DEVELOPMENT OF A FIRE HAZARD ASSESSMENT METHOD TO EVALUATE THE FIRE SAFETY OF PASSENGER TRAINS

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Development of a Fire Hazard Assessment Method to Evaluate the Fire Safety of Passenger Trains

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ABSTRACT

U.S. passenger train fire safety has historically been addressed primarily through the citation of small-scale flammability and smoke emission tests and performance criteria promulgated by the Federal Railroad Administration (FRA). This approach has focused on the primary combustible materials **of** rail car components such as seats and wall and ceiling panels. As fire safety regulations for buildings move toward performance codes, there has been interest in the application of fire hazard assessment to passenger rail cars using modeling techniques. To develop such an alternative approach, a systematic study **of** the fire performance characteristics of current rail car materials was conducted. First, the heat release and smoke production of actual materials in use were characterized in the Cone Calorimeter. Next, full-scale assembly tests of components such as seats and interior panels constructed of these same materials were conducted in a furniture calorimeter. Finally, full-scale tests of passenger rail cars incorporating the tested components were conducted. The predictive accuracy of fire hazard modeling techniques was assessed against the full-scale test results. The model's utility in evaluating alternative fire safety improvements, such as automatic suppression or smoke venting was demonstrated. The paper provides an overview of work to date. It is expected that this work could lead to the recognition of fire hazard-based methods as an alternative to the current prescriptive requirements for passenger rail and transit vehicles.

CURRENT FRA REQUIREMENTS

As part of the passenger rail equipment rulemaking process required by Congress, the Federal Railroad Administration (FRA) has published requirements that passenger train materials meet certain flammability and smoke emission test methods and performance criteria[1]. These requirements are based on guidelines for intercity and commuter rail cars that FRA first issued in 1984 and revised in 1989[2,3]. The 1984 FRA guidelines were identical to Urban Mass Transportation Administration (UMTA), now Federal Transit Administration **(FTA)** recommended practices for rail transit vehicles, also issued in 1984[4]. The FRA issued revised guidelines in 1989 that used terms and categories to more closely reflect passenger train design and furnishings; smoke emission performance criteria for floor coverings and elastomers were also included.

Based primarily on small-scale test methods that demonstrate fire characteristics of individual materials, the FRA requirements form a prescriptive set of design specifications that historically have been used to evaluate rail car material fire performance. This approach provides a screening device to allow interested parties to identify particularly hazardous materials and to select preferred combinations of individual components; material suppliers can independently evaluate the fire safety

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performance of their own materials. The FRA has funded a study by the Volpe National Transportation Systems Center (Volpe Center) and the National Institute of Standards and Technology **(NIST)** to develop an alternative approach using heat release rate (HRR) and fire hazard analysis using computer modeling techniques.

TYPICAL RAIL CAR MATERIALS

Passenger rail cars are constructed primarily of stainless steel; some newer designs incorporate aluminum components. Due to the typically longer distances traveled, the furnishing of conventional passenger rail cars is more complex than in a rail transit vehicle (e.g., subway, light rail). Most intercity and many commuter rail cars are equipped with upholstered seats. Multilevel cars have stairways that allow passengers to move from one level to another. Intercity passenger trains may consist of coach cars, café/lounge cars, dining cars, and sleeping cars. In addition, cooking equipment, heat and air conditioning systems, AC and DC power equipment, and lavatories are included in various passenger rail car designs.

Intercity passenger interior wall and ceiling linings consist **of** fiberglass-reinforcedpolymer (FRP) material or metal, or are covered with carpet or fabric glued to a perforated sheet metal base material. The underside of the overhead luggage storage rack is covered either with the same carpet or rigid polyvinyl chloride **(PVC)** / acrylic. Polycarbonate windows ***are*** usually used. Fabric drapes are used at windows in many cars. Elastomeric materials are used as gasketing at door edges, around windows and between cars. Polymeric materials are used in nonpassenger-accessible spaces, such as pipe wrap, ventilation and air ducting. The majority of rail car floors are constructed of plywood/metal (plymetal) panels. Fiberglass insulation is used in the floors, sidewall, end wall, and air ducts in the cars. The floor covering consists of carpet and resilient rubber matting.

Coach cars contain rows of upholstered seats, windows and overhead luggage storage space. Coach seats consist of fabric / vinyl-covered foam cushions installed on steel seat frames with plastic seat shrouds, back shrouds, and food trays. Seat support diaphragms provide flexible support for the seat bottom. Certain coaches used for longer distances are equipped with padded arm and leg rests, and foot rests, as well as window drapes. The seats in first-class sections are similar to coach seats but plush fabric upholstery and thicker foam cushions provide a higher level of comfort. Single level café/lounge car interior furnishings are similar to the coach cars. The café/lounge cars have a minimal food service area and reduced seat density and may be equipped with tables. Dining cars contain an extensive separate food preparation area, laminated tables and walls, and vinyl upholstered seats. Dining tables are phenolic laminate over plymetal. Seat assemblies use similar materials to the coach cars except that vinyl is used for the seat covering.

Sleeping cars contain a series of individual rooms arranged along a corridor plus luggage storage space. Seat configuration in the individual rooms is somewhat different than coach seat configuration, but comparable materials are used in the seat assemblies. The seats convert to beds with fabric-covered foam mattresses; pillows, cotton sheets, and wool blankets provided. Fabric curtains line the doors to provide privacy. Partitions between sleeping compartments and hallways are constructed of plymetal panels.

Materials selected for evaluation were provided by Amtrak that provides U. S. intercity rail passenger service. The Amtrak fleet consists of several generations of passenger rail cars, which include cars providing coach or first class seating, food service, or overnight sleeping accommodations. Selected materials reflecting a broad cross section of interior materials (representing the bulk of the fire **load found** in most passenger rail cars) were **used** throughout the study. Table 1 lists the materials selected and tested.

Table 1. Selected Passenger Train Materials Evaluated in the Study

Category	Sample No.*	Material Description (Components)
Seat and Bed Assemblies	1a, 1b, 1c, 1d	Seat cushion, (foam, interliner, fabric/PVC cover)
	2a, 2b, 2c	Seat cushion, (foam, interliner, fabric cover)
	3	Graphite-filled foam
	4	Seat support diaphragm, chloroprene elastomer
	5	Seat support diaphragm, FR cotton muslin
	6	Seat shroud, PVC/acrylic
	7	Armrest pad, coach seat (foam on metal support)
	a	Seat footrest cover, chloroprene elastomer
	9	Seat track cover, chloroprene elastomer
	10a, 10b, 10c	Mattress (foam, interliner, ticking)
	11a, 11b, 11c	Bed pad (foam, interliner, ticking)
Wall and Window Surfaces	12	Wall finishing, wool carpet
	13	Wall finishing, wool fabric
	14	Space divider, polycarbonate
	15	Wall material, FRP/PVC
	16	Wall panel, FRP
	17	Window glazing, polycarbonate
	18	Window mask, FRP
Curtains, Drapes, And Fabrics	19	Privacy door curtain and window drape, wool/nylon
	20	Window drape, polyester
	21	Blanket, wool fabric
	22	Blanket, modacrylic fabric
	23a, 23b	Pillow, cotton fabric/polyester filler
Floor Coverings	24	Carpet, nylon
	25	Rubber mat, styrene butadiene
Misc	26	Cafe/lounge/diner table, phenolic/wood laminate
	27	Air duct, neoprene
	28	Pipe wrap insulation foam
	29	Window gasketing, chloroprene elastomer
	30	Door gasketing, chloroprene elastomer

* - Letters indicate individual component materials in an assembly.
Individual component materials are listed in order in parentheses following the material description
Note: All foam except Sample 3 is the identical type

COMPARISON OF CONE CALORIMETER TEST DATA WITH EXISTING FRA TEST DATA

HRR and fire hazard analysis are the primary focus of this current study of passenger train fire safety. HRR is the key indicator of fire performance of a material or construction, including ignition, flammability’, and smoke emission[6] properties. Accordingly, HRR data are necessary to conduct fire hazard analyses and can also be used to predict real-scale fire behavior. Passenger rail car materials have historically been tested according to other test methods and performance criteria not directly related to HRR. In this section, the Cone Calorimeter test data are compared to test data obtained from **Amtrak** for FRA-cited test methods. This comparison is intended to provide a better understanding of the relationships and limitations of Cone Calorimeter test data relative to FRA-cited test method data. A detailed report is available'.

FRA-Cited Test Method

Several FRA-cited test methods include American Society for Testing and Materials (ASTM) and Federal Aviation Administration (FAA) measures of material flammability in terms of flame spread (ASTM E 162, D 3675, and E 648) or ignition/burn resistance (FAA FAR 25.853 (a) and ASTM C 542). ASTM E 162 and D 3675 measure downward flame spread on a near vertically mounted specimen (the specimen is tilted 30° fiom the vertical with the bottom of the specimen further away from the radiant panel than the top of the specimen). FAA FAR 25.853 (a) and ASTM C 542 are small burner tests that measure a material's resistance to ignition and burning for a small sample of material. ASTM E 648 measures lateral flame spread on a horizontally mounted specimen. Since ASTM E 648 was designed to measure fire performance of flooring materials, it is the only test method that attempts to replicate end-use conditions. Material flammability and smoke emission test data were obtained for 30 materials from manufacturers and/or suppliers. Review of additional data from related studies[8, 9, 10] show performance similar to the current tests.

Of the materials currently in use, only the polycarbonate space divider does not meet the FRA flammability performance criterion of 35; used as a window glazing, the same material meets the FRA performance criterion of 100. ASTM E 648 was used to evaluate two floor-covering materials: nylon carpet and resilient rubber floor mat. The test data indicated that both met the FRA performance criteria. The FAA FAR 25.853 (a) bum length test data available for 4 of the 10 materials indicated they met the FRA performance criteria. Flame time was available for only 3 of the 10 materials that also passed the criterion.

Available ASTM E 662 test data showed that the majority of samples met FRA smoke emission criteria. Exceptions such as the seat support diaphragm, armrest pad, footrest pad, seat track cover, and window and door gasketing) represent a small portion of the fire load in a typical vehicle interior. Amtrak is considering replacement materials with better fire performance.

Cone Calorimeter Test Method

Individual material data were obtained from Cone Calorimeter tests. Details of the data are available[7, 11]. All Cone Calorimeter tests in this study were conducted at a heat flux exposure of 50 kW/m^2. This level represents a severe fire exposure consistent with actual train fire tests. With the high performance typical of currently used materials, flux exposures higher than 50 kW/m^2 are unlikely. A spark ignitor was used to ignite the pyrolysis gases. All specimens were wrapped in aluminum foil on all sides except for the exposed surface. A metal frame was used and where necessary a wire grid was added to prevent expanding samples from entering into the cone heater. Included in the data are ignition time, peak HRR, and average specific extinction area smoke data (SEA a) for the first 180 s of each test.

Times to ignition varied from 5 s for the cotton interliner used in the seat assemblies to 115 s for the window glazing. In general, seat and bedding materials and drapery/curtain and fabric materials exhibited the shortest times to ignition, typical of thin materials. Wall and window surfaces, as well as window and door gaskets, had the longest times to ignition, typical of thicker materials.

Peak HRR varied over an order of magnitude from 65 kW/m^2 for the graphite foam to 745 kW/m^2 for the wall fabric. The majority of the 34 individual sample materials tested had peak HRR between 100 kW/m^2 and 600 kW/m^2:

- 6 materials had peak HRR below 100 kW/m^2 – including all the seat and mattress foams;
- 25 materials had peak HRR between 100 kW/m^2 and 600 kW/m^2; and,
- 3 materials had peak HRR over 600 kW/m^2 – usually thin materials.

Since the seat foam is one of the largest single combustible materials in a rail car, the low HRR results are particularly important.

Smoke SEA data showed a larger distribution for the 180 s average, σ (m^2/kg), as compared to the peak HRR. Peak σ varied from 30 m^2/kg for seating foam to 1400 m^2/kg for a seat support diaphragm and a rubber floor covering material.

Several materials showed elevated HRR and smoke values over an extended period of time. Although the peak HRR of these materials fall into an intermediate range, the extended duration of the HRR curve makes these materials important for study in future fire hazard analysis efforts.

For component assemblies of materials, the exposed layer of material controlled the time to ignition. The peak HRR for assemblies was generally between the highest and lowest peak **HRR** for individual component materials making up the assembly. Smoke data was greatly reduced compared to individual component materials with 180 s average σ varying from **30** m^2/kg for a mattress assembly to 560 m^2/kg for a pillow.

Cone Calorimeter data from the 1984 FRA/Amtrak study [8], 1990 National Highway Traffic Safety Administration (NHTSA) school bus study [9], and 1996 Maryland ***Area*** Rail Commuter **(MARC)** system rail car **study** [12] shows material performance similar to the materials tested for this study. In addition, the NHTSA and MARC data includes tests conducted at a range of incident fluxes that showed an expected increase in peak **HRR** as incident heat flux increased.

Implication of Small-Scale Test Results on Current Passenger Rail Car Design

For the majority of materials, the relative ranking from "best" to "worst" was similar in both test methods. While the materials tested represent a range of those currently used in passenger rail cars, many other material combinations are possible in actual use. Moreover, new materials and designs are better judged through a systems approach that considers the impact of material and design choices on the overall fire safety of the system. The use of HRR data in a hazard analysis applied to passenger trains could provide such an overall system evaluation.

ASSEMBLY TESTING

The outstanding passenger train fire safety record shows that current requirements have been successful in preventing small ignition sources from causing major fires. To provide data for fire hazard analysis, selected real-scale assemblies fiom Amtrak trains were tested in the furniture calorimeter. All of the assemblies tested were extremely resistant to ignition. The assemblies tested require an initial fire source ranging from 25 kW to 200 kW to ignite. Some of the materials do not contribute to the fire even with these ignition sources.

These assembly tests include a range of materials used in intercity passenger rail cars and are consistent with those tested in the Cone Calorimeter. The tests were arranged in **six** groups:

- Ten trash bag tests, **with** six taken **from an** actual Amtrak overnight train and four filled with newspaper to match the HRR of the trash-filled bags with a more repeatable filling. Newspaper-filled trash bags were used as **an** ignition source for the seating and bedding tests described below.
- **Four** coach seat assembly tests to study the burning behavior of entire seating assemblies to varying ignition sources. The assemblies were placed next to a noncombustible wall representative of an **Amtrak** coach car wall and overhead luggage rack.
- Three bedding assembly tests in a compartment sized to be representative of an economy room on an overnight train. Although the construction materials for the bedding assemblies are similar to the seating assemblies, the geometry of the compartments is significantly different from that in a coach car.

- Four wall and ceiling carpet tests. In some configurations, wall and ceiling carpet comprise a significant fraction of the surface area in a car. The extent to which the carpeting supports the spread of fire is a controlling factor in fire spread from a seat assembly to the upper walls and luggage rack.
- Six window drape and door privacy curtain tests. Like the carpet, drapes and curtains can be a path for fire spread to the upper walls and luggage rack.
- Two window assembly tests, including window glazing and window masks from Amtrak coach cars. The window assemblies comprise a significant fraction of the wall surface area in a car.

Assembly Test Results

The assemblies tested require an initial fire source ranging from 25 kW to 200kW to ignite. Some of the materials so not contribute to the fire even with these ignition sources. Peak HRR values were measured during each of the 29 tests conducted. For the assemblies tested, the peak HRR ranged fiom **27** kW for a coach seat assembly (including the TB 133 burner) to **9**18 kW for a sleeping compartment assembly (including both lower and upper berths, bedding, window drapes, and a trash bag ignition source). Table **2** summarizes the data from the assembly tests.

Table **2.** Peak HRR Measured During Furniture Calorimeter Assembly Tests

Test Assembly	Ignition Source (kW)	Range of Peak HRR* (kW)	Net Peak HRR (kW)
Trash bags ranging in weight from 4 lb to 21 lb. (1.8kg to 9.5 kg)	25	50 - 280	25 - 260
Coach seat assemblies	17 - 200	30 - 490	10 - 290
Lower bed with bedding and pillow	200	760 - 840	550 - 640
Upper and lower beds with bedding and pillow	200	920	720
Wall carpet on a wait *or* a wall and ceiling	50	340 - 850	330 - 800
Window drape or privacy curtain assemblies	25	70-200	40 – 170
Window assemblies	50 - 200	130-450	80 - 250

All the assemblies tested were extremely resistant to ignition. The assemblies tested require an initial fire source ranging from 25 kW to 200 kW to ignite. Materials and products that comply with the current FRA-cited fire tests and performance are difficult to ignite, requiring ignition source strengths of **2** to 10 times those used for similar materials and products found outside of the rail car operating environment. Some of the materials do not contribute to the fire even with these ignition sources. Like the 1983 tests conducted on real-scale mockups **of** Amtrak coach cars, wall carpet and window assemblies are seen as the most important materials for fire growth'. These assemblies are typical **of** intercity passenger rail cars. While commuter rail cars or rail transit vehicles may have different levels of furnishings, results for some of the assemblies (such as the seat assemblies) may be appropriate **for** these applications as well. Since the focus of this report is primarily passenger rail car interior design, all of these results apply to interior ignition scenarios. Exterior ignition sources, which may be important in some environments, particularly in the design of tunnel ventilation systems, were not considered. Such scenarios have been considered elsewhere[13].

Implications of Assembly Test Results on Current Passenger Rail Car Design

Clearly, it takes a significant ignition source for any of the items tested to become involved in a fire. All assemblies tested were exposed to an initial ignition source ranging from 17 kW to 200 kW. Some of the materials do not contribute to the fire even with these ignition sources. For example, the seat cushions do not produce a significant HRR even with the severity of the near 200 kW newspaper-filled trash bag ignition source. For the seat assemblies, the HRR results largely from burning of carpet attached to the rear of the assemblies.

Conversely, if a severe ignition source exists, some of the materials can contribute to further fire growth. The wall carpeting and window glazing, though difficult to ignite, produce high HRR values once ignited. This is consistent with earlier National Bureau of Standards (NBS, predecessor to NIST) real-scale mockup assembly tests conducted on Amtrak coach interior materials[8]. In these earlier tests, the wall covering (carpeting or window mask) adjacent to the seating were seen as important to the growth of fire in the tests. Like the earlier NBS tests, the effect of geometry can be significant. In the bed tests, the small enclosed geometry of the sleeping compartment results in a much larger HRR for the bed assembly tests than for the seat assembly tests, even though the materials are similar.

Following the 1983 Amtrak fire tests, the use of carpeting on the underside of the luggage racks was discontinued. Similarly, the identification of trash bags as an ignition source capable of producing a significant fire has led Amtrak to enclose in fire resistant containers. Other observations have resulted in a new awareness of ignition source strengths and the benefits of enclosed luggage bins as opposed to open racks. The results from these tests are clearly having an influence on both design and operating practices.

FIRE HAZARD ANALYSIS

Traditionally, techniques for fire hazard analysis typically involve a process for the evaluation of hazard of a product or products in a specific scenario[14]. For the analysis of passepger trains, this process limits the evaluation to the contribution of specific products without providing an overall assessment of the performance of the entire system.

Therefore, the procedure was revised for this project to better reflect the minimum appropriate performance of the overall rail car system while maintaining an evaluation of a specific design as compared to that required minimum performance level. For this systems-based analysis, the process is also conducted in four steps:

- Define the rail car design and performance criteria,
- Calculate the rail car fire performance,
- Evaluate specific rail car fire scenarios, and
- Evaluate the suitability of the proposed rail car design.

Steps 1 and 4 are largely subjective and depend on the expertise of the user. Step 2, which involves hand calculations or the use of computer software, requires expertise in fire safety engineering. Step 2, the heart of fire hazard analysis, is a sequence of procedures implemented in computer software to calculate the development of hazardous conditions over time, calculate the time needed by occupants to escape under those conditions, and estimate the resulting effects on the occupants, based on tenability criteria. In addition to evaluating the hazard resulting from specific products used in the design, the new procedure proposed in this paper determines the worst-case fire that allows the overall passenger rail car system to meet chosen design criteria. Step 3 evaluates the specific fires that are likely to occur in the rail car. Step 4 compares the results of steps 2 and 3 and evaluates the appropriateness of the calculations performed, as well as determining whether or not the proposed design meets the design goals established in step 1.

Three different passenger car designs were considered: a single level coach car, a bi-level dining car, and a bi-level sleeping car. For each of these designs, a range of design fires were used which are represented by a power law relation, expressed as:

$$\dot{Q} = \alpha t^n \qquad (1)$$

where $\dot{Q}$ is the HRR (kW), α is the fire intensity coefficient (kW/s^n), t is time (s), and n is a power chosen to best represent experimental data. For most flaming fires, n=2, the so-called t-squared growth rate is an excellent representation.

Figure 1 illustrates the results of the baseline coach car analysis. **A** series **of** specific t-squared fires labeled slow, medium, fast, and ultra-fast, with fire intensity coefficients (α) such that the fires reached **1055** kW (1000 BTU/s) in ***600*** s, **300** s, 150 s, and **75** s, respectively were used. In addition to the t-squared design fires, data from the small-scale and assembly-scale tests of actual rail car materials were used **as** input to the computer fire model CFAST, to predict the conditions within the rail car that result fiom a specified fire and place the design fires in context.

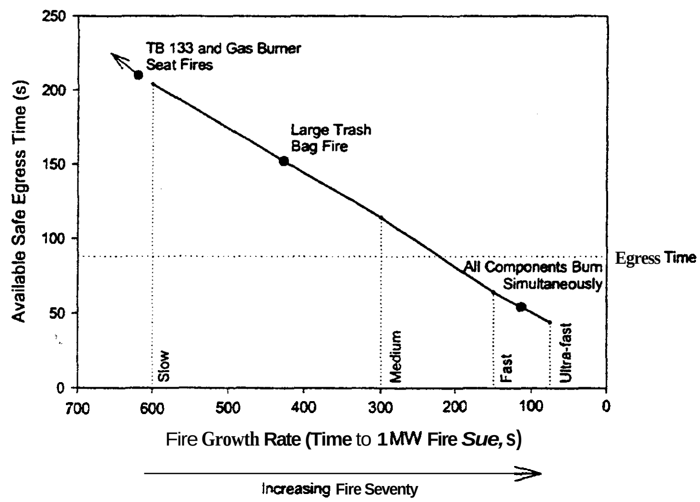

Figure 1 Calculated Fire Performance Graph for Baseline Fire Hazard Analysis of Coach Car Configuration

Key Observations from the Fire Hazard Analysis

Fire hazard analysis can quantify the consequences of specific, interior rail car fire scenarios on the safety of passengers and crew in typical intercity coach, sleeping, and dining cars. Such an analysis can provide information on:

- the worst-case fire that still provides sufficient time to ensure that passengers and crew are safe from unreasonable risk of death or injury from interior fires. For example, materials or products exhibiting fire growth rates at or below a medium t-squared level would provide sufficient time for egress for the design fires considered in Figure 1.
- by comparing the largest design fire to specific fire scenarios involving materials used in the construction of passenger rail cars, the acceptability of the materials can be judged. For example, materials and products that comply with the current FRA requirements **for** fire performance exhibit fire growth rates below the medium t-squared level, and thus would be acceptable under the design criteria presented in Figure 1.

The quantity, arrangement, and **fire** performance characteristics (ignitability and fire growth characteristics) of items brought aboard by passengers as baggage, and materials brought aboard **as** supplies such as packaging materials associated with food or cleaning supplies, could affect the analysis. The impact of items such as baggage could be quantified in a more detailed analysis. However, for all but the most severe ignition sources, conditions in all three rail car designs studied remain tenable sufficiently long to allow safe passenger egress, e.g., more than 10 min in some cases.

The effects of severe fire scenarios may be potentially mitigated by precluding any fire having a fire growth rate of faster than medium t-squared, or modifying the egress system. For example, Amtrak has addressed the severe scenario where all components are ignited by a large trash bag through a redesign of trash containers and modification of operational procedures to reduce accumulations of trash in the rail cars.

EVALUATION OF MODEL PREDICTIONS WITH FULL-SCALE TESTS

From the fire hazard analysis, the obvious question that arises is "How good are the model predictions?" The only widely accepted method of verifying the model predictions is to test them against actual controlled experiments. Full-scale rail car experiments were conducted to examine the model predictions.

Two different types of tests were conducted to evaluate the accuracy of the results of fire hazard analyses conducted: 1) a series of gas burner tests to evaluate the accuracy of the fire performance curves for an actual rail car geometry and 2) a series of other interior tests to evaluate fire spread and growth for actual train car furnishings exposed to a range of initial fire sources. In a fire hazard analysis, the fire performance curves show the predicted response of the chosen car geometry to a range of typical fire growth rates and determine the available safe egress time from a car exposed to an arbitrary fire. These calculations are then compared to the time necessary to evacuate passengers from the car to determine the largest fire growth rate and size that is allowable for a chosen car geometry. To evaluate the accuracy of the model calculations of the fire performance curves, a series of gas burner fires covering a range of fire size and growth rate were used to experimentally determine a fire performance curve for an actual rail car. The experimental fire performance curve determined from temperature and gas concentration measurements made during the tests can then be compared against the predicted fire performance curve to determine any differences and their significance. Figure 2 shows one of the medium t-squared growth rate gas burner tests. Table 3 shows some of the test results from the tests.

Figure 3 includes a fire performance graph determined from experimental measurements in the gas burner tests along with fire model predicted curves calculated for the test rail car. For a medium growth rate t-squared fire, the time to incapacitation determined from the replicate gas burner tests was (126 ± 7) s. For other growth rate fires, the time to incapacitation ranged from (40 ± 4) s for the ultra-fast growth rate fire to (230 ± 12) s for the slow growth rate fire. On average, the uncertainty of the experimentally determined times to these untenable conditions was less than 7 % (based on one standard deviation).

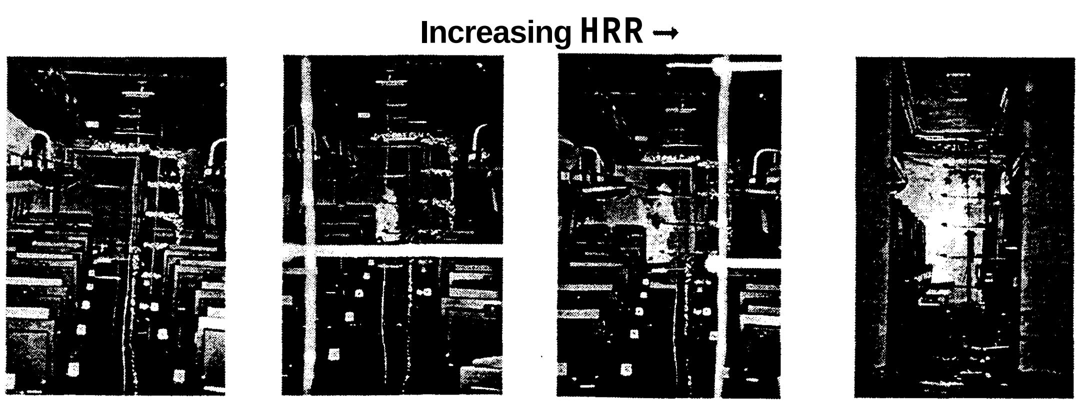

Figure 2. Typical T-squared Gas Burner Fire Growth

Table 3. Selected Results from Full-Scale Tests of an Amfleet I Coach Car

	Gas Temperature (°C / °F)				Heat Flux (kW/m^2)		Gas Concentration (volume %)					
	Upper Layer		Lower Layer				O_2		CO_2		CO	
	Peak	At Time	Peak	At Time	Peak	At Time	Min	At Time	Peak	At Time	Peak	At Time
Slow t^2 gas burner	398 / 748	600	106 / 223	600	19	625	16	630	3.0	620	0.02	– a
Medium t^2 gas burner	331 / 628	320	81 / 178	315	16	317	17	330	2.4	325	0.01	–
Fast t^2 gas burner	376 / 709	155	79 / 172	155	15	155	16	170	2.8	190	0.01	–
Ultra-fast t^2 gas burner	372 / 702	80	73 / 163	80	14	80	17	95	2.3	95	0.03	–
Window Drape with 25 kW burner	53 / 127	510	32 / 90	600	0.31	540	20	600	0.31	–	0.01	–
Wall carpet with Trash Bag	183 / 361	300	61 / 142	320	9	270	17	290	3.7	300	0.2	280
TB 133 ignition on seat	47 / 117	600	32 / 90	365	0.24	560	21	–	0.23	–	0	–
25 kW burner ignition on seat	53 / 127	565	31 / 88	255	0.46	505	21	–	0.32	–	0	–
Trash bag on seat	363 / 685	270	131 / 268	260	27	90	12	285	6.6	290	1.4	285

a – measured condition is at an ambient or near-ambient value and roughly constant throughout the test.

Key Observations from Full-Scale Tests

The gas burner tests served three primary purposes: verification of the fire modeling results from the Phase II hazard analysis report, calibration of the HRR measurements taken through the stack at the end **of** the rail car, and estimation of the uncertainty of the measurements. The replicate measurements from the gas burner tests proved to be very repeatable. **As an** example, the average uncertainty of the upper layer temperature measurements for the slow, medium, fast and ultra-fast t-squared fires ranged from **3.1** percent to 10.8 percent. The uncertainty of the HRR measurements ranged from ±5 kW to ±21kW.

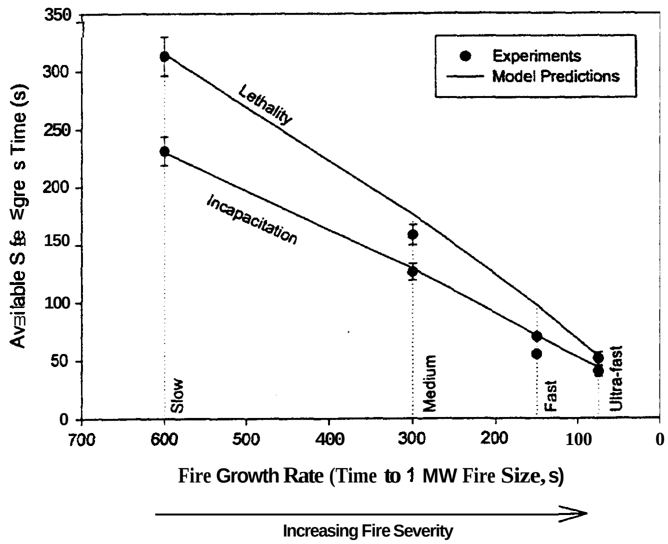

Figure **3.** Comparison of Experimental and Predicted Fire Performance Curves for Incapacitation and Lethality in a Coach **Car.**

The full-scale car flame spread and growth tests clearly supported the conclusion from the full-scale assembly tests in Phase II that a significant ignition source was necessary to **sustain** significant flame spread. The three tests which used small ignition sources **(25** kW burner on seat, TB **133** burner **on** seat, and **25** kW burner on curtains), each yielded temperature and species levels near or slightly above ambient after ***6*** min. The tests that used the trash bag as an ignition source (trash bag in corner and trash bag on the seat) exhibited sustained flame spread and extension, producing temperatures and species concentrations sufficient to render the main compartment untenable before ***6*** min had elapsed.

Visually, the comparison between the experimentally determined fire performance curves and the curves calculated with the CFAST computer fire model is quite good. The relative difference between experimental and calculated times averages **13 %** for all fire growth rates and **both** tenability criteria. Comparisons of model predictions with fire test experimental measurements more typically show agreement within 20 % **to** 25 %. Therefore, the average agreement of **13** % for these calculations should be considered excellent.

SUMMARY

This paper presented an overview of an ongoing research study intended to demonstrate the use of HRR measurements and hazard analysis techniques when applied to passenger rail car fire safety. The results of this project are intended to: (1) provide additional information useful in refining existing fire safety provisions, and **(2)** allow rail car builders and passenger train system operators design flexibility to employ a broader array of materials and designs in future passenger rail cars. The successful application of this approach to complement material screening tests could provide a more cost-effective way to evaluate the actual fire performance of passenger rail car materials.

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