Paper presented at 28th International Conference on Fire Safety
Columbus, Ohio July 28, 1999

DEVELOPMENT OF U.S. PASSENGER TRAIN FIRE SAFETY STANDARDS

Stephanie H. Markos, Volpe National Transportation Systems Center, Research and Special Programs Administration, U.S. DOT, Cambridge, MA

N. Thomas Tsai, Office of Research and Development, Federal Railroad Administration, U.S. DOT, Washington, DC

Richard W. Bukowski, Building and Fire Research Laboratory, National Institute of Standards and Technology, Gaithersburg, MD

ABSTRACT

A main focus of current U.S. passenger train fire safety requirements is the use of individual test methods to evaluate the flammability and smoke emission characteristics of individual materials. The use of fire hazard analyses using test methods based on heat release rate (HRR) data could provide a means to more realistically predict the actual fire performance of rail car materials and component assemblies at lower cost. The Federal Railroad Administration (FRA) is sponsoring a major fire research program to investigate the applicability of this alternative approach to evaluate the fire safety of intercity and commuter rail passenger trains. The intent is to provide the necessary information to permit a more systems-oriented approach to passenger equipment fire safety regulations. This paper discusses the fire safety requirements for passenger equipment recently issued by the FRA and the related research program.

1. INTRODUCTION

Fire safety is an area of particular interest for both conventional intercity passenger and commuter rail trains and new, high-speed passenger trains. A systems approach to fire safety addresses rail car design and materials, detection and suppression, passenger evacuation, and their interaction. The FRA has recognized the importance of this approach in maintaining and improving the level of passenger train fire safety.

In 1984, the FRA issued guidelines recommending test methods and performance criteria for flammability and smoke emission characteristics of materials in passenger cars [1]. Later updated in 1989 [2], these guidelines have been followed voluntarily by passenger railroads. As part of the development of new comprehensive safety standards for rail passenger equipment, these earlier FRA recommendations were revised in a FRA rule published on May 12, 1999 [3]. As part of a two-phase development plan, the initial final rule requires that: 1) intercity passenger and commuter rail equipment materials meet certain minimum performance criteria based on the earlier FRA guidelines, and 2) operating railroads conduct preliminary and final fire hazard analyses of their new and existing rail passenger equipment.

In 1993, the FRA published a research study by the National Institute of Standards and Technology (NIST) directed by the Volpe National Transportation Systems Center (Volpe Center) that concluded that an alternative evaluation approach based on the use of heat release rate (HRR) data could more realistically predict the actual fire performance of materials and component assemblies and their interaction with other system elements [4]. Accordingly, the FRA is funding a follow-up fire research program directed at providing the technical basis for using HRR data in fire hazard analyses using a computer model to more realistically predict the actual fire performance of materials and component assemblies used in passenger rail cars. The results of this research program will be considered by the FRA in further refining the fire safety requirements of the passenger equipment standards.

This paper describes the historical background of the FRA fire safety material requirements issued on May 12, 1999 and the results to date of the ongoing research program directed by the Volpe National Transportation Systems Center (Volpe Center).

2. BACKGROUND

Prior to the issuance of the passenger equipment initial final rule on May 12, 1999, the FRA approach to fire safety focused on passenger train materials. The FRA published fire safety guidelines in 1984 that recommended the use of certain flammability and smoke emission test methods and performance criteria for intercity passenger and commuter rail cars [1]. The guideline objectives were to prevent fire, retard its growth and spread, and provide adequate evacuation time for passengers and crew. Those test methods and performance criteria in the 1984 guidelines published were identical to Urban Mass Transportation Administration (UMTA), now Federal Transit Administration (FTA) recommended practices for rail transit vehicles, also issued in 1984 [5]. 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 [2]. (Section 3 of this paper discusses the revision of the 1989-specified test methods and performance criteria as contained in Appendix B of the May 12, 1999 initial final rule).

For convenience, the remainder of this paper uses the term "requirements" generically to include: regulations, standards, rules, specifications, guidelines, recommendations, and recommended practices. It should be noted that regulations and rules are the only requirements that can be and usually are legally enforceable unless other requirements are included in contracts or jurisdictional codes.

The majority of the material requirements contained in the Amtrak passenger rail car fire safety specification [6], and National Fire Protection Association (NFPA) *130 Standard for Fixed Guideway Transit Systems* [7] are nearly identical to those of FRA/UMTA (now FTA). The draft flammability and smoke emission specifications for rail transit vehicles, originally developed by the Volpe Center in the 1970s [8], provides the basis for all these rail "vehicle" material requirements.

The individual test methods measure one or more of four different fire performance phenomena: ignition resistance, flame spread, smoke emission, and fire endurance. The requirements are based in large part on two small-scale American Society for Testing and Materials (ASTM) test methods: *ASTM E 162, Surface Flammability of Materials Using a Radiant Energy Source* [9] (with a variant, *ASTM D 3675* for cellular materials [10]; and *ASTM E 662, Specific Optical Density of Smoke Generated by Solid Materials* [11]. Several other requirements are specified for individual material functions including: *ASTM E 648, Critical Radiant Flux of Floor Covering Systems Using a Radiant Energy Source* [12]; *ASTM C 542, Specification for Lock-Strip Gaskets* [13]; and *14 CFR, Part 25, Subsection 25.853 (a) Compartment Interiors* for fabrics [14]. All of the test methods are designed to study aspects of a material's fire behavior in a fixed configuration and exposure, with the exception of *ASTM E 119, Fire Tests of Building Construction and Materials* (a large-scale fire endurance test) [15].

Based primarily on small-scale test methods which demonstrate fire characteristics of individual materials, the FRA and other similar transportation vehicle requirements form a prescriptive set of design specifications which historically have been used to evaluate material fire performance. This approach provides a screening device to allow interested parties to identify particularly hazardous materials and select preferred combinations of individual components; material suppliers can independently evaluate the fire safety performance of their own materials. However, the inability of the small-scale test methods and performance criteria to account for interactions between materials and for different end-use geometries is a major concern. Section 5 describes the progress of the ongoing research program that is investigating the applicability of using this alternative HRR-based approach to evaluate passenger equipment rail material fire performance.

3. FRA FIRE SAFETY REGULATIONS - PHASE I

In 1997, the FRA issued a Notice of Proposed Rulemaking (NPRM) proposing that the 1989 FRA-specified test methods and performance criteria be made mandatory and that each operating railroad develop a fire protection engineering plan [16]. To address comments by interested parties and to take into account the preliminary results of the FRA-funded fire research program, the Volpe Center recommended that certain revisions be made to the fire safety requirements. These changes including changes to the table contained in the 1989 guidelines which appeared as Appendix B of the 1997 NPRM. The intent of the revision to the table requirements was to maintain current high levels of passenger rail fire safety while developing the framework for the FRA regulatory format. The major changes to the test methods and performance criteria in Appendix B of the FRA passenger equipment initial final rule issued on May 12, 1999 included:

- Reorganization to a simplified format,
- Updating of ASTM standards where appropriate,
- Inclusion of new test methods as possible alternates,
- Addition of new sections providing test methods and performance criteria for wire and cable and small, miscellaneous parts and,
- Addition of a test requirement to address structural elements other than floors.

The Appendix B table revisions were based on the results of analysis of input from several resources. (A detailed rationale for all revisions is contained in a supporting document [17]. First, the comments of the parties who responded to the NPRM were reviewed. In particular, one commenter noted that the classification of items listed in the categories and functions in the table contained in Appendix B in the 1997 NPRM (based on the FRA 1989 guidelines) has caused confusion and conflict as to what materials should be tested according to what test methods. Second, a document containing the rationale for the development of the original flammability and smoke emission tests and performance criteria was reviewed [18]. Third, the previous *Federal Register* notices were reviewed pertaining to test methods and performance criteria published in the 1989 FRA guidelines [] and previously published as recommended practices by FTA (then-UMTA) for rail transit vehicles [][19] and later by FTA for transit buses and vans [20]. Fourth, the input from railroad operators, carbuilders, and consultants who participated in a Workshop held at the NIST Building and Fire Research Laboratory in July 1997 was considered [21]. Fifth, documentation prepared by the NFPA Railroad Task Force for the NFPA 130 Committee was reviewed [22][23]. Sixth, the available results of the ongoing FRA-sponsored fire safety research program were reviewed; as well as the results of tests jointly funded by Amtrak and FRA using alternative seat assemblies considered for use in Amtrak's high-speed trainsets [24]. Seventh, the results of the National Transportation Safety Board (NTSB)-funded fire tests conducted for MARC commuter rail cars were reviewed [25]. It should be noted that the May 12, 1999 rule introduced and permits the use of HRR-based test methods [26][27] for seat assemblies and small parts in certain cases when fire hazard analyses are conducted.

The fire safety analysis requirements listed in Part 238.103 of the May 12, 1999 Phase I final rule include the conduct of written preliminary and final analyses for new and existing equipment to "ensure that fire safety considerations and features in the design of the equipment reduce the risk of personal injury and equipment damage caused by fire to an acceptable risk." One potential means of meeting this requirement would be the conduct of the fire hazard analysis using a computer model with HRR data inputs for materials; the computer model can also include the impact of alternative rail car geometry, materials, detection and suppression systems, and evacuation routes. The next section provides an overview of the use of HRR and fire hazard analysis.

4. HEAT RELEASE RATE

With the exception of seat assemblies and small parts, the recently issued FRA passenger rail equipment material fire safety requirements, remain based on individual test methods that evaluate the flammability and smoke emission characteristics of individual materials.

As the 1993 NIST report notes, HRR is considered to be a key indicator of fire performance and is defined as the amount of energy that a material produces while burning [4]. For a given confined space (e.g., rail car interior), the air temperature is increased as the HRR increases. Even if passengers do not come into direct contact with the fire, they could be injured by high temperatures, heat fluxes, and/or smoke and gases emitted by materials involved in the fire. Accordingly, the fire hazard to passengers of these materials can be directly correlated to the HRR of a real-world fire.

That 1993 report also noted that assembly and real-scale tests provide the advantage of material assessment in an actual end-use configuration. This is critical to permit the evaluation of the effects of material interaction and geometry in an end-use condition. However, such larger-scale testing does have disadvantages. Real-scale tests of complete assemblies are often several orders of magnitude more expensive than small-scale tests. In addition, the advantage of providing an overall assessment of the fire behavior of a material also can represent a disadvantage. By quantifying the outcome of the fire without a knowledge of the factors leading to the resulting fire and without relating the observed fire behavior to basic material properties, little insight into the intrinsic performance of the materials may result [28].

HRR and other data measurements generated from oxygen consumption calorimeters (e.g., Cone Calorimeter can be used as an input to evaluate the contribution of a material's overall contribution to the fire hazard in a particular rail car. Fire modeling and hazard analysis techniques allow evaluation of a range of design parameters, including material flammability, geometry, fire detection and fire suppression systems, and evacuation, as well as design tradeoffs which may arise from combinations of these parameters. However, further tests and assessment are considered necessary to evaluate the suitability of fire modeling and hazard analysis techniques for application to typical passenger train fire scenarios (See Section 5). Testing a range of materials according to HRR test methods will also allow evaluation of the ability of a predictive fire model to minimize, but not eliminate, the need for real-scale tests to assess overall passenger train fire performance. Limited real-scale tests may still be required to verify the accuracy of fire hazard analysis calculations, particularly when dramatically new designs or materials are incorporated into new passenger rail equipment.

Quantitative fire modeling and hazard analysis techniques have the potential of providing significant cost savings. Alternative protection strategies can be studied within the hazard analysis framework to give the benefit-cost relation for each. In addition, rail car fire protection elements are evaluated as a system with their many interactions, including the impact of both structure and contents. Providing these alternatives promotes design flexibility which reduces redundancies and cost without sacrificing safety. New technology can be evaluated before it is brought into practice, thereby reducing the time lag currently required for acceptance. Thus, quantitative hazard analysis can be a powerful complement to existing fire performance requirements and a useful tool in evaluating improvements to them.

The 1993 NIST report also contains a detailed review and evaluation of the comparability and potential equivalence of selected European fire protection approaches to the FRA and other U.S.-related requirements. That report noted that several European countries also have active programs to improve passenger train fire safety evaluation. A major effort is underway to relate small-scale and real-scale performance by the use of fire modeling. An extensive research program sponsored by the European Railway Research Institute (ERRI) is underway to relate small-scale and real-scale fire performance using HRR and fire modeling for passenger trains. ERRI has also conducted Cone Calorimeter and Furniture Calorimeter tests to provide input data for fire and hazard modeling of passenger coaches[29][30]. Thus, the FRA-sponsored fire safety research program is consistent with the European approach.

5. FRA/VOLPE CENTER/NIST RESEARCH PROGRAM

The FRA-published 1993 NIST report concluded that a more credible alternative approach to evaluating actual real world material fire performance would be the use of fire hazard analysis using heat release rate (HRR) data [4].

In a follow-on effort, funded by the FRA, NIST is performing a multi-phase fire safety research program directed by the Volpe Center. This program is investigating the use of HRR data and computer models to evaluate passenger rail car interior material fire performance. The scope of the NIST research consists of the following phases:

- During Phase I, selected rail car interior materials were evaluated using the Cone Calorimeter test method. The use of this test method and resulting HRR data were reviewed with respect to current FRA-specified tests, performance criteria, and flammability and smoke emission test data to compare the relative performance of current materials.

- During Phase II, the applicability of fire modeling and hazard analysis techniques to predict rail car fire hazards and mitigate those hazards was evaluated. Real-scale tests of components, such as seat assemblies, was conducted to obtain component fire performance data. The evaluation included changes in rail car design and materials, detection and suppression systems, and passenger evacuation, to assess the relative impact on fire safety for a range of design parameters.

- During Phase III, selected full-scale proof tests of passenger rail car equipment, in actual end-use configuration, will be performed to verify the predicted system performance against the small-scale and real-scale assembly fire tests and fire hazard analyses.

A Peer Review Committee consisting of representatives from passenger train system operators, rail car builders, material manufacturers, and test laboratories was established to provide technical advice on the NIST research program test plan, results, and practicality of recommendations.

The following sections provide a summary of the specific phases of the research program.

5.1 Phase I

During Phase I, a review of U.S. transportation vehicle requirements and related research and a review and update of European regulations and research efforts related to passenger train fire safety was performed. The major focus of this phase was the conduct of Cone Calorimeter tests for 30 materials including seat upholstery and foam cushions, wall and ceiling panels, floor covering, glazing, etc. The test results provided multiple fire performance measures for passenger rail car component materials and assemblies including:

- ignitability,
- HRR, and
- release rate for smoke, products of combustion, and toxic gases.

The Cone Calorimeter data were obtained under identical fire exposure conditions and were correlated to data obtained from FRA-specified test method reports. For the majority of materials, the relative ranking from "best" to "worst" was similar in both test methods. The Phase I report is now available on request [31].

5.2 Phase II

Phase II of the NIST research program used the HRR and other measurements generated from the Cone Calorimeter tests conducted in Phase I as an input to the NIST-developed CFAST computer fire model. Additional data obtained as a result of passenger rail car assembly tests using a furniture calorimeter was also used. Hazard analyses were then conducted for a single-level coach car, and bi-level dining and sleeping cars to evaluate the contribution of the materials to overall passenger train fire safety.

In the fire hazard analyses, a series of t-squared fires ranging in size from slow (reaches a 1 MW fire size in 600 s) to ultra-fast (reaches a 1 MW fire size in 75 s) were used. The fire performance curves showed the predicted response of the chosen rail passenger car configuration to a range of typical fire growth rates and determined the available safe egress time from the respective types of rail cars exposed to an arbitrary fire. These calculations were compared to the time necessary to evacuate passengers from the different rail cars to determine the largest fire growth rate and size that are allowable for the chosen car geometry. Detection and water mist suppression systems were evaluated in terms of increasing evacuation time. The Phase II draft report is currently being reviewed by the FRA and the Peer Review Committee.

5.3 Phase III

Full-scale tests will be conducted in Phase III to verify the computer model used to perform the hazard analyses in Phase II. Amtrak has donated an Amfleet I coach car to be used in the full-scale tests. The full-scale tests are scheduled to be conducted at the U.S. Army Test Center located at Aberdeen, MD in late July and early August, 1999.

Two different types of full-scale tests will be conducted to evaluate the accuracy of the results of fire hazard analyses conducted in Phase II: 1) a series of gas burner tests conducted to evaluate the accuracy of the fire performance curves for an actual passenger rail car geometry, and 2) a smaller series of experiments to evaluate fire spread and growth for actual passenger train car furnishings exposed to a range of initial fire sources.

The series of gas burner fires will cover a range of fire sizes and growth rates. A portion of the Amfleet rail car will be fitted with non-combustible surface linings and the tests run only until selected tenability criteria are reached to prevent damage to the car during these tests. Prior to the tests, it will be necessary to characterize the car in terms of dimensions, furnishing materials, and leakage. The gas burner fires will provide a carefully controlled and known HRR to match the design fires used to develop the fire performance curves. The experimental fire performance curve determined from temperature and gas concentration measurements made during the tests will then be compared against the predicted fire performance curve to determine any differences and their significance.

With four different fire growth rates and two replicates of each rate, a total of eight tests will be conducted for the gas burner tests.

The Phase II test results showed that materials and products that comply with the current FRA requirements for fire 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 transportation environment. Still, it was also evident from the furniture calorimeter tests that significant fires can develop with sufficiently severe ignition sources. Accordingly, for the fire growth and spread tests, initial ignition sources ranging from the gas burner up to and including large trash bags are planned. These tests will allow the comparison of the assembly tests with actual fire growth in the rail car where the HRR may change due to the effects of the car geometry and/or proximity of materials to each another.

6. FRA FIRE SAFETY REGULATIONS - PHASE II

The FRA has received comments from several interested parties regarding the revision of the material requirements contained in Appendix B of the May 12, 1999 initial final rule. In addition, the FRA received comments requesting further guidance and explanation of the fire safety analyses required in Part 238.103. The FRA is carefully reviewing those comments. A further notice in the near future to clarify certain revisions made to the table of test methods and performance criteria for materials may be necessary. In addition, the FRA will consider the final results of the ongoing Volpe Center/NIST fire research program and may further revise the table of requirements in Appendix B to allow the use of HRR-based test methods for other rail car equipment components and assemblies and expand the use of HRR data in conducting the fire safety analysis required in Part 238.103.

REFERENCES

1. Federal Railroad Administration (FRA). "Rail Passenger Equipment; Guidelines for Selecting Materials to Improve Their Fire Safety Characteristics." *Federal Register*, Vol. 49, No. 162, August 20, 1984. Notices. 33076-33078. Reissued in *Federal Register*, Vol. 49, No. 217, November 7, 1984. 44082-44584. U.S. Department of Transportation (USDOT). National Archives and Records Administration, Washington, DC.

2. FRA. "Rail Passenger Equipment: Reissuance of Guidelines for Selecting Materials to Improve Their Fire Safety Characteristics." *Federal Register*, Vol. 54, No. 10, January 17, 1989. Notices. 1837-1840. National Archives and Records Administration, Washington, DC.

3. FRA. 49 CFR, Transportation, "Parts 216, 223, 229, 231, 232, and 238: Passenger Equipment Safety Standards, Final Rule." *Federal Register*, Vol. 64, No. 91, May 12, 1999. Rules and Regulations. 25540-25705. U.S. Department of Transportation (USDOT). National Archives and Records Administration, Washington, DC.

4. Peacock, R.D., et al. *Fire Safety of Passenger Trains: A Review of U.S. and Foreign Approaches.* National Institute of Standards and Technology (NIST). Prepared for FRA, USDOT. Washington, DC. Final Report. Report Nos. DOT/FRA/ORD-93/23, DOT-VNTSC-FRA-93-26, December 1993.

5. Urban Mass Transportation Administration (UMTA). "Recommended Fire Safety Practices for Rail Transit Materials Selection." *Federal Register,* Vol. 49, No. 158, August 14, 1984. Notices. 32482-32486. USDOT. National Archives and Records Administration, Washington, DC.

6. National Railroad Passenger Corporation. *Specification for Flammability, Smoke Emissions and Toxicity.* Amtrak Specification No. 352, April 29, 1991.

7. National Fire Protection Association. *NFPA 130, Standard for Fixed Guideway Transit Systems.* Quincy, MA, 1997.

8. Litant, I. *Guideline for Flammability and Smoke Emission Specifications.* TSC-76-LFS-6, Transportation Systems Center (TSC), USDOT, 1976.

9 American Society for Testing and Materials (ASTM). *Standard Test Method for Surface Flammability of Materials Using a Radiant Heat Energy Source.* ASTM E 162, 1997.

10. ASTM. *Standard Test Method for Surface Flammability of Cellular Materials Using a Radiant Heat Energy Source.* ASTM D 3675, 1998.

11. ASTM. *Standard Test Method Specific Optical Density of Smoke Generated by Solid Materials.* ASTM E-662, 1997.

12. ASTM. *Standard Test Method for Critical Radiant Flux of Floor Covering Systems Using a Radiant Heat Energy Source.* ASTM E 648, 1997.

13. ASTM. *Specification for Lock-Strip Gaskets.* ASTM C-542, Annual Book of ASTM Standards, 1994.

14. Federal Aviation Administration (FAA). *14 CFR, Aeronautics and Space; Subchapter C; Part 25, Airworthiness Standard, Transport Category Airplanes; Section 25.853(a). Compartment Interiors.* USDOT. As of January 1, 1997. National Archives and Records Administration. Washington, DC.

15. ASTM. *Fire Tests of Building Construction and Materials.* ASTM E 119 95A, Annual 1998.

16. FRA. 49 CFR, Transportation, "Parts 216, 223, 229, 231, 232, and 238: Passenger Equipment Safety Standards, Notice of Proposed Rulemaking (NPRM)." *Federal Register*, Vol. 62, No.184, September 23, 1997. Proposed Rules. 49728-49824. National Archives and Records Administration, Washington, DC.

17. Zicherman, J. B and S. H. Markos. *Recommendations for Revising the Fire Safety Performance Requirements in Federal Railroad Administration Notice of Proposed Rulemaking (NPRM) For Passenger Equipment, September 23, 1997.* DRAFT Project Memorandum. December, 1998.

18. Hathaway, W.T. and I Litant. *Rationale for Recommended Fire Safety Practices for Rail Transit Materials Selection.* Transportation Systems Center. Final Report. Report nos: DOT-MA-06-0098-82-1, and DOT-TSC-UMTA 81-74. January, 1983.

19. UMTA. "Recommended Fire Safety Practices for Rail Transit Vehicle Materials Selection." *Federal Register,* Vol. 47, No. 228, November 26, 1982. (53559-53563); Notices. USDOT. National Archives and Records Administration, Washington, DC.

20. Federal Transit Administration (FTA) (Formerly UMTA). "Recommended Fire Safety Practices for Transit Buses and Van Materials Selection." *Federal Register,* Vol. 55 No. 201, July 2, 1990. Notices. 27402-27404; Vol. 57, No. 8, January 13, 1992. Notices. 1360- 1363; and Vol. 58, No. 201, October 20, 1993 Notices. 54250-54254. USDOT. National Archives and Records Administration, Washington, DC.

21. Zicherman, J.B. "Follow-Up Notes: NIST/CFR FRA Project, Meeting/Workshop of 7/23/97." September 15, 1997.

22. Zicherman, J.B. "Proposed Revision of NFPA 130, Table 4-2.4, Recommendations for Testing the Flammability and Smoke Emission Characteristics of Rail Transit Vehicle Materials; Review Paper - Status Update." NFPA 130 Press Working Group Meeting of 8/15/97.

23. Zicherman, J.B. "Proposed Revision of NFPA 130, Table 4-2.4, Recommendations for Testing the Flammability and Smoke Emission Characteristics of Rail Transit Vehicle Materials; Review Paper - Status Update." NFPA 130 Press Working Group Meeting of 10/15/97.

24. Zicherman, J.B. and S.H. Markos. "Passenger Rail Car Seat Tests: ASTM 1537/CAL TB 133." DRAFT Project Memorandum. December 1998.

25. Quintiere, J.G.. *Interpretive Report Flammability and Smoke Compliance and Fire Analysis (MARC/Amtrak Collision, February 16, 1996.* Prepared for National Transportation Safety Board. University of Maryland. Final Report. December 16, 1996.

26. ASTM. *Standard Test Method for Fire Tests of Upholstered Seating Furniture.* ASTM E-1537. 1998.

27. ASTM. *Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter.* ASTM E-1354. 1997.

28. Peacock, R.D. and V. Babrauskas. "Analysis of Large-Scale Fire Test Data." *Fire Safety Journal* 17: 387-414. 1991.

29. ERRI. *Improvement of the Protections Against Fire of Passenger Rolling Stock; Progress Report on the Tests Carried Out Using A Cone Calorimeter and the Calculations with HAZARD 1.1. Software Package.* ERRI C 204/RP 1. Utrecht, 1994.

30. Young, R., Scientifics/British Railway Board. Edited by A. Kaminski, ERRI Technocal Advisor. *Improvement of the Fire Protection of Passenger Rolling Stock, Results of Additional Cone Calorimeter Tests on Seat Materials and Furniture Calorimeter Tests on Mock-Up Seats.* ERRI C204.1/DT319. Utrecht, 1995.

31. Peacock, R.D., et al. *Fire Safety of Passenger Trans Phase I: Material Evaluation (Cone Calorimeter).* NIST. Prepared for FRA, USDOT. Interim Report. Report nos. DOT/FRA/ORD-99/01 DOT-VNTSC-FRA-98-26. January, 1999. Published as NISTR-6132.