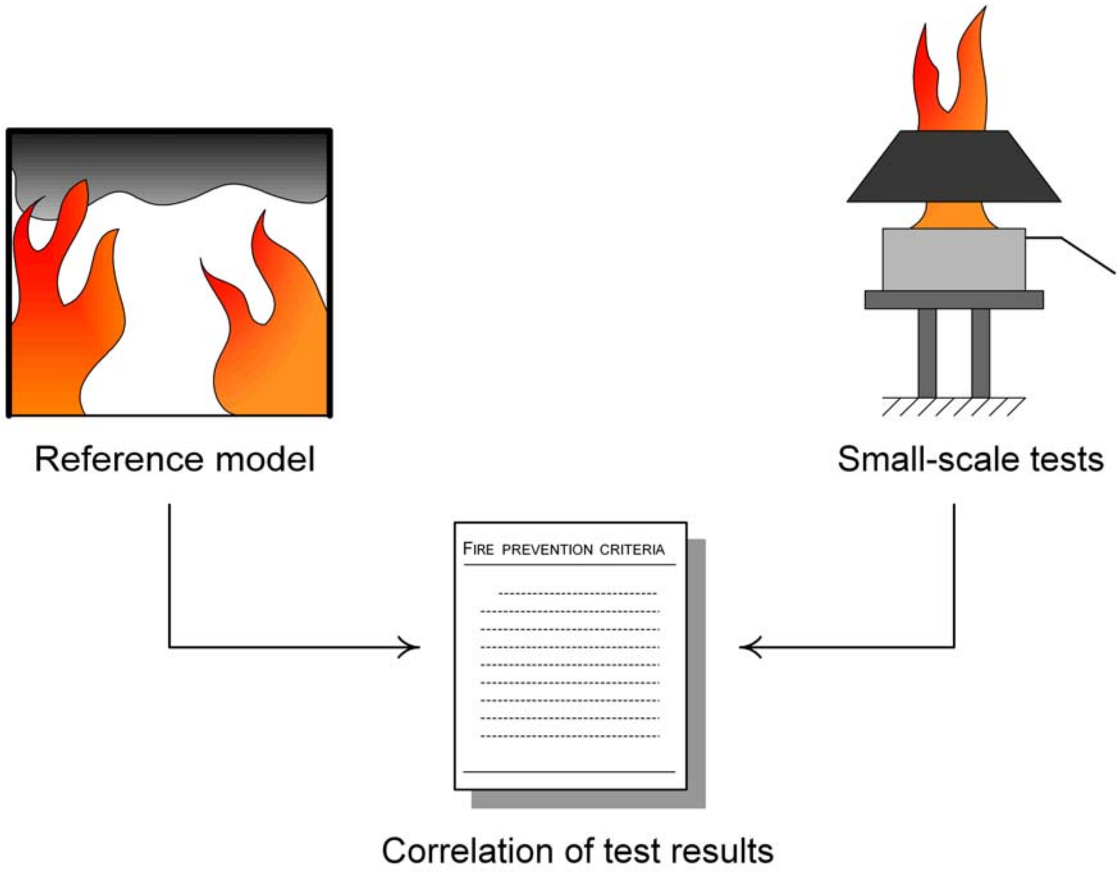
Material	ISO 5660-1	NFPA 286	
	MARHE (kW/m^2)	Peak HRR at 5 min (kW)	Peak HRR (kW)
Nomex® rail panel	76 HL3	54	1260
Plywood rail panel	107 HL1	42	1268
FRP	86 HL3	49	400
Plywood	148 HL1	293	2142

EN performance requirements

Comparison of EN requirements to reference model results

Material	ISO 5659-2	NFPA 286	
	CIT(8.0)	FED(5.0)	FEC(5.0)
Nomex® rail panel	0.44 HL4	0.08	0.07
Plywood rail panel	0.40 HL4	0.08	0.23
FRP	0.11 HL4	0.05	0.05
Plywood	0.18 HL4	0.19	0.45

Scaling test results from small- to large-scale



Hazard-based regulations through the scaling of small-scale test metrics to large-scale hazard parameters

Scaling performance: heat release

- Relate small-scale metrics to large-scale heat measurements

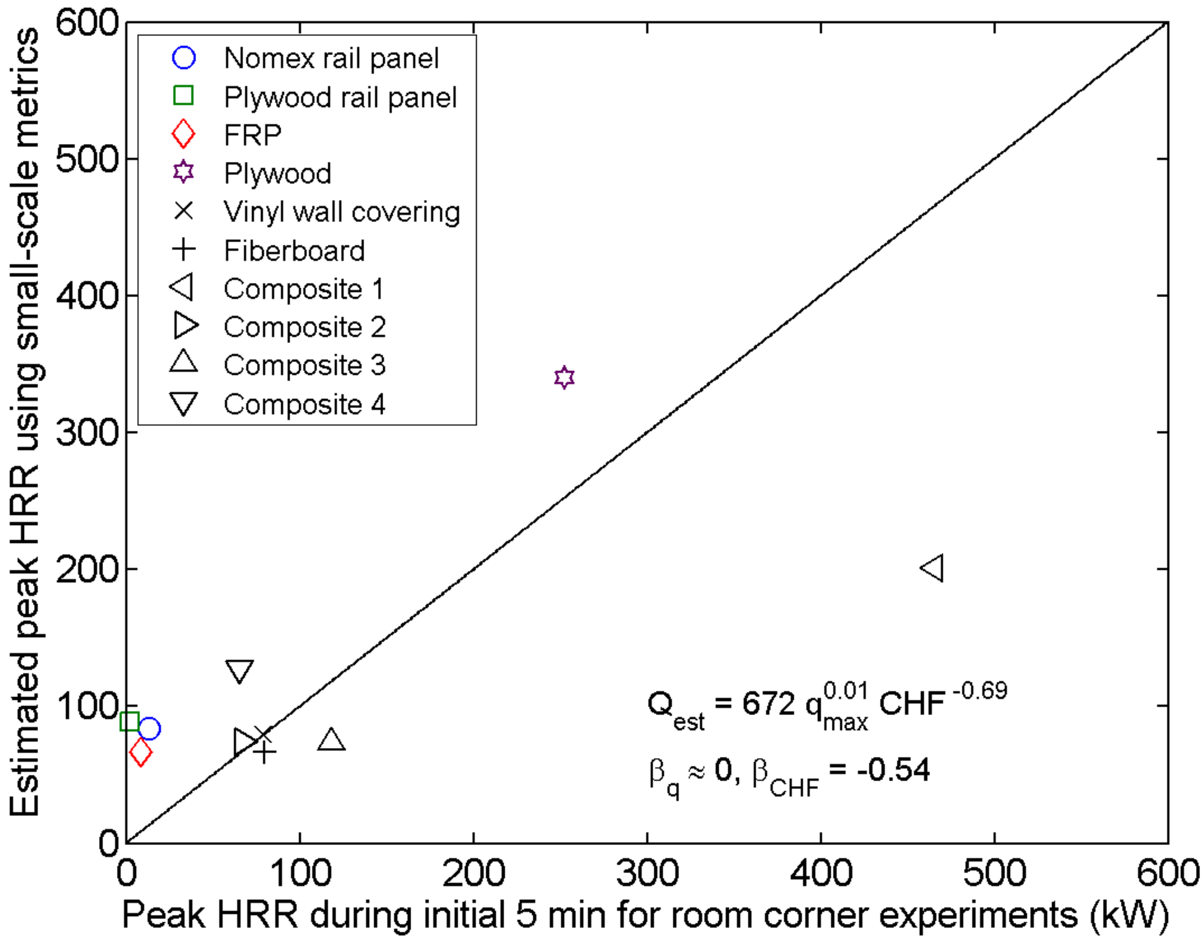
$$Q = f(q, \text{CHF})$$

Q : Heat release rate from room corner test

q : Heat release rate from cone calorimeter

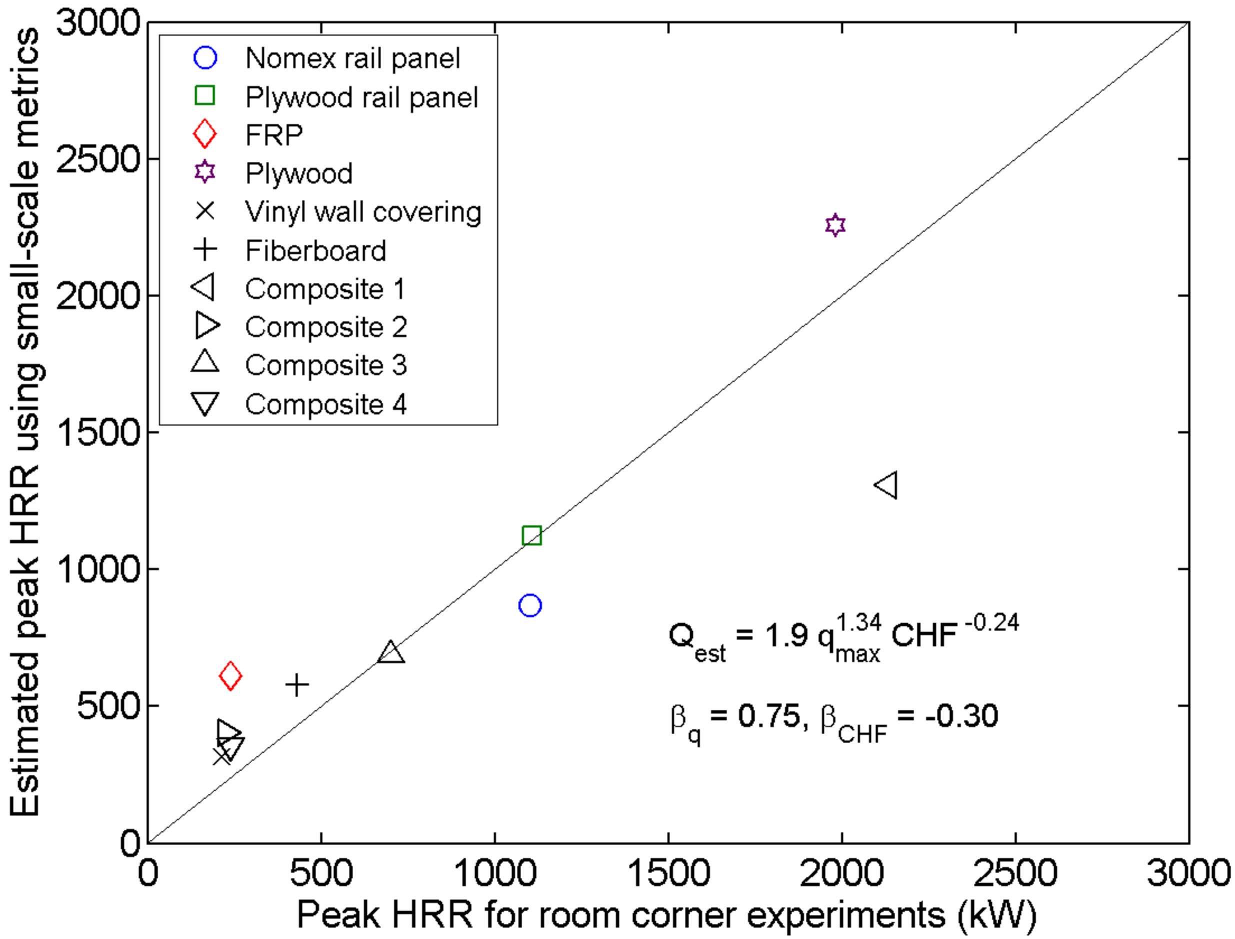
CHF : Critical heat flux at extinguishment from LIFT

Scaling performance: peak HRR at 5 min



Comparison of estimated and experimental peak HRR at 5 minutes

Scaling performance: peak HRR



Comparison of estimated and experimental peak HRR up to point of flashover

Scaling performance: smoke release

- Relate small-scale metrics to large-scale smoke measurements

$$\text{SRR} = f(q, \sigma, h_c, \text{CHF})$$

SRR : Smoke release rate from room corner test

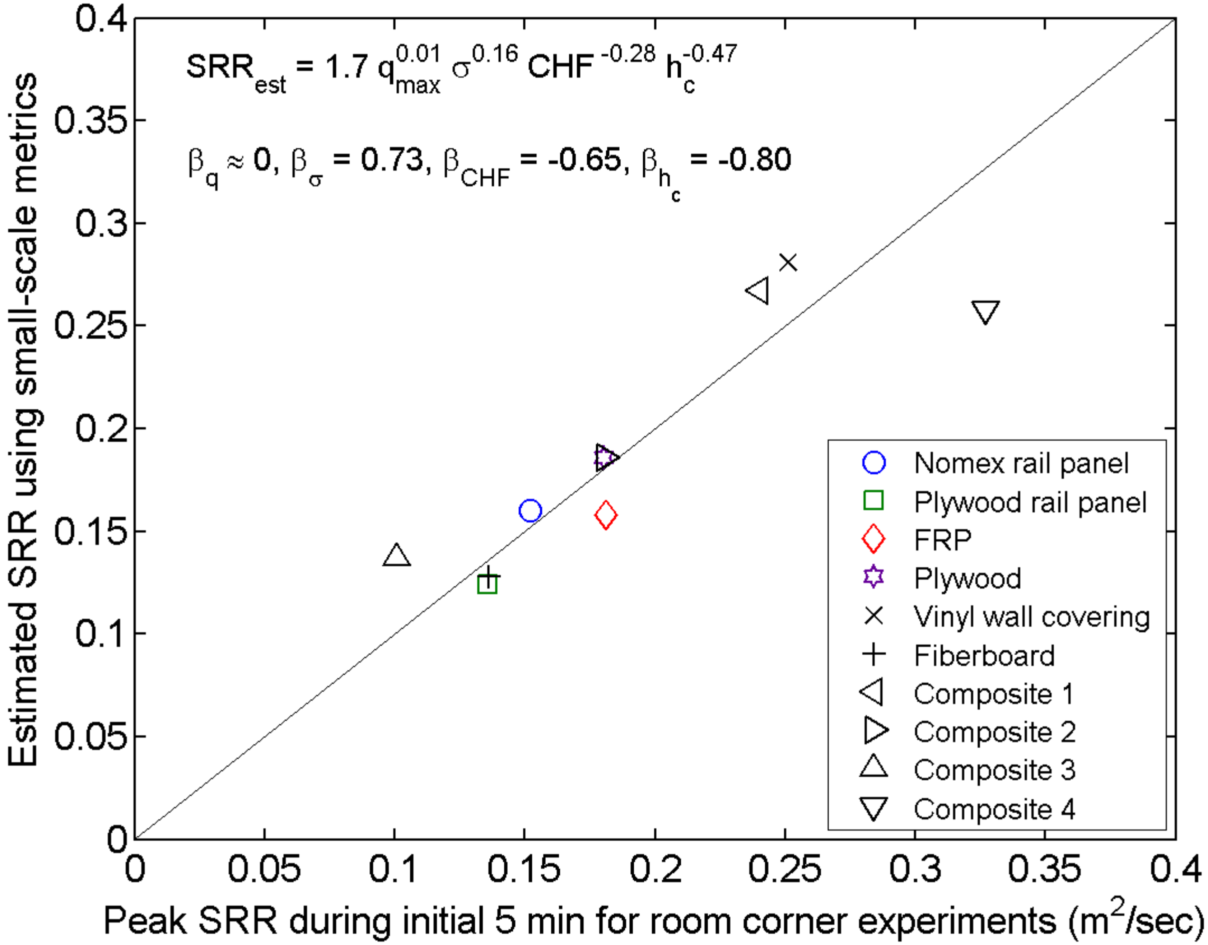
q : Heat release rate per unit area from cone calorimeter

σ : Extinction cross-sectional area from cone calorimeter

h_c : Heat of combustion from cone calorimeter

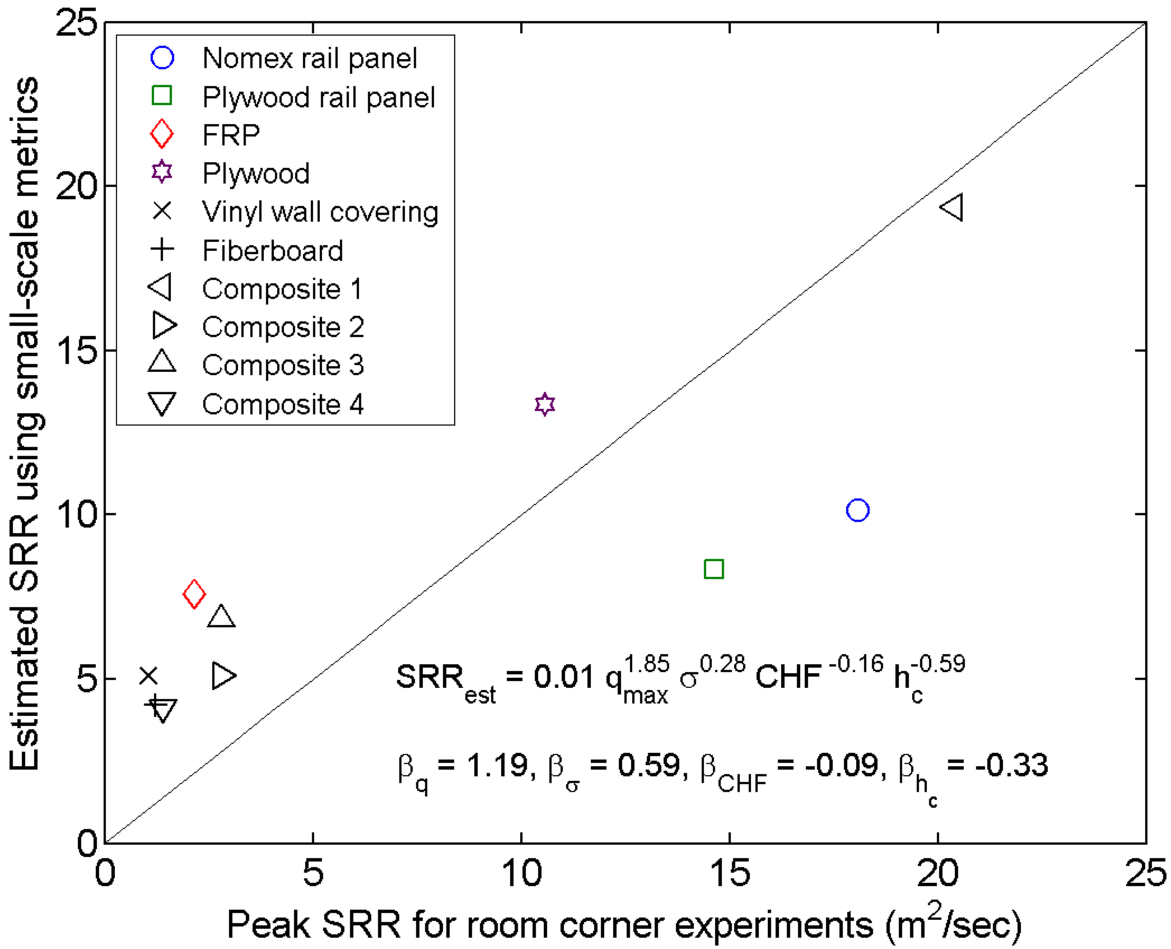
CHF : Critical heat flux at extinguishment from LIFT

Scaling performance: peak SRR at 5 min



Comparison of estimated and experimental peak SRR at 5 minutes

Scaling performance: peak SRR



Comparison of estimated and experimental peak SRR up to point of flashover

Scaling performance: toxicity

- Relate small-scale metrics to large-scale toxicity measurements

$$\mathrm{FEC_{LS}} = f(\mathrm{FEC_{SS}}, \mathrm{CHF})$$
$$\mathrm{FED_{LS}} = f(\mathrm{FED_{SS}}, \mathrm{CHF})$$

$\mathrm{FEC_{LS}}$: Fractional effective concentration from room corner test

$\mathrm{FEC_{SS}}$: Fractional effective concentration from cone calorimeter

$\mathrm{FED_{LS}}$: Fractional effective dose from room corner test

$\mathrm{FED_{SS}}$: Fractional effective dose from cone calorimeter

CHF : Critical heat flux at extinguishment from LIFT

Fractional Effective Dose

Fractional Effective Dose (FED) is given as (ISO/TS 13571, 2002; Purser, 2002)

$$\mathrm{FED} = \sum_{t_1}^{t_2} \frac{\varphi_{\mathrm{CO}}}{35{,}000}\Delta t + \sum_{t_1}^{t_2} \frac{\exp\left(\varphi_{\mathrm{HCN}} / 43\right)}{220}\Delta t$$

φ_{CO} : concentration of CO (in ppm)

φ_{HCN} : concentration of CO (in ppm)

Δt : time increment (in min)

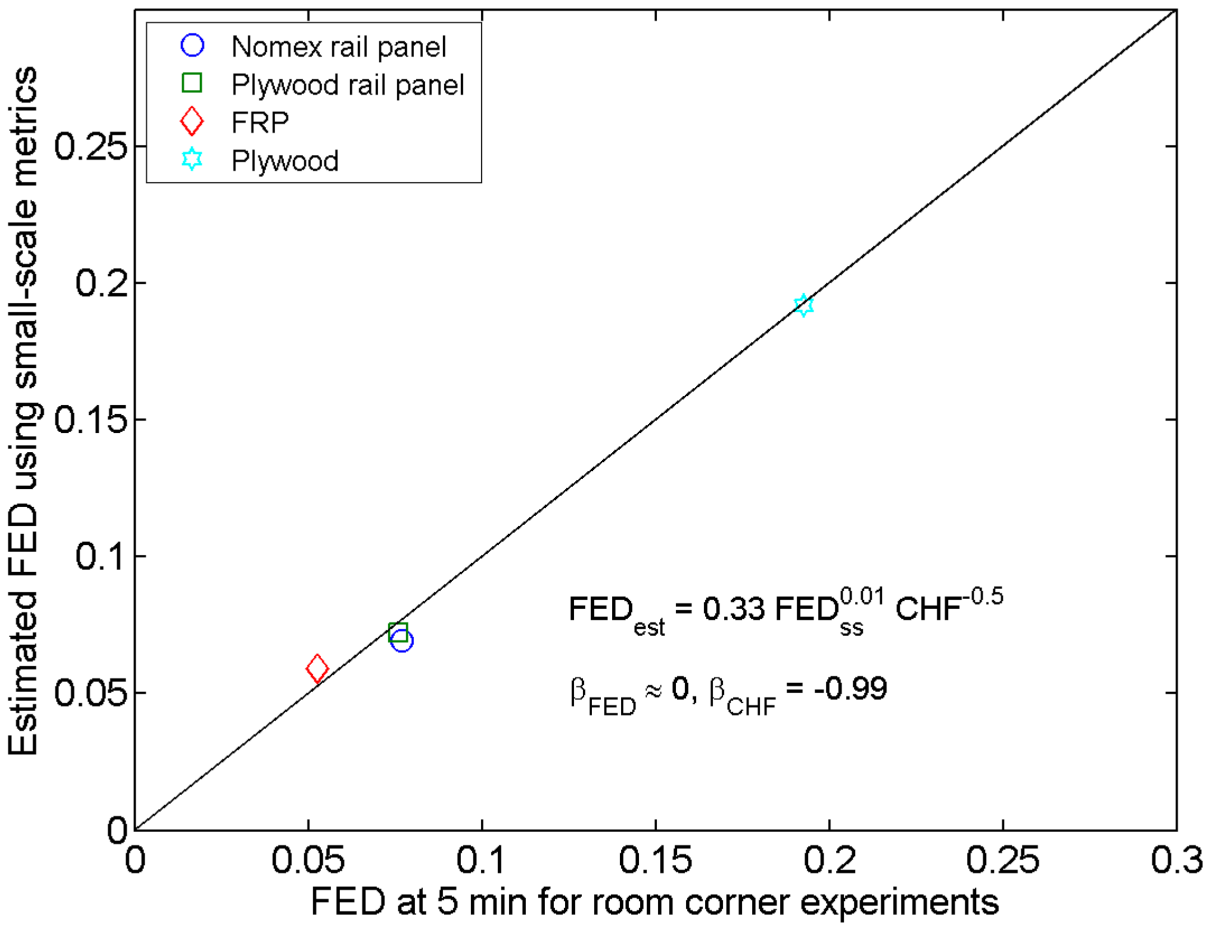
Fractional Effective Concentration

Fractional Effective Concentration (FEC) is given as (ISO/TS 13571, 2002; Purser, 2002)

$$\mathrm{FEC} = \frac{\varphi_{\mathrm{HCl}}}{1{,}000} + \frac{\varphi_{\mathrm{HBr}}}{1{,}000} + \frac{\varphi_{\mathrm{HF}}}{500} + \frac{\varphi_{\mathrm{SO_2}}}{150} + \frac{\varphi_{\mathrm{NO_2}}}{250} + \frac{\varphi_{\mathrm{acrolein}}}{30} + \frac{\varphi_{\mathrm{formaldehyde}}}{250}$$

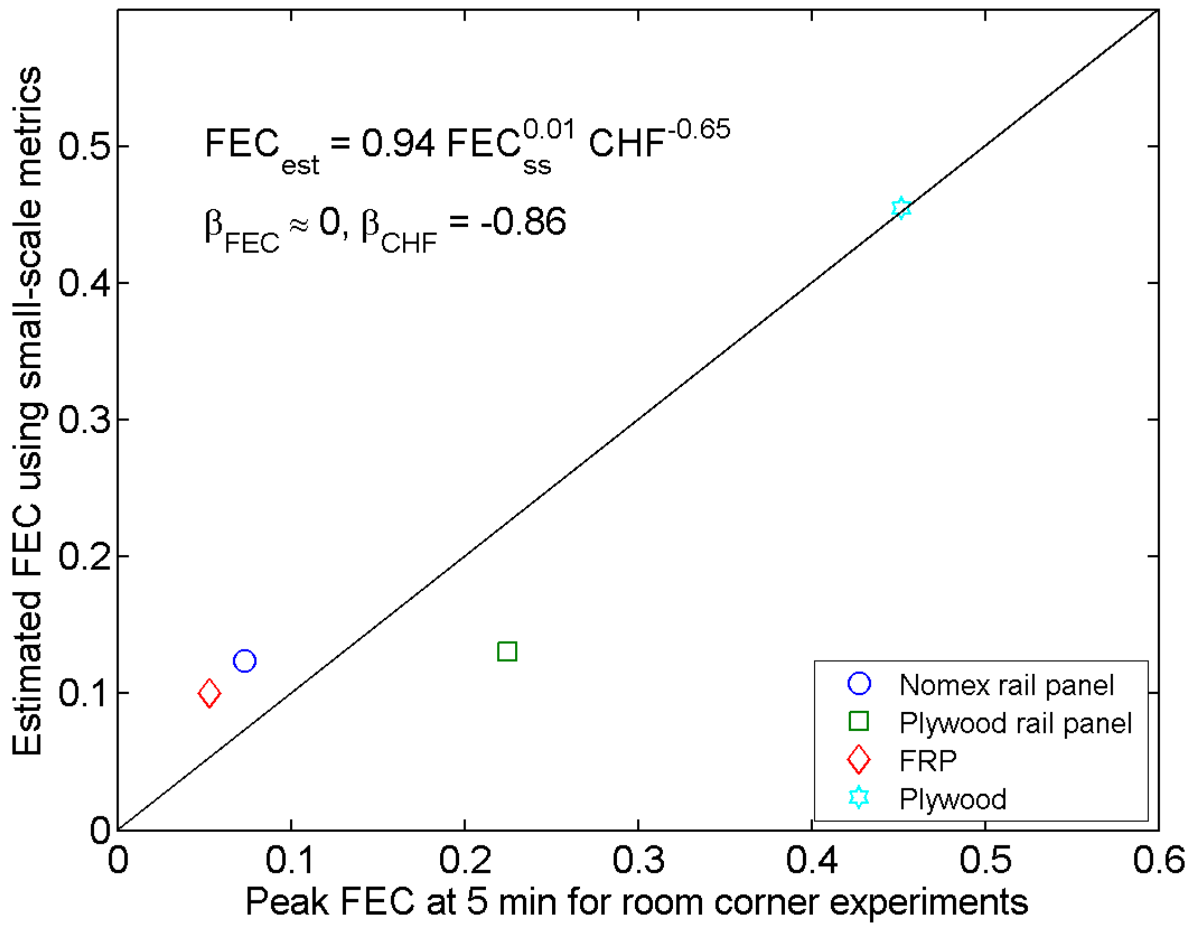
φ : concentration of gas (in ppm)

Scaling performance: FED at 5 min



Comparison of estimated and experimental peak fractional effective concentration (FED)

Scaling performance: peak FEC at 5 min



Comparison of estimated and experimental peak fractional effective concentration (FEC)

Bus data analysis

- Comparison of bus regulations and reference model (ASTM E 1537)
- Heat release rate

TB 133 requirements

- State of California Technical Bulletin 133 “Flammability test procedure for seating furniture for use in public occupancies” (January 1991 edition)
  - Maximum heat release rate < 80 kW
  - Total heat released in first 10 min < 25 MJ

NHTSA performance requirements

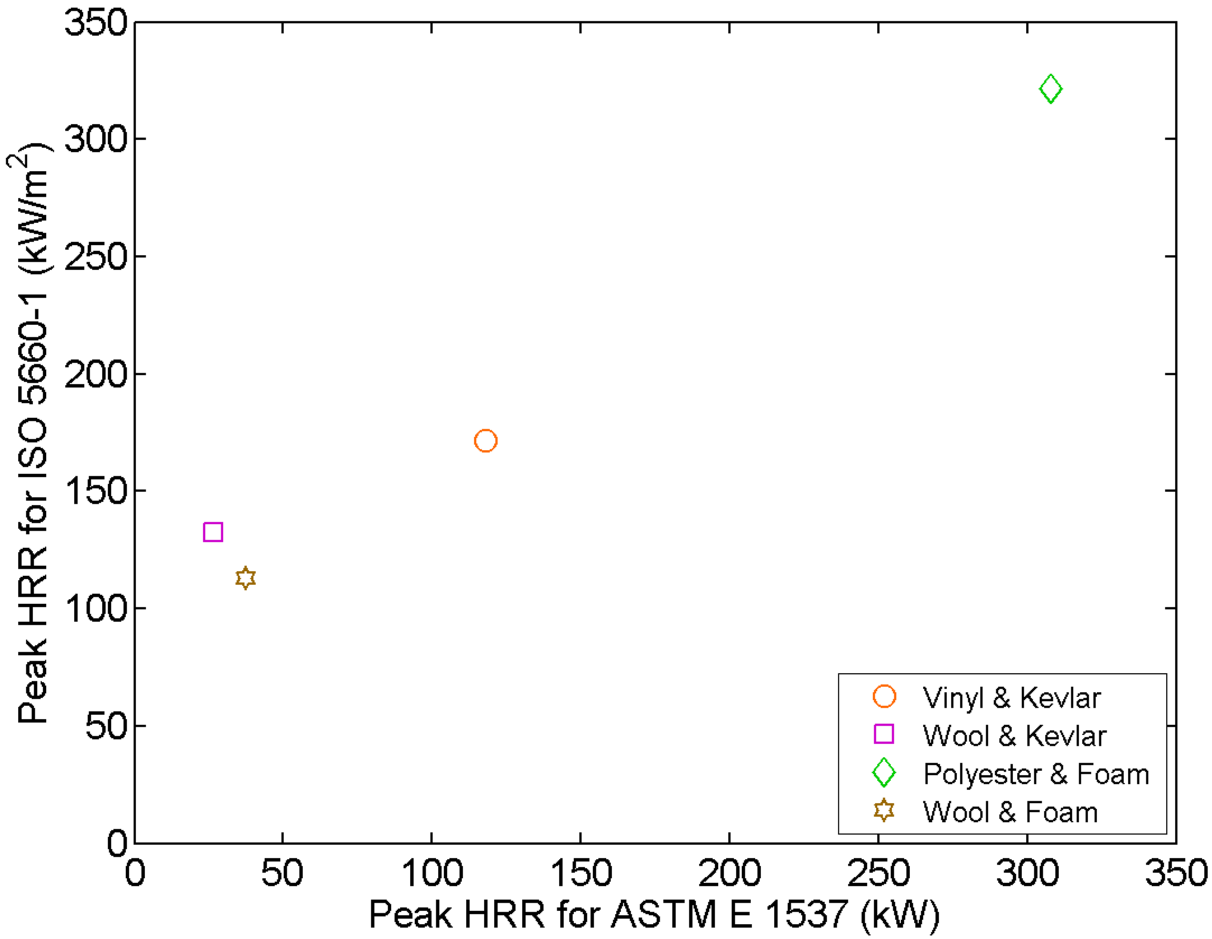
Comparison of NHTSA performance requirements to large-scale results

Material	FMVSS 302	ASTM E 1537		
	Burn rate < 102 mm/min?	Peak heat release rate (kW)	Total heat at 10 min (MJ)	Peak smoke release rate (m^2/sec)
Vinyl & Kevlar®	Self extinguished	118†	5.14	1.75
Wool & Kevlar®	Self extinguished	27	2.07	0.04
Polyester & foam	62, 71 mm/min‡	308	58.90	2.73
Wool & foam	DNI, 71 mm/min‡	38	3.02	0.04

† Average of three trials: 203, 74, 77 kW

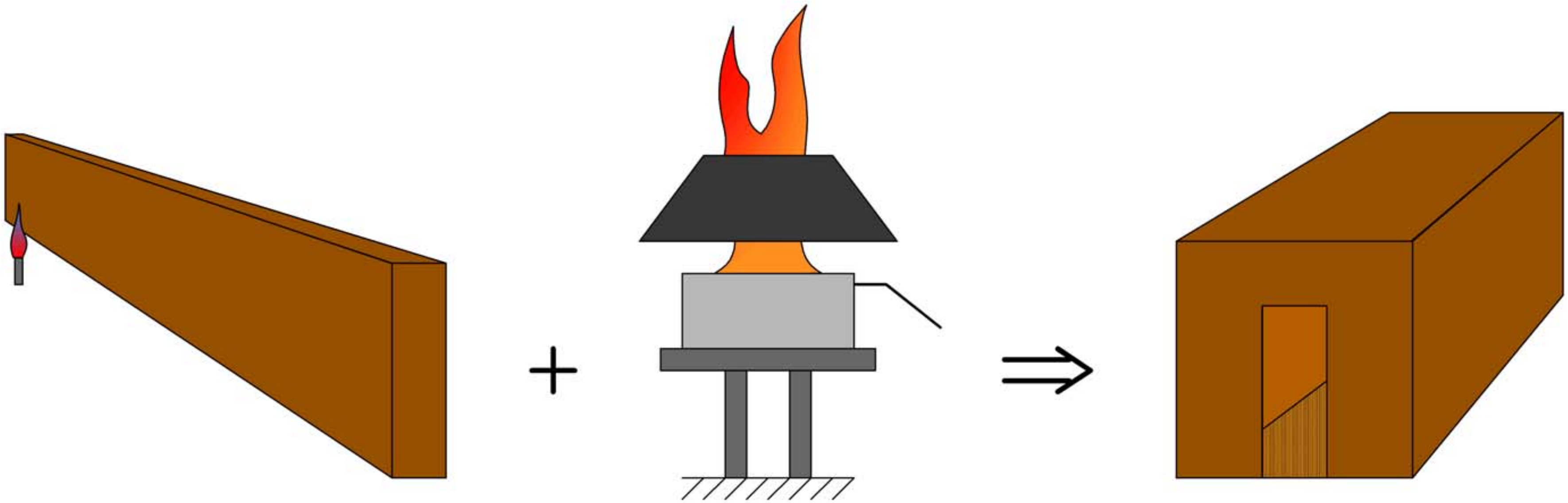
‡ Fabric and foams were tested separately for FMVSS 302

Scaling performance: peak HRR



Comparison of ISO 5660-1 and ASTM E 1537 peak HRR

Task 4: Identify fire performance metrics

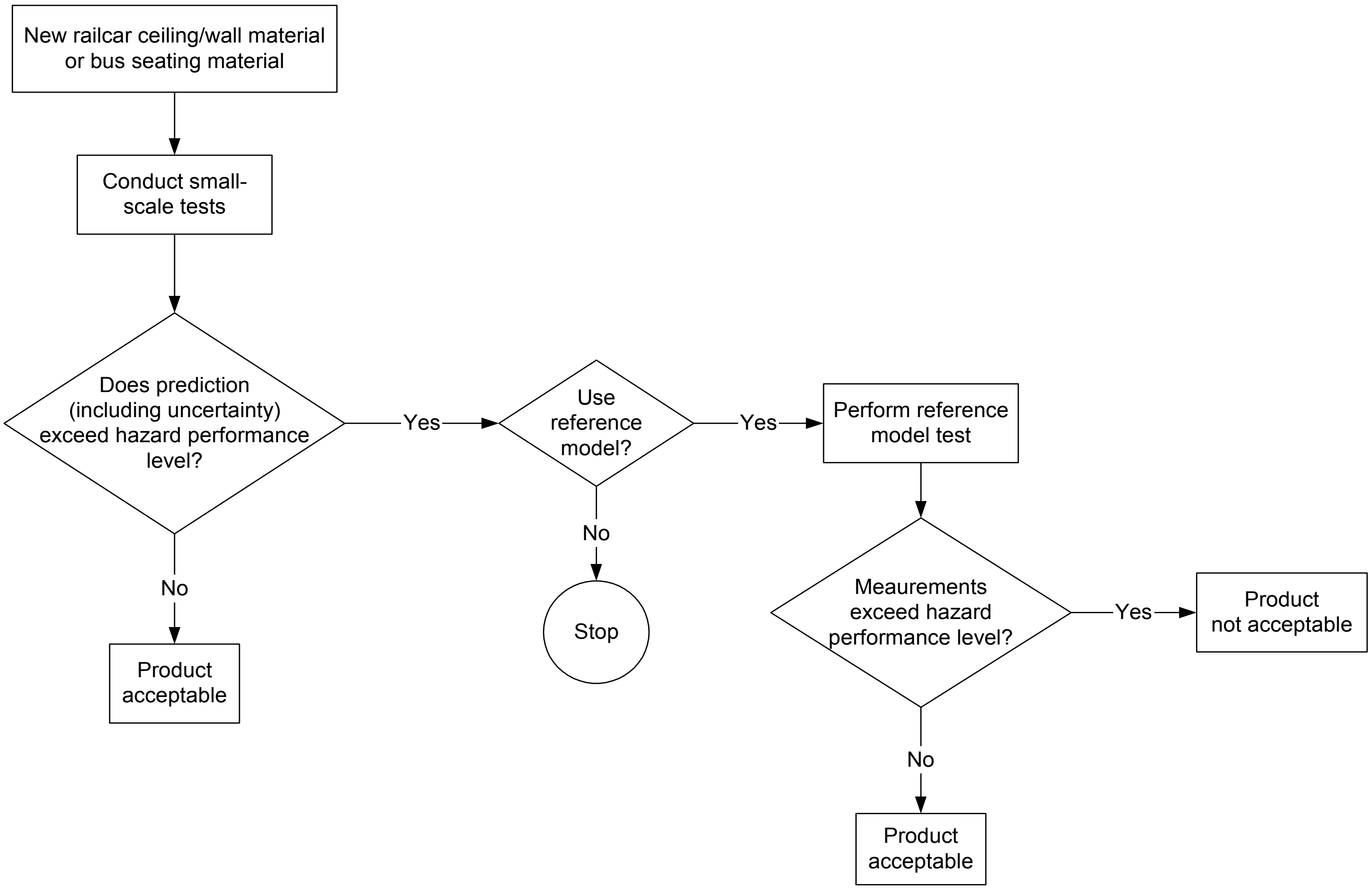


Use of small-scale fire performance metrics to to assess fire growth in reference model

Small-scale fire performance metrics

- Heat
  - Heat release rate (HRR) from Cone Calorimeter (ISO 5660-1)
  - Critical heat flux at extinguishment (CHF) from LIFT (ISO 5658-2)
- Smoke
  - Extinction cross-sectional area from Cone Calorimeter (ISO 5660-1)
  - Heat of combustion from Cone Calorimeter (ISO 5660-1)
  - Critical heat flux at extinguishment (CHF) from LIFT (ISO 5658-2)
- Gas toxicity
  - Gas concentrations measured using FTIR apparatus applied to Cone Calorimeter (ISO 5660-1)
  - Critical heat flux at extinguishment (CHF) from LIFT (ISO 5658-2)

Assessment of materials



Flowchart illustrating the assessment of materials using fire performance metrics

Summary & conclusions of railcar study

- ASTM E 162 does not accurately reflect spread of fire in a larger-scale fire test
- Results from Cone Calorimeter and LIFT may be used to assess wall and ceiling materials' potential for fire growth
- Results from small-scale tests (Cone Calorimeter and LIFT) may be used to represent the threshold hazard in the reference model
  - Additional data, at and below the threshold hazard, may need to be developed to add to the robustness of the correlation between the small-scale tests and reference test

Summary & conclusions of bus study

- FMVSS 302 does not accurately reflect fire performance of full-scale bus seats
- Cone calorimeter could be used to indicate bus seats' potential as a large fire source

Project overview

- Common railcar and bus materials were identified and tested
- Results suggest that current FRA and NHTSA requirements may need to be updated
- Hazard-based regulations can be used for fire safety on railcars and buses
- Small-scale metrics can be scaled to assess fire growth in reference model (within a given confidence range)

Future work

- Work with Technical Advisory Committee to establish fire prevention criteria
  - Develop/identify hazard thresholds for reference model(s)
  - Establish fire prevention criteria in terms of small-scale metrics and validate with reference model
- Develop additional data at and below the threshold hazard (of the reference model) to add to the robustness of the correlations
- Supplement/validate results with computer simulations (e.g. Fire Dynamics Simulator)
  - Perform additional experimental tests to develop input data for computer simulations

References

ASTM E 162 (2006). Standard test method for surface flammability of materials using a radiant heat energy source. In *2006 Annual Book of ASTM Standards*, Vol. 04.07. West Conshohocken, Pennsylvania: American Society for Testing and Materials.

ASTM E 662 (2006). Standard test method for specific optical density of smoke generated by solid materials. In *2006 Annual Book of ASTM Standards*, Vol. 04.07. West Conshohocken, Pennsylvania: American Society for Testing and Materials.

ASTM E 1537 (2007). Standard test method for fire testing of upholstered furniture. In *2007 Annual Book of ASTM Standards*, Vol. 04.07. West Conshohocken, Pennsylvania: American Society for Testing and Materials.

Ahrens, M. (2005). U.S. vehicle fire trends and patterns (Technical Report). Quincy, Massachusetts: National Fire Protection Association.

Ahrens, M. (2006). Vehicle fires involving buses and school buses (Technical Report). Quincy, Massachusetts: National Fire Protection Association.

Braun, E. (1975). Fire hazard evaluation of the interior of WMATA Metrorail cars (NBS Report Number: NBSIR 75-971). Washington, D.C.: National Bureau of Standards.

Braun, E. (1978). Fire hazard evaluation of BART vehicles (NBS Report Number: NBSIR 78-1421). Washington, D.C.: National Bureau of Standards.

References

Braun, E., Davis, S., Klote, J. H., Levin, B. C., and Paabo, M. (1990). Assessment of the fire performance of school bus interior components (NIST Report Number: NISTIR 4347). Gaithersburg, Maryland: National Institute of Standards and Technology.

FMVSS 302 (2002). Flammability of interior materials. In Federal Motor Vehicle Safety Standards and Regulations, Part 571 (pp. 740-743). Washington, DC: National Highway Traffic Safety Administration.

FRA (2005). Subpart B – Safety planning and general requirements. In *Passenger Equipment Safety Standards*, Part 238 (pp. 660-667). Washington, DC: Federal Railroad Administration.

FRA (2005). Appendix B to Part 238 – Test methods and performance criteria for the flammability and smoke emission characteristics of materials used in passenger cars and locomotive cabs. In *Passenger Equipment Safety Standards*, Part 238 (pp. 711-715). Washington, DC: Federal Railroad Administration.

ISO 5658-2 (2006). Reaction to fire tests - Spread of flame - Part 2: Lateral spread on building and transport products in vertical configuration. In *International Standard*. Geneva, Switzerland: International Organisation for Standardisation.

ISO 5659-2 (2006). Plastics - Smoke generation - Part 2: Determination of optical density by a single-chamber test. In *International Standard*. Geneva, Switzerland: International Organisation for Standardisation.

References

ISO 5660-1 (2006). Reaction-to-fire tests - Heat release, smoke production and mass loss rate - Part 1: Heat release rate (cone calorimeter method). In International Standard. Geneva, Switzerland: International Organisation for Standardisation.

ISO/TS 13571 (2002). Life-threatening components of fire – Guidelines for the estimation of time available for escape using fire data. In *International Standard*. Geneva, Switzerland: International Organisation for Standardisation.

NFPA 130 (2000). *Standard for fixed guideway transit and passenger rail systems*. Quincy, Massachusetts: National Fire Protection Association.

NFPA 286 (2006). *Standard methods of fire tests for evaluating contribution of wall and ceiling interior finish to room fire growth*. Quincy, Massachusetts: National Fire Protection Association.

Peacock, R. D. & Braun, E. (1984). Fire tests of Amtrak passenger rail vehicle interiors (NBS Technical Note 1193). Washington, D.C.: National Bureau of Standards.

Peacock, R. D. & Braun, E. (1999). Fire safety of passenger trains; phase 1: material evaluation (cone calorimeter) (NIST Report Number: NISTIR 6132). Gaithersburg, Maryland: National Institute of Standards and Technology.

References

Peacock, R. D., Reneke, P. A., Averill, J. D., and Bukowski, R. W., & Klote, J. H. (2002). Fire safety of passenger trains; phase 2: application of fire hazard analysis techniques (NIST Report Number: NISTIR 6525). Gaithersburg, Maryland: National Institute of Standards and Technology.

Peacock, R. D., Averill, J. D., Madrzykowski, D., Stroup, D. W., Reneke, P. A., & Bukowski, R. W. (2004). Fire safety of passenger trains; phase 3: evaluation of fire hazard analysis using full-scale passenger rail car tests (NIST Report Number: NISTIR 6563). Gaithersburg, Maryland: National Institute of Standards and Technology.

Purser, D. A. (2002). Toxicity assessment of combustion products. In *SFPE Handbook of Fire Protection Engineering (Third Edition)* (pp. 2-83 – 2-171). Quincy, Massachusetts: National Fire Protection Association.

Sundström, B. ed. (1995). Fire safety of upholstered furniture: the final report on the CBUF research programme (Report EUR 16477 EN). London, England: Interscience Communications Ltd.

Wieczorek, C. J. & Dembsey, N. A. (2001). Human variability correction factors for use with simplified engineering tools for predicting pain and second degree skin burns. *Journal of Fire Protection Engineering*, *11*(2), 88–111.

Investigation of the Fire Performance of Materials and Products for Use in U.S. Railcar and Bus Applications

UL Final Report

Project Nos. 07CA38486, 07CA38487,
07CA38488, 07CA38489, 07CA38490

Prepared for

National Association of State Fire Marshals (NASFM)
Safe Energy and Transportation Task Force

June 16, 2008

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Foreword

The sole purpose of this investigation was to develop data to evaluate the fire performance of ceiling/wall materials for U.S. railcars and seats in buses. The data will be used by the National Association of State Fire Marshals' (NASFM) Safe Energy and Transportation Task Force for their assessment of fire hazards relating to U.S. railcars and buses.

Investigations are normally conducted by Underwriters Laboratories Inc. for Classification, Listing, or Recognition and Follow-Up Service on proprietary materials. However, Underwriters Laboratories Inc. has conducted investigations without Classification, Listing, or Recognition and Follow-Up Service when a need for test data has been established by users of the product under examination and for authorities of jurisdiction. Such investigations do not result in specific conclusions, nor any form of Recognition, Listing, or Classification of the products involved. It is on this basis that Underwriters Laboratories Inc. will undertake the investigation described herein.

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Information conveyed by this Report applies only to the specimens actually involved in these tests. UL has not established a factory Follow-Up Service Program to determine the conformance of subsequently produced material, nor has any provision been made to apply any registered mark of UL to such material.

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Executive summary

This investigation was conducted at the request of the National Association of State Fire Marshals to investigate ceiling/wall materials for railcars and seating for buses. Currently in the U.S., fire safety regulations require compliance of these materials/products using standardized tests methods (e.g. ASTM E 162, ASTM E 662, FMVSS 302). This investigation assessed these test methods' ability to serve as fire performance predictors for materials in a large-scale setting and also evaluated other tests that may provide a better fire hazard assessment. The specific objectives of the investigation were as follows: (1) review current fire performance regulations for railcars and buses, (2) develop fire performance data on railcar and bus materials/products, (3) identify fire performance metrics, and (4) work with the NASFM technical advisory committee to recommend best practices to be used for the selection of materials/products in railcars and buses.

The fire hazard situation was first analyzed to determine an appropriate approach. If the railcar or bus is in operation during a fire event, egress of passengers may be difficult; therefore fire prevention and control of fire to the first item ignited is important for ensuring the safety of passengers. This hazard-based approach then led to the identification of key fire performance metrics and the tests that may be used to quantify these metrics.

The railcar portion of the study examined test methods currently used in U.S. railcar regulations (i.e. ASTM E 162, ASTM E 662) and test methods that are part of the proposed European railcar regulations (i.e. ISO 5658-2, ISO 5659-2, ISO 5660-1). These tests include the Cone Calorimeter (ISO 5660-1) and the LIFT (Lateral Ignition and Flame spread Test) apparatus (ISO 5658-2), in addition to a smoke measurement test (ISO 5659-2). In order to provide a context for these test results, the room corner test, as described in NFPA 286, was identified as a reference test model. Four materials were tested: a Nomex® railcar panel (aluminum-Nomex®-aluminum composite), a plywood railcar panel (aluminum-plywood-aluminum composite), a high-performance FRP (fiberglass-reinforced plastic), and common plywood. Both railcar materials complied with the U.S. standardized test methods, however they did not consistently comply with the European measure of flame spread (ISO 5658-2). In addition, both materials caused flashover when placed in the reference test model (i.e. NFPA 286).

The bus portion of the study examined U.S. testing regulations (i.e. FMVSS 302) regarding bus seats, in addition to ISO test methods that may be of interest (i.e. ISO 5658-2, ISO 5660-1). In order to provide a context for interpreting the small-scale test results (i.e. reference model), full-scale bus seats were tested in accordance with ASTM E 1537. This test is used in current regulations for upholstered furniture (i.e. California TB 133). Four different bus seat constructions were tested: a vinyl-Kevlar® composite on a metal and plastic frame, a wool-Kevlar® composite on a metal and plastic frame, polyester and foam on a metal frame, and wool and foam on a metal frame. All bus materials complied with FMVSS 302, however when full-scale seats were tested, only two of the four types of seats clearly complied with TB 133.

Experimental results demonstrate that the current U.S. test methods for evaluating the fire performance of railcar ceiling and wall materials does not accurately represent fire growth measured in the room corner test (reference test model). However, an analysis indicates that results from the LIFT apparatus (ISO 5658-2) and the Cone Calorimeter (ISO 5660-1) may be correlated to the fire performance of materials in the room corner test (NFPA 286). Additional data is needed in order to develop a robust statistical basis and to provide measures of uncertainty for the correlations between the small-scale tests and the reference model.

Experimental results for the bus seat samples showed that FMVSS 302 does not predict the fire performance of full-scale bus seats (i.e. reference test model). An alternative approach, recommended in this report, is to use the ASTM E 1537 test with requirements based upon California TB 133. Results from the small-scale tests showed that the Cone Calorimeter (ISO 5660-1) may be suitable to screen bus seat materials.

Keywords: bus safety, cone calorimeter, fire hazard, fire prevention, fire regulations, furniture calorimeter, heat release rate, LIFT, railcar safety, room fire growth, smoke release rate, toxicity

Acknowledgements

This research project was funded by the U.S. Department of Transportation, Federal Transportation Administration (FTA) under Project No. DC-26-5243, granted to the National Association of State Fire Marshals (NASFM). The purpose of this grant was to evaluate the fire performance of ceiling/wall materials present in U.S. railcars and seats in buses. NASFM provided overall support and project direction on all of the Tasks for the project.

A Technical Advisory Committee was established for this research project. Members of this Technical Advisory Committee include: Jack Alexander (Chairman), former Kansas State Fire Marshal; Jacob Borgerson, Underwriters Laboratories Inc.; David Bryson, National Highway Traffic Safety Administration; Ralph Buoniconti, SABIC Innovative Plastics; Pravinray Gandhi, Underwriters Laboratories Inc.; Joseph Kolly, National Transportation Safety Board; Michael Nelson, Montgomery County Fire and Rescue Service; Richard Peacock, National Institute of Standards and Technology; and Victor Size, Washington Metropolitan Area Transit Authority.

The FTA liaison team was comprised of the following individuals: Levern McElveen, Iyon Rosario, and Richard Wong.

Some of the data presented in this report was obtained from a previous project conducted by Underwriters Laboratories Inc. for GE Advanced Materials Research (now SABIC Innovative Plastics), *Report on the investigation of the fire performance of composite panels* (Underwriters Laboratories Inc., 2007).

Contents

List of Figures

List of Tables

List of symbols

c_i	concentration of the *i*th gas
C_i	reference concentration of the *i*th gas
D_S	specific optical density
h_c	heat of combustion
I_S	flame spread index
$\dot{m}$	mass loss rate
Q	heat release rate
q	heat release rate per unit area
t	time
Δt	change in time
σ	extinction cross-sectional area
φ	concentration of gas

List of abbreviations

ARHE	Average Rate of Heat Emission
ASTM	American Standards for Testing and Materials
CBUF	Combustion Behaviour of Upholstered Furniture
CFE	Critical Flux at Extinguishment
CIT	Conventional Index of Toxicity
DNI	Did Not Ignite
EN	European Nations
FEC	Fractional Effective Concentration
FED	Fractional Effective Dose
FRP	Fiberglass-Reinforced Plastic
FTIR	Fourier Transform Infrared spectroscopy
GE	General Electric
FMVSS	Federal Motor Vehicle Safety Standards
FRA	Federal Railroad Administration
HL	Hazard Level
HRR	Heat Release Rate
ISO	International Organization for Standardization
LIFT	Lateral Ignition and Flame spread Test
MARHE	Maximum Average Rate of Heat Emission
NASFM	National Association of State Fire Marshals
NFPA	National Fire Protection Association
NIST	National Institute of Standards and Technology
NTSB	National Transportation Safety Board
SABIC	Saudi Basic Industries Corporation
SRR	Smoke Release Rate
TB	Technical Bulletin
TGA	Thermogravimetric Analysis
UL	Underwriters Laboratories Inc
UMTA	Urban Mass Transportation Administration
VOF4	Valeur Obscurcissement Fumée in 4 minutes

Investigation of the Fire Performance of Materials and Products for Use in U.S. Railcar and Bus Applications

FINAL REPORT

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1 Introduction

This investigation was conducted at the request of the National Association of State Fire Marshals (NASFM) to investigate ceiling/wall materials for railcars and seat materials for buses.

1.1 Project objectives

The sole purpose of this project was to study the fire performance of railcar and bus materials/components using small-scale and large-scale test methods. Data from these various small- and large-scale tests could then be used by NASFM for their assessment and development of appropriate fire protection approaches.

Based upon discussions with the NASFM's Safe Energy and Transportation Task Force, project objectives were developed and can be summarized as follows:

- Conduct review of current U.S. and EN requirements for fire performance for railcars and buses.
- Identify fire performance metrics, including: heat release rate, extinction cross-sectional area, critical heat flux at extinguishment, and gas concentrations.
- Develop fire performance data on materials/products that may be used in railcars and buses using the appropriate test methods.
- Work with NASFM to develop improved practices to be used for selection of materials and products used in railcars and buses.

While railcar seats are not being examined, the methodology that will be developed for bus seats could potentially be applied to railcar seats due to the similarities between city bus seats and commuter train seats (and also intercity bus seats and intercity railcar seats). Similarly, the methodology for interior railcar walls could be applied to interior bus walls.

1.2 Project overview

In order to achieve the objectives described in the previous section, a technical plan was developed consisting of the following tasks:

TASK 1: Conduct situation analysis

TASK 2: Develop fire performance data for products currently allowed in U.S. railcars and buses using small-scale testing and large-scale testing

TASK 3: Analyze data

TASK 4: Identify fire performance metrics for materials used in railcars and buses

TASK 5: Develop final report

TASK 6: Produce consensus of best practices

A schematic flow chart giving an overview of the tasks for this research investigation is depicted in Figure 1; specific deliverables for each task are also provided.

Task 1 presented fire incident data, fire regulations, and previous research on railcars and buses [1]. An effort was made to summarize the most relevant literature on the topic of railcar and bus fire safety. The methodology for evaluating the fire performance of materials was then introduced and appropriate test methods for the project were identified. Test samples, representative of railcar and bus interior components, were finally selected.

Task 2 focused on developing fire performance data on interior materials for railcars and buses [2]. First, cone calorimeter tests [3] were used to screen candidate materials. Once samples had been selected to obtain a broad range of performance, small-scale and large-scale tests were performed. A variety of small-scale tests were performed in order to evaluate several fire performance metrics. Large-scale tests were then performed in order to enable correlations to be made to the small-scale test results. Finally, the small-scale test results for the current regulations were compared to the large-scale test results.

Task 3 analyzed the data. Relationships were developed between the small-scale data and the large-scale fire results, using various analysis techniques.

Task 4 used the results from Task 3 to recognize important fire performance metrics. Here, the goal was to identify fire performance metrics that can describe fire growth in a larger-scale environment.

Task 5 details the project as a final technical report. This final report describes the samples, test procedures, results, and analyses of the research investigation.

Task 6 is anticipated to begin after the technical advisory panel has reviewed the report. Underwriters Laboratories Inc. staff will work with the technical advisory panel to develop recommendations for improvements to the current fire performance regulations for railcar ceiling/wall materials and bus seat materials.

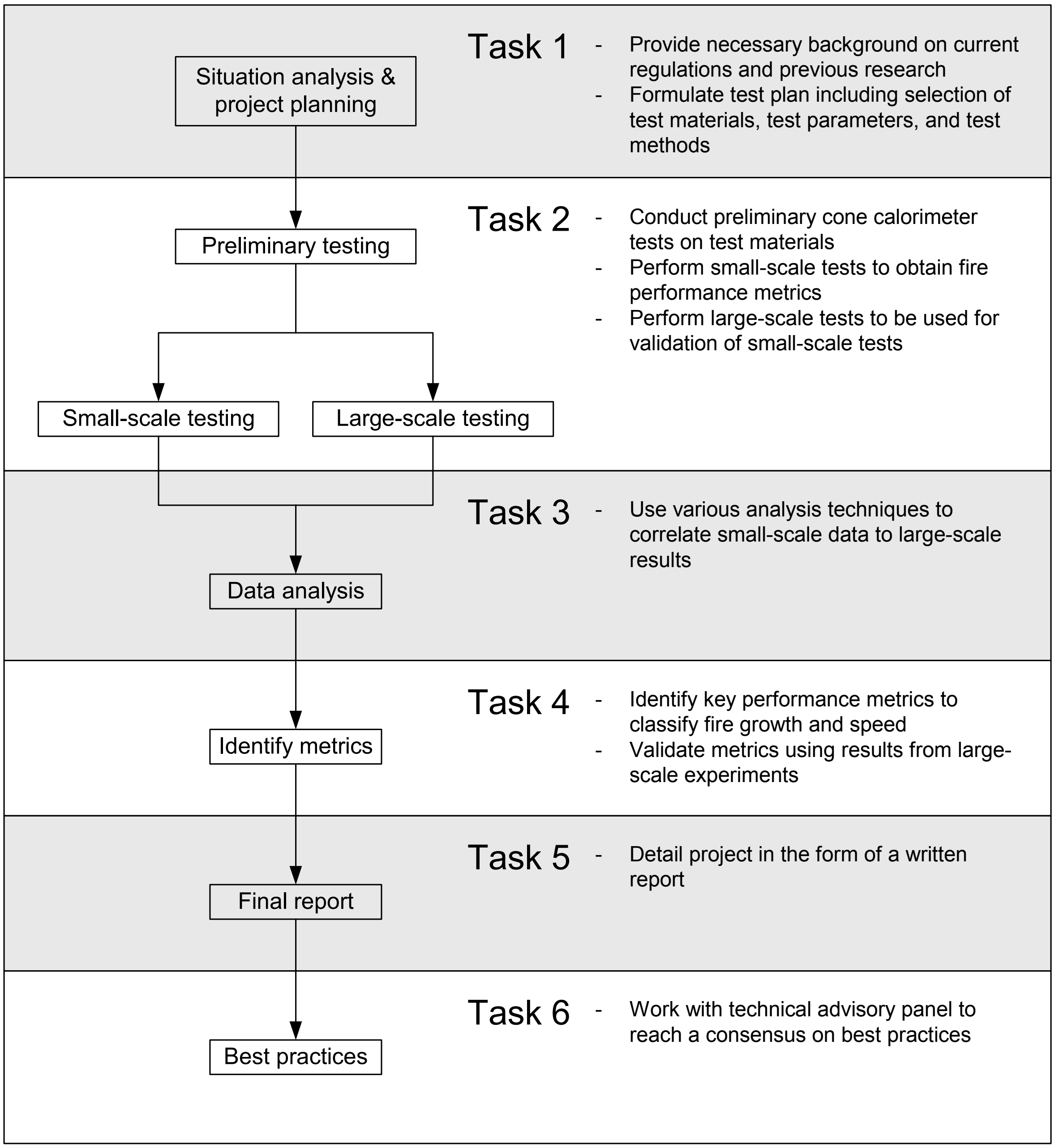

Figure 1: Schematic flow chart giving an overview of the tasks for the research investigation

2 Background

This section focuses on discussing (1) notable fire incidents involving railcars and buses, (2) current regulations in the U.S. and internationally, and (3) previous research on fire performance testing for railcars and buses.

2.1 Fire incidents

Passenger railcars and buses have a wide range of combustible materials and products. These environments have inherent heat sources (e.g. cooking equipment, heaters) that may develop malfunctions (e.g. short circuits, overheated engine). In addition, passengers traveling in railcars and buses may bring additional hazards (e.g. cigarettes, lighters, matches).

While fire-related rail and bus incidents are relatively rare, when they do occur, the potential exists for a fatal outcome. Because exits for trains and buses are limited (e.g. few doors, confined space, blocked pathways), it can be difficult for passengers to escape in a timely fashion. In the event that the doors of the railcar or bus are blocked, this will require many people to exit quickly and calmly through a window or other emergency exit. The limited number of exits coupled with a high stress situation and an unfamiliar environment, can cause passengers to feel overwhelmed when a fire occurs. This section describes major fire incidents involving railcars and buses.

2.1.1 Railcar fire incidents

There have been a number of passenger railcar fire incidents within and outside the U.S. There were approximately 700 reported fire-related incidents involving passenger railcars in the U.S. from 1999 to 2003, causing an estimated 25 deaths and 335 injuries [4]. Table 1 shows notable fire incidents involving passenger railcars over the last 30 years, with an emphasis on recent years. In cases when the railcar is in a confined space [5] or when overcrowding occurs [6,7], a fire can be disastrous.

The incident in Kaprun, Austria is one such example [5]. Here, a train was traveling through a tunnel when a fire initiated from an electric heater overheating. The fire quickly engulfed the train. While several passengers were able to escape through the windows of the railcar, they were not able to survive the fire effluent gases that accumulated in the tunnel. Consequently, only 12 of the 162 passengers survived.

A fire incident in Cairo, Egypt involved an explosion of a propane gas cylinder from a portable gas stove [6,7]. The number of passengers in each railcar was over twice the capacity, due to many people traveling for holiday. Because of the large number of people in each railcar, it was difficult for passengers to escape the fire and reach an exit, causing them to be trapped. Before the fire was finally extinguished, there were 363 fatalities.

A train traveling near Nancy, France caught fire due to a jacket being placed near a hot plate [8,9]. The fire started in a sleeping car, which became filled with toxic smoke. Because the train possessed no smoke detectors and the fire started late at night, passengers were slow to become aware of the fire. Smoke is believed to be the cause for the deaths of the 12 passengers.

While these railcar fire cases are infrequent, these incidents reveal that managing the egress of the passengers is difficult.

Table 1: Notable fire incidents involving passenger railcars

Date	**Location**	**Description**	**Ignition source**	**Reference**
Aug 25, 2007	Micro, North Carolina	Intercity train. Engine room fire. No injuries.	Engine	[10]
May 15, 2003	Ladhowal, India	Intercity train. Fire origin unknown. 39 dead. 15 seriously injured.	Unknown	[11]
Nov 6, 2002	Nancy, France	Intercity train. Hot plate igniting jacket. 12 dead.	Kitchenette hot plate	[8,9]
Feb 20, 2002	Cairo, Egypt	Intercity train. Propane gas cylinder explosion. 363 dead.	Propane gas cylinder	[6,7]
Nov 11, 2000	Kaprun, Austria	Commuter train. Overheating and ignition of electric heater. 155 dead.	Electric heater	[5]
June 23, 1982	Gibson, California	Intercity train. Cigarette discarded on a cushion. 2 dead. 2 seriously injured.	Cigarette	[12]
Jan 17, 1979	San Francisco, California	Commuter train. Short circuit started fire. 1 dead. 40 seriously injured.	Short circuit	[13]
Jul 6, 1978	Taunton, England	Intercity train. Electric heater igniting plastic bags and dirty linen. 12 dead. 15 seriously injured.	Electric heater	[14]

∗ Fire incidents related to collisions or terrorist attacks were not considered in this investigation

2.1.2 Bus fire incidents

It is estimated that six bus or school bus fires occur every day [15]. Table 2 shows notable fire incidents involving buses. Similar to the railcar incidents described earlier, the outcome of a fire on a bus can be fatal when the evacuation of the passengers is impaired [16,17].

Two years ago, a motorcoach (i.e. intercity bus) traveling to Dallas, Texas caught fire [17]. The bus was carrying elderly persons and their nursing staff, which was part of an evacuation due to Hurricane Rita. The wheel assembly of the bus was improperly lubricated, which lead to excess friction, heat generation, and finally flames. Because several of the bus passengers were elderly, their ability to escape was limited and contributed to the deaths of 23 of the 44 passengers.

In a related incident, a bus in Panama City was subjected to fire when the engine overheated, igniting the insulation [16]. While most city transit buses will have two doors (one in the front of the bus and one towards the rear), motor coach buses will typically have one door located at the front and may (or may not) have a door located at the rear. For the case in Panama City, there was not a second exit at the rear of the bus and the passengers were required to exit via the front door or through the emergency windows. Once it was realized that the bus was on fire, people began to exit, but passengers toward the back of the bus were not able to escape in time.

Table 2: Notable fire incidents involving passenger buses

Date	Location	Description	Ignition source	Reference
Aug 27, 2007	Lewisburg, Pennsylvania	Intercity bus. Engine fire. No injuries.	Engine	[18]
Oct 23, 2006	Panama City, Panama	Intercity bus. Engine overheated, igniting insulation. 18 dead. 25 seriously injured.	Engine	[16]
Sept 23, 2005	Wilmer, Texas	Intercity bus. Improper lubrication of wheel assembly, leading to excess friction and heat generation. 23 dead. 2 seriously injured.	Wheel assembly	[17]
Jan 29, 1991	Bellwood, Illinois	Commuter bus. High-voltage power line fell on a bus. 1 dead. 1 seriously injured.	Power line	[19]

∗ Fire incidents related to collisions or terrorist attacks were not considered in this investigation

As described earlier, intercity buses (i.e. motorcoaches) can present particularly dangerous situations. However, given enough time, all passengers should be able to safely escape through a door or an emergency window. For example, if one could have controlled the growth and speed of the fires in the previous two cases (i.e. if more time was allotted for evacuation), more passengers may have survived.

2.2 Current U.S. and international regulations

This section presents a review of fire safety approaches used in the United States and Europe for the combustibility of railcar wall/ceiling materials and bus seating materials. The discussion identifies the test methods and the fire performance requirements. The review includes both the U.S. and the proposed European Nations (EN) requirements.

2.2.1 Railcar regulations

Currently, both the Federal Railroad Administration (FRA) and the National Fire Protection Association (NFPA) have safety requirements that address the flammability and smoke characteristics of intercity and commuter passenger railcar materials through the use of standardized bench-scale tests [20-22]. The FRA and NFPA have the same requirements for the interior walls of railcars; both require ASTM E 162 [23] and ASTM E 662 [24]. It is noteworthy that the recommendations of the Federal Transit Administration (FTA) [25] for wall and ceiling materials in rail vehicles are identical to that of the regulations for FRA and NFPA. Table 3 gives a summary of U.S. railcar requirements as it pertains to this study.

ASTM E 162 [23] is a test method for evaluating surface flammability (see Figure 2). A flame is placed at the top of the inclined test specimen while the specimen is exposed to a radiant heat source. A flame spread index, I_S, is then calculated from the rate of heat liberation and the rate of downward progression of the flame front. Both the FRA and the NFPA require that this factor not exceed 35; in addition, materials cannot exhibit any flaming running or flaming dripping [21,22].

Table 3: U.S. fire performance requirements for rail and bus materials

Form of transport	Application	Test procedure	Performance criteria	Organization
Rail	Ceiling & wall	ASTM E 162	Flame spread index † $I_S \leq 35$	FRA, NFPA
Rail	Ceiling & wall	ASTM E 662	Specific optical density $D_S(1.5) \leq 100$, $D_S(4.0) \leq 200$	FRA, NFPA
Bus	Seating	FMVSS 302	Burn rate < 102 mm/min	NHTSA

† Materials cannot exhibit any flaming running or flaming dripping

(a) Overview of apparatus without specimen (b) Detail of apparatus with specimen

Figure 2: Experimental set-up for ASTM E 162 [23]

ASTM E 662 [24] assesses the density of smoke. The method measures the attenuation of a light beam due to the smoke generated when a specimen is exposed to a flux level of 25 kW/m^2. The FRA and NFPA require the application of ASTM E 662 [24], testing both flaming and nonflaming exposure at a heat flux of 25 kW/m^2. Both organizations specify that the specific optical density, D_S, should not exceed 100 and 200 at 1.5 and 4.0 minutes, respectively [20-22]. Figure 3 shows a typical test in progress for ASTM E 662 [24].

(a) Overview of apparatus (b) Detail of apparatus

Figure 3: Experimental set-up for ASTM E 662 [24]

It is also the intention of the European Nations (EN) to address flammability and smoke regulations on public rail transport by incorporating similar bench-scale tests [26,27]. The EN requirements for railcar interior walls and ceilings are based on the results of ISO 5658-2 [28], ISO 5659-2 [29], and ISO 5660-1 [3].

The European standards [26,27] consider the design characteristics of the vehicle, in addition to the operating environment of the railcar. Based on the design and environment, the railcar is then given a *hazard level* of 1 through 3 (3 being the worst case and 1 being best case). The hazard level then dictates the performance requirements of the railcar materials. For example, a railcar with a hazard level of 3 (i.e. HL3) would require the highest fire performance level for its interior walls (e.g. CFE ≥ 20; $D_S(4.0) \leq 150$). Table 4 gives a summary of the EN railcar requirements as it pertains to this study.

Table 4: EN fire performance requirements for rail materials [26,27]

Application	Test procedure	Performance criteria
Ceiling & wall	ISO 5658-2	Critical heat flux at extinguishment† HL1: CFE ≥ 20 HL2: CFE ≥ 20 HL3: CFE ≥ 20
Ceiling & wall	ISO 5659-2	Specific optical density HL1: $D_S(4.0) \leq 600$ HL2: $D_S(4.0) \leq 300$ HL3: $D_S(4.0) \leq 150$
Ceiling & wall	ISO 5659-2	Valeur obscurcissement fumée in 4 min HL1: VOF4 ≤ 1200 HL2: VOF4 ≤ 600 HL3: VOF4 ≤ 300
Ceiling & wall	ISO 5659-2	Conventional index of toxicity at 8 min HL1: CIT ≤ 1.2 HL2: CIT ≤ 0.9 HL3: CIT ≤ 0.75
Ceiling & wall	ISO 5660-1	Max average rate of heat emission HL1: - HL2: MARHE ≤ 90 HL3: MARHE ≤ 60

† If flaming droplets occur or material does not ignite, then additional tests should be conducted: (1) ISO 5660-1 with MARHE ≤ 90 and (2) EN 11925-2 with 30 sec flame application no spread greater than 150 mm within 60 sec and shall not have burning droplets

ISO 5658-2 [28] measures the lateral flame spread along the surface of a vertically orientated sample. This method, similar to ASTM E 162 [23], measures the flame propagation and heat development in a sample when subjected to an ignition source. EN regulations [26,27] specify minimum values for the critical heat flux at extinguishment depending upon the design and environment of the railcar, as shown in Table 4. For example, a railcar with a hazard level of 3 (i.e. HL3 being the worst case scenario) would require CFE ≥ 20. Figure 4 shows the experimental arrangement for ISO 5658-2 [28].

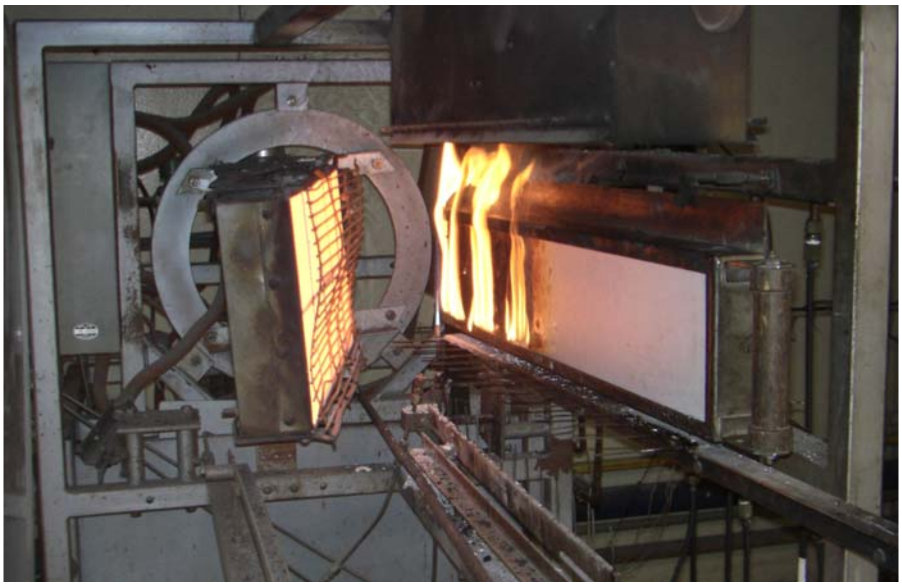

Figure 4: Experimental set-up for ISO 5658-2 [28]

ISO 5659-2 [29] is similar to ASTM E 662 [24]; it measures the smoke density. The primary differences between the two approaches are the radiant heater used to heat the sample and the sample orientation. Contrary to U.S. regulations, European regulations require a heat flux of 50 kW/m^2 without a pilot flame for smoke measurements [27]. Figure 5 shows the experimental arrangement for 5659-2 [29].

(a) Overview of apparatus (b) Detail of apparatus

Figure 5: Experimental set-up for ISO 5659-2 [29]

The proposed European regulations [26,27] introduce two metrics, VOF4 and CIT, which are presented here for completeness. The Valeur Obscurcissement Fumée in 4 minutes (VOF4) is the area under the D_S versus time curve during the period t = 0 to t = 4; using trapezoidal rule with discrete time step of t = 1 min

$$\mathrm{VOF4} = \sum_{i=0}^{3} \frac{t\left(D_S(i) + D_S(i+1)\right)}{2} \tag{1}$$

where D_S is the specific optical density and t is time [27]. The Conventional Index of Toxicity (CIT) is a dimensionless summation of relative amounts of gas components

$$\mathrm{CIT} = 0.0805 \sum_{i=0}^{8} \frac{c_i}{C_i} \tag{2}$$

where c_i is the concentration of the ith gas and C_i is the reference concentration of the ith gas (defined in Table 5).

Table 5: Reference concentration of gas components for calculation of Equation 2

Gas components		Reference concentration (mg/m^3)
CO_2	Carbon dioxide	72,000
CO	Carbon monoxide	1380
HF	Hydrogen flouride	25
HCl	Hydrogen chloride	75
HBr	Hydrogen bromide	99
HCN	Hydrogen cyanide	55
NO_2	Nitrogen dioxide	38
SO_2	Sulphur dioxide	262

EN regulations stipulate criteria for the area under the D_S versus time curve (i.e. VOF4, valeur obscurcissement fume in 4 min). In addition, the toxic fume requirements are specified in terms of the CIT at 8 minutes. For a railcar with a hazard level of 3, EN regulations require that $D_S(4.0) \leq 150$, VOF4 ≤ 300, and CIT(8.0) ≤ 0.75. On the opposite end of the spectrum, for a hazard level of 1, $D_S(4.0) \leq 600$, VOF4 ≤ 1200, and CIT(8.0) ≤ 1.2.

ISO 5660-1 [3], often referred to as the cone calorimeter test, determines the heat and smoke release rate of a specimen when exposed to various levels of irradiance (e.g. 25, 35, 50, 75 kW/m^2). Figure 6 shows the experimental arrangement for ISO 5660-1 [3].

(a) Overview of apparatus

(b) Detail of apparatus

Figure 6: Experimental set-up for ISO 5660-1 [3]

EN regulations specify the application of ISO 5660-1 [3] at a heat flux of 50 kW/m^2. A heat flux exposure of 50 kW/m^2 represents a severe fire exposure consistent with actual train fire tests; with the high performance of currently used materials, flux exposures higher than 50 kW/m^2 are unlikely [30]. EN regulations use heat release data from ISO 5660-1 [3] to determine the maximum average rate of heat emission (MARHE). The Maximum Average Rate of Heat Emission is the maximum value of the Average Rate of Heat Emission (ARHE) curve; the ARHE at time *t* is defined as the cumulative heat emission in the period *t* = 0 to *t* = *t* divided by *t*

$$\mathrm{ARHE}(t_i) = \frac{\sum_{i=2}^{n}\left((t_i - t_{i-1}) \times \frac{(q_i + q_{i-1})}{2}\right)}{t_i - t_1} \tag{3}$$

where *q* is the heat release rate per unit area [27]. For a railcar with a hazard level of 3, EN regulations require that MARHE ≤ 60; for a hazard level of 1, there are no requirements for the MARHE [27].

2.2.2 Bus regulations

Currently, there are only a few U.S. regulations governing the fire performance of bus components. In fact, there really only exists one test that is required for bus seating materials, FMVSS 302 [31]. It should be noted that the Federal Transit Administration (FTA) does provide several recommendations for testing procedures [32] for bus seating materials, however these are solely recommendations and are not required by law.

The safety standard, FMVSS 302 [31], published by the National Highway Traffic Safety Administration applies to passenger cars, trucks, buses, and multipurpose vehicles. The purpose of this standard is to regulate the burn resistance of single or composite materials used in the occupant compartment air space of motor vehicles. Specifically, a test sample is exposed to an open flame and the length of time for the flame to travel across a specified distance is measured. The standard states that the burn rate (i.e. velocity) should not be greater than 102 mm/min (see Table 3).

Similarly in Europe, there are no specific requirements for bus seating materials, however materials used in bus seats must also comply with FMVSS 302 [31].

2.3 Literature review on previous research

It can be seen from Table 3 and the previous discussion, current U.S. standards can be improved. This section will describe previous research and recent advancements that have occurred in attempt to improve upon the U.S. regulations for rail and bus transportation.

2.3.1 Railcar research

The Fire Research Division at NIST (National Institute of Standards and Technology) has been actively involved with the study of fire safety in rail transportation. Their research is the result of a series of studies for the Washington Metropolitan Area Transit Administration, Urban Mass Transportation Administration, and the U.S. Federal Railroad Administration (FRA).

NIST became involved with passenger rail transportation in the mid 1970s with an investigation for the rail system in the Washington D.C. area [33]. The purpose of the investigation was to assist in identifying potential fire hazards for the interior of new subway cars. It was determined, for the materials under investigation, that the primary fire hazards were the seats and walls of the car. Both the smoke development and spread of flame were causes of concern. In addition, it was found that the small-scale test results were a poor indicator of fire performance of the entire system.

Soon thereafter, cars were evaluated in the San Francisco area, which looked at potential fire hazards for subway cars [34]. Similar to the previous study, the seat assemblies for the cars were found to be a major contributor to fire growth.

Later, a study was conducted on Amtrak passenger railcars for the FRA [35]. Here, the intention was to evaluate the burning behavior of passenger railcar interior components. Small-scale, full-scale, and real-scale tests were performed. It was discovered that the interaction between materials for actual geometries are a crucial element of fire performance, something that small-scale tests generally do not consider. As a result, in many cases this will require performing full-scale tests (a costly procedure) in order to ascertain the acceptability of materials for their application.

Recently, NIST has completed a three-phase research program for the FRA [36-38]. Phase 1 used the cone calorimeter test method to evaluate various properties (e.g. ignitability, heat release rate) of railcar interior materials [36]. Phase 2 used the heat release rate data from the previous phase in conjunction with results from full-scale assembly tests to perform fire analysis with the aide of computer modeling [37]. Phase 3 performed real-scale tests on a railcar to evaluate the extent that the small-scale tests, large-scale tests, and computer modeling could predict the fire behavior for an actual car [38]. In this final report, it was concluded that computer modeling could be used to evaluate passenger railcar safety.

2.3.2 Bus research

Compared to railcars, little research has been conducted on the performance of materials in buses. In the early 90s, NIST (National Institute of Standards and Technology) completed a series of studies on the fire performance of school bus components, focusing primarily on the seat assemblies [39,40]. This investigation was motivated by a fire-related bus accident in 1988 that caused the deaths of 27 individuals [41][1].

The purpose of the NIST school bus investigation was to evaluate the development of hazardous conditions for the interior of a bus [39]. The study found that small-scale (i.e. bench) tests were unable to provide consistent information for material selection at real-scale (i.e. results from small-scale tests do not translate to real-scale). The underlying problem with this translation of results is that the small-scale tests do not account for the effects of varied geometry in actual interiors. This should not be surprising because earlier studies also found this to be the case when examining railcars, years earlier [33,35]. In an attempt to predict the fire behavior of real-scale bus systems, full-scale testing (i.e. simulated system) and computer modeling were then used to determine the time-to-untenable conditions in actual vehicle geometries.

As it can be seen, there has been considerable research performed in the area of railcars; however, little work has been performed on the topic of buses. Despite the recent progress made in fire safety as it pertains to passenger rail, there are still opportunities for advancements. In the sections that follow, potential opportunities for improvements to current U.S. regulations regarding rail and bus transportation are explored.

3 Fire prevention approach

There are several stages of fire development, starting with a precipitating fire event (e.g. electrical malfunction, overheating, discarded cigarette), causing ignition of combustible item(s) in the proximity, and then leading to fire growth. At each stage of fire growth, specific strategies may be identified, such as: preventive measures, fire growth control, egress, and fire mitigation. Figure 7 shows these stages of fire development within fire prevention and mitigation.

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[1] In this incident, the gas tank of a church bus was punctured in a collision with a pickup truck, causing a fire to immediately erupt.

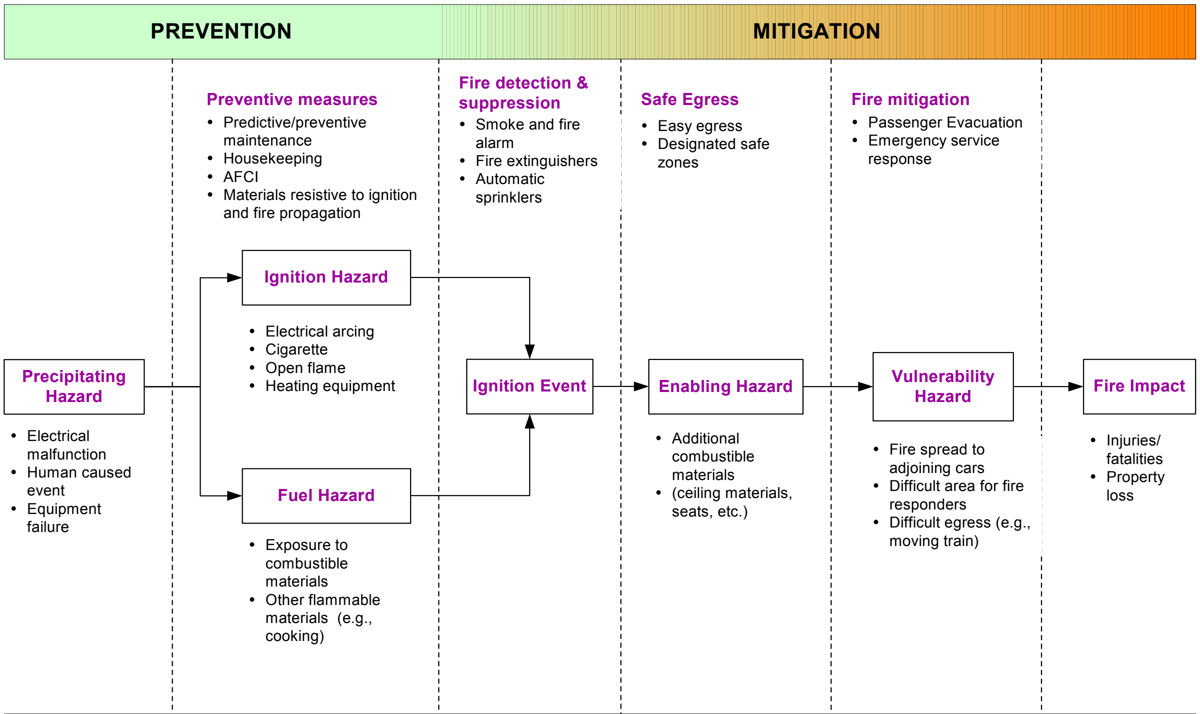


Figure 7: Schematic diagram showing stages of fire development within fire prevention and mitigation

An alternative view of the fire prevention approach is to examine an event tree, as shown in Figure 8. The specific fire protection strategies are provided along the top-level bar and the outcome of the strategy (i.e. Y for success and N for failure) is provided at each element of the event tree. Thus, successive failures of the strategies would lead to an increased severity of the consequences.

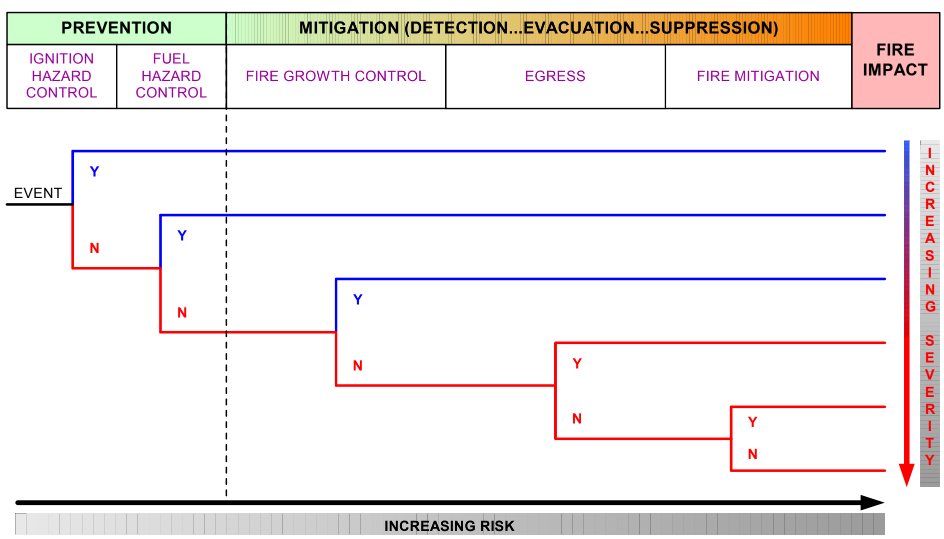


Figure 8: Event tree showing that as the fire continues to develop, the overall risk and severity of the fire impact will increase

For a railcar or bus, it is anticipated that a fire event could occur while it is in operation and therefore safe egress of the passengers may be difficult. Consequently, it may be beneficial to focus on (i) preventing fires and (ii) reducing the potential of fire growth when a fire incident does occur.

The importance of prevention and limiting fire growth may be illustrated by Wieczorek and Dembsey's investigation [42]. In this study, two simplified models were provided for determining the time to achieve pain and second-degree burns, based on the incident radiant heat flux (see Figure 9). Figure 9 (adapted from Wieczorek and Dembsey's paper) shows incident heat flux as a function of exposure time for limits on pain and second degree burns. As one might expect, as the incident heat flux increases, the time required to attain pain/burns decreases rapidly. For ease of comparison, Table 6 provides exposure times for pain and second degree burns to the skin for four different incident heat fluxes. Figure 9 and Table 6 show that for relatively low amounts of heat, only a short exposure time is needed for an individual to sustain injuries.

The preceding discussion suggests that a strategy adopted to either prevent or limit the fire growth potential of the combustibles would be an attractive alternative to managing fire events (i.e. egress and fire mitigation efforts). Thus, a testing methodology may be identified that includes the use of small-scale fire tests that measure the fire performance of the materials, aligning with the above fire protection strategy.

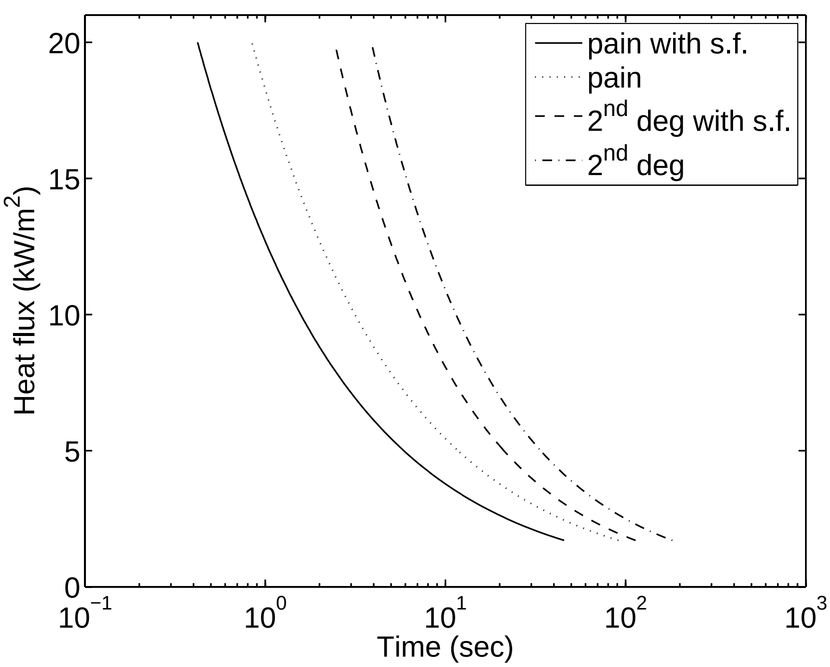


Figure 9: Incident heat flux as a function of exposure time for limits on pain and second degree burns, with and without safety factors (s.f.) applied [42]

Table 6: Heat flux with corresponding exposure times for pain and second degree burns to the skin [42]

Heat flux (kW/m^2)	Time to pain with s.f. (sec)	Time to pain (sec)	Time to 2^{nd} degree burn with s.f. (sec)	Time to 2^{nd} degree burn (sec)
2.5	22	44	62	100
5.0	6	12	21	34
7.5	3	5	11	18
10.0	2	3	7	12

The fire prevention approach that is implemented in this study, first evaluates the interior materials of railcars and buses by measuring several different fire hazard metrics using small-scale tests. These hazard metrics obtained from small-scale tests will then be used to describe fire growth in a larger-scale environment. Large-scale tests are used as reference models to provide a context to interpret the results of the small-scale tests. In addition, the reference models provide an alternative method to evaluate fire performance of materials. This concept of developing hazard-based criteria through the use of small- and large-scale testing (reference model) is illustrated in Figure 10.

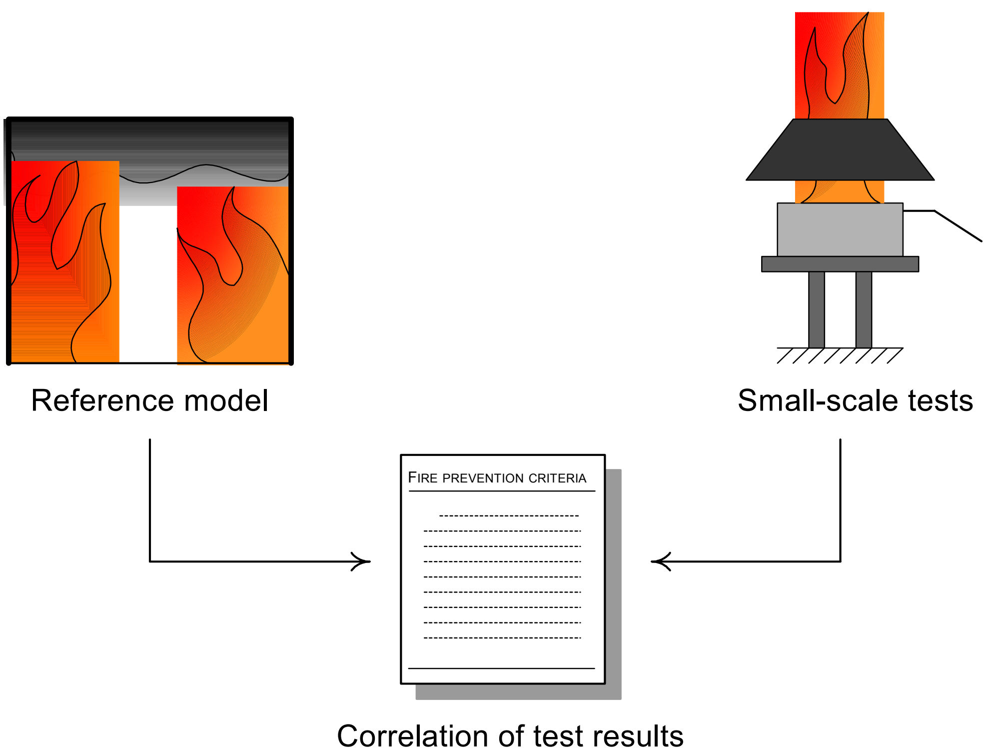


Figure 10: Schematic diagram showing hazard-based regulations through the scaling of small-scale test metrics to large-scale hazard parameters

4 Test materials

Railcars will generally possess composite panel walls. Earlier studies [33-35] have recognized the importance of wall materials, due to the wall's ability to contribute to the spread of fire. As a result, it is logical to study the fire performance of the materials used in the railcar interior walls and ceilings.

Most intercity (i.e. motorcoach) and commuter buses possess upholstered seats. Because seat assemblies represent a large type of combustible fuel [39], it is important to consider the seat assembly when studying the fire performance of bus materials and components.

Based upon a literature review and discussions with the National Association of State Fire Marshals' (NASFM) Safe Energy and Transportation Task Force, a list of sample materials for ceiling and wall lining materials and various seating composite combinations was developed. The materials include current materials used for the ceiling/wall of railcars and the seating assemblies of buses, in addition to others that provide a broader range of fire performance (for benchmarking purposes). An effort was made to select materials that are commercially available and representative of typical railcar interior walls and bus seating.

4.1 Railcar ceiling and wall test materials

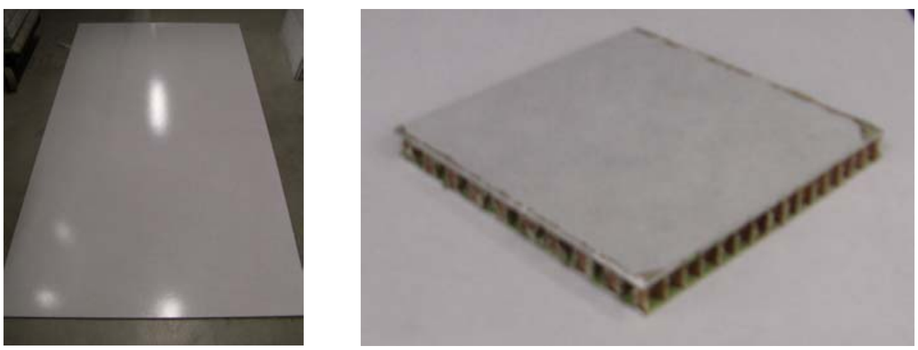
The interior walls and ceilings for railcars will typically consist of composite materials. The particular rail application will dictate the type of material that is used for the railcar. Typical walls may consist of plymetal (plywood core, metal skin), honeycomb panels (either an aluminum or Nomex® core), in addition to other materials.

Table 7 lists the materials that have been chosen for the railcar portion of the investigation; these materials represent different interior applications, in addition to varying fire performances. A detailed physical description of the materials can be observed in Figure 11 through Figure 14.

Table 7: Test materials for railcar investigation

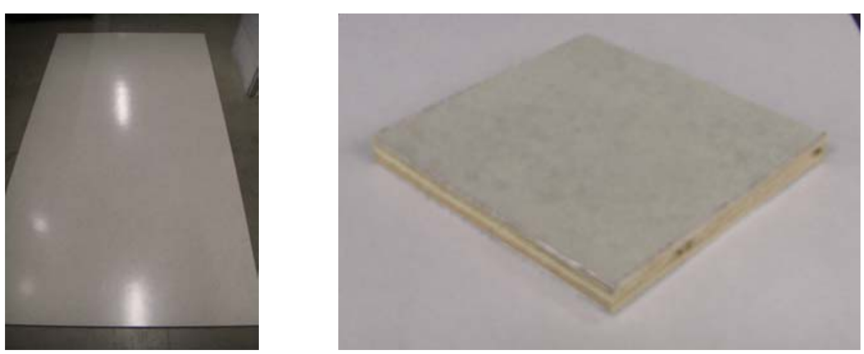
Material	Description	Application
Nomex® rail panel	Melaminium (melamine fused to aluminum) face, Nomex® honeycomb core (0.25” cell size), aluminum backer	Ceiling and wall for intercity railcar
Plywood rail panel	Melaminium (melamine fused to aluminum) face, plywood core, aluminum backer	Ceiling and wall for intercity railcar
FRP	Fiberglass-reinforced plastic†	Fume hood liner for laboratory, ceiling and wall for clean room
Plywood	Plywood, C-D Exposure 1 (CDX)†	Furniture, houses

† Used for benchmarking purposes



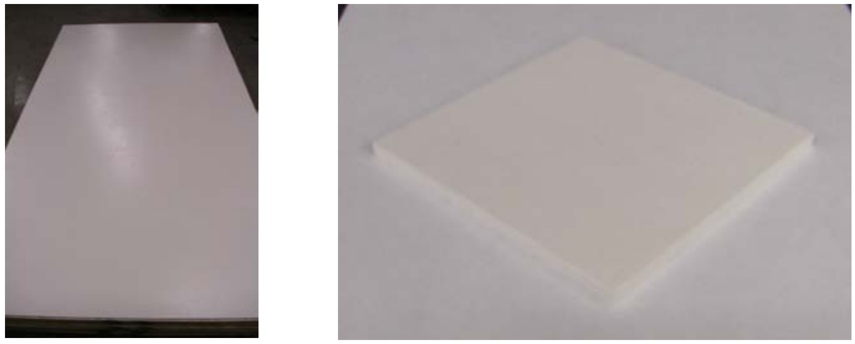
(a) 4’ × 8’ sheet of test material (b) Detail of test material

Figure 11: Melaminium (melamine and aluminum) face, Nomex® honeycomb core, aluminum backer



(a) 4’ × 8’ sheet of test material (b) Detail of test material

Figure 12: Melaminium (melamine and aluminum) face, plywood core, aluminum backer



(a) 4’ × 8’ sheet of test material (b) Detail of test material

Figure 13: Fiberglass-reinforced plastic

(a) 4’ × 8’ sheet of test material (b) Detail of test material

Figure 14: Plywood, C-D Exposure 1 (CDX)

4.2 Bus seat test materials

City buses are typically upholstered in vinyl or fabric with or without a Kevlar® backing layer[2]. Conversely, coach buses will tend to possess seats upholstered in fabric with a core of polyurethane foam. Table 8 shows the test materials selected for the bus investigation. These materials are typical for city and intercity (i.e. coach) buses, in addition to exhibiting diverse reactions to fire. Figure 15 show the four different bus seat constructions that were examined in this study.

[2] A Kevlar® backing layer is typically chosen over padded foam inserts due to issues of vandalism; in some instances (e.g. Los Angeles) only a fabric layer is used.

Table 8: Test materials for bus investigation

Seat type	Description	Application
Vinyl & Kevlar®	Vinyl cover with Kevlar® backing layer	Seating for city bus
Wool & Kevlar®	Wool fabric cover with Kevlar® backing layer	Seating for city bus
Polyester & foam	Polyester fabric cover with polyurethane foam insert	Seating for intercity coach
Wool & foam	Wool fabric cover with polyurethane foam insert	Seating for intercity coach

(a) Vinyl & Kevlar® (b) Wool & Kevlar® (c) Polyester & foam (d) Wool & foam

Figure 15: Bus seat assemblies used for bus investigation

5 Fire performance data

Several standardized test methods were used to develop fire performance data for the selected materials (i.e. railcar ceiling/wall lining materials and bus seating materials). These test methods included (i) current tests for U.S. regulations, (ii) proposed tests for European regulations, and (iii) appropriate large-scale test methods (i.e. reference test models).

5.1 Railcar fire performance data

This section presents fire performance data for ceiling/wall materials in passenger railcars. Two ASTM tests were performed on the railcar interior materials, ASTM E 162 [23] and ASTM E 662 [24]. In addition, three ISO tests were conducted on the railcar materials, ISO 5658-2 [28], ISO 5659-2 [29], and ISO 5660-1 [3]. Finally, room corner tests were conducted in accordance with NFPA 286 [43].

5.1.1 ASTM E 162

Table 9 provides a summary of the ASTM E 162 [23] test results for the various railcar materials (see Table 7). It can be seen in Table 9 that, with exception to the ordinary plywood, the other three materials comply with FRA and NFPA requirements [20-22] for surface flammability.

Table 9: Summary of surface flammability test results according to ASTM E 162 [23] for railcar investigation

Material	Ignition time (min)	Flame spread index
Nomex® rail panel	1.1	3
	2.1	2
	2.4	2
	5.5	3
average	**2.8**	**3**
Plywood rail panel	4.1	6
	4.4	7
	4.8	5
	4.6	6
average	**4.5**	**6**
FRP	3.1	11
	5.0	7
	5.6	6
	4.4	7
average	**4.5**	**8**
Plywood	1.2	141
	1.1	143
	1.2	133
	1.1	148
average	**1.1**	**141**

5.1.2 ASTM E 662

Table 10 provides a summary of smoke density test results according to ASTM E 662 [24] for the four different materials. Based on these test results, all of the materials comply with the smoke density requirements.

Table 10: Summary of smoke density test results according to ASTM E 662 [24] for railcar investigation

Material	Test mode	Ignition time (min:sec)	D_S (1.5)	D_S (4.0)
Nomex® rail panel	Flaming	4:15	1.1	52.1
	Flaming	3:42	0.9	76.3
	Flaming	2:53	10.2	142.3
average	**Flaming**	**3:37**	**4.1**	**90.2**
	Non-flaming	DNI	0.2	0.9
	Non-flaming	DNI	0.0	31.1
	Non-flaming	DNI	0.0	8.0
average	**Non-flaming**	**-**	**0.1**	**13.3**
Plywood rail panel	Flaming	DNI	0.2	30.4
	Flaming	DNI	0.3	60.2
	Flaming	5:22	0.6	74.2
average	**Flaming**	**-**	**0.4**	**54.9**
	Non-flaming	DNI	0.0	0.0
	Non-flaming	DNI	0.0	0.0
	Non-flaming	DNI	0.0	0.0
average	**Non-flaming**	**-**	**0.0**	**0.0**
FRP	Flaming	0:51	0.7	38.8
	Flaming	0:48	0.7	65.5
	Flaming	0:52	1.2	45.4
average	**Flaming**	**0:50**	**0.9**	**28.1**
	Non-flaming	DNI	0.0	5.4
	Non-flaming	DNI	0.0	7.8
	Non-flaming	DNI	0.0	4.0
average	**Non-flaming**	**-**	**0.0**	**5.7**
Plywood	Flaming	0:31	1.2	3.8
	Flaming	0:35	2.7	2.0
	Flaming	1:36	1.3	1.1
average	**Flaming**	**0:54**	**1.7**	**2.3**
	Non-flaming	DNI	3.6	18.2
	Non-flaming	DNI	3.1	34.6
	Non-flaming	DNI	2.5	66.0
average	**Non-flaming**	**-**	**3.1**	**39.6**

5.1.3 ISO 5658-2

Table 11 provides results for the four materials when tested in accordance with ISO 5658-2 [28]. Here, it can be seen that the two types of materials representative of typical wall/ceiling panels in railcars do not consistently meet the EN requirements. Only the FRP is able to comply with the EN requirement for flame spread.

Table 11: Summary of surface flammability test results according to ISO 5658-2 [28] for railcar investigation

Material	Ignition time (min:sec)	Peak heat release rate (kW)	Critical flux at extinguishment (kW/m^2)	Maximum flame travel (mm)
Nomex® rail panel	0:36	2.0	23.7	350
	0:27	1.4	18.5	400
	0:38	2.0	23.7	350
average	**0:34**	**1.8**	**22.0**	**367**
Plywood rail panel	1:32	2.8	18.5	400
	1:01	1.7	18.5	400
	1:25	2.6	23.7	350
average	**1:19**	**2.4**	**20.2**	**383**
FRP	1:32	2.1	30.5	300
	1:35	1.7	30.5	300
	1:48	2.2	30.5	300
average	**1:38**	**2.0**	**30.5**	**300**
Plywood	0:05	4.4	2.7	750
	0:07	4.7	2.7	750
	0:11	4.8	3.4	700
average	**0:08**	**4.6**	**2.9**	**733**

5.1.4 ISO 5659-2

Table 12 provides results for the four materials when tested in accordance with ISO 5659-2 [29]. While both of the railcar materials (Nomex® rail panel and plywood rail panel) do satisfy HL1 requirements, only the plywood rail panel complies with an HL3 design requirement. It is interesting to note that ordinary plywood complies with the strictest EN requirement [27] for smoke generation.

In order to calculate the CIT (Conventional Index of Toxicity), the gases were analyzed by FTIR (Fourier Transform Infrared) technology as described in the EN document [27]. Gas effluent composition was characterized using an FTIR Spectrometer equipped with a 10-meter path length optical cell. Prior to conducting the test, a reference background spectrum was collected based on the average of 64 scans.

During the test, an average of 8 scans was collected every 10 seconds. Using, a gas calibration library, the concentration of the gas components were detected and calculated.

Table 12: Summary of smoke generation test results according to ISO 5659-2 [29] for a heat flux of 50 kW/m^2, non-flaming for railcar investigation

Material	Ignition time (min:sec)	D_S (4.0)	VOF4	CIT(8.0)
Nomex® rail panel	4:10	139.4	282.0	0.33
	2:35	220.3	336.0	0.45
	2:41	158.6	300.4	0.54
average	**3:09**	**172.8**	**306.1**	**0.44**
Plywood rail panel	5:57	69.8	90.3	0.37
	5:23	78.4	118.9	0.42
	6:12	72.6	94.8	0.40
average	**5:51**	**73.6**	**101.3**	**0.40**
FRP	3:37	151.4	147.9	0.12
	2:47	193.5	231.6	0.12
	3:47	160.4	165.9	0.10
average	**3:24**	**168.4**	**181.8**	**0.11**
Plywood	0:43	98.5	198.5	0.19
	0:41	112.9	259.9	0.17
	0:33	87.1	230.5	0.18
average	**0:39**	**99.5**	**229.6**	**0.18**

5.1.5 ISO 5660-1

Table 13 and Table 14 provides combustibility test results for the four materials when tested in accordance to ISO 5660-1 [3] for heat fluxes of 25 kW/m^2 and 35 kW/m^2. Table 15 provides results for the EN regulations (50 kW/m^2); it can be seen that neither of the railcar materials comply with the strictest EN requirement for heat generation.

For the purposes of this investigation, the FTIR apparatus was used to identify the gases by attaching the FTIR probe to the cone calorimeter duct, approximately 540 mm from the hood. The parameters for data collection were the same as previously described in Section 5.1.4.

Table 13: Summary of combustibility test results according to ISO 5660-1 [3] for a heat flux of 25 kW/m^2 for railcar investigation

Material	Ignition time (sec)	Peak heat release rate (kW/m^2)	Heat of combustion (kJ/g)	Peak smoke release rate (m^2/sec)	Extinction cross-sectional area (m^2/g)
Nomex® rail panel	291	134	20.0	0.03	0.225
	357	139	17.9	0.04	0.592
	651	95	14.6	0.02	0.281
average	**433**	**123**	**17.5**	**0.03**	**0.366**
Plywood rail panel	635	183	9.5	0.01	0.030
	595	196	10.0	0.02	0.070
	584	214	10.7	0.02	0.039
average	**605**	**198**	**10.1**	**0.02**	**0.046**
FRP	508	99	13.6	0.03	0.347
	434	100	14.2	0.03	0.344
	420	97	15.1	0.03	0.191
average	**454**	**99**	**14.3**	**0.03**	**0.294**
Plywood	152	49	3.9	0.01	0.013
	112	138	13.2	0.01	0.043
	121	97	7.7	0.01	0.015
average	**128**	**95**	**8.2**	**0.01**	**0.024**

Table 14: Summary of combustibility test results according to ISO 5660-1 [3] for a heat flux of 35 kW/m^2 for railcar investigation

Material	Ignition time (sec)	Peak heat release rate (kW/m^2)	Heat of combustion (kJ/g)	Peak smoke release rate (m^2/sec)	Extinction cross-sectional area (m^2/g)
Nomex® rail panel	167	144	16.7	0.04	0.437
	180	141	16.4	0.04	0.400
	122	162	19.0	0.04	0.271
average	**156**	**149**	**17.3**	**0.04**	**0.369**
Plywood rail panel	309	146	9.7	0.01	0.039
	319	175	10.5	0.02	0.097
	283	155	10.9	0.01	0.052
average	**304**	**159**	**10.3**	**0.01**	**0.062**
FRP	253	111	14.5	0.04	0.341
	282	114	12.9	0.06	0.460
	234	116	15.1	0.04	0.316
average	**256**	**113**	**14.2**	**0.04**	**0.372**
Plywood	60	214	13.4	0.02	0.077
	62	208	13.7	0.02	0.031
	61	236	14.0	0.02	0.032
average	**61**	**219**	**13.7**	**0.02**	**0.047**

Table 15: Summary of combustibility test results according to ISO 5660-1 [3] for a heat flux of 50 kW/m^2 for railcar investigation

Material	Ignition time (sec)	Peak heat release rate (kW/m^2)	Heat of combustion (kJ/g)	Maximum average rate of heat emission (kW/m^2)	Peak smoke release rate (m^2/sec)	Extinction cross-sectional area (m^2/g)
Nomex® rail panel	49	112	11.1	55	0.02	0.024
	75	193	17.3	91	0.08	0.397
	64	198	18.8	84	0.07	0.194
average	**63**	**168**	**15.7**	**76**	**0.06**	**0.205**
Plywood rail panel	109	192	10.9	107	0.03	0.010
	104	199	10.6	105	0.02	0.019
	108	211	12.2	108	0.02	0.013
average	**107**	**201**	**11.2**	**107**	**0.02**	**0.014**
FRP	175	136	14.6	84	0.06	0.300
	169	143	15.1	86	0.06	0.375
	154	133	16.0	87	0.04	0.257
average	**166**	**137**	**15.2**	**86**	**0.05**	**0.311**
Plywood	22	268	14.7	141	0.01	0.013
	30	239	15.2	152	0.02	0.011
	25	207	15.8	150	0.02	0.021
average	**26**	**238**	**15.2**	**148**	**0.02**	**0.015**

5.1.6 NFPA 286

The room corner tests were conducted in accordance with NFPA 286 [43]. Figure 16 gives a schematic diagram of the room that was used in the experiments. The three walls nearest to the burner and the ceiling were lined with the respective material (the wall with the door was not lined).

In addition to the typical experimental arrangement, an FTIR probe was placed approximately 50 mm below the top of the doorway, parallel with the ground. The sampling probe was approximately 800 mm in length with a 3.5 mm inside diameter and consisted of 5 sampling ports. The parameters for data collection were the same as previously described in Section 5.1.4.

The purpose of the room corner fire tests was to provide fire performance data for materials in an environment similar to the interior of a railcar. These tests were then used to help validate the results from the small-scale tests. Table 16 and Table 17 provide summaries of the room corner test results. Figure 17 through Figure 20 shows representative room corner tests at specific increments in time.

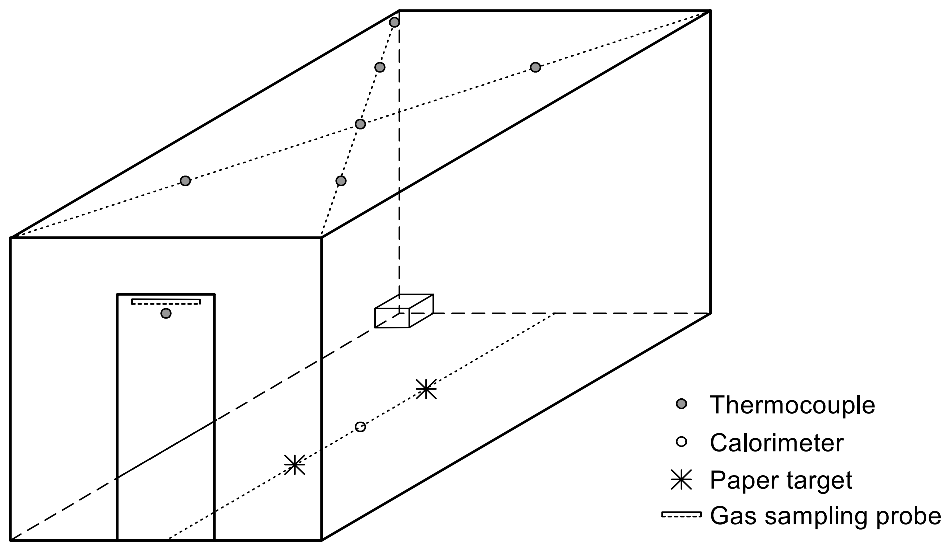


Figure 16: Experimental set-up for NFPA 286 [43]

Table 16: Summary of room corner test results in accordance with NFPA 286 [43] for railcar investigation

Wall/ceiling type	Peak heat release rate (kW)	Peak smoke release rate (m^2/sec)	Max floor heat flux (kW/m^2)	Max ceiling temp (°C)	Termination time (min:sec)
Nomex® rail panel	1130	17.74	26.1	770	7:22
	1390	18.43	25.0	766	7:02
average	**1260**	**18.09**	**25.6**	**768**	**--**
Plywood rail panel	1291	14.30	35.4	779	10:09
	1244	15.00	58.7†	785	9:54
average	**1268**	**14.65**	**47.1**	**782**	**--**
FRP	358	1.66	5.3	451	15:01
	443	2.68	8.4	532	15:02
average	**401**	**2.17**	**6.9**	**492**	**--**
Plywood	2520	11.66	25.7	755	5:37
	1764	9.49	26.2	756	5:31
average	**2142**	**10.58**	**26.0**	**756**	**--**

† The heat flux gauge was calibrated in the range of 0-50 kW/m^2

Table 17: Times of flashover conditions' occurrences for room corner test results in accordance with NFPA 286 [43] for railcar investigation

Wall/ceiling type	Heat release rate > 1 MW	Floor heat flux > 20 kW/m^2	Ceiling temp > 600 °C	Flames exit doorway	Autoignition of paper target	Flashover time
Nomex® rail panel	7:13	7:13	6:29	7:01	7:14	7:01
	7:00	6:55	6:18	6:51	6:57	6:51
Plywood rail panel	10:03	9:48	8:46	9:22	9:31	9:22
	9:42	9:37	8:58	9:36	9:39	9:36
FRP	--	--	--	--	--	--†
	--	--	--	--	--	--†
Plywood	5:22	5:22	5:09	5:17	5:25	5:17
	5:17	5:20	5:10	5:18	5:27	5:17

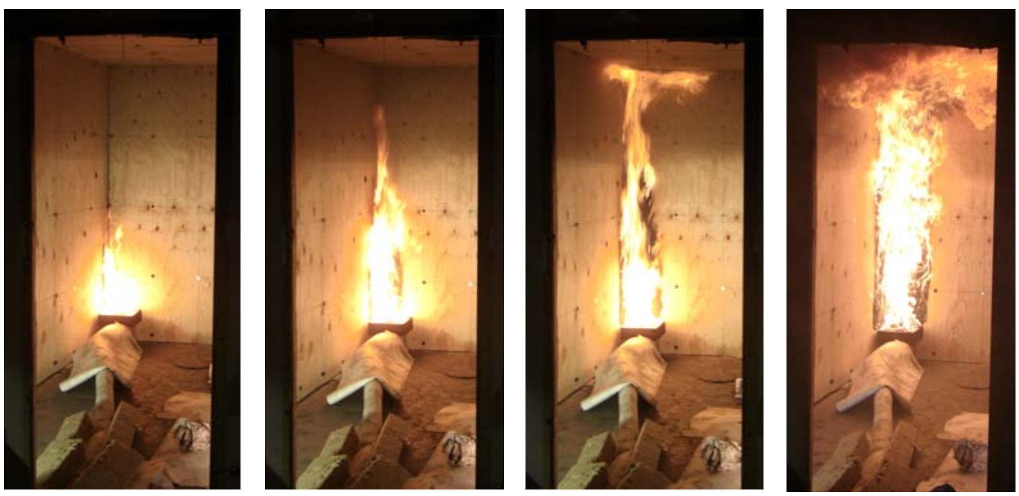
† The FRP did not flashover

(a) 1 minute (b) 2 minutes (a) 4 minutes (b) 6 minutes

Figure 17: Representative room corner test according to NFPA 286 [43] for Nomex® rail panel

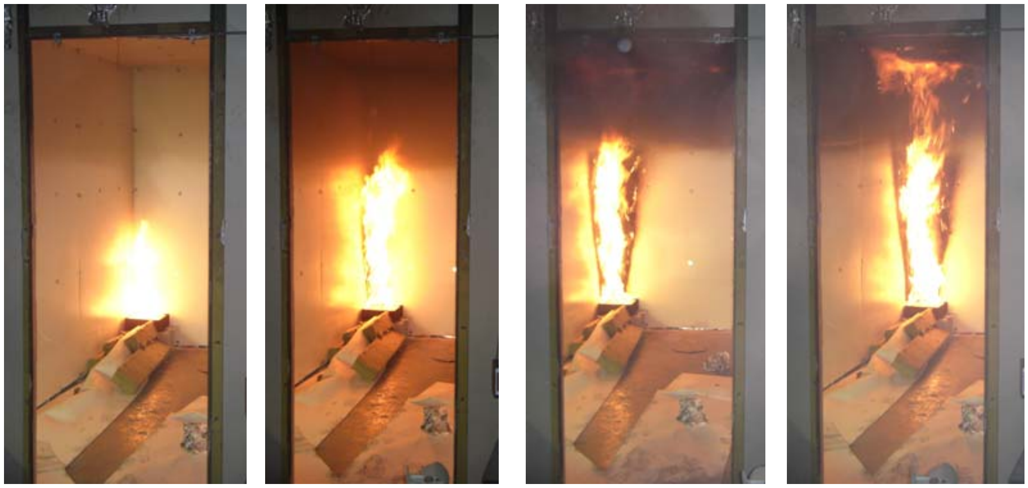
(a) 1 minute (b) 3 minutes (a) 6 minutes (b) 9 minutes

Figure 18: Representative room corner test according to NFPA 286 [43] for plywood rail panel



(a) 1 minute (b) 2 minutes (a) 3 minutes (b) 5 minutes

Figure 19: Representative room corner test according to NFPA 286 [43] for plywood



(a) 1 minute (b) 5 minutes (a) 10 minutes (b) 14 minutes

Figure 20: Representative room corner test according to NFPA 286 [43] for FRP

5.2 Bus fire performance data

FMVSS 302 [31] was applied to the bus seating materials since it is required for motor vehicles. ISO 5658-2 [28], ISO 5660-1 [3], and ASTM E 1537 [44] were also performed to develop a methodology for evaluating the fire performance of the materials.

5.2.1 FMVSS 302

The safety standard, FMVSS 302 [31], states that the burn rate (i.e. velocity of flame) should not be greater than 102 mm/min. Table 18 shows that the fabrics and foams, and therefore the seating assemblies comply with FMVSS 302 [31].

Table 18: Summary of flammability test results according to FMVSS 302 [31] for bus investigation

Material	Burn rate (mm/min)	Comments
Vinyl & Kevlar®	-	Self extinguished before timing could begin (i.e. 38 mm)
	-	Self extinguished before timing could begin (i.e. 38 mm)
	-	Self extinguished before timing could begin (i.e. 38 mm)
	-	Self extinguished before timing could begin (i.e. 38 mm)
average	**-**	-
Wool & Kevlar®	-	Self extinguished before timing could begin (i.e. 38 mm)
	-	Self extinguished before timing could begin (i.e. 38 mm)
	-	Self extinguished before timing could begin (i.e. 38 mm)
	-	Self extinguished before timing could begin (i.e. 38 mm)
average	**-**	-
Polyester	-	Burned less than 51 mm in 60 sec
	52	-
	68	-
	67	-
average	**62**	-
Wool	-	Did not ignite
	-	Did not ignite
	-	Did not ignite
	-	Did not ignite
average	-	-
Foam	63	-
	56	-
	80	-
	83	-
average	**71**	-

5.2.2 ISO 5658-2

The lateral flame spread along the surface of the seating materials was determined according to ISO 5658-2 [28]. Table 19 shows that the wool combinations (i.e. Wool & Kevlar®, Wool & foam) performed better than the polyester-foam combination.

Table 19: Summary of surface flammability test results according to ISO 5658-2 [28] for bus investigation

Material	Ignition Time (sec)	Peak heat release rate (kW)	Critical flux at extinguishment (kW/m^2)	Maximum flame travel (mm)
Vinyl & Kevlar®	0:02	2.6	10.1	500
	0:02	2.8	10.1	500
	0:02	2.9	10.1	500
average	**0:02**	**2.8**	**10.1**	**500**
Wool & Kevlar®	0:01	3.1	23.7	350
	0:02	3.0	23.7	350
	0:02	2.7	23.7	350
average	**0:02**	**2.9**	**23.7**	**350**
Polyester & foam	0:02	5.1	2.7	750
	0:02	6.2	2.7	750
	0:01	5.9	2.7	750
average	**0:02**	**5.7**	**2.7**	**750**
Wool & foam	0:01	3.2	23.7	350
	0:02	3.2	23.7	350
	0:02	3.3	23.7	350
average	**0:02**	**3.2**	**23.7**	**350**

5.2.3 ISO 5660-1

ISO 5660-1 [3] was also applied to the various seating materials. Table 20, Table 21, and Table 22 summarizes the results for the seating combinations. The testing found that at a heat flux of 35 kW/m^2, the vinyl-Kevlar® combination had the earliest ignition time, while the polyester-foam combination had the highest heat release rate.

Table 20: Summary of combustibility test results according to ISO 5660-1 [3] for a heat flux of 25 kW/m^2 for bus investigation

Material	Ignition time (sec)	Peak heat release rate (kWm^2)	Heat of combustion (kJ/g)	Peak smoke release rate (m^2/sec)	Extinction cross-sectional area (m^2/g)
Vinyl & Kevlar®	27	149	13.0	0.09	0.460
	26	151	14.3	0.08	0.522
	26	147	13.8	0.09	0.498
average	**26**	**149**	**13.7**	**0.09**	**0.493**
Wool & Kevlar®	121	123	12.9	0.06	0.462
	122	130	12.8	0.05	0.312
	135	125	8.8	0.06	0.355
average	**126**	**126**	**11.5**	**0.06**	**0.376**
Polyester & foam	DNI	4	0.2	0.01	0.779
	DNI	1	0.0	0.01	0.375
	DNI	0	0.0	0.01	0.216
average	**DNI**	**2**	**0.1**	**0.01**	**0.457**
Wool & foam	135	85	4.2	0.02	0.082
	101	81	2.9	0.02	0.071
	126	82	3.2	0.03	0.112
average	**121**	**83**	**3.4**	**0.02**	**0.088**

Table 21: Summary of combustibility test results according to ISO 5660-1 [3] for a heat flux of 35 kW/m^2 for bus investigation

Material	Ignition time (sec)	Peak heat release rate (kWm^2)	Heat of combustion (kJ/g)	Peak smoke release rate (m^2/sec)	Extinction cross-sectional area (m^2/g)
Vinyl & Kevlar®	13	172	14.0	0.13	0.630
	7	169	10.7	0.12	0.490
	12	174	11.7	0.10	0.379
average	**11**	**172**	**12.1**	**0.12**	**0.500**
Wool & Kevlar®	102	134	10.8	0.07	0.349
	64	135	11.7	0.08	0.378
	72	129	12.9	0.07	0.232
average	**79**	**133**	**11.8**	**0.07**	**0.320**
Polyester & foam	29	326	21.5	0.08	0.359
	50	319	20.6	0.07	0.383
	38	320	21.7	0.06	0.306
average	**39**	**322**	**21.3**	**0.07**	**0.349**
Wool & foam	93	113	14.4	0.05	0.132
	60	109	14.8	0.03	0.066
	74	116	15.6	0.05	0.049
average	**76**	**113**	**14.9**	**0.04**	**0.082**

Table 22: Summary of combustibility test results according to ISO 5660-1 [3] for a heat flux of 50 kW/m^2 for bus investigation

Material	Ignition time (sec)	Peak heat release rate (kWm^2)	Heat of combustion (kJ/g)	Peak smoke release rate (m^2/sec)	Extinction cross-sectional area (m^2/g)
Vinyl & Kevlar®	7	199	13.4	0.13	0.587
	11	205	13.4	0.14	0.632
	8	187	12.8	0.13	0.553
average	**9**	**197**	**13.2**	**0.13**	**0.591**
Wool & Kevlar®	29	182	12.9	0.11	0.327
	26	172	14.1	0.10	0.300
	65	193	12.3	0.09	0.325
average	**40**	**182**	**13.1**	**0.10**	**0.317**
Polyester & foam	18	319	19.9	0.08	0.249
	30	303	19.7	0.07	0.302
	26	351	21.2	0.07	0.248
average	**25**	**324**	**20.3**	**0.07**	**0.266**
Wool & foam	36	154	15.6	0.05	0.229
	26	179	14.4	0.06	0.334
	38	165	16.3	0.05	0.214
average	**33**	**166**	**15.5**	**0.05**	**0.259**

5.2.4 ASTM E 1537

Bus seats were tested in accordance with ASTM E 1537 [44]; tests were performed in an open calorimeter (i.e. furniture calorimeter). Figure 21 shows the placement of the thermocouples on the seat. This test provided fire performance data for bus seating material when applied to an actual seat assembly.

Table 23 provides a summary of bus seat test results. It should be noted that the second experiment conducted on the vinyl-Kevlar® seat did not yield similar results to the first experiment. As a result, a third experiment was conducted. Figure 22 through Figure 26 shows representative bus seat tests at specific increments in time. Figure 22 shows images representing the first experiment conducted on the vinyl-Kevlar® seat, while Figure 23 shows images representing the second and third experiments. Based on observations made during the three tests, the difference in the experimental results for the vinyl-Kevlar® seat appears to be the consequence of a manufacturing flaw/defect in the stitching of the vinyl on the seat back. Experiments conducted on the other seating combinations gave relatively consistent results. For comparative purposes, recall that the TB 133 requirements [45] specify that the maximum heat release rate must be less than 80 kW and the total heat released in the first 10 minutes must be less than 25 MJ.

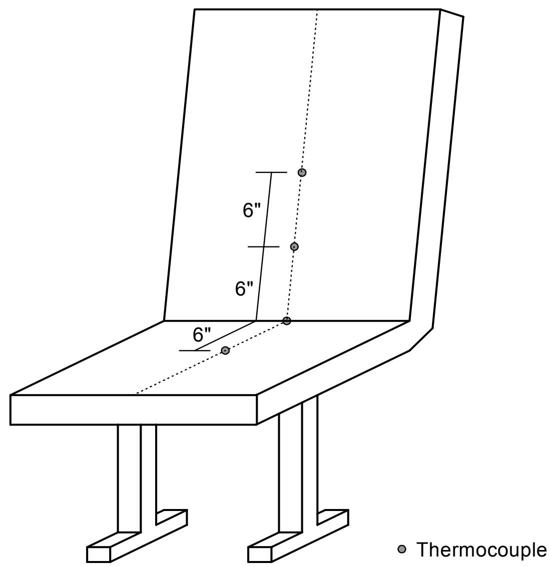
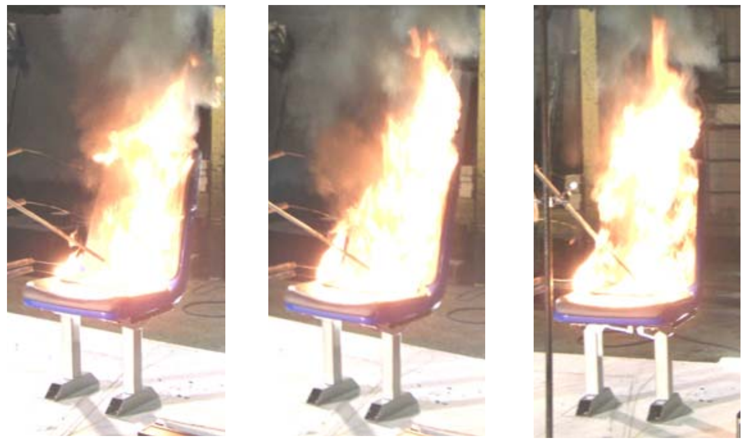


Figure 21: Thermocouple placement on bus seat for ASTM E 1537 [44]

Table 23: Summary of bus chair test results in accordance with ASTM E 1537 [44]

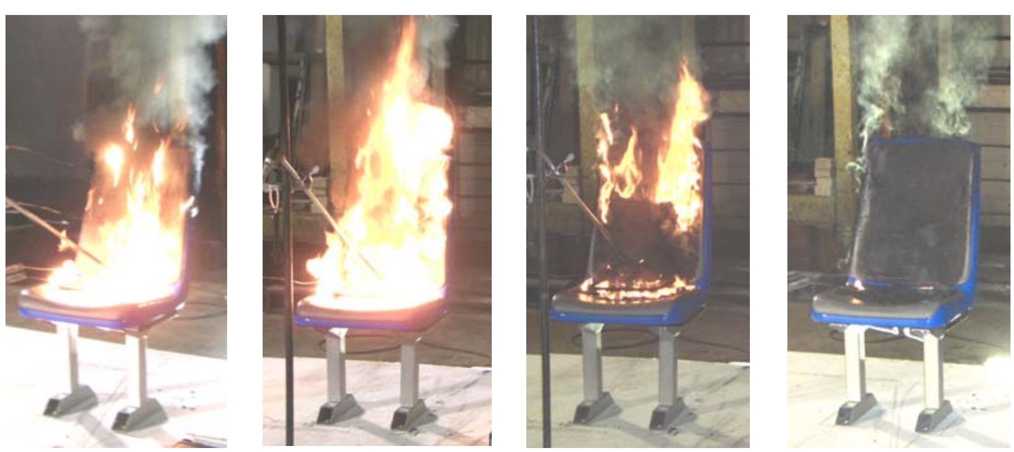
Material	Peak heat release rate (kW)	Total heat at 10 min (MJ)	Peak smoke release rate (m^2/sec)	Max seat cushion temp (°C)	Max back cushion temp (°C)
Vinyl & Kevlar®	203	5.44	1.68	797	779
	74	4.63	1.70	839	843
	77	5.36	1.88	708	758
average	**118**	**5.14**	**1.75**	**781**	**793**
Wool & Kevlar®	27	1.90	0.04	595	686
	26	2.24	0.04	580	743
average	**27**	**2.07**	**0.04**	**588**	**715**
Polyester & foam	308	55.12	2.53	870	877
	308	62.67	2.92	855	880
average	**308**	**58.90**	**2.73**	**863**	**879**
Wool & foam	37	2.39	0.04	772	768
	38	3.64	0.04	637	788
average	**38**	**3.02**	**0.04**	**705**	**778**



(a) 20 sec (b) 35 sec (c) 1 min

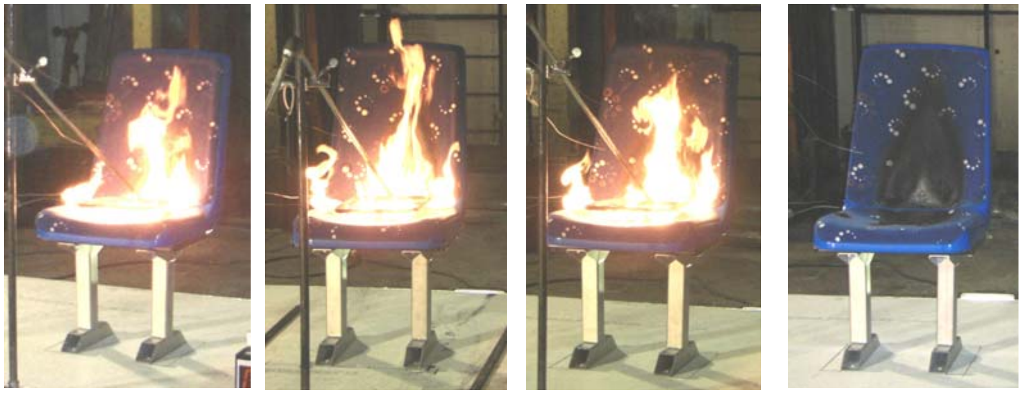
(d) 2 min 5 sec (e) 16 min 30 sec (f) 40 min

Figure 22: Representative bus seat test according to ASTM E 1537 [44] for vinyl & Kevlar® with severe damage



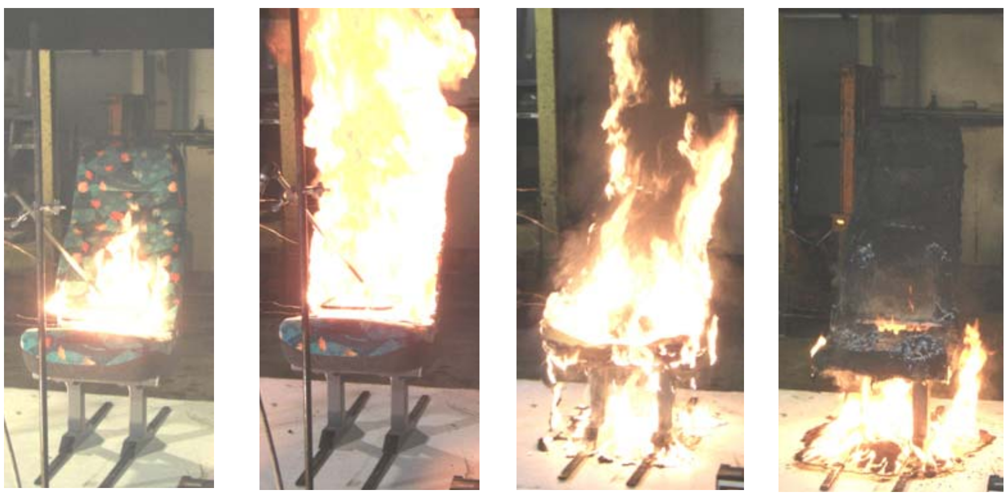
(a) 10 sec (b) 30 sec (c) 1 min 25 sec (d) 2 min 15 sec

Figure 23: Representative bus seat test according to ASTM E 1537 [44] for vinyl & Kevlar® showing mild damage



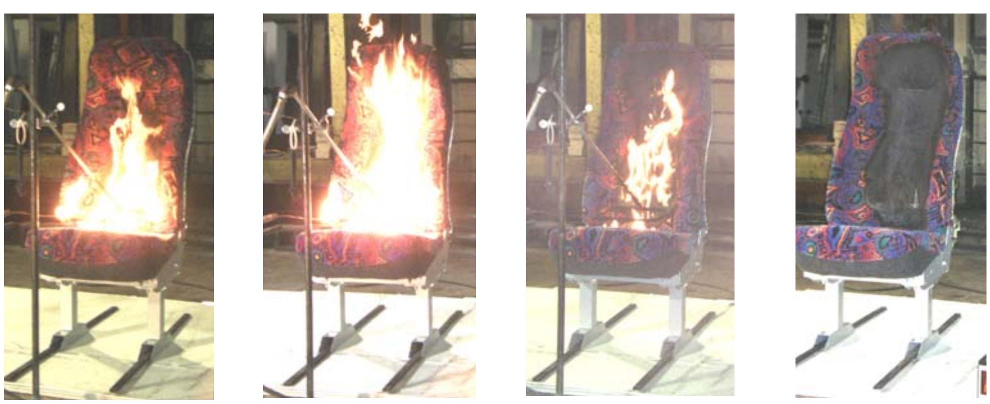
(a) 15 sec (b) 40 sec (c) 1 min 10 sec (d) 2 min 20 sec

Figure 24: Representative bus seat test according to ASTM E 1537 [44] for wool and Kevlar®



(a) 10 sec (b) 1 min (c) 3 min 30 sec (d) 7 min

Figure 25: Representative bus seat test according to ASTM E 1537 [44] for polyester and foam



(a) 20 sec (b) 1 min 10 sec (c) 1 min 25 sec (d) 5 min 30 sec

Figure 26: Representative bus seat test according to ASTM E 1537 [44] for wool and foam

6 Data analysis

In this section, results from the small-scale tests were further analyzed, compared, and correlated to large-scale fire growth. For the railcar ceiling/wall materials, results from small-scale tests were correlated to results from the room corner tests (NFPA 286). For the bus seat materials, the small-scale tests were correlated to full-scale chair tests (ASTM E 1537).

Previous research [46-48] has identified several critical small-scale parameters that may be used to indicate large-scale behavior. Similarly, this study attempts to identify metrics and evaluate their relative significance for aiding in the estimation of large-scale behavior. In the sections that follow, empirical relationships will be developed between small-scale test results and large-scale test results (i.e. acquired from the reference models).

6.1 Railcar data analysis

Three hazards were examined for the railcar study: heat release rate, smoke release rate, and toxicity. Results from the railcar test requirements for ceiling and wall materials were first compared to the NFPA 286 [43] results. Next, an attempt was made to draw relationships between data obtained from the cone calorimeter (ISO 5660-1) and the LIFT apparatus (ISO 5658-2) with results from the reference model (NFPA 286).

6.1.1 Comparison of railcar regulations and reference model (NFPA 286)

The flame spread index according to ASTM E 162 [23] is representative of the rate at which the flame is expected to spread. The higher the number, the faster the expected flame spread; however, there appears to be little correlation between the results from ASTM E 162 [23] and the reference model (NFPA 286, room corner test) as shown in Table 24. Both the Nomex® and plywood rail panel comply with the current railcar regulation for flame spread (see Table 24 and Table 3), however they both achieved flashover when placed in a large-scale environment.

Table 24: Comparison of FRA flame spread performance requirements to reference model results; results for ASTM E 162 are an average of 4 trials, results for NFPA 286 are an average of 2 trials

	ASTM E 162	NFPA 286
Material	**Flame spread index**	**Flashover time (min:sec)**
Nomex® rail panel	3	6:56
Plywood rail panel	6	9:29
FRP	8	--
Plywood	141	5:17

ASTM E 662 [24] provides the potential for smoke generation for materials. Comparing the results (see Table 25), between ASTM E 662 [24] and NFPA 286 [43] (reference model), reveals little correlation.

Table 26 compares the critical flux for extinguishment obtained from ISO 5658-2 [28] (required in the proposed EN regulation) with time to achieve flashover in the room corner test. It is anticipated that lower the critical flux for extinguishment, the faster is the fire growth. The results in Table 26 reflect this relationship, with exception to the Nomex rail panel, where the failure of the glue appears to have precipitated the faster fire growth in the room corner test. In this investigation, FRP was the only material that complied with the proposed EN flame spread requirement and was also the only material that did not flashover when placed in a large-scale test setting.

Table 25: Comparison of FRA smoke performance requirements to reference model results; results for ASTM E 662 are an average of 3 trials, results for NFPA 286 are an average of 2 trials

	ASTM E 662		NFPA 286		
Material	D_S **(1.5)**	D_S **(4.0)**	**Peak SRR at 5 min (m^2/sec)**	**Total Smoke at 5 min (m^2)**	**Peak SRR (m^2/sec)**
Nomex® rail panel	4.1	90.2	0.15	23.20	18.09
Plywood rail panel	0.4	54.9	0.14	19.63	14.65
FRP	0.9	28.1	0.18	18.89	2.17
Plywood	3.1	39.6	0.18	18.73	10.58

Table 26: Comparison of EN flame spread performance requirements to reference model results; results for ISO 5658-2 are an average of 3 trials, results for NFPA 286 are an average of 2 trials

	ISO 5658-2	NFPA 286
Material	**CFE (kW/m²)**	**Flashover time (min:sec)**
Nomex® rail panel	22.0† --	6:56
Plywood rail panel	20.2‡ --	9:29
FRP	30.5 HL4	--
Plywood	2.9 --	5:17

†Average of three trials: 23.7, 18.5, 23.7 kW/m^2
‡Average of three trials: 18.5, 18.5, 23.7 kW/m^2

In an attempt to better understand the differences between the radiant panels for ASTM E 162 and ISO 5658-2, the heat flux distribution was determined along the length of the 18-inch sample at prescribed increments (i.e. 3, 6, 9, 12, 15 inches) and was compared to that of LIFT apparatus. Figure 27 shows the experimentally determined distributions. Here, it can be seen that a sample tested in accordance with ASTM E 162 [23] is subjected to a lower heat flux, when compared to ISO 5658-2 [28].

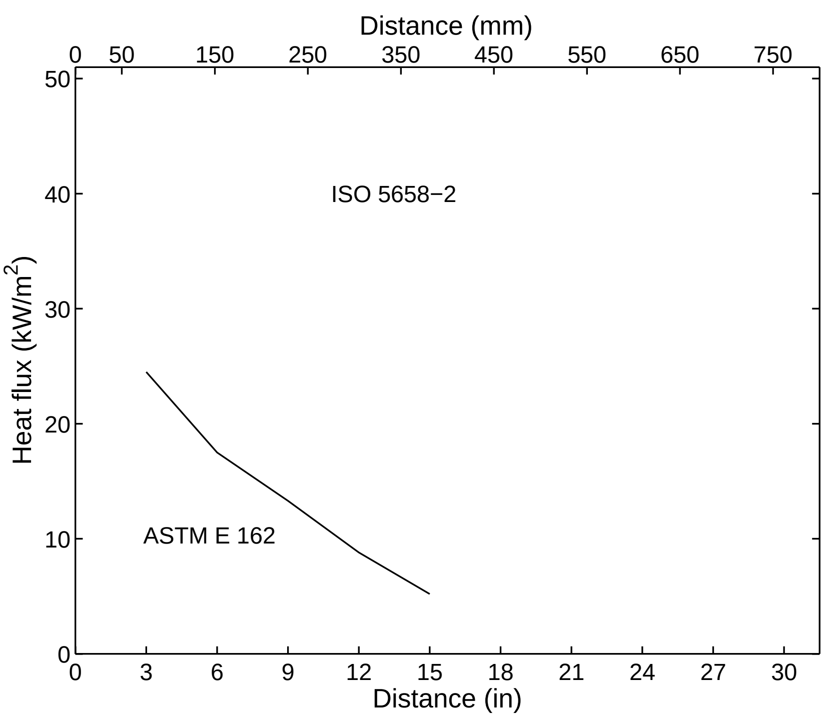


Figure 27: Comparison of heat flux distributions for ASTM E 162 [23] and ISO 5658-2 [28]

Table 27 and Table 28 provide a comparison of the EN smoke requirement with the reference model. The comparison shows that the smoke density values determined in the small-scale test do not correlate to the results from the room corner tests (see Table 27).

Table 27: Comparison of EN smoke performance requirements to reference model results; results for ISO 5659-2 are an average of 3 trials, results for NFPA 286 are an average of 2 trials

	ISO 5659-2		NFPA 286		
Material	D_S **(4.0)**	**VOF4 (min)**	**Peak SRR at 5 min (m^2/sec)**	**Total Smoke at 5 min (m^2)**	**Peak SRR (m^2/sec)**
Nomex® rail panel	172.8 HL2	306.1 HL2	0.15	23.20	18.09
Plywood rail panel	73.6 HL3	101.3 HL3	0.14	19.63	14.65
FRP	168.4 HL2	181.8 HL3	0.18	18.89	2.17
Plywood	99.5 HL3	229.6 HL3	0.18	18.73	10.58

Table 28: Comparison of EN toxicity performance requirements to reference model results; results for ISO 5659-2 are an average of 3 trials, results for NFPA 286 are an average of 2 trials

	ISO 5659-2	NFPA 286	
Material	**CIT(8.0)**	**FED(5.0)**	**FEC(5.0)**
Nomex® rail panel	0.44 HL3	0.08	0.07
Plywood rail panel	0.40 HL3	0.08	0.23
FRP	0.11 HL3	0.05	0.05
Plywood	0.18 HL3	0.19	0.45

Table 29: Comparison of EN heat performance requirement to reference model results; results for ISO 5660-1 are an average of 3 trials, results for NFPA 286 are an average of 2 trials

	ISO 5660-1	NFPA 286	
Material	**MARHE (kW/m^2)**	**Peak HRR at 5 min (kW)**	**Peak HRR (kW)**
Nomex® rail panel	76 HL2	54	1260
Plywood rail panel	107 HL1	42	1268
FRP	86 HL2	49	400
Plywood	148 HL1	293	2142

Table 28 compares the results of the gas toxicity obtained from ISO 5659-2 [29] using the EN protocol [26,27] to the results from the NFPA 286 tests [43]. All four materials tested, meet the HL3 requirements of the EN regulations and have FED and FEC values [49,50] that are relatively low; however the values from the small-scale test do not reflect the values obtained in the reference model (see Section 6.1.4 for a brief description of FED and FEC). For example, ordinary plywood has the highest FED and FEC values [49,50] from NFPA 286 [43], but has a comparatively low CIT value from ISO 5659-2 [29].

Finally, Table 29 gives the EN heat performance requirement and the heat results from the reference model. Plywood generated the most amount of heat in both the Cone Calorimeter and the room corner test.

6.1.2 Heat release rate: correlating small-scale test results to large-scale

Heat release measurements obtained from the reference model (NFPA 286) were correlated to results from small-scale test methods.

The heat release rate for the room corner test at any time may be expressed as a summation over the discrete burning areas

$$Q(t) = \sum q(t) dA_f \tag{4}$$

where $Q(t)$ is the heat release rate at time t and q is the heat release rate per unit area over the burning area dA_f. It was assumed that the rate of growth of the burning area depends inversely upon the critical flux at extinguishment (i.e. the lower the critical flux, the faster the growth of the burning area). Thus, the heat release rate measured in the room corner test (NFPA 286) may be related to the heat release rate per unit area from the cone calorimeter and the critical heat flux at extinguishment from the LIFT apparatus. A relationship was established in the following form

$$Q = f(q, \text{CFE}) \tag{5}$$

where Q is the peak heat release rate from NFPA 286 [43], q is the peak heat release rate per unit area from ISO 5660-1 [3], and CFE is the critical flux at extinguishment from ISO 5658-2 [28]. Using the small-scale and large-scale data, a form of Equation 5 was found using a least-squares approach. It should be noted that the cone calorimeter results used in the correlation were obtained at a heat flux 50 kW/m^2, which is also the heat flux proposed for the European standards [26,27].

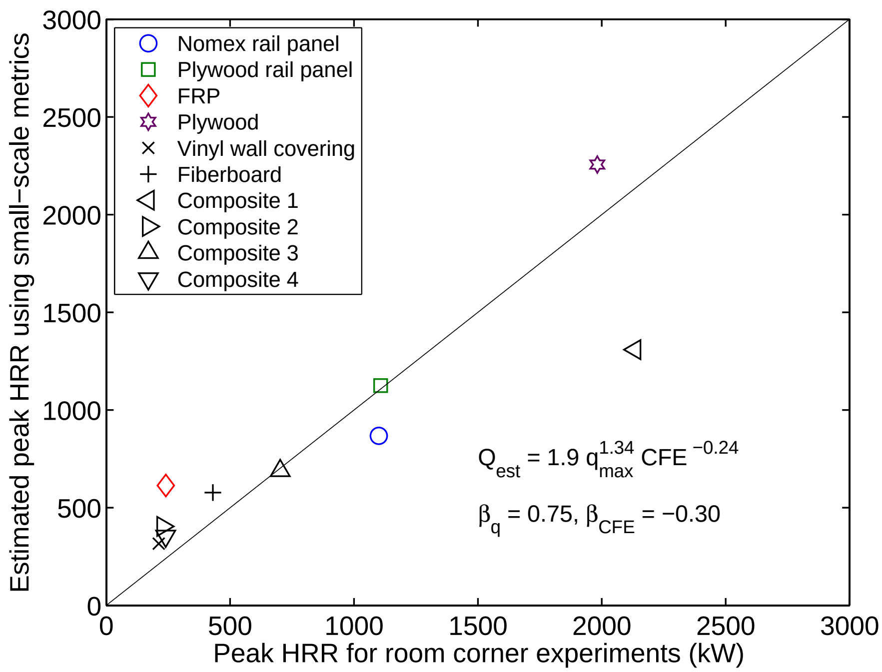


Figure 28: Comparison of estimated and experimental peak HRR up to point of flashover

Figure 28 shows the correlation between the estimated and experimental peak HRR for the reference model (NFPA 286) up to the point of flashover. A correlation line (at a 45 degree angle) is shown in Figure 28, which illustrates the perfect correlation; data points below the line underestimate the large-scale test results, while points above the line overestimate the large-scale results. Note that the correlation line should not be confused with a best-fit line. Figure 28 contains data from the current study and data from a previous project [51] conducted by UL for GE Advanced Materials Research (Composite 1, 2, 3, and 4), in addition to data obtained from an internal UL study. This additional set of six materials was used to strengthen the correlation. The beta coefficients (i.e. beta weights) were then calculated to evaluate the relative importance of the different metrics. Here, it was found that the peak heat release rate from the cone calorimeter was more significant than the critical heat flux at extinguishment. The correlation in Figure 28 appears to be relatively strong, given a wide range of materials with varying fire performances.

6.1.3 Smoke release rate: correlating small-scale test results to large-scale

Smoke release measurements obtained from the reference model (NFPA 286) during the early phase of the fire were correlated to results from the small-scale test methods.

The smoke release rate for the room corner test depends on both the combustibility of the materials and the ventilation. During the early stages of fire growth, the fire is well ventilated and is representative of the conditions in the small-scale tests (e.g. ISO 5660-1). The smoke release rate may be expressed as a product of mass loss rate and extinction cross-sectional area

$$\mathrm{SRR} = \dot{m}\sigma \tag{6}$$

where SRR is the smoke release rate, $\dot{m}$ is the mass loss rate, and σ is the extinction cross-sectional area. The mass loss rate is related to the heat release rate

$$Q = \dot{m}h_c \tag{7}$$

where h_c is the heat of combustion. Equation 6 can then be expressed as

$$\mathrm{SRR} = \frac{Q}{h_c}\sigma\,. \tag{8}$$

Equation 8 identifies important variables, which can be obtained from small-scale test methods. As such, the smoke release rate measured in the room corner test (NFPA 286) was related to the extinction cross-sectional area from the cone calorimeter, heat of combustion from the cone calorimeter, and the critical heat flux at extinguishment from the LIFT apparatus. As before, the critical flux at extinguishment was used to describe the growth rate of the fire over the test sample(s). Here, a relationship was established in the following form

$$\mathrm{SRR} = f\left(q, \sigma, h_c, \mathrm{CFE}\right) \tag{9}$$

where SRR is the peak smoke release rate from NFPA 286 [], q is the peak heat release rate per unit area from ISO 5660-1 [3], σ is the extinction cross-sectional area from ISO 5660-1 [3], h_c is the heat of combustion from ISO 5660-1 [3], and CFE is the critical heat flux at extinguishment from ISO 5658-2 [28]. As was done previously, the results used from the cone calorimeter were obtained at a heat flux 50 kW/m^2.

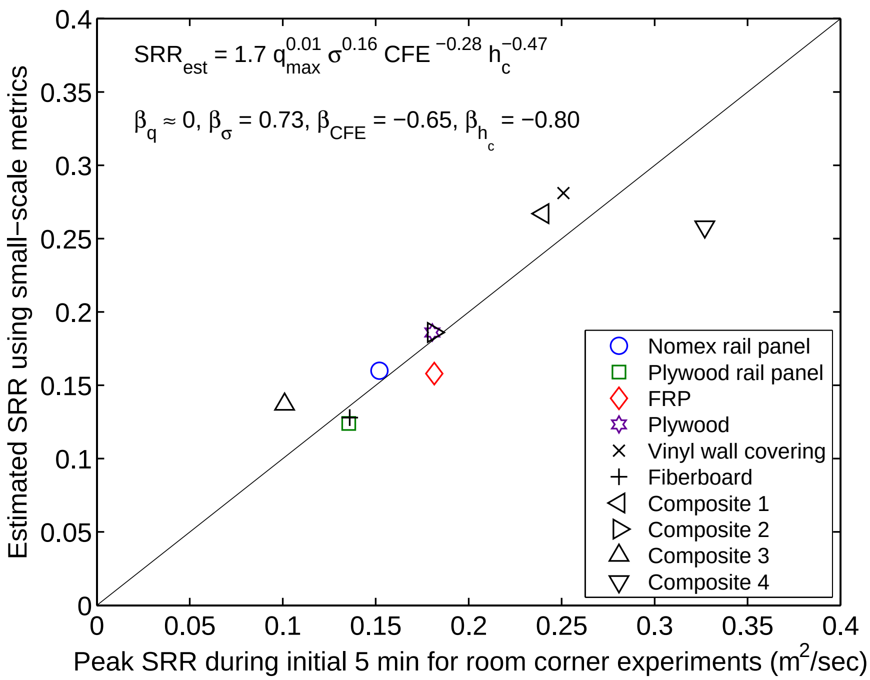


Figure 29: Comparison of estimated and experimental peak SRR at 5 minutes

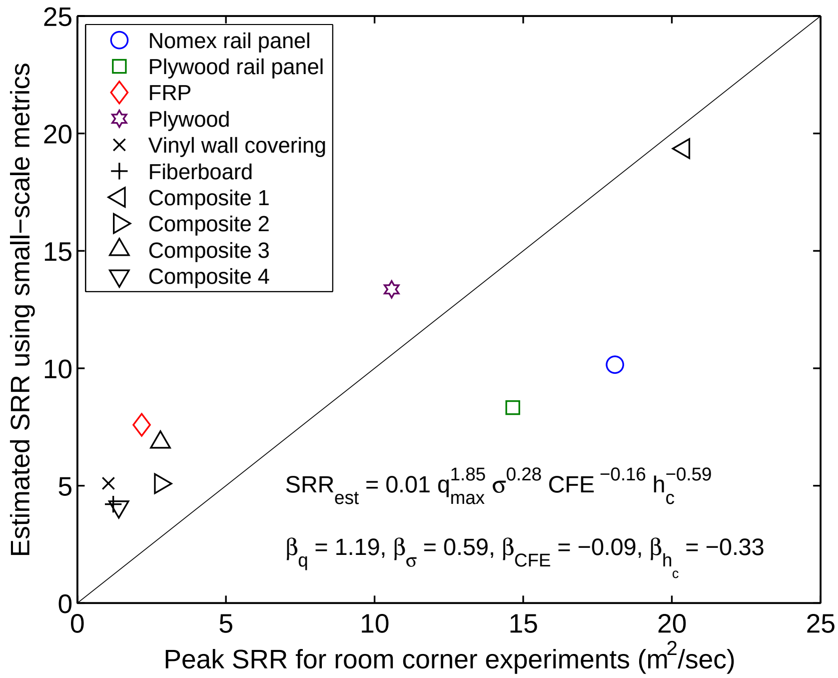


Figure 30: Comparison of estimated and experimental peak SRR up to point of flashover

Figure 29 shows a comparison of estimated and experimental peak SRR at 5 minutes. The extinction cross-sectional area, heat of combustion, critical heat flux at extinguishment all have approximately the same impact (β_{σ} = 0.73, β_{CFE} = -0.65, β_{hc} = -0.80), with the heat of combustion and extinction cross-sectional area being the most significant. Based on the data presented, there appears to be a correlation between the small-scale metrics and the large-scale SRR measurement at early phases in the fire.

Figure 30 gives a comparison of the estimated and experimental peak SRR up to point of flashover. Comparing Figure 29 and Figure 30, it can be observed that the relative impact of the flame spread parameter is less during the late phase of the fire, while the heat release rate is more critical during the late phase.

6.1.4 Toxicity: correlating small-scale test results to large-scale

The gas toxicity from the room corner tests (NFPA 286) was correlated to the small-scale test results. Gases generated in the room corner test depend upon the test materials, in addition to the ventilation conditions. As the fire grows, from initiation to flashover, the ventilation conditions change from a well-ventilated fire (early stages) to an under-ventilated fire (time of flashover). During the later stages, the generation of carbon monoxide gas will significantly increase. Since the conditions for the small-scale tests (e.g. ISO 5658-2, ISO 5660-1) are representative of the early stages of fire development in the room corner test, correlations were performed at 5 minutes into the room corner experiment.

The gas concentrations were measured in the room corner test (NFPA 286), which were then related to the concentrations measured in the cone calorimeter and the critical heat flux at extinguishment from the LIFT apparatus. Two toxicity parameters were examined: Fractional Effective Concentration (FEC) and Fractional Effective Dose (FED). Relationships were established in the following forms

$$\mathrm{FED}_{\mathrm{LS}} = f\left(\mathrm{FED}_{\mathrm{SS}}, \mathrm{CFE}\right) \tag{10}$$

$$\mathrm{FEC}_{\mathrm{LS}} = f\left(\mathrm{FEC}_{\mathrm{SS}}, \mathrm{CFE}\right) \tag{11}$$

where FED_{LS} and FEC_{LS} are the calculated values from the large-scale test, while FED_{SS} and FEC_{SS} are calculated from the small-scale test (i.e. cone calorimeter). FED and FEC can be calculated as

$$\mathrm{FED} = \sum_{t_1}^{t_2} \frac{\varphi_{CO}}{35{,}000} \Delta t + \sum_{t_1}^{t_2} \frac{\exp\left(\varphi_{HCN} / 43\right)}{220} \Delta t \tag{12}$$

$$\mathrm{FEC} = \frac{\varphi_{\mathrm{HCl}}}{1{,}000} + \frac{\varphi_{\mathrm{HBr}}}{1{,}000} + \frac{\varphi_{\mathrm{HF}}}{500} + \frac{\varphi_{\mathrm{SO_2}}}{150} + \frac{\varphi_{\mathrm{NO_2}}}{250} + \frac{\varphi_{\mathrm{acrolein}}}{30} + \frac{\varphi_{\mathrm{formaldehyde}}}{250} \tag{13}$$

where φ represents the concentration of the gas (in ppm) and Δt is the time increment (in minutes) [49,50]. As was done previously, the cone calorimeter results used in the previous equations were obtained at a heat flux 50 kW/m^2.

Figure 31 and Figure 32 show the relationship between the small-scale parameters and the reference model (i.e. the room corner test). The FED calculated from the cone calorimeter was done over the duration of the whole experiment, 33 minutes; for the room corner tests the FED was calculated up to 5 minutes. Figure 32 uses the peak FEC for the duration of the whole cone calorimeter test and the peak FEC for the first 5 minutes of the room corner test. Interestingly the toxicity metrics (i.e. FED and FEC) have little impact on the relationship; both correlations are dominated by the CFE. The calculation of the beta coefficients shows how dominate the CFE metric is in the relationship. While there are only four data points, Figure 31 and Figure 32 indicate that there may be a relationship between the small-scale metrics and the toxic components in the large-scale test.

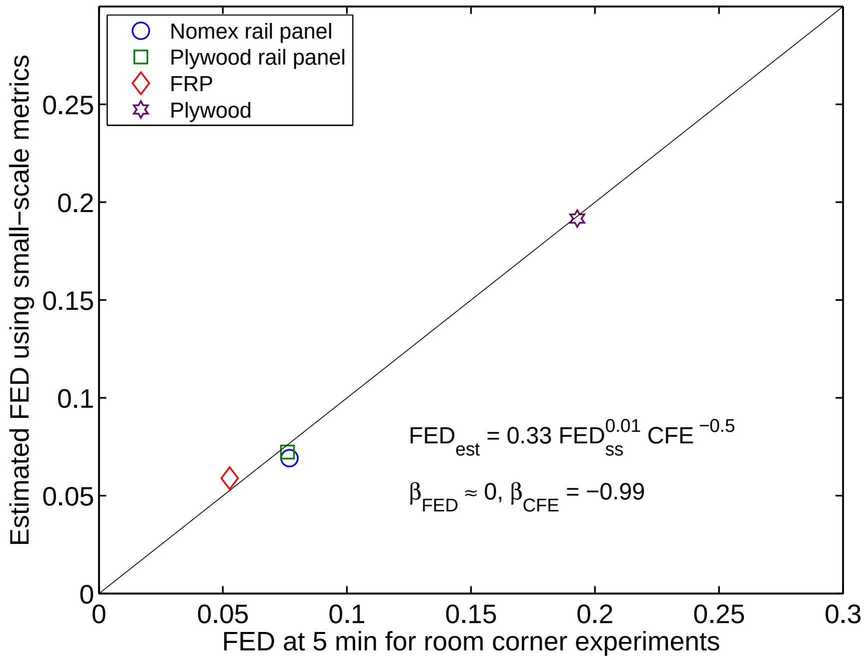


Figure 31: Comparison of estimated and experimental peak fractional effective dose (FED) at 5 minutes

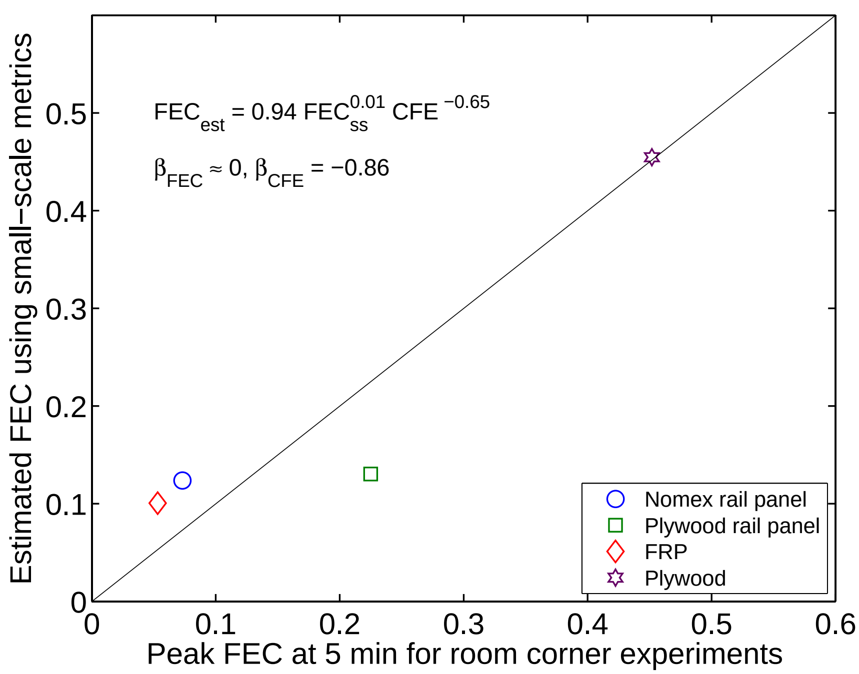


Figure 32: Comparison of estimated and experimental peak fractional effective concentration (FEC) at 5 minutes

6.2 Bus data analysis

For the bus study, current regulations were first compared with the reference test model, ASTM E 1537 [44]. Then, heat release measurements from the cone calorimeter (ISO 5660-1) were compared to the reference model (ASTM E 1537). In addition, the CBUF Model I [48] was applied to the data set.

6.2.1 Comparison of bus regulations and reference model (ASTM E 1537)

Table 30 shows a comparison of the FMVSS 302 test results (NHTSA performance requirement) with the reference model results. Recall that compliance of FMVSS 302 requires the burn rate to be less than 102 mm/min; all of the bus seating materials comply with the regulation. TB 133 [45] requires that the maximum heat release rate be less than 80 kW and the total heat released in the first 10 minutes be less than 25 MJ. It should be noted that the reference test model for the polyester-foam seat does not comply with TB 133 [45]; in addition, the vinyl-Kevlar seat does not consistently comply. Here it is shown that the FMVSS 302 [31] test results does not adequately address fire growth in the reference model.

Table 30: Comparison of NHTSA performance requirement to reference model results; results for FMVSS 302 are an average of 5 trials, results for ASTM E 1537 are an average of 2 trials

	FMVSS 302	**ASTM E 1537**		
Material	**Burn rate (mm/min)**	**Peak HRR (kW)**	**Total heat at 10 min (MJ)**	**Peak SRR (m^2/sec)**
Vinyl & Kevlar®	Self extinguished	118†	5.14	1.75
Wool & Kevlar®	Self extinguished	27	2.07	0.04
Polyester & foam	62, 71‡	308	58.90	2.73
Wool & foam	DNI, 71‡	38	3.02	0.04

†Average of three trials: 203, 74, 77 kW
‡Fabric and foams were tested separately for FMVSS 302

6.2.2 Heat release rate: correlating small-scale test results to large-scale

Heat release rate measured in the furniture calorimeter (ASTM E 1537) was related to heat release rate per unit area taken from the cone calorimeter (ISO 5660-1). Here, the cone calorimeter results were obtained at a heat flux 35 kW/m^2, which has been done in other studies on furniture items [47,48].

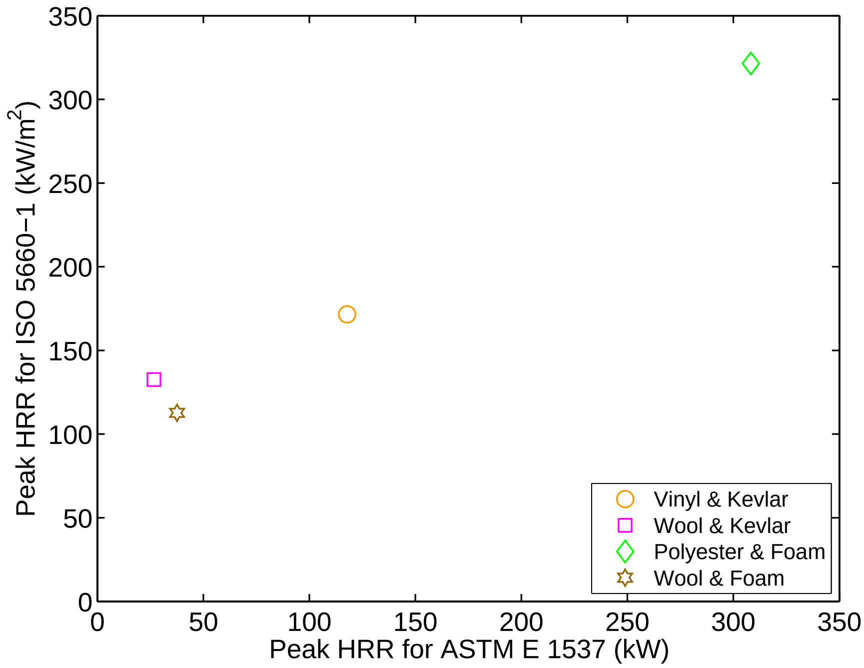


Figure 33: Comparison of peak heat release rate per unit area from ISO 5660-1 [3] and peak heat release rate from ASTM E 1537 [44]

Figure 33 compares the peak heat release rate per unit area from ISO 5660-1 [3] and the peak heat release rate from ASTM E 1537 [44]. Because of the simplified relationship presented here, no empirical correlation was developed. While only four different types of chairs were tests, based on this limited set of data (see Figure 33), the peak heat release rate per unit area measured from the cone calorimeter gives an indication of the peak heat release rate for the full-size chair.

6.2.3 CBUF Model I

The CBUF (Combustion Behaviour of Upholstered Furniture) research program has done considerable work on the fire performance of furniture items [48]. Their work [48] provides a good reference for fire performance characteristics of furniture, which is applicable to bus seats.

Here, the CBUF Model I will be investigated. This model provides a more robust prediction of the fire performance of furniture items. The CBUF Model I estimates heat and smoke behavior for furniture items that exhibit propagating behavior, based on cone calorimeter data (see Table 21 and Table 31), the masses of the materials (Table 32), and a style factor (Table 32) that is based on the type of furniture.

Table 33 shows a comparison of the ASTM E 1537 [44] experimental results with the prediction obtained from CBUF Model I. The results for the polyester and foam seat show that the model fairly accurately predicts the performance of bus seats that exhibit propagating behavior. The other three bus seat styles do not exhibit propagating behavior, but the results are presented for completeness.

Table 31: Additional combustibility test results according to ISO 5660-1 [3] for a heat flux of 35 kW/m^2 for CBUF Model I

Material	60 sec average heat release rate (kW/m^2)	300 sec average heat release rate (kW/m^2)	Total heat (MJ/m^2)
Vinyl & Kevlar®	154	53	17.6
	142	43	13.2
	150	48	15.5
average	**149**	**48**	**15.5**
Wool & Kevlar®	118	44	17.9
	120	51	19.5
	103	49	21.9
average	**113**	**48**	**19.8**
Polyester & foam	212	197	71.0
	201	183	67.7
	205	193	71.5
average	**206**	**191**	**70.1**
Wool & foam	77	30	68.6
	58	30	64.6
	85	28	72.3
average	**73**	**29**	**68.5**

Table 32: Seating style and mass of materials for CBUF Model I

Seat type	Style factor A	Mass of upholstery (kg)	Mass of upholstery (kg)
Vinyl & Kevlar®	1.0	0.53	4.45
Wool & Kevlar®	1.0	0.69	4.61
Polyester & foam	1.0	3.04	3.04
Wool & foam	1.0	3.34	3.34

Table 33: Comparison of ASTM E 1537 experimental results with prediction obtained from CBUF Model I [48]

	ASTM E 1537			CBUF Model I		
Material	**Peak HRR (kW)**	**Total heat (MJ)**	**Total smoke (m^2)**	**Peak HRR (kW)**	**Total heat (MJ)**	**Total smoke (m^2)**
Vinyl & Kevlar®	203	114.1	597.7			
	74	4.7	100.8	29†	22.1†	563.2†
	77	6.8	103.9			
Wool & Kevlar®	27	1.9	2.3	14†	23.6†	432.5†
	26	2.5	2.1			
Polyester & foam	308	66.7	653.6	279	58.2	528.5
	308	69.9	706.1			
Wool & foam	37	2.4	7.9	89†	44.9†	189.6†
	38	4.4	6.2			

†These chairs do not exhibit propagating behavior; results are presented for completeness

7 Fire performance metrics

Based on the analysis in the preceding section, small-scale fire performance metrics that describe fire hazards in a real-scale environment were identified; this concept is illustrated in Figure 34.

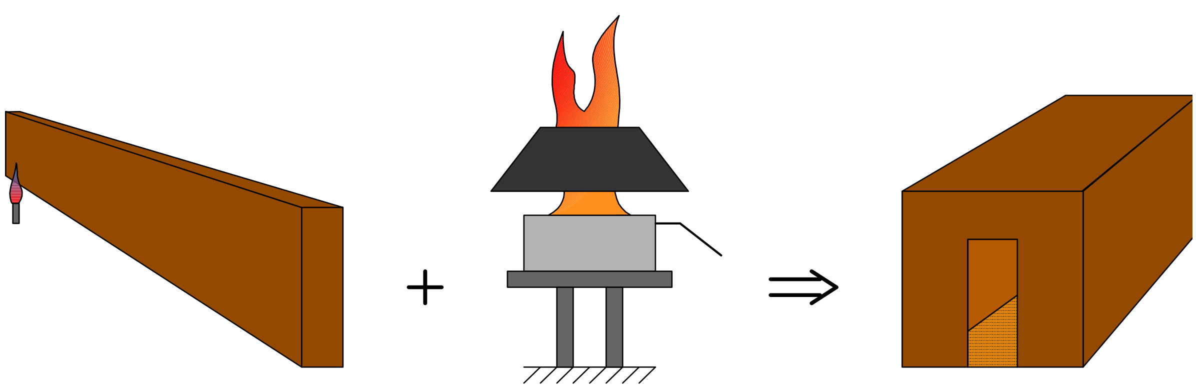


Figure 34: Schematic diagram showing the use of small-scale fire performance metrics to assess fire growth in reference test model

7.1 Railcar ceiling and wall material fire performance metrics

For the railcar study, three hazards were examined: heat release rate, smoke release rate, and gas toxicity (i.e. FED and FEC). Each of these entities could create a potentially dangerous situation.

For the railcar ceiling and wall materials, the room corner test according to NFPA 286 [43] was used as a reference model; this test is used in regulatory codes (e.g. NFPA 101, International Building Code) in the U.S. for defining the fire performance of interior finish materials. Using NFPA 286 as a reference model, allowed for the investigation of fire growth through flame propagation along the ceiling and walls.

Based on the limited data set, it was found that results from the Cone Calorimeter and the LIFT apparatus could be used to estimate the fire performance of materials in a large-scale room setting. There is some uncertainty in the smoke correlations at later stages (point of flashover); depending on the specified hazard performance level, the relationship may not be suitable.

Table 34 summarizes the small-scale performance metrics that were related to the reference model hazards. It is interesting to note that the critical heat flux at extinguishment was found to be important in all three hazards (as determined by the calculation of the beta coefficients), particularly during the initial stages of the fire development.

Table 34: Summary of scaling of hazards from small- to large-scale (reference model)

Hazard	Small-scale performance metrics	Reference model measurement
Heat	Heat release rate per unit area (ISO 5660-1) Critical heat flux at extinguishment (ISO 5658-2)	Heat release rate
Smoke	Extinction cross-sectional area (ISO 5660-1) Heat of combustion (ISO 5660-1) Critical heat flux at extinguishment (ISO 5658-2)	Smoke release rate
Gas toxicity	Fractional effective dose (ISO/TS 13571) Fractional effective concentration (ISO/TS 13571) Critical heat flux at extinguishment (ISO 5658-2)	Fractional effective dose Fractional effective concentration

7.2 Bus seating material fire performance metrics

For the bus study, heat release rate was the primary hazard examined because the seat could serve as a secondary source of fire growth to other combustibles in its proximity.

Due to the complexity of bus seat construction (e.g. fabric, foam, backing material, stitching), full-scale tests should be conducted. The ASTM E 1537 (or TB 133) is a relatively simple test method and can assess the fire performance of the bus seat assembly. Currently, California regulates the fire performance of upholstered furniture (California TB 133) by limiting the peak heat release rate to less than 80 kW and total heat released during the first 10 minutes to less than 25 MJ.

Based on the analysis, the heat release rate per unit area obtained from the Cone Calorimeter could provide a reasonable estimation of the heat release rate for a full-scale chair test, however the correlation was based upon only four test samples. Given a more robust correlation, the Cone Calorimeter could be used by the manufacturers for quality assurance of incoming materials and components.

7.3 Assessment of materials using fire performance metrics

Once the hazard levels for the reference model are identified, the developed relationships (i.e. correlation results) may be used to estimate the large-scale fire performance of the materials, based on the small-scale tests. Due to the limited number of samples tested in this study, additional test data should be generated to provide a better statistical basis for the correlation and to develop ranges of uncertainty. An approach for assessing new materials using fire performance metrics is shown in Figure 35.

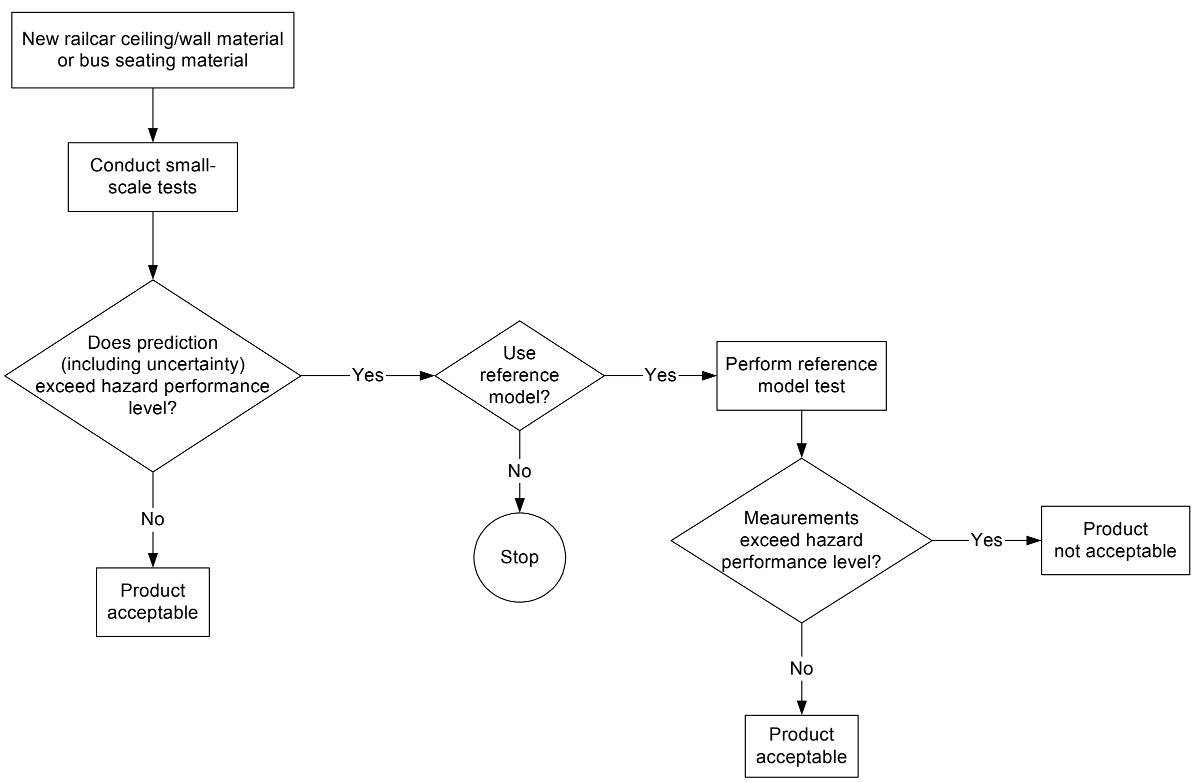


Figure 35: Schematic flowchart showing the assessment of materials using fire performance metrics

8 Summary of findings

Approximately 140 passenger railcars fires and 2,200 bus fires are reported annually [15]. In many instances, the fire initiates when the railcar or bus is in operation, making it challenging for the passengers to plan and execute egress. As such, an approach based upon fire prevention and limiting fire growth was identified as enhancing passenger safety.

This project examined current U.S. fire regulations for ceiling/wall materials in railcars and seating materials in buses. First, commercially available materials that currently exist in railcars and buses were selected. Next, small-scale test methods, related to both current and proposed regulations, were conducted. Suitable reference test models (i.e. NFPA 286 and ASTM E 1537) were established for both the railcar and the bus study. The small-scale data was then compared to the large-scale test results. These results were then used to develop correlations relating the small-scale test metrics to the large-scale hazard parameters. Finally, small-scale fire performance metrics were determined based on the data analysis.

For the railcar portion of the study, U.S. fire performance regulations governing railcar ceiling and wall materials were examined. Results from the fire tests required by current U.S. regulations (i.e., ASTM E 162, ASTM E 662) did not correlate to the fire performance of the materials tested in the reference test model (i.e., room corner test). However, results from other small-scale test methods (i.e. ISO 5658-2, ISO 5660-1) could be combined, using multivariate analysis, to develop correlations to the results from the reference model.

For the bus portion of the study, U.S. fire performance regulations for bus seat materials were investigated. The required small-scale test method (FMVSS 302) was compared to a full-scale bus seat test (ASTM E 1537). When tested, some of the bus seats were completely consumed, despite complying with the FMVSS 302 [31] test method.

9 Future work

There are several areas that may be considered for future work. The following is a brief list of topics that could be explored for continuing research in the area of U.S. railcar and bus fire regulations.

- **In conjunction with the Technical Advisory Committee, develop and establish fire prevention criteria in terms of small-scale metrics.** This project report has established that small-scale metrics can indicate the materials' ability to contribute to large-scale fire growth. Results from the small-scale tests (e.g. Cone Calorimeter and LIFT) may then be used to represent a threshold hazard in the reference model. Once the range of uncertainty in the correlations has been determined, small-scale criteria can then be established to evaluate the fire performance of materials.

- **Develop additional data for the reference test model.** While correlations have been developed relating small-scale performance metrics to large-scale measurements, there exists only a limited amount of data from the reference test model (i.e. room corner experiments). Additional data at and below the threshold hazard should be developed to add to the robustness of the correlation between the small-scale tests and the reference model.
- **Supplement and validate experimental results with computer simulations (e.g. Fire Dynamics Simulator).** Computer-based fire analysis should be conducted in order to examine its suitability as a predictor for actual fire tests. Because many railcar and bus materials are multilayered composites, particular emphasis will be placed on examining these types of materials/components. Additional experimental tests (e.g. ASTM D 1929 determination of ignition temperature, vertical panel experiments) may need to be conducted to develop input data for the computer simulations.

A Description of test materials

A.1 Density measurements

Table 35: Density of test materials for railcar investigation

Material	Description	Density (kg/m^3)
Nomex® rail panel	Melaminium (melamine fused to aluminum) face, Nomex® honeycomb core (0.25" cell size), aluminum backer	527
Plywood rail panel	Melaminium (melamine fused to aluminum) face, plywood core, aluminum backer	867
FRP	Fiberglass-reinforced plastic	1612
Plywood	Plywood, C-D Exposure 1 (CDX)	549

Table 36: Density of test materials for bus investigation

Material	Areal density (g/m^2)	Thickness (mm)	Density (kg/m^3)
Vinyl	778	0.98	-
Wool	1121	2.26	-
Polyester	481	0.99	-
Kevlar®	292	0.93	-
Polyurethane foam	-	-	67

A.2 Thermogravimetric analysis

Thermogravimetric analysis (TGA) is a testing procedure, in which the changes in weight of a specimen are recorded as the specimen is heated. In this test, a sample is lowered into a furnace and the temperature of the furnace is then increased to a maximum temperature of 850 °C at a rate of 10 ºC/min. The change in sample weight is then monitored during the test.

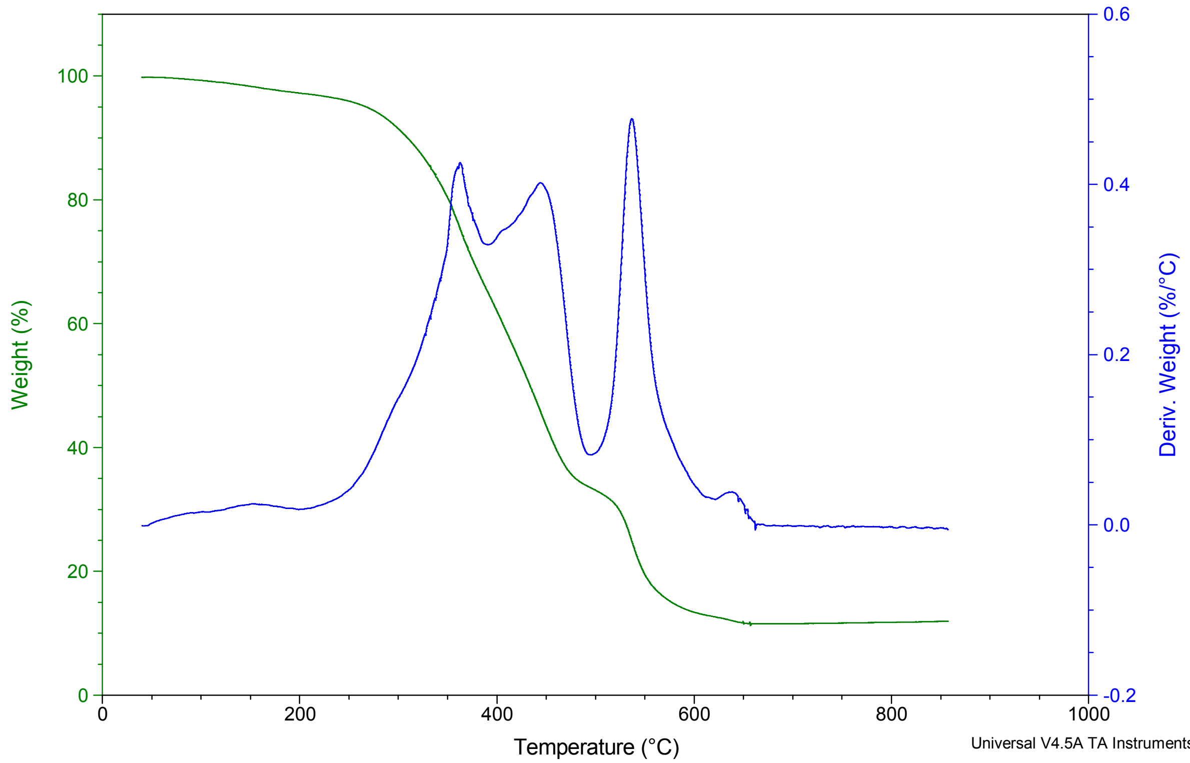


Figure 36: Percent weight as a function of temperature for Nomex® rail panel adhesive

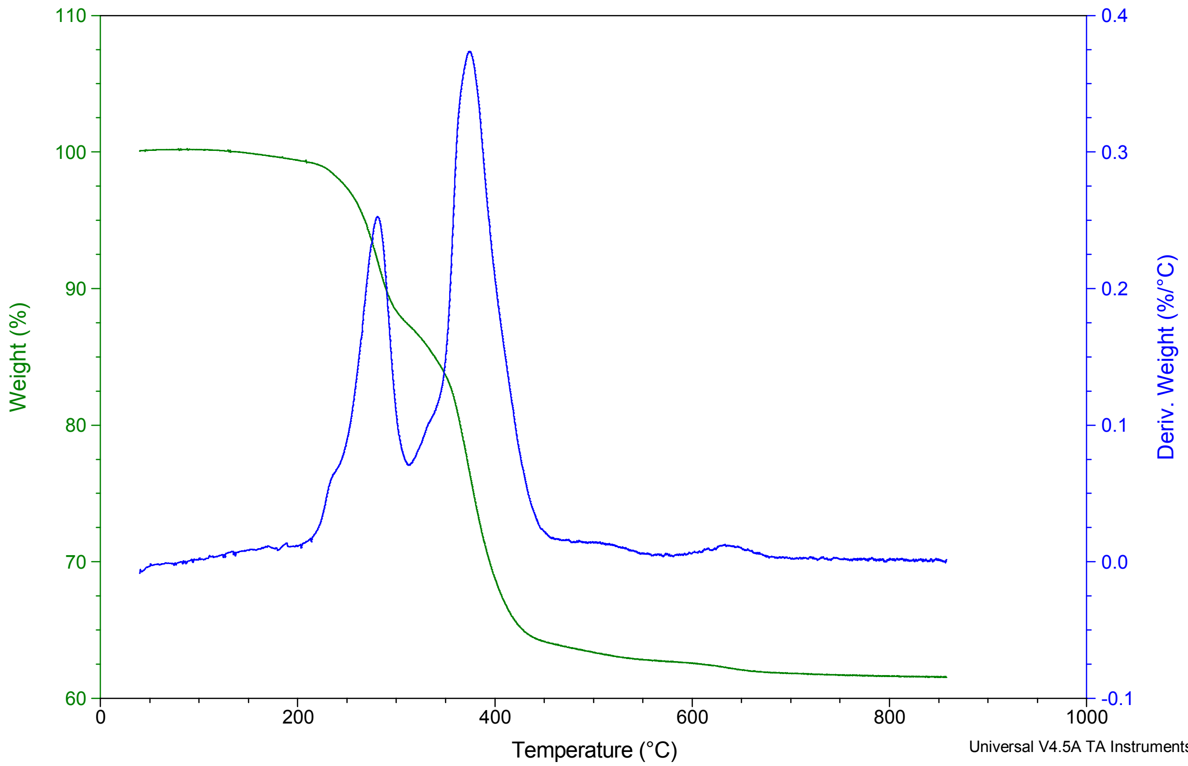


Figure 37: Percent weight as a function of temperature for FRP

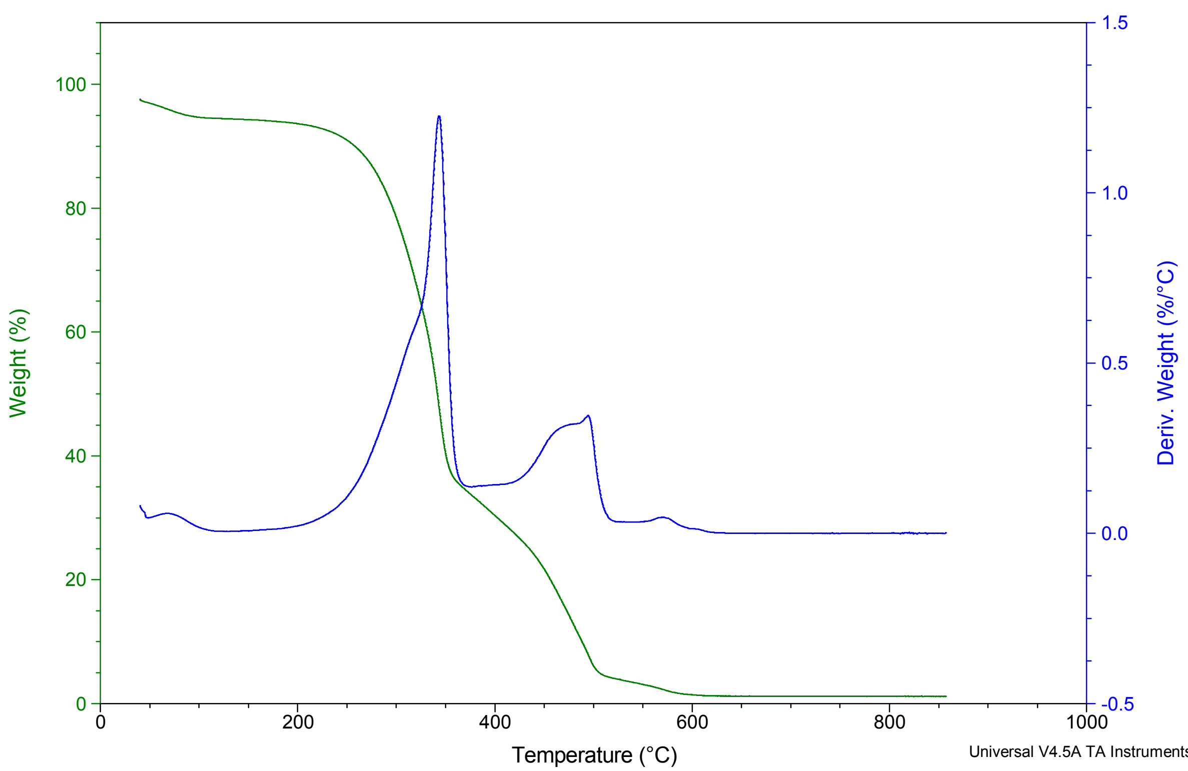


Figure 38: Percent weight as a function of temperature for plywood

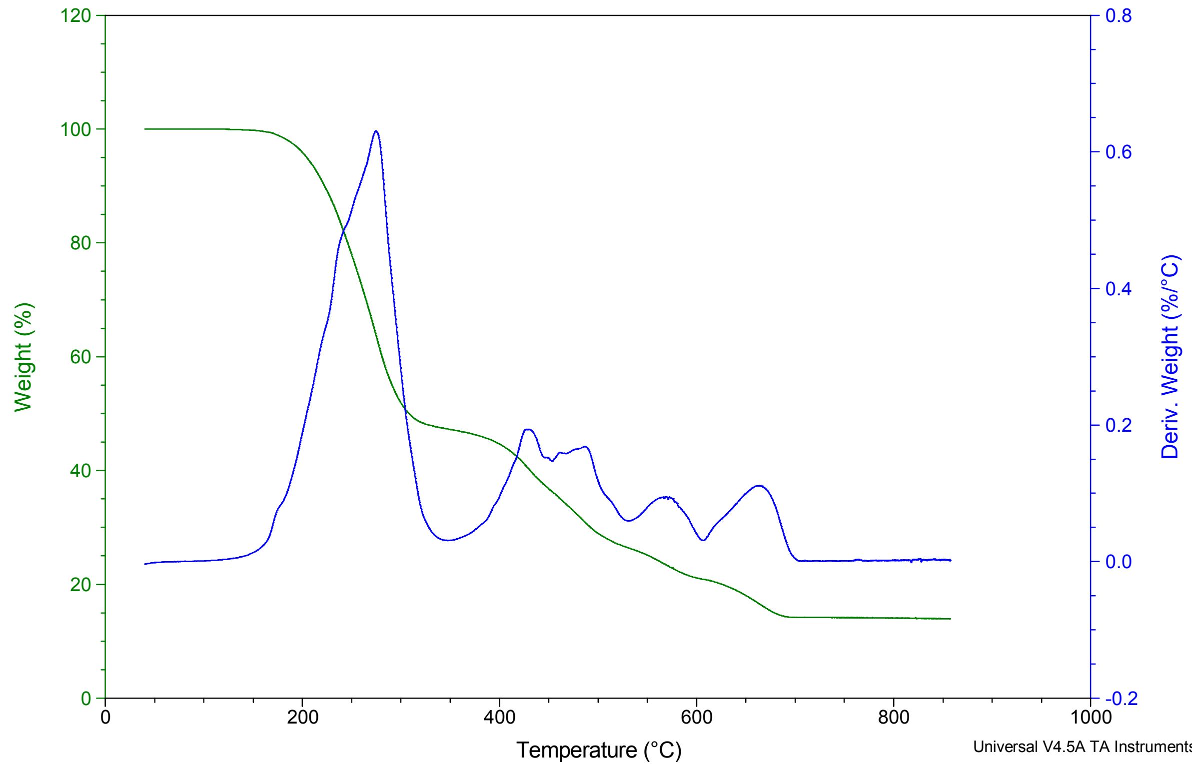


Figure 39: Percent weight as a function of temperature for vinyl

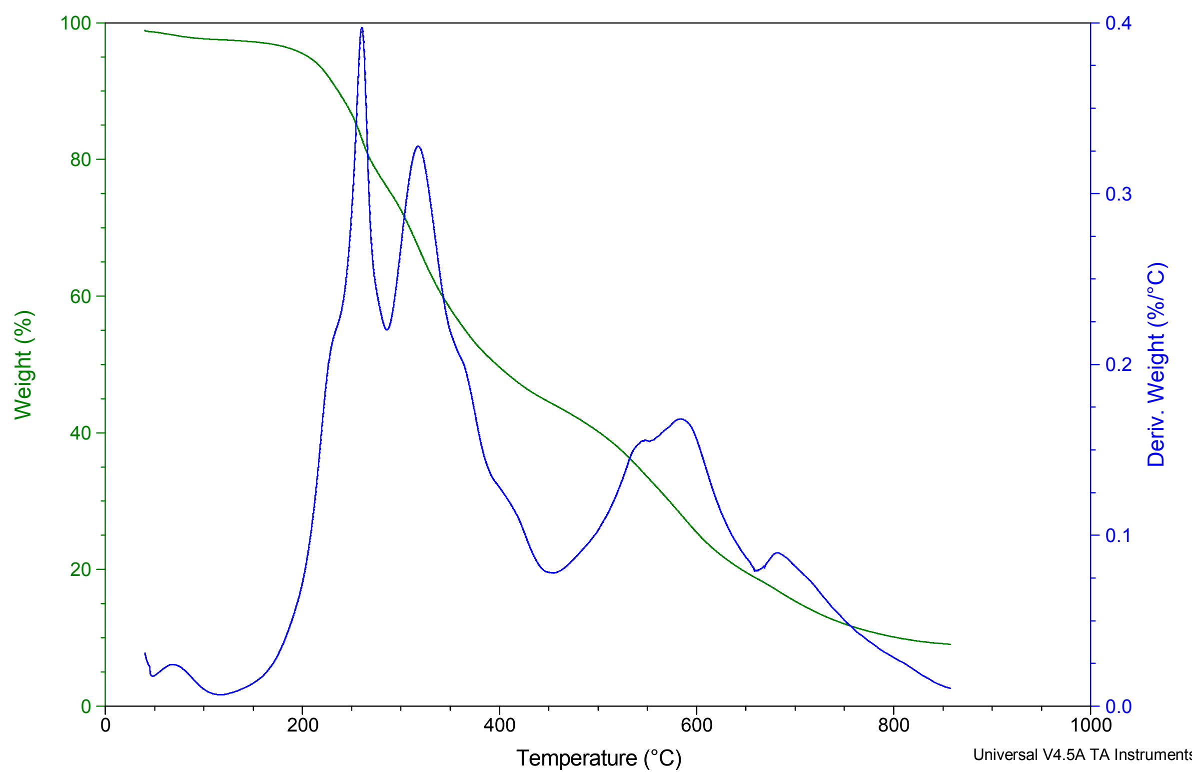


Figure 40: Percent weight as a function of temperature for wool

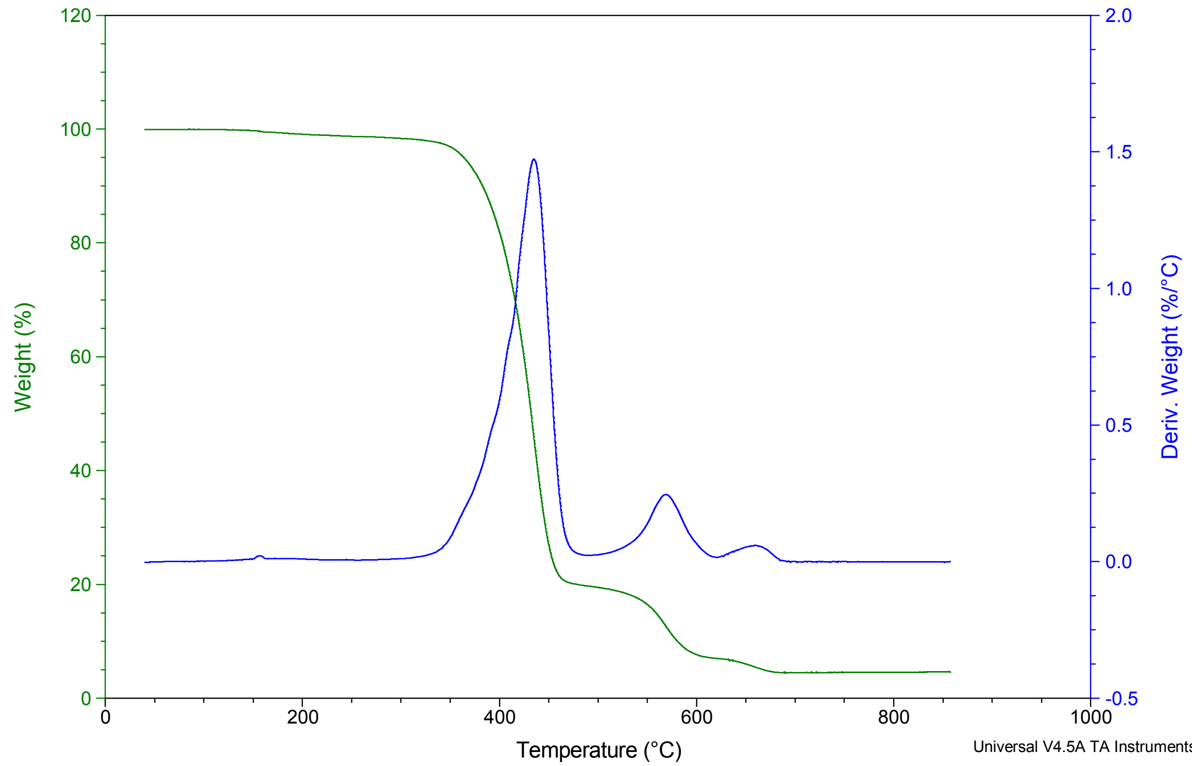


Figure 41: Percent weight as a function of temperature for polyester

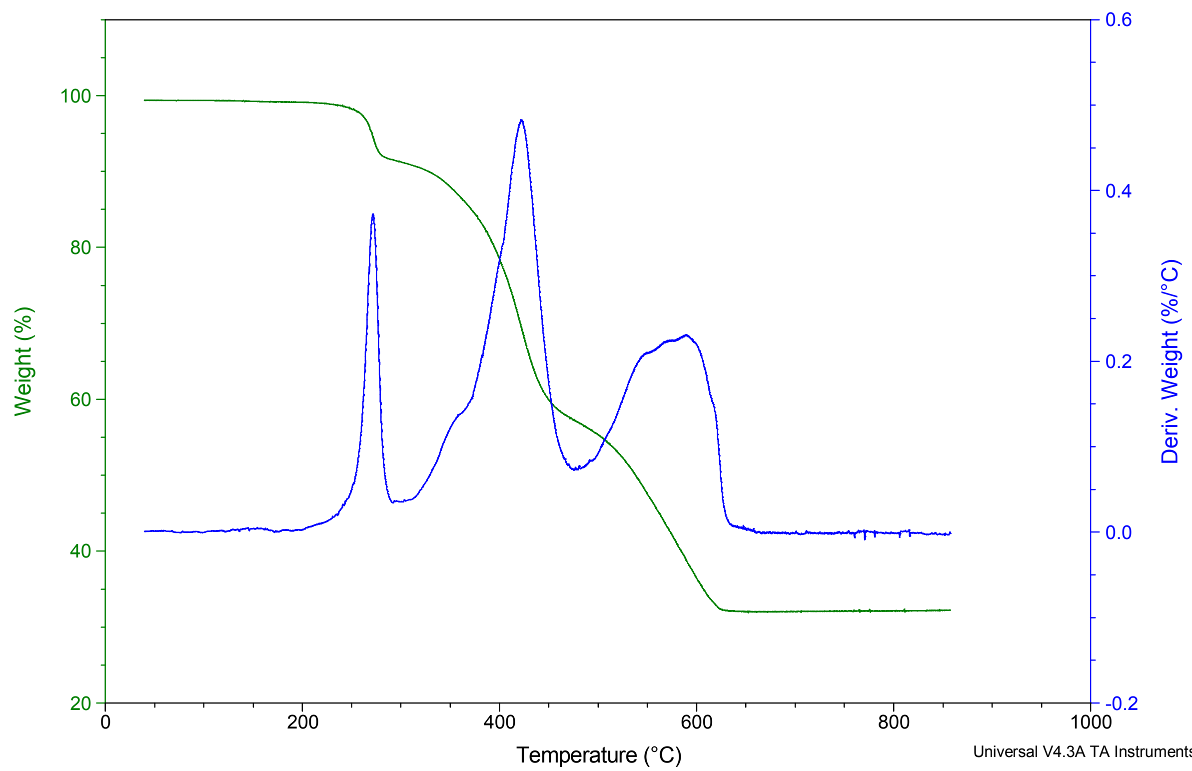


Figure 42: Percent weight as a function of temperature for Kevlar®

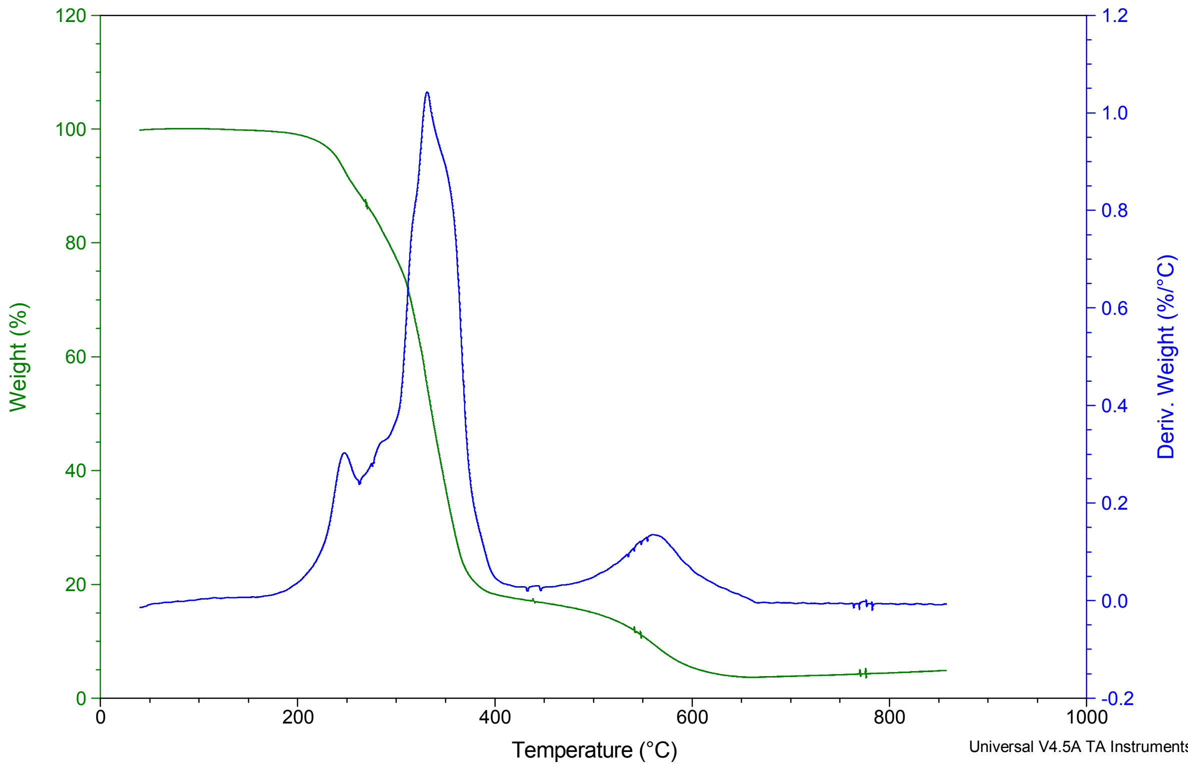


Figure 43: Percent weight as a function of temperature for polyurethane foam

References

[1] Underwriters Laboratories Inc. (2007). *Investigation of the Fire Performance of Materials and Products for Use in U.S. Railcar and Bus Applications: Task 1 Report (Situation analysis and project planning)* (Project No. 07CA38486). Northbrook, Illinois: Underwriters Laboratories Inc.

[2] Underwriters Laboratories Inc. (2008). *Investigation of the Fire Performance of Materials and Products for Use in U.S. Railcar and Bus Applications: Task 2 Report (Develop fire performance data)* (Project No. 07CA38487). Northbrook, Illinois: Underwriters Laboratories Inc.

[3] ISO 5660-1 (2006). Reaction-to-fire tests - Heat release, smoke production and mass loss rate - Part 1: Heat release rate (cone calorimeter method). In *International Standard*. Geneva, Switzerland: International Organization for Standardization.

[4] Ahrens, M. (2006). *U.S. vehicle fire trends and patterns* (Technical Report). Quincy, Massachusetts: National Fire Protection Association.

[5] Tribune News Services (2000). Grim task of removing victims of Alpine cable car fire begins. *Chicago Tribune*, November 13, 2000, Section: News, pp. 4.

[6] El Deeb, S. (2002). Rage rising in Egypt over deadly train fire. *Chicago Tribune*, February 22, 2002, Section: News, pp. 4.

[7] Slackman, M. (2002). Train blaze kills 400 in packed cars: Cooking gas blast blamed for grisly disaster in Egypt. *Chicago Tribune*, February 21, 2002, Section: News, pp. 3.

[8] Associated Press (2002). France: Hot plate started deadly train fire. *Chicago Tribune*, November 26, 2002, Section: News, pp. 4.

[9] Sciolino, E. (2002). 5 Americans among 12 dead in French rail fire. *Chicago Tribune*, November 7, 2002, Section: News, pp. 4.

[10] Miller, M. (2007). Atlantic County residents unhurt in Amtrak fire in North Carolina. *The Press of Atlantic City*, August 26, 2007, pp. C2.

[11] Reuters (2003). At least 38 killed in fire on train in India. *The New York Times*, May 15, 2003, Section: Foreign Desk, pp. 9.

[12] NTSB (1983). *Fire Onboard Amtrak Passenger Train No. 11, Coast Starlight, Gibson, California, June 23, 1982* (NTSB Report Number: RAR-83-03). Washington, D.C.: National Transportation Safety Board.

[13] Demoro, H. W. (1987). BART learned its lesson in 1979 Transbay Tube fire. *The San Francisco Chronicle*, November 19, 1987, Section: News, pp. A24.

[14] Department of Transport British Railways (1980). *Railway accident: Report on the fire that occurred in a sleeping-car train on 6th July 1978 at Taunton*. London, England: Department of Transport.

[15] Ahrens, M. (2006). *Vehicle fires involving buses and school buses* (Technical Report). Quincy, Massachusetts: National Fire Protection Association.

[16] Tribune News Services (2006). Fire on bus leaves 18 dead, 25 injured. *Chicago Tribune*, October 24, 2006, Section: News, pp. 12.

[17] NTSB (2007). *Highway Accident Report: Motorcoach Fire on Interstate 45 During Hurricane Rita Evacuation, Near Wilmer, Texas, September 23, 2005* (NTSB Report Number: HAR-07-01). Washington, D.C.: National Transportation Safety Board.

[18] Tribune News Services (2007). Bus with kids catches fire. *Chicago Tribune RedEye Edition (IL)*, August 28, 2007, pp. 10.

[19] Copeland, M. (1991). Power line hits pace bus; woman killed. *Chicago Tribune*, January 30, 1991, Section: Chicagoland, pp. 3.

[20] FRA (2005a). Subpart B – Safety planning and general requirements. In *Passenger Equipment Safety Standards*, Part 238 (pp. 660-667). Washington, DC: Federal Railroad Administration.

[21] FRA (2005b). Appendix B to Part 238 – Test methods and performance criteria for the flammability and smoke emission characteristics of materials used in passenger cars and locomotive cabs. In *Passenger Equipment Safety Standards*, Part 238 (pp. 711-715). Washington, DC: Federal Railroad Administration.

[22] NFPA 130 (2000). *Standard for fixed guideway transit and passenger rail systems*. Quincy, Massachusetts: National Fire Protection Association.

[23] ASTM E 162 (2006). Standard test method for surface flammability of materials using a radiant heat energy source. In *2006 Annual Book of ASTM Standards*, Vol. 04.07. West Conshohocken, Pennsylvania: American Society for Testing and Materials.

[24] ASTM E 662 (2006). Standard test method for specific optical density of smoke generated by solid materials. In *2006 Annual Book of ASTM Standards*, Vol. 04.07. West Conshohocken, Pennsylvania: American Society for Testing and Materials.

[25] Urban Mass Transportation Administration (1984). Recommended fire safety practices for rail transit materials selection. *Federal Register*, *49*(158), 32482-32486.

[26] prCEN/TS 45545-1 (2008). Railway applications – Fire protection on railway vehicles – Part 1: General. In *European Standard*. Brussels, Belgium: European Committee for Standardization.

[27] prCEN/TS 45545-2 (2008). Railway applications – Fire protection on railway vehicles – Part 2: Requirements for fire behavior of materials and components. In *European Standard*. Brussels, Belgium: European Committee for Standardization.

[28] ISO 5658-2 (2006). Reaction to fire tests - Spread of flame - Part 2: Lateral spread on building and transport products in vertical configuration. In *International Standard*. Geneva, Switzerland: International Organization for Standardization.

[29] ISO 5659-2 (2006). Plastics - Smoke generation - Part 2: Determination of optical density by a single-chamber test. In *International Standard*. Geneva, Switzerland: International Organization for Standardization.

[30] Peacock, R. D., Bukowski, R. W., Reneke, P. A., Averill, J. D. & Markos, S. H. (2001). Development of a fire hazard assessment method to evaluate the fire safety of passenger trains. In *Fire and Materials - Proceedings of 7th International Conference and Exhibition* (pp. 67-78).

[31] FMVSS 302 (2002). Flammability of interior materials. In *Federal Motor Vehicle Safety Standards and Regulations*, Part 571 (pp. 740-743). Washington, DC: National Highway Traffic Safety Administration.

[32] Federal Transit Administration (1993). Recommended fire safety practices for transit bus and van materials selection. *Federal Register*, *58*(201), 54250-54254.

[33] Braun, E. (1975). *Fire hazard evaluation of the interior of WMATA Metrorail cars* (NBS Report Number: NBSIR 75-971). Washington, D.C.: National Bureau of Standards.

[34] Braun, E. (1978). *Fire hazard evaluation of BART vehicles* (NBS Report Number: NBSIR 78-1421). Washington, D.C.: National Bureau of Standards.

[35] Peacock, R. D. & Braun, E. (1984). *Fire tests of Amtrak passenger rail vehicle interiors* (NBS Technical Note 1193). Washington, D.C.: National Bureau of Standards.

[36] Peacock, R. D. & Braun, E. (1999). *Fire safety of passenger trains; phase 1: material evaluation (cone calorimeter)* (NIST Report Number: NISTIR 6132). Gaithersburg, Maryland: National Institute of Standards and Technology.

[37] Peacock, R. D., Reneke, P. A., Averill, J. D., and Bukowski, R. W., & Klote, J. H. (2002). *Fire safety of passenger trains; phase 2: application of fire hazard analysis techniques* (NIST Report Number: NISTIR 6525). Gaithersburg, Maryland: National Institute of Standards and Technology.

[38] Peacock, R. D., Averill, J. D., Madrzykowski, D., Stroup, D. W., Reneke, P. A., & Bukowski, R. W. (2004). *Fire safety of passenger trains; phase 3: evaluation of fire hazard analysis using full-scale passenger rail car tests* (NIST Report Number: NISTIR 6563). Gaithersburg, Maryland: National Institute of Standards and Technology.

[39] Braun, E., Davis, S., Klote, J. H., Levin, B. C., and Paabo, M. (1990). *Assessment of the fire performance of school bus interior components* (NIST Report Number: NISTIR 4347). Gaithersburg, Maryland: National Institute of Standards and Technology.

[40] Braun, E., Klote, J. H., Davis, S., Levin, B. C., Paabo, M., & Gann, R. G. (1991). An assessment methodology for the fire performance of school bus interior components. In *Fire Safety Science – Proceedings of the Third International Symposiums* (pp. 855-864).

[41] NTSB (1989). *Pickup Truck/Church Activity Bus Head-on Collision and Fire Near Carrollton, Kentucky May 14, 1988* (NTSB Report Number: HAR-89-01). Washington, D.C.: National Transportation Safety Board.

[42] Wieczorek, C. J. & Dembsey, N. A. (2001). Human variability correction factors for use with simplified engineering tools for predicting pain and second degree skin burns. *Journal of Fire Protection Engineering*, *11*(2), 88–111.

[43] NFPA 286 (2006). *Standard methods of fire tests for evaluating contribution of wall and ceiling interior finish to room fire growth*. Quincy, Massachusetts: National Fire Protection Association.

[44] ASTM E 1537 (2007). Standard test method for fire testing of upholstered furniture. In *2007 Annual Book of ASTM Standards*, Vol. 04.07. West Conshohocken, Pennsylvania: American Society for Testing and Materials.

[45] Technical Bulletin 133 (1991). *Flammability test procedure for seating furniture for use in public occupancies*. North Highlands, California: State of California, Department of Consumer Affairs.

[46] Quintiere, J. G. (1982). Smoke measurements: an assessment of correlations between laboratory and full-scale experiments. *Fire and Materials*, *6*(3-4), 145–160.

[47] Ohlemiller, T. J. (1995). An examination of the correlation between cone calorimeter data and full-scale furniture mock-up fires. In *International Conference on Fire Research and Engineering* (pp. 217-222).

[48] Sundström, B. ed. (1995). Fire safety of upholstered furniture: the final report on the CBUF research programme (Report EUR 16477 EN). London, England: Interscience Communications Ltd.

[49] ISO/TS 13571 (2002). Life-threatening components of fire – Guidelines for the estimation of time available for escape using fire data. In *International Standard*. Geneva, Switzerland: International Organization for Standardization.

[50] Purser, D. A. (2002). Toxicity assessment of combustion products. In *SFPE Handbook of Fire Protection Engineering* (Third Edition) (pp. 2-83 – 2-171). Quincy, Massachusetts: National Fire Protection Association.

[51] Underwriters Laboratories Inc. (2007a). *Report on the investigation of the fire performance of composite panels* (Project Nos. 05CA18390, 05CA43165, 05CA48920, 05CA48921). Northbrook, Illinois: Underwriters Laboratories Inc.

TAB III:
BACKGROUND ON
NASFM
ADVISORY COMMITTEES

FTA Project
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Kansas State Fire Marshal (Retired)

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Montgomery County, Maryland

Victor Size
Washington Metropolitan Area Transit Authority

FTA Technical Advisory Committee Meeting
Tuesday, May 6, 2008
National Institute for Standards and Technology, Gaithersburg, MD

The meeting agenda is attached to these notes.

Objectives:

1. Assess acceptability of fire safety risks allowed under current requirements.
2. Establish relevance of current test requirements to characterize full-scale fire performance.
3. Recommend new performances levels-tests and how they might be obtained and by whom.

In support of Objective 1: Assess acceptability of fire safety risks allowed under current requirements.

A. Develop proposals for NFPA 130 (Standard for Fixed Guideway Transit and Passenger Rail Systems) and NFPA 556 (Guide for Identification and Development of Mitigation Strategies for Fire Hazard to Occupants of Passenger Road Vehicles).

B. Assign NASFM Science Advisory Committee to develop rationale for strengthening requirements.

In support of Objective 2: Establish relevance of current test requirements to characterize full-scale fire performance.

A. Report speaks for itself – Need an executive summary with some data.

B. Locate other work that comes to same/similar conclusions, e.g., FM's work by Jim Quintieri and Richard Lyons

C. Promote findings in the study by submitting final report to:
   - Fire Technology Journal (editor Jack Watts serves on NASFM's Science Advisory Committee)
   - Fire and Materials 2009, January 26-28, 2009, San Francisco (see call for papers at http://www.intercomm.dial.pipex.com/html/events/fm09cfp.htm)
   - TRB 88th Annual Meeting, January 11-15, 2009, Washington, DC (see calls for papers at http://www.trb.org/am/cfp/default.asp?event=445)
   - APTA (Contact: Tom Peacock) - Bus Technical, Maintenance & Procurement Workshop, Oct 5-8, 2008, San Diego, CA (see information at http://www.apta.com/conferences_calendar/busequip/) - may need to act quickly if hope to present at 2008 conference.

In support of Objective 3: Recommend new performances levels - tests and how they might be obtained, and by whom they must be accepted.

A. Determine how much time is needed to get everyone out.

B. Tenability criteria already established by other research (ISO document)

C. Understand how they arrived at standards in Europe and Japan – rationales.

D. Need understanding of how existing materials perform under proposed new requirements (reference of choices vs. requirements)

E. Determine what is acceptable in reference model and tie to small-scale test methods:
   - flashover
   - tenability (temperature/smoke/toxicity)

F. Get buy-in from recipients to phrase recommendations in a way that will make them palatable.

Chairman Alexander appointed three members of the Technical Advisory Committee as a task group to draft "best practices" for new performance levels for railcar materials for presentation to the Committee: Ralph Buoniconti of SABIC, Rick Peacock of NIST, and Jacob Borgerson of UL. The task group will report back to the full Committee when it has completed its work.

FTA Technical Committee Meeting
Tuesday, May 6, 2008

National Institute of Standards and Technology
Room B245, Building 224
100 Bureau Drive, Gaithersburg, MD

AGENDA

8:30am	**Breakfast and Opening Remarks** *Jack Alexander, Chairman*
9:00am	**Overview of the fire performance testing data and methodology** Pravinray D. Gandhi, Ph.D, P.E. and Jacob Borgerson, Ph.D., Underwriters Laboratories, Inc.
10:00am	**Committee review and comments on Draft Final Report** *Jack Alexander, Chairman*
12:00pm	**Working lunch**
12:30pm – 4:30pm	**Discuss recommended best practices and steps to completion**
	Adjournment

National Association of State Fire Marshals Science Advisory Committee

(Updated October 15, 2008)

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TAB IV:
NASFM PROPOSAL TO FTA
FOR PROJECT NO. DC-26-5243-00

A Proposal from the National Association of State Fire Marshals to the Federal Transit Administration to Conduct Research and Recommend Best Practices Related to the Fire Performance of Materials and Products Used in Railcars in the United States.

OVERVIEW

United States Department of Transportation statistics reveal approximately 1,500 fires on heavy rail passenger vehicles. Experts tend to agree that these fires are seriously underreported. The New York City Fire Department alone reports responses to hundreds of fires in the city's extensive subway system.

Railcar fires may ignite from electrical sources, friction from braking systems, consumer carelessness and criminal activity. Improvised explosive devices may be easily concealed. Their use may prove fatal to those closest to an explosion, but the greater harm may come from the ensuing fire.

Whether accidental or intentional, these fires may grow rapidly in size and intensity because of combustible materials brought on board by riders and accumulated waste, but also because of the interior materials and products used in the construction of the railcars. In the time required to report a fire, stop the vehicle and initiate exiting, these fires may produce significant quantities of highly toxic gases, smoke to obscure vision and high levels of heat. A rapidly escalating fire impedes passenger escape and emergency response, especially in the confines of a subway tunnel.

Mass transit authorities work hard to maintain railcars and keep the infrastructure free of combustible waste. Mass transit and public safety authorities do their best to prevent criminal activity on board these vehicles, but is virtually impossible to regulate riders' personal items, the vast majority of which are innocuous but nonetheless combustible.

The purpose of this project is to address a fire safety factor that is well within the control of the public sector – the fire performance of the materials and products used in the construction of the interiors of railcars. This project begins with research into the real-world adequacy of existing railcar fire safety standards, and then to an investigation of potential improvements in the test methods and criteria that may be used with railcars. An experts' panel will review the research and recommend best practices to reduce the contribution of the materials and products from future railcar fires.

The project will be managed under the auspices of the Safe Energy and Transportation Task Force of the National Association of State Fire Marshals (NASFM). More information on NASFM and its Task Force follows this proposal.

PROPOSAL

Objectives

- Review the current US requirements for fire performance for railcars
- Develop integrated fire performance metrics including ignitability, combustibility, and toxicity of combustion effluents in railcars
- Validate fire performance metrics with experimental data
- Recommend best practices to be used in the choice of materials and products used in railcars

Scope

The scope of this research will be limited to interior wall and ceiling lining materials. It is anticipated that the fire performance concepts and methodology developed may be used for other combustible items in a railcar.

Technical Plan

The technical plan will be coordinated by Pravinray Gandhi, Ph.D., Manager, Fire Research and Technology, Underwriters Laboratories (UL). The Technical Plan will consist of the following tasks:

Task 1 – Situation analysis
- Review of current US requirements
- Review of proposed EN requirements
- Comparison of the fire performance with available test data
- Review and identification of gaps in the fire performance requirements
    - Fire safety objectives and relevant measurements for railcars
    - Validation using large-scale fire test (e.g., NFPA 286 room corner test)
- Selection of material and products for the research

Task 2 – Development of fire performance data for products currently allowed in the US railcars
- Tests in accordance with Federal Railway Authority (FRA) document 49 CFR Part 238
- Tests in accordance with proposed EN 45545-2
- Toxicity testing with state-of-the-art ISO test methods
- Large-scale tests in accordance with NFPA 286, room corner tests

Task 3 – Analysis of data

- Correlation of fire and smoke growth between FRA tests and NFPA 286 fire tests
- Correlation of fire and smoke growth between EN 45545-2 tests and NFPA 286 fire tests
- Correlation of gas effluents in small-scale and NFPA 286 tests

Task 4 – Recommendation of fire performance metrics for wall and ceiling lining materials including:

- Ignitability
- Heat release
- Smoke release
- Gas effluent composition

Task 5 – Final research report

- Situation analysis
- Test procedures, data
- Data analysis
- Recommendations

<u>Consensus Best Practices</u>

Task 6 – Produce consensus best practices

- Establish experts' panel to review the progress of and final recommendations of the research project described above, and reach consensus on best practices reflecting those findings. This panel shall be appointed by the President of NASFM's Board of Directors and consist of two experts from each of the following: the American Public Transportation Association (APTA); the fire service; suppliers to the mass transit authorities; and the scientific community.
- Submit best practices by the end of calendar year 2007 to NASFM, APTA and the Federal Transit Administration (FTA).

Schedule

Complete project and final research report, four months after award of research.
Produce best practices, four months after conclusion of research.

Costs

Estimated to be $210,000 based upon the following deliverables and activities:

- Situation analysis
- Development of fire performance data
    - o 8 new materials/products will be tested
    - o 49 CFR Part 238 tests
    - o prEN 45545-2 specified tests
    - o NFPA 286 tests
- Data analysis and correlations between small-scale and large-scale fire tests; fire modeling using FDS for fire growth in railcar (validation of input for FDS will be performed with results from NFPA 286 tests)

- Recommendations for fire performance of wall and ceiling lining materials in railcars
- Final research report
- Expert panel meetings resulting in consensus best practices.
- Project management

This estimate is contingent on UL's access to data produced by the National Institute of Standards and Technology for FTA and data produced by UL on behalf of a UL client.

Cost Sharing

NASFM will cover all costs related to the meetings of the experts' panel. These costs are being made "in kind" and are estimated to be $60,000. In addition, NASFM will arrange for project management.

NASFM is seeking $150,000 from FTA to cover the estimated costs of the research project described here.

Option

Research and recommendations related to the fire performance of bus interiors may follow the project described above. Upon satisfactory completion of this project, NASFM and FTA may elect to proceed with a similar project related to bus fire safety.

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About the National Association of State Fire Marshals and its Safe Energy and Transportation Task Force.

The National Association of State Fire Marshals (NASFM) consists of senior state-level public safety officials. NASFM's mission is to protect life, property and the environment from fire and other hazards. State Fire Marshals' responsibilities vary from state to state, but they tend to be responsible for fire safety code adoption and enforcement, fire and arson investigation, fire incident data reporting and analysis, public education and advising Governors and State Legislatures on fire protection. Some State Fire Marshals are responsible for fire fighter training, hazardous materials incident responses, wildland fires and the regulation of natural gas and other pipelines.

NASFM programs are conducted by three task forces. The Consumer Product Fire Safety Task Force addresses the threat of fire in the home. The Catastrophic Fire Prevention Task Force addresses very large fires capable of harming large numbers of persons very quickly. The Safe Energy and Transportation Task Force works primarily with the United States Department of Transportation to bring together emergency responders, federal and state regulators, industry and scientists on the safety of pipelines, LNG terminals and alternative energy. For more information, please visit NASFM's website at www.firemarshals.org.