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Fire Safety of Passenger Trains; Phase III: Evaluation of Fire Hazard Analysis Using Full-Scale Passenger Rail Car Tests

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Building and Fire Research Laboratory

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Abstract

A comprehensive multi-phase fire safety research program is being conducted by the National Institute of Standards and Technology to demonstrate the practicality and effectiveness of heat release rate-based test methods and hazard analysis techniques when applied to passenger train fire safety. This document presents the Phase III results of the program which focused on the real-scale evaluation of the fire hazard analysis techniques studied in Phase II of the project. Also included are comparisons of the real-scale test results with small- and full-scale test results conducted in the first two phases of the research.

Comparison of times to untenable conditions for a range of fire sizes determined from these experimental measurements with those calculated by the CFAST fire model showed agreement which averaged approximately 13 %. The range of ignition source strengths indicated that an ignition source size between 25 kW and approximately 200 kW is necessary to promote significant fire spread, which is consistent with the conclusions from earlier research that the ignition source strength of passenger rail car materials is 2 to 10 times greater than typical office furnishings.

Keywords

Cone calorimeters; egress; fire hazards assessment; fire models; furniture calorimeters; heat release rate; railroad safety; test methods; transportation

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Stephanie Markos, Volpe Center, provided overall project technical direction, specific oversight of Phase III task progress, and technical review of all Phase III work products.

A Peer Review Committee was established to guide the development of this research program. Members of this committee who provided comments on the draft Phase III interim report include: Douglas Karan, Alstom Transportation, Inc., formerly of Amtrak; Vytenis Babrauskas, Fire Science and Technology, Inc.; Nancy McAtee, U.S. National Transportation Safety Board; Steven Roman, LTK Engineering; Arthur Bendelius and William Kennedy, Parsons Brinckerhoff Quade & Douglas, Inc.; Thomas Fritz, Armstrong World Headquarters; Arthur Grand, formerly of Omega Point Laboratories; Charles Ogburn, Chestnut Ridge Foam, Inc.; William Segar and Michael Fesko, Bombardier Corporation; William Rice, Long Island Railroad, Marc Janssens, Southwest Research Institute; and John Hall, National Fire Protection Association. Their scientific and practical knowledge, candid discussions relating to fire safety and rail transportation vehicle material selection are also greatly appreciated.

The FRA, Volpe Center and NIST recognize the critical role of George Binns, Senior Director of Rolling Stock Engineering, Amtrak, who approved the donation of the Amfleet I passenger rail coach car for use in the full-scale fire tests. The following Amtrak personnel were instrumental in arranging the car move from Wilmington, Delaware to the test site in Aberdeen, Maryland, and providing other important logistical support: Robert Brown, Thomas Butler, John Gaskill, B. Hastings, Vincent Nesci, and John Wiesinger.

The full-scale tests were conducted at the Army Test Center (ATC) located at the Aberdeen Proving Ground, Aberdeen, MD (APG). The following ATC individuals provided important logistical support: William Bolt, William Newton, Bernard Sokolis, and Charles Valz. In addition, APG Fire Department Chief, Charles Jones, and Assistant Chiefs Edward Buddnick and Robert Barry, provided fire suppression management during the fire test program.

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1. INTRODUCTION

Fire safety is an area of particular interest for both conventional intercity and commuter passenger trains, and new high-speed trains. A systems approach to fire safety addresses passenger rail car design and materials, detection and suppression, passenger and train crew evacuation, and their interactions. The Federal Railroad Administration (FRA) is sponsoring a multi-phase research program directed at providing the scientific basis for using a systems approach to evaluate the level of passenger train fire safety already achieved through the current prescriptive material requirements. Previously published interim reports document the research program results to date [1][2]. Phase I focused on the evaluation of passenger rail car interior furnishing materials using data from existing FRA-cited small-scale test methods and from an alternative test method using the cone calorimeter (ASTM International E-1354) [3]. In Phase II, full-scale tests were conducted of selected interior material component assemblies using a larger scale furniture calorimeter; fire hazard analyses were then conducted for three types of intercity passenger rail cars, using data from both types of tests.

This Phase III interim report compares the results of Phases I and II of the research program, with a series of full-scale fire tests conducted in an Amtrak coach rail car. The goal of Phase III was to evaluate the extent that the results of the small- and full-scale tests and fire hazard analyses using the Consolidated Model of Fire and Smoke Transport (CFAST) computer model are predictive of actual passenger rail car material burning behavior.

Currently, the U.S. and European approaches to passenger train fire safety rely primarily on individual small-scale test methods to evaluate material fire performance. As part of the FRA passenger rail equipment safety standards (49 CFR, Part 238) [4], the FRA requires that certain materials used to construct new rail passenger cars and locomotives or rebuild, refurbish, or overhaul that type of equipment be evaluated using flammability and smoke emission test methods and performance criteria. The FRA first issued the fire safety regulations on May 12, 1999 and issued a clarification on June 25, 2002 [5][6]. The regulation requirements are based on earlier FRA guidelines initially published in 1984 and revised in 1989 [7][8]. The original 1984 FRA guidelines were identical to recommended practices also published in 1984 by the Federal Transit Administration (then Urban Mass Transportation Administration [UMTA]) for rail transit vehicles [9].

The FRA fire safety regulations permit the use of heat release rate (HRR) test methods and performance criteria for seat and mattress assemblies and certain small parts. In addition to the material test requirements, the FRA also requires that a fire safety analysis be conducted by intercity passenger and commuter rail operators for new and existing passenger rail equipment.

1.1 USE OF HRR TO EVALUATE PASSENGER TRAIN FIRE SAFETY

A 1993 study by the National Institute of Standards and Technology (NIST), sponsored by the FRA, concluded that fire hazard[1] assessment techniques could provide a more credible and cost-effective means to predict the fire performance of passenger rail car materials [10]. This approach employs fire hazard assessment techniques, using fire modeling based on test methods using HRR data. An extensive effort sponsored by the European Railway Research Institute (ERRI) is also underway to relate small-scale and real-scale fire performance using HRR and fire modeling.

Based primarily on small-scale test methods which measure fire characteristics of individual materials, the majority of the current FRA and other similar transportation passenger vehicle requirements form a prescriptive set of design criteria which historically have been used to evaluate material fire performance. This approach has provided 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

[1] Fire hazard: the potential for harm associated with fire. A fire may pose one or more types of hazard to people, animals, or property. These hazards are associated with the environment and with a number of fire-test-response characteristics of materials, products, or assemblies including but not limited to ease of ignition, flame spread, rate of heat release, smoke generation and obscuration, toxicity of combustion products, and ease of extinguishment.

performance of their own materials. However, in most ground transportation applications, end-use assemblies have not previously been tested.

Considerable advances in fire safety engineering have been made since the original development of the initial FRA material requirements. Much of the data obtained from the current test methods provide a relative ranking of materials under the specified exposure conditions. However, those test methods do not provide quantitative data that can be used for computer fire modeling and hazard analysis. Moreover, the 1993 NIST study and several other studies have concluded that the impact of material interactions and changes in passenger rail car interior geometry are also critical factors to be evaluated in predicting actual fire behavior. These factors cannot be evaluated through small-scale tests alone.

In contrast, HRR and other data measurements generated from small-scale test methods, such as the 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 passenger rail car application. In addition to cone calorimeter tests, full-scale component assemblies can be tested using the furniture calorimeter [11] to determine how individual materials interact in passenger rail car applications. Finally, full-scale tests that include HRR measurement can be used to quantify the interaction of materials in an actual passenger rail car geometry. The data generated in small-scale and assembly tests can be used as inputs for fire modeling as part of a fire hazard analysis. In addition to material flammability and smoke emission, fire modeling and hazard analysis techniques allow evaluation of a range of passenger rail car design parameters, including geometry, fire detection and suppression, and evacuation, as well as design tradeoffs, which may arise from the interaction of several of those parameters.

The successful use of fire modeling and hazard analysis depends on the ability of the computer models to correctly predict conditions in a given geometry. Full-scale fire tests in an appropriate end-use geometry can provide data to evaluate the predictive capability of fire models for passenger rail cars.

To assess the feasibility of applying HRR test methods, fire modeling techniques, and hazard analysis to U.S. passenger trains, the John A. Volpe National Transportation Systems Center (Volpe Center) and NIST developed a comprehensive multi-phase fire safety research program.

1.2 SUMMARY OF PHASE I AND II RESULTS

During Phase I, small-scale HRR data were developed for currently available passenger rail car materials using the cone calorimeter test method. The cone calorimeter test data were compared with data from FRA-cited small-scale test methods to determine relative material fire performance. For the majority of materials, the relative ranking from "best" to "worst" was similar in both test methods. Key in the use of small-scale test data is the ability to use the data to determine end-use behavior, typically through the use of experimental correlations or predictive models. The Phase I interim report concluded that new passenger rail car designs and materials are better assessed through a systems approach that considers the impact of material and design choices on the overall fire safety of the system.

The Phase II interim report documented the use of fire hazard analysis techniques applied to three passenger rail car designs. Using fire modeling, the relative importance of material, geometry, and other system design parameters was quantified through the use of representative fire performance curves. These curves showed the available egress time as a function of fire growth rate for a range of fire sizes. The available egress time, or how long tenable conditions remain within the rail car, was compared to the minimum time necessary for the occupants to evacuate through one end of the car to an adjacent car. Tenable conditions were evaluated in terms of elevated temperature and smoke obscuration.

The results of the analyses were presented for typical single level coach, and bi-level dining and bi-level sleeping car designs. For the three example analyses conducted, passengers and crew were deemed safe from unreasonable hazard of death or injury from interior fires involving materials or products exhibiting fire growth rates at or below a medium "t-squared" fire[2], similar to the fire growth and HRR of a typical upholstered sofa. 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 minutes in some cases. The exceptions were associated

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[2] During the growth phase, fires can be reasonably represented by a power law relation, which is expressed as: $\dot{q} = \alpha t^n$ 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 the chosen experimental data. For most flaming fires, the so-called t-squared (n = 2) growth rate is an excellent representation. A set of specific t-squared fires labeled slow, medium, fast, and ultra-fast, with fire intensity coefficients (α) such that the fires reached 1 MW (1000 BTU/s) in 600 s, 300 s, 150 s, and 75 s, respectively, are typically used.

Historically, t-squared fire growth rates have been expressed in a time to 1000 BTU/s or 1055 kW and noted as a time to 1 MW in SI units. Throughout this report, the approximation of time to 1 MW is used to indicate a fire growth to 1055 kW, consistent with this convention.

with the potential for fires in some locations that block egress from the lower level of bi-level dining and sleeping cars to adjacent cars while the train is moving since lower level doors that open directly to the car exterior are not safely usable from a moving train.

Although based on an existing passenger rail coach car design, the evaluation in this interim report represents only the verification of an example demonstrating the use of fire hazard analysis techniques, using computer modeling. During the conduct of the research described in this study, Amtrak had already initiated a major passenger rail car overhaul and refurbishment program. Accordingly, this example does not represent an evaluation of any particular existing car configuration in operation or the actual fire hazard.

These fire hazard analysis calculations were in part based on a comparison of the calculated available egress time with estimates of the minimum egress time required for passenger evacuation. However, the accuracy of these estimates has not been studied for passenger rail cars. Like the 90-second certification testing for aircraft, this egress time is simply a consistent point of comparison for different rail car configurations and fire scenarios. It is important to remember that this calculated egress time does not include impact of the fire on the train passengers, panic, scattered luggage in a post-crash rail car, or bodily injury to occupants prior to evacuation. A number of special evacuation characteristics for rail cars could not be considered with the simple egress calculations considered in Phase II. Any effects of more complex evacuation strategies to areas of safety outside the train were considered beyond the scope of these simple egress calculations. All of these effects could have a significant impact on evacuation in an actual accident and thus warrant further study.

Alternative analyses to the baseline passenger rail car analyses conducted in Phase II showed that design features, in addition to materials, can have an impact on the resulting fire safety of the overall design. These features include the geometry of the car, passive and active fire protection measures, emergency egress, and emergency procedures. Design changes such as detection, smoke management, and/or suppression systems were shown to have a greater impact than further improvements in the materials which already exhibit strong fire performance characteristics.

1.3 OTHER RELATED FIRE SAFETY STUDIES

Several specific fire safety studies previously conducted in the U.S. and Europe are summarized below. Part of the purpose of the current NIST research program is to extend the research from these rail car and related fire safety studies to account for the effects of material interaction and compartment geometry on overall passenger train fire safety.

1.3.1 Previous FRA-Sponsored Studies

In addition to the Phase I and II studies and the 1993 study, all cited above, the FRA funded an Amtrak fire safety study that was published in 1984 [12]. This earlier study included a series of tests to assess the large-scale burning behavior of materials used for Amtrak passenger rail car interior furnishings. Small-scale cone calorimeter tests, and full-scale furniture calorimeter assembly tests were conducted. The comparison of small-scale flammability and smoke emission test data with real-scale test data showed that the small-scale tests were able to effectively quantify the effect of changes in materials within the same real-scale geometry. However, when the geometry of the full-scale rail coach car test mockup was changed, the chosen small-scale tests failed to predict the effects of the changes. Small-scale seat assemblies, and real-scale mock-up test data were compared. The relative fire performance of these materials (from lowest HRR to highest HRR) was consistent in mockup tests (for a given geometry of the full-scale mockup).

The Amtrak test data represented the results of only a limited number of tests. The effects of changes in component materials, material interaction, and rail car geometry were identified as important issues requiring further study.

1.3.2 Related European Rail Research

In 1992, the ERRI published a report that recommended supplementary studies be conducted to account for smoke opacity and toxicity hazards of materials [13]. Later in 1992, the ERRI proposed that computer model software be used to model half-scale and full-scale tests already carried out in order to compare computer results with actual results [14]. ERRI considered the use of the cone calorimeter to be the only small-scale apparatus suitable for providing useful data for computer modeling. A series of reports document the completion of ERRI rail coach tests [15][16][17][18][19][20]. In a test application, ERRI used the HAZARD I model to simulate a fire in the British 10 ft (3 m) test cube and concluded that the use of the model to simulate fires in a railway vehicle was feasible. Additional cone calorimeter and furniture calorimeter tests were conducted and numerous model simulations of fires within passenger rail coaches were performed. The results of the simulations were primarily aimed at comparing the model prediction to full-scale experiments and evaluating the ability of the model to be used in a rail environment. The use of fire models to validate the design of a passenger rail car in terms of passenger evacuation was proposed. In the ERRI modeling study [18], the impact of the ventilation system in compartmented coaches was noted as important to the results of the simulation, reducing the overall temperatures in the simulation. Expert judgment was required to determine whether simplifications necessary to model the ventilation system were acceptable. For a burning seat cushion with a peak HRR of approximately 120 kW, temperatures in the upper gas layer ranged from 120 °F to 680 °F (60 °C to 360 °C) were noted, depending on the coach configuration and location within the coach.

Numerous international conferences have been held and a very large research project was conducted in Norway under the auspices of EUREKA (European Research Coordination Agency) by nine Western European nations. A 1995 EUREKA test report reviewed 24 fire incidents over 20 years (1971-1991) and presented the results of a series of tests in a tunnel utilizing aluminum and steel-bodied German (DB) Inter-City and Inter-City Express rail cars [21]. An extensive series of full-scale fire tests were conducted and HRR values were developed. Although the primary focus of these tests was to determine the effect of a burning vehicle on the environment within the tunnel, the results provide guidance on the burning properties of passenger rail car materials appropriate for fire hazard analysis that can be compared to the data used for this report. In addition to heat release rate, information on gas concentrations and smoke emission are included for a range of European passenger rail and transit cars. Temperatures within rail vehicles in the tests typically approached 1800 °F (1000 °C) for fully-involved fires.

The Eureka report also includes test results intended to evaluate the environment within a sealed passenger rail car used as an area of safe refuge during a tunnel fire involving other cars in the train. The report concluded that a sealed car can provide a safe environment for up to 45 minutes for cars about 330 ft (100 m) from the car involved in the fire.

As part of the standardization efforts in the European Union, the FIRESTARR project examined the fire behavior of passenger railway vehicle component materials using small- and full-scale testing [22]. The program included small-scale testing of 32 materials in the cone calorimeter, along with additional ignition and flame spread tests on some materials. The same materials were tested in full-scale using the ISO 9705 room-corner test, furniture calorimeter, and compartment tests in a single 10 m^3 compartment. Results for small-scale tests [20] and full-scale tests [23] are available . It was noted that the cone calorimeter allow products to be separated by ignition time into categories of non-ignitable, difficult to ignite, or easy to ignite. The cone calorimeter also proved to be an appropriate tool for assessing heat release and dynamic smoke generation. Full-scale test results correlated well with small-scale tests for wall and ceiling linings, but less well for seating products due to the low number of seats ignited in the full-scale tests.

1.3.3 Related FTA-Sponsored Studies

In 1975 and 1978, rail transit car fire hazard evaluation reports for the Washington Metropolitan Area Transit Administration (WMATA) [24] and Bay Area Rapid Transit District (BART) systems [25] were published.

The WMATA subway car fire evaluation consisted of individual small-scale tests of several interior materials and seven full-scale tests to determine the overall effects of an assembled system as compared to the fire characteristics of the individual components. The intent was to assist WMATA in assessing the potential fire hazard in new Metrorail subway cars. One criterion was that the ignition not spread from the area of origin. While the small-scale test results indicated that the car interior may not be readily ignited by very small ignition sources, the full-scale test results showed that the materials failed to perform in their end-use configuration as would have been predicted. For mock-up tests with urethane foam seat cushions, significant smoke obscuration was evident in approximately 5 minutes. Vinyl/chloroprene seat cushions were seen as less hazardous than an integral skin urethane foam assembly.

The BART rail car evaluation included the review of interior and exterior car design, communication system, materials (tests and performance), fire detection and suppression, fire statistics, and scenarios. No tests were conducted.

1.4 OVERALL PROJECT OBJECTIVE

The overall project objective is to fully demonstrate the practicality and effectiveness of HRR-based test methods and hazard analysis methodology in quantifying the threat of catastrophic fire conditions in a passenger train environment. The results of this project are intended to provide: (1) the FRA with additional information to use in refining the fire safety provisions in 49 CFR, Part 238, and (2) car builders and passenger train system operators with design flexibility to employ a broader array of materials and designs in future passenger rail cars. The successful application of this alternative approach to complement material screening tests could provide a more credible and cost-effective way to evaluate the real-world fire performance of passenger train cars while maintaining or improving the level of passenger train fire safety.

1.5 OVERALL PROJECT TECHNICAL APPROACH

To evaluate the applicability of fire modeling and hazard analysis when applied to passenger rail car design, appropriate HRR data must be obtained, fire modeling and hazard analysis conducted, and the results of the methodology tested against full-scale fire simulations designed to verify the predicted outcome. The research study consists of the following three phases:

- During Phase I, selected passenger 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-cited tests, performance criteria, and flammability and smoke emission data to compare the relative performance of current materials.

- During Phase II, the applicability of fire modeling and hazard analysis techniques to predict passenger rail car fire hazards and mitigate those hazards were evaluated. Full-scale tests of assemblies, such as seats, were conducted to obtain component fire performance data. The evaluation included changes in passenger 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 tests of a passenger rail car, in actual end-use configuration, were performed to verify the predicted system performance against the small-scale and full-scale assembly tests and hazard analysis studies. This interim report documents the results of the Phase III research tasks.

1.6 PHASE III SCOPE

Phase III consists of the following major efforts:

- Conduct gas burner tests to verify the accuracy of the predicted conditions associated with typical fire growth rates by the computer model for an actual coach car geometry

- Conduct full-scale passenger rail car interior fire tests using an entire coach car,

- Compare small- and full-scale data to explore the feasibility of a small-scale screening method, and

- Assess the predictive capability of fire hazard analysis techniques applied to passenger rail cars.

1.7 REPORT ORGANIZATION

Chapter 2 provides an overview of typical component materials used for the passenger rail coach car interior which were used in the full-scale tests.

Chapter 3 describes the full-scale car fire tests and results for passenger rail coach car component materials. The results of a series of gas burner tests conducted to evaluate the accuracy of the fire growth estimated in the baseline analysis for an actual passenger rail car coach geometry are described. A series of full-scale interior component material fire tests using various ignition sources are described. Small- and full-scale assembly HRR data from Phase I and Phase II are also summarized.

Chapter 4 compares material performance in the small-, full-scale tests. A comparison of both flammability and smoke emission data is presented. Implications on the use of small-scale test data for materials qualification are discussed.

Chapter 5 examines how the predictions of the computer-based fire hazard analysis conducted in Phase II compare with fire test measurements in an Amtrak Amfleet I coach test car. The use of fire hazard analysis predictions for passenger rail car system safety analysis is discussed with respect to the accuracy of the comparisons.

Chapter 6 presents a summary of accomplishments to date and summarizes the results of the comparisons conducted for this interim report.

Appendix A contains the FRA fire safety regulations in 49 CFR, Subpart 238.103.

Appendix B provides detailed full-scale passenger rail coach car test data.

2. PASSENGER RAIL CAR TEST CONFIGURATION AND MATERIALS

Amtrak donated an Amfleet I passenger rail coach car to FRA for the research program. The tests described in this report were conducted during the summer of 1999, after the rail car was moved to the U.S. Army Aberdeen Proving Ground test facility located in Aberdeen, Maryland. Materials installed in the test car reflect a cross section of typical interior component materials used in current Amtrak passenger trains. The seat assemblies, wall and ceiling lining materials, and floor coverings represent the greatest mass of interior fire load found in the test car and in most passenger rail cars.

2.1 TEST CAR - GENERAL

Figure 1 shows the test car interior before modifications were made for the full-scale fire test program. The interior length of the car is 72.5 ft (22.1 m). The interior width of the car, at the floor level, is 8.9 ft (2.7 m). The center aisle ceiling height is 7.1 ft (2.2 m) in the seating area and 6.6 ft (2 m) at each end of the car for the first 8.8 ft (2.7 m) from each end of the car. 10 rows of seat assemblies were installed on both sides of the center aisle. The instrumentation for the test car is described in Chapter 3.

Figure 1. Amfleet I Test Car - Interior

The exterior of the car is constructed of corrugated stainless steel (Figure 2). The "B end" of the car had significant structural damage, including a roof penetration. However, there was very little damage to the interior of car on the "A end." The car was equipped with a vestibule area at each end of the car; each end also had 2 side doors (one on each side) and interior end doors. The total car length is 85 feet (26 m).

Figure 2. Amfleet I Test Car - Exterior

2.2 TEST CAR COMPONENT MATERIALS

The test car interior is comprised of several component materials. The major furnishings are shown in Figure 3. These and other car materials are described below and are identified by their installed location and use in Table 1.

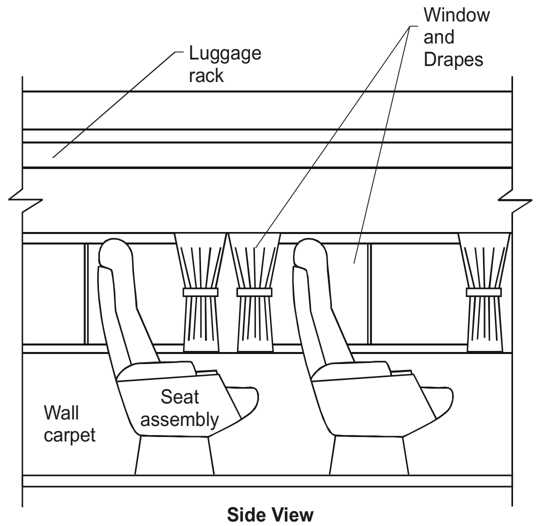


Figure 3. Amfleet I Test Car - Seat and Wall Assembly

Starting with the upper portion of the car, the center ceiling panels of the car consist of a laminated sandwich of melamine and aluminum plywood (plymetal). The curved portions of the ceilings and walls are sheathed with wool carpet (Phase I, Sample 12), glued to perforated metal. The carpet is covered by rigid polyvinyl chloride acrylic (PVC) panels (Phase I, Sample 6). The window masks consist of fiberglass-reinforced plastic (FRP) polycarbonate (Phase I, Sample 18). A layer of vinyl fabric covers a thin layer of foam on the underside of the luggage rack. PVC/ acrylic rigid panels are attached over the vinyl. The top of the luggage rack has metal sheeting.

Wool carpet is used to cover the lower portions of the wall and the full height of the permanent end of car interior bulkhead (Phase I, Sample 12) while nylon carpet over foam padding covers the floors (Phase I, Sample 24).

The seat cushions are composed of neoprene/polyurethane foam, covered with a cotton fabric interliner, with a fabric/vinyl upholstery (Phase I, Samples 1a through 1c). The seat support diaphragm (flat "spring") is made of chloroprene elastomer (Phase I, Sample 4). The seats have steel frames with PVC acrylic shrouds (Phase I, Sample 6). The armrest pad is chloroprene elastomer over a steel support.

Table 1. Amfleet I Car - Test Materials

LOCATION	SAMPLE NO.*	MATERIAL DESCRIPTION (COMPONENTS)**
SEAT ASSEMBLIES**	1a, 1b, 1c	Seat cushion, (foam, interliner, fabric cover***)
	4	Seat support diaphragm, chloroprene elastomer
	6	Seat shroud, PVC/acrylic
	7****	Armrest pad, coach seat, chloroprene elastomer
WALL AND WINDOW SURFACES	12	Wall finishing, wool carpet
	13	Wall finishing, wool fabric
	15	Wall material, FRP/PVC
	17	Window glazing, polycarbonate
	18	Window mask, FRP
CURTAINS, DRAPES, AND FABRICS**	20	Window drape, wool/nylon
FLOOR COVERINGS	24	Carpet, nylon
MISC	29	Window gasketing, chloroprene elastomer
	30	Door gasketing, chloroprene elastomer

* Sample numbers are included for small-scale test samples from the Phase I report, reference [1]. Letters indicate individual component materials in an assembly. Individual component materials are listed in order in parentheses following the material description.

** Samples not included in this list are either not currently used in coach cars or are materials used in sleeping compartments

*** The seat cushions used in the full-scale car tests were different from those tested in Phase I and II since they did not include vinyl fabric (Sample 1d).

**** The armrest pad consisted of a higher density elastomer than that in Sample 9, Phase I.

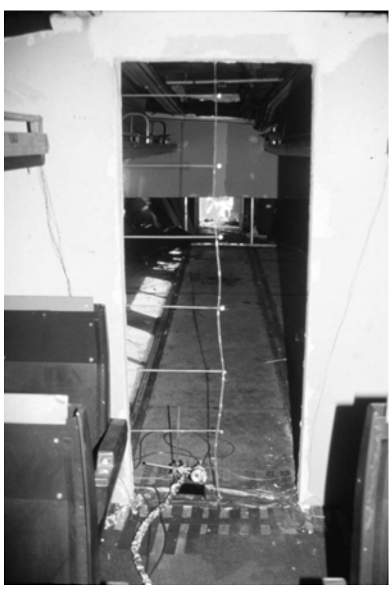
The windows in the car are composed of polycarbonate (Phase I, Sample 17) and they are held in place by a chloroprene elastomer gasket (Phase I, Sample 29). Wool/nylon window drapes used to line the windows in some business class and longer distance service were also included in the test program (Phase I, Sample 20).

2.3 TEST CAR MODIFICATIONS

The interior of the car was divided into two main sections by a bulkhead with a 6.6 ft (2 m) high by 2.5 ft (0.75 m) wide doorway. This doorway had the same dimensions as the interior doorways on either end of the car. The fire test area was on one side of the bulkhead while the other side of the rail car, the damaged "B" end, was used as a smoke collection area.

In addition to the center bulkhead, steel frame walls covered with gypsum board and calcium silicate were used to create a fire resistant bulkhead in the area where the handicapped rest room module had been removed from the "A" end of the car. A smoke curtain consisting of the steel and gypsum board and calcium silicate construction from the ceiling to half the height of the interior was added to the smoke collection area ("B" end) of the car. These bulkheads were added to protect the fire end of the car during repeated fire tests and to allow for the measurement of HRR by oxygen consumption in the smoke collection area. Calcium silicate board was also installed on the ceiling above the gas burner to protect the "A" end of the car from repeated fire tests. The area between the "A" end bulkhead and the seat assemblies provided a location for the gas burner used in some of the tests.

Figure 4 shows the mid-car and rear bulkhead locations, used to separate the front "A" end of the car from the "B" end rear of car, and the front bulkhead and door location at the "A" end of the car.



(a) Mid-Car and "B" End Rear (Including Thermocouple Array)

(b) "A" End Front Doorway

Figure 4. Amfleet I Test Car - Interior Fire Test Area Bulkhead Locations

On the “A” end of the car, 10 rows of seat frames were installed on each side of the center aisle. Seat cushions were placed in the seat frames. The interior dimensions and car configuration modifications are shown in Figure 5. Figure 6 shows the location of the exterior smoke collection stack.

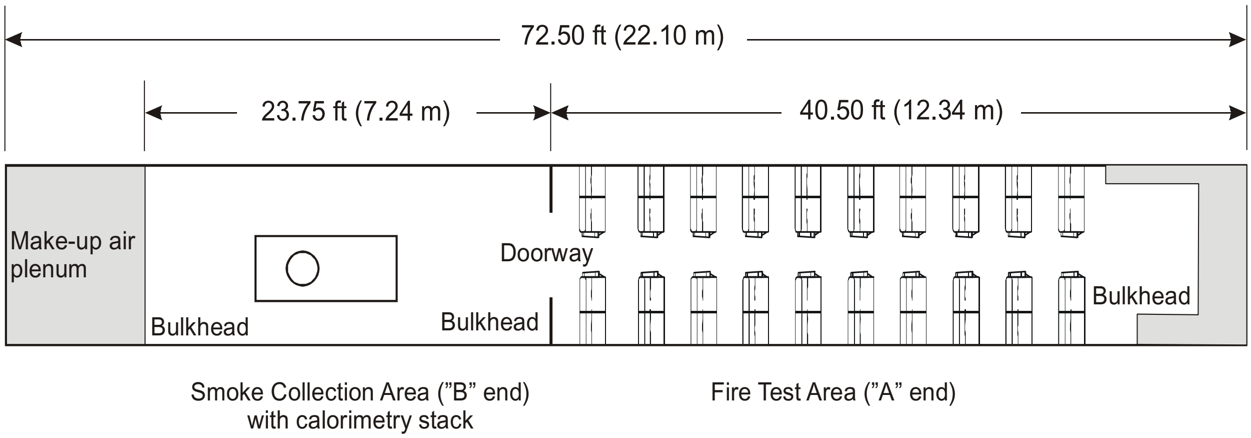


Figure 5. Amfleet I Test Car - Interior Fire Test Area Arrangement

Figure 6. Amfleet I Test Car - Exterior “B” End: Calorimeter Exhaust Stack

2.4 TEST CAR INSTRUMENTATION

The test instrumentation used in these experiments consisted of thermocouples; heat flux gauges; smoke obscuration meters; and oxygen, carbon dioxide and carbon monoxide analyzers. The installed locations of the instrument arrays and the gas sampling points are shown in Figure 7.

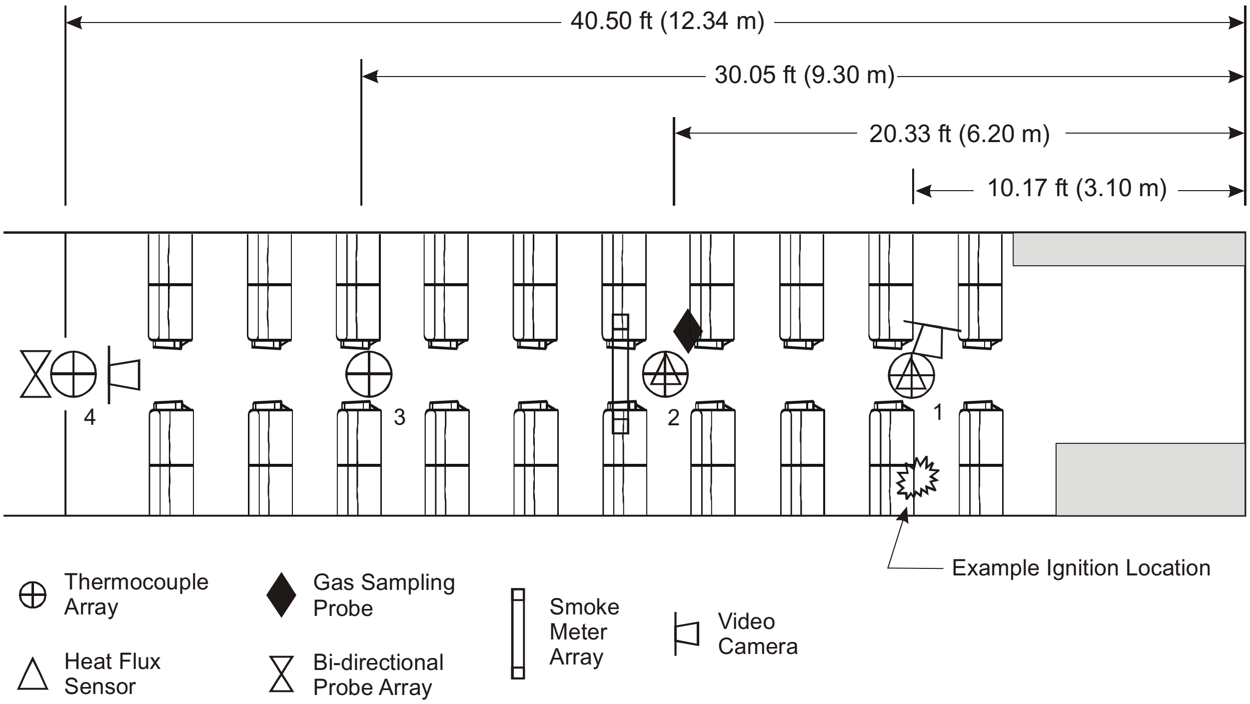


Figure 7. Amfleet I Test Car - Interior "A" End Instrumentation

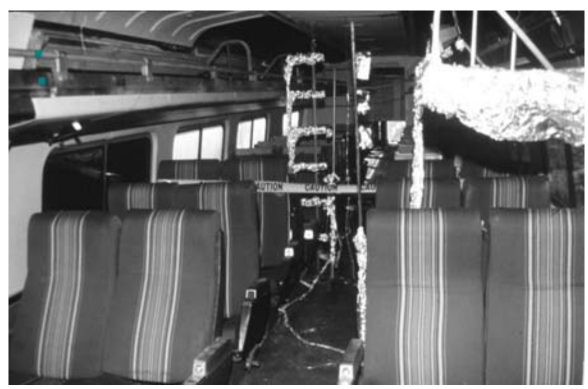


Figure 8. Amfleet I Test Car - "A" End Seating Area with Thermocouple Array

Thermocouples, used to measure temperature, were installed in vertical arrays in the test section of the rail car. Four thermocouple arrays were installed along the centerline of the test section. Figure 8 shows the thermocouple array in the front of the seat section ("A" end). Type K, 0.01 in (0.25 mm) diameter wire was spot welded together to form the junction. Each array had a thermocouple located at 1 ft (0.31 m), 2 ft (0.61 m), 3 ft (0.92 m), 4 ft (1.22 m), 5 ft (1.53 m) and 6 ft (1.83 m) below the center ceiling panels.

With the exception of the array positioned in the bulkhead doorway, the other three arrays also have a thermocouple located 1 in (25 mm) below the ceiling. Additional thermocouple pairs are placed adjacent to each of the arrays in the test section ("A" end) of the car at elevations of 1 ft (0.31 m) below the center ceiling (above the luggage rack) and 2 ft (0.61 m) below the center ceiling (below the luggage rack).

These thermocouple arrays were used to determine the average temperature of the relatively hot gases in the upper portion of the vehicle near the ceiling and relatively cooler gases nearer to the floor. In well-ventilated fires, a fairly distinct separation between these two gas layers is typical and occurs near the center of the vehicle from floor to ceiling. In practice, upper layer temperature was estimated by averaging thermocouples within 3 ft (1 m) of the ceiling; lower layer temperature was estimated by averaging thermocouples within 3 ft (1 m) of the floor. In chapter 4, these average temperatures are noted as an "average upper layer temperature" for the hot gases and an "average lower layer temperature" for the cooler gases. For the gas burner tests, two thermocouples are positioned above the burner, 1 in (25 mm) below the ceiling centered above the burner, and 1 in (25 mm) above the burner surface.

Heat flux gauges measure the thermal energy to which a surface area is exposed. In these experiments, two total heat flux gauges were used; one to measure the heat flux from the fire and the other to measure the heat flux from the hot gas layer. The heat flux gauge for the fire is located approximately 4.6 ft (1.4 m) from the fire source, oriented perpendicular to the fire. The gauge is 3 ft (0.91 m) above the floor. The second heat flux gauge is oriented to face perpendicular to the ceiling, and is located at the center of the experiment section floor area, 3 ft (0.91 m) above the floor.

Optical density was measured using laser-based light extinction measurement smoke meters. A laser beam's signal strength is measured over a set path length. As smoke passes through the laser beam, the smoke absorbs and reflects a fraction of the light, reducing the light level at an in-line receiver. These smoke meters were used to determine the height of the smoke layer in the compartment at a given time after the start of the fire. Smoke meters were installed at 1 ft (0.31 m), 2 ft (0.61 m), 3 ft (0.92 m), 4 ft (1.22 m), 5 ft (1.53 m) and 6 ft (1.83 m) below the center ceiling panels, in the center of the experimental section of the car.

A gas-sampling probe measured oxygen depletion, carbon dioxide generation and carbon monoxide generation in the fire gases. The probe was installed at an elevation of 5 ft (1.5 m) above the floor, in the center of the experiment section of the car, to sample gases at a height where standing people would inhale these gases.

The exhaust stack located in the "B" end of the car was instrumented to measure HRR using oxygen consumption calorimetry. The data from the gas burner experiments were used to calibrate the exhaust stack. In practice, the success of the HRR measurement was limited due to leakage throughout the rest of the vehicle.

3. PASSENGER RAIL CAR FULL-SCALE TESTS

HRR and other data measurements generated from small-scale test methods, such as the cone calorimeter [9] can be used as an input to evaluate a material's overall contribution to the fire hazard in a particular passenger rail car application. In addition to cone calorimeter tests, full-scale component assembly tests can be used to determine how individual materials interact in rail car applications. Finally, full-scale tests that include HRR measurement can be used to quantify the interaction of materials in an actual passenger rail car geometry. The data generated in small-scale and component assembly tests can be used as inputs for fire modeling as part of a fire hazard analysis. In addition to material flammability and smoke emission, fire modeling and hazard analysis techniques allow evaluation of a range of passenger rail car design parameters, including geometry, fire detection and suppression, and evacuation, as well as design tradeoffs, which may arise from the interaction of several of those parameters.

The successful use of fire modeling and hazard analysis depends on the ability of the models to correctly predict conditions in a given geometry. Full-scale fire tests in an appropriate end-use geometry can provide data to evaluate the predictive capability of fire models. The tests described in this chapter included several gas burner calibration tests and actual passenger rail car material assembly tests conducted inside a donated Amfleet I single level coach car.

3.1 TEST PROGRAM

Two different types of full-scale tests were conducted to evaluate the accuracy of the results of the passenger rail car fire hazard analyses conducted in Phase II of this research program: 1) a series of gas burner tests conducted in a fire-hardened end of the car to evaluate the accuracy of the baseline analysis fire growth rates for an actual coach car geometry, and 2) a smaller series of fire tests to evaluate fire spread and growth for actual passenger rail car furnishings exposed to a range of initial fire sources. Most of these tests were terminated prior to extensive damage to the car to allow additional tests to be conducted. Table 2 shows the tests conducted in the Amfleet I coach test car. Extensive details of the test results are included in Appendix B of this report. Small-scale test data for selected materials and full-scale component assembly data are contained in the Phase I and Phase II interim reports for this research study [1][2].

Table 2. Amfleet I Test Car - Tests Conducted

TEST NUMBERS	TEST TYPE AND IGNITION SOURCE	
1-3	Slow t^2 gas burner (3 replicates)	
4-6	Medium t^2 gas burner (3 replicates)	
7-9	Fast t^2 gas burner (3 replicates)	
10-12	Ultra-fast t^2 gas burner (3 replicates)	
13	Window Drape	25 kW gas burner on lower edge
14	Corner Test	Trash Bag in corner next to wall carpet and FRP panel
15	Seating Area	25 kW gas burner below seat
16		TB 133 gas burner on seat
17		Trash bag on seat

3.1.1 Gas Burner Tests

For the fire hazard analysis conducted in Phase II, the fire performance curves indicate predicted response of the chosen passenger rail car geometry to a range of typical fire growth rates and
determine the minimum available safe egress time from the particular car exposed to these fires. These calculations are compared to the minimum time necessary to evacuate passengers and crew from the car in order to determine the largest fire growth rate and size that are allowable for the 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 growth rates was used. Figure 9 shows the test apparatus used for the gas burner tests.

Figure 9. Amfleet I Test Car "A" End - Gas Burner Test Apparatus

For the fire hazard analyses conducted in
Phase II, slow, medium, fast, and ultra-fast t-squared fires were used to develop the fire performance curves. The gas burner fires provide a carefully controlled and known HRR to match the t-squared design fire performance curves. The t-squared fire growth rates (where the

HRR grows proportional to the time from ignition squared) are generally accepted as encompassing the typical range of fire growth rates [26].

The slow fire takes 600 s to reach 1 MW, while the medium, fast and ultra-fast fires take 300 s, 150 s, and 75 s, respectively. These growing fire curves were duplicated for the full-scale tests using a NIST-developed computer controlled gas burner. Figure 10 shows a typical growth of a medium t-square fire using this gas burner in the "A" end of the car. The experimental fire performance curve determined from temperature and gas concentration measurements made during the tests could then be compared against the predicted fire performance curve to determine any differences and their significance.

Increasing HRR →

Figure 10. Amfleet I Test Car - Typical Medium T-squared Gas Burner Fire Growth

3.1.2 Fire Growth and Spread Tests

The Phase II assembly test results showed that component materials that comply with the current FRA fire safety criteria 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 transportation environment. However, it was also evident from the assembly tests, that significant fires can develop with sufficiently severe ignition sources. Accordingly, for the Phase III fire growth and spread tests, initial ignition sources ranging from small gas burners to large trash bags were used. These tests allow the comparison of the previously conducted assembly tests with actual fire growth in the test car; the HRR may change due to the effects of the car geometry and/or proximity of materials to each other.

Figure 11 shows the three fire ignition sources used for the seat tests. The TB 133 burner (Figure 11a), developed by Ohlemiller and Villa [27], is used in California for flammability testing of commercial seating furniture [28]. This burner uses a 0.82 ft (0.25 m) square constructed of 0.5 in (13 mm) diameter tube with a series of holes for the flow of gas. It is designed to simulate ignition with several sheets of crumpled newspaper. Details of construction are provided in the TB 133 standard. For the TB 133 test, the burner uses propane at a flow rate of 3.4 gal/min (13 L/min) for 80 s, and the burner is located 1 in (25 mm) above the seat cushion and 2 in (50 mm) from the back cushion. The nominal HRR of this burner is 17 kW.

(a) TB 133 gas burner

(b) Gas sand burner

(c) Trash bag / trash bin

Figure 11. Amfleet I Test Car - Ignition Sources Used for Fire Growth and Spread Tests

In the 6.8 in (0.17 m) square, 25 kW burner (Figure 11b), the gas flow was diffused by traveling through a layer of gravel and sand. This type of burner, often called a “sand burner,” was used for the ignition source for the HRR rates of 25 kW. Both natural gas and propane were used in the gas sand burner. For all seat and the window drape tests where the gas sand burner was used, it was ignited at the start of the test and continued to burn at a constant HRR throughout the experiment.

For one of the seat tests and the wall lining test, a newspaper-filled trash bag (Figure 11c) served as the primary ignition source for the test assemblies. This trash bag was designed to simulate the burning characteristics of actual Amtrak train trash bags and thus represents a severe ignition source that may be present on the train. (Trash bins in enclosed compartments are also used.)

According to assembly tests conducted in Phase II of this research study, peak HRR for the trash bags averaged 205 kW ± 35 kW, including the 25 kW sand burner used to ignite the bags. Average HRR over the entire duration of burning was 77 kW ± 24 kW.

3.2 GAS BURNER TEST RESULTS

The primary advantage of the gas burner tests is that the HRR of the fire is a known quantity. The HRR (expressed in units of kJ/s or kW) is simply the flow rate of the gas (expressed as m^3/s) times the heat of combustion, or the amount of energy released per unit volume (expressed as kJ/m^3). This provides a known baseline from which to make relevant conclusions regarding the material fire growth and spread tests. Four t-squared fire growth rates were used for the tests: slow, medium, fast, and ultra-fast. The slow fire takes 600 s to reach 1 MW, while the medium, fast and ultra-fast fires take 300 s, 150 s, and 75 s, respectively. Each test was terminated when the HRR reached 1 MW.

Figure 12 shows the measured and ideal calculated HRR for the four fire growth rates used for this study. Experimental values were measured in open burning in a furniture calorimeter. Average uncertainties (expressed as one standard deviation of replicate tests) for the measured slow, medium, fast, and ultra-fast fire growth rates were ± 21 kW, ± 19 kW, ± 19 kW, and ± 5 kW respectively.

Three tests were conducted for each fire growth rate. The results for each of these four fire growth rates are discussed below.

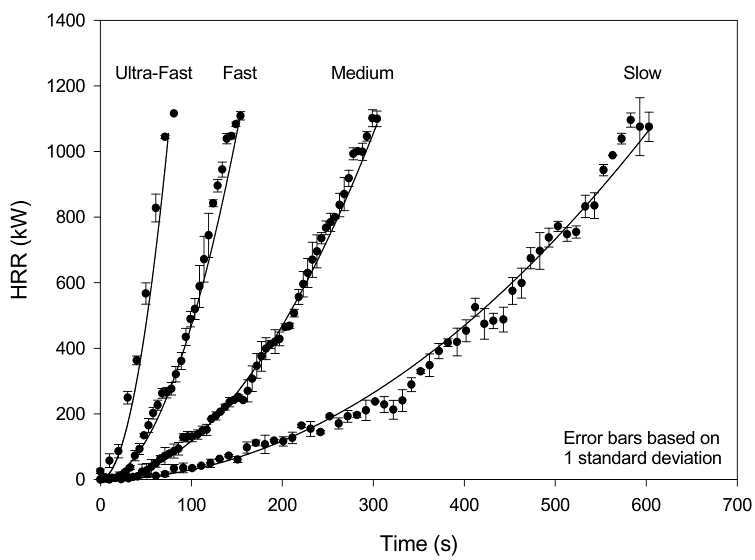


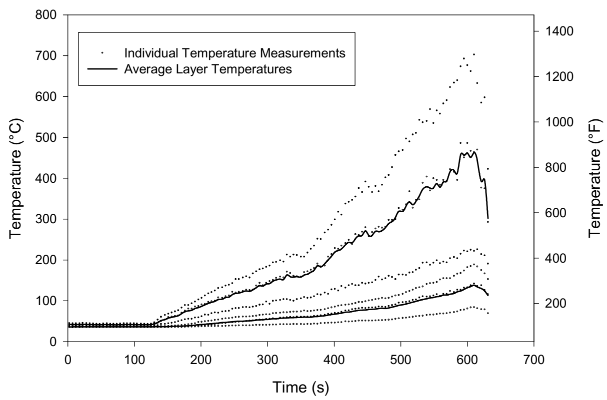
Figure 12. Amfleet I Test Car - Measured and Calculated HRR for Gas Burner Fires

3.2.1 Slow Fire Growth Rate

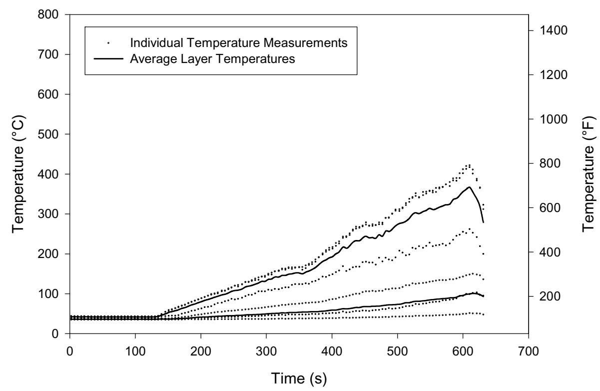
The “slow” growth fires take approximately 600 s to reach a HRR of 1 MW. The slow growth fires were conducted as Test Numbers 1, 2, and 3. Figure 13 shows the measured temperatures for each of four thermocouple arrays. Thermocouples in the upper layer were averaged at each time point to obtain a representative upper layer temperature. Similarly, thermocouples located in the lower layer were averaged to obtain lower layer temperatures. Figure 14 shows these average values for the upper and lower layers in the rail car. The upper layer temperature reached an average peak of 748 °F ± 38 °F (398 °C ± 21 °C), while the lower layer reached an average peak of 223 °F ± 13 °F (106 °C ± 7 °C). The heat flux gauge oriented towards the fire measured an average peak value of approximately 19 kW/m^2 ± 1.3 kW/m^2. Since the peak heat flux for the gas burner tests was always noted at the end of the test when the fire reached 1 MW, it is expected that the peak heat flux from the four gas burner tests should be similar since the time to the peak heat flux decreases in proportion to the increase in fire growth rate. Finally, gases were collected at the center of the fire compartment. Carbon monoxide did not significantly vary from ambient levels. Oxygen reached an average minimum value of 16 percent by volume ± 1.1 percent by volume and carbon dioxide had an average peak concentration of 3 percent by volume ± 0.5 percent by volume. A summary of important data results is shown in Table 3.

3.2.2 Medium Fire Growth Rate

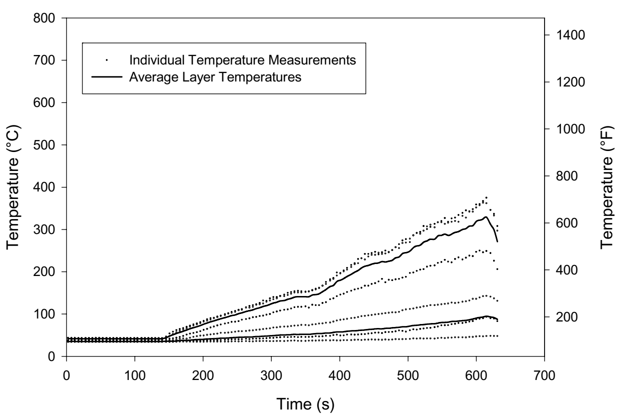
The “medium” growth fires take approximately 300 s to reach a HRR of 1 MW. The medium growth fires were conducted as Test Numbers 4, 5, and 6. Important values for the medium growth fires are shown in Table 3. Figure 14 shows the average upper layer temperature. The average upper layer temperature reached 628 °F ± 32 °F (331 °C ± 18 °C), while the lower layer reached an average peak of 178 °F ± 14 °F (81 °C ± 8 °C). Normally, the upper layer temperature should follow a sequence, i.e., to decrease systematically from slow to ultra-fast t-squared growth rates as the compartment walls have more time to heat up for slow-growing fires. The upper layer temperature for the medium t-squared gas burner experiments does not follow the sequence and would be expected to be higher than measured. Lower layer temperatures follow the expected trend. The heat flux gauge oriented towards the fire measured an average peak value of approximately 16 kW/m^2 ± 1.8 kW/m^2. Carbon monoxide values stayed at the ambient level. Oxygen had an average minimum concentration of 17 percent by volume ± 0.4 percent by volume and carbon dioxide had an average peak concentration of 2.4 percent by volume ± 0.5 percent by volume.



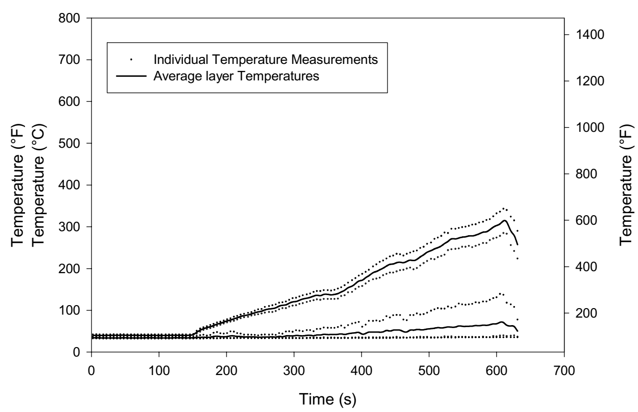
Temperature Array 1
10.2 ft (3.1 m) from car end



Temperature Array 2
20.3 ft (6.2 m) from car end



Temperature Array 3
30.1 ft (9.3 m) from car end



Temperature Array 4
40.5 ft (12.3 m) from car end

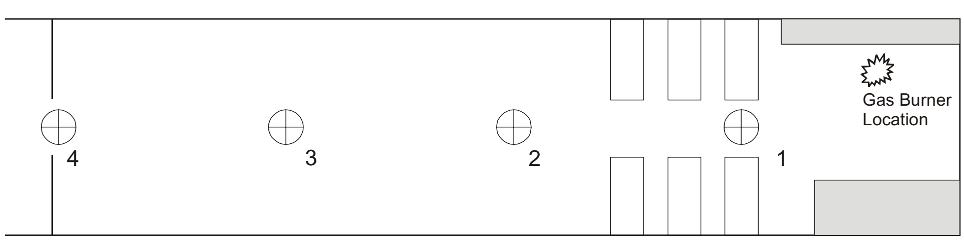


Figure 13. Amfleet I Test Car - Measured Gas Temperature Profiles From Floor to Ceiling at Four Positions During a Slow Fire Growth Rate Gas Burner Test

Table 3. Amfleet I Test Car - Selected Full-scale Test Data

PASSENGER RAIL CAR TESTS	GAS TEMPERATURE (°F / °C)				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	748 / 398	600	223 / 106	600	19	625	16	630	3.0	620	0.02	_*
Medium t^2 gas burner	628 / 331	320	178 / 81	315	16	317	17	330	2.4	325	0.01	–
Fast t^2 gas burner	709 / 376	155	172 / 79	155	15	155	16	170	2.8	190	0.01	–
Ultra-fast t^2 gas burner	702 / 372	80	163 / 73	80	14	80	17	95	2.3	95	0.03	–
Window Drape with 25 kW burner	127 / 53	510	90 / 32	600	0.31	540	20	600	0.31	–	0.01	–
Corner Test (Wall carpet and FRP panel) with trash bag	361 / 183	300	142 / 61	320	9	270	17	290	3.7	300	0.2	280
TB 133 ignition on seat	117 / 47	600	90 / 32	365	0.24	560	21	–	0.23	–	0	–
25 kW burner ignition on seat	127 / 53	565	88 / 31	255	0.46	505	21	–	0.32	–	0	–
Trash bag on seat	685 / 363	270	268 / 131	260	27	90	12	285	6.6	290	1.4	285

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

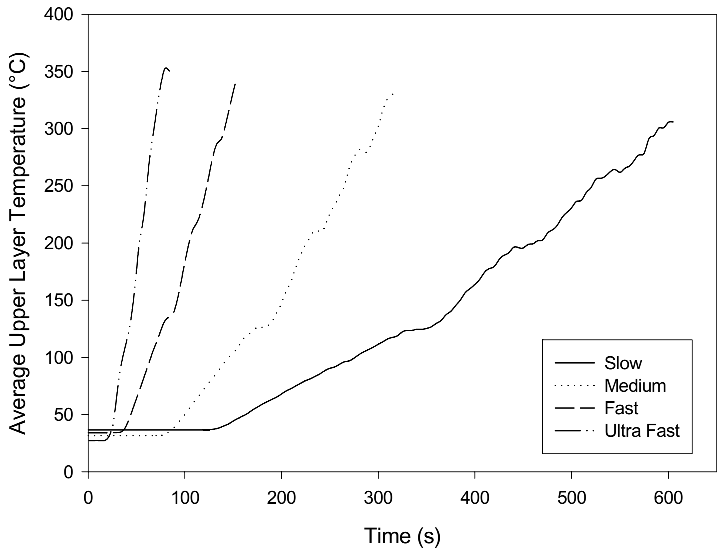


Figure 14. Amfleet I Test Car - Average Upper Layer Temperature for Several Gas Burner Tests

3.2.3 Fast Fire Growth Rate

The "fast" growth fires take approximately 150 s to reach a HRR of 1 MW. The fast growth fires were conducted as Test Numbers 7, 8, and 9 and the data are summarized in Table 3. Figure 14 shows the average upper layer temperature for the "fast" fires. The average upper layer temperature reached 709 °F ±20 °F (376 °C ± 11 °C) while the lower level reached an average peak of 172 °F ± 16 °F (79 °C ± 9 °C). The heat flux from the fire measured an average peak value of approximately 15 kW/m^2 ± 1 kW/m^2. Carbon monoxide values stayed at the ambient level. Oxygen had an average minimum concentration of 16 percent by volume ± 0.2 percent by volume and carbon dioxide had an average peak concentration of 2.9 percent by volume ± 0.2 percent by volume.

3.2.4 Ultra-Fast Fire Growth Rate

The "ultra-fast" growth fires take approximately 75 s to reach a HRR of 1 MW. The ultra-fast growth fires were conducted as Test Numbers 10, 11, and 12. The results for the ultra-fast growth fires are shown in Table 3. Figure 14 shows the average upper layer temperature. The average upper layer temperature reached 702 °F ± 72 °F (372 °C ± 40 °C), while the lower layer reached an average peak of 163 °F ± 32 °F (73 °C ± 18°C). The heat flux gauge oriented towards the fire measured an average peak value of approximately 14 kW/m^2 ± 2.5 kW/m^2.

Carbon monoxide values stayed at the ambient level. Oxygen had an average minimum concentration of 17 percent by volume ± 0.9 percent by volume and carbon dioxide had an average peak concentration of 2.3 percent by volume ± 0.6 percent by volume.

3.3 FIRE GROWTH AND SPREAD TEST RESULTS

Five fire growth and spread tests were conducted in order to evaluate the representative hazard of existing passenger rail car component material configurations. A range of ignition sources was chosen to evaluate the rail car geometry and materials. To evaluate fire growth in the car, three ignition sources were used with ignition on or below a passenger seat. A large trash bag was chosen as a severe ignition source that would promote flame spread. In addition, the California Technical Bulletin (TB) 133 gas burner and a 25 kW gas sand burner were used to represent less severe ignition sources. To evaluate the contribution of more severe ignition sources, two additional tests were conducted with combinations of these ignition sources: a 25 kW gas sand burner impinging upon a trash bag in a seat and the same trash bag / 25 kW gas sand burner in the forward "A" end corner of the test car impinging upon the wall carpeting and FRP wall panel. Duration of the fire growth and spread tests ranged from 560 s to 645 s. Each of these tests is discussed below.

3.3.1 Window Drape Test with 25 kW Gas Sand Burner Ignition Source

The 25 kW gas sand burner and window drape test, shown in Figure 15 resulted in a peak upper layer temperature in the car of 127 °F (53 °C), largely as a result of the gas burner. The lower layer temperature was near ambient. The heat flux gauge facing the fire measured a peak value of 0.3 kW/m^2. The concentration of carbon monoxide remained near ambient levels. Oxygen concentration decreased slightly to approximately 20.5 percent by volume. Carbon dioxide reached a peak concentration of 0.3 percent by volume. Smoke obscuration for the 750 s test in the car was negligible. Figures 16 and 17 show the gas temperature and gas concentrations during the test. Examination of the car interior after the test showed some heat damage to the window drape and the underside of the luggage rack. However, there was no evidence of fire spread beyond the area in direct contact with the sand burner flame.

(a) Before test (b) During test (c) After test

Figure 15. Amfleet I Test Car - Window Drape Test with 25 kW Gas Sand Burner Ignition

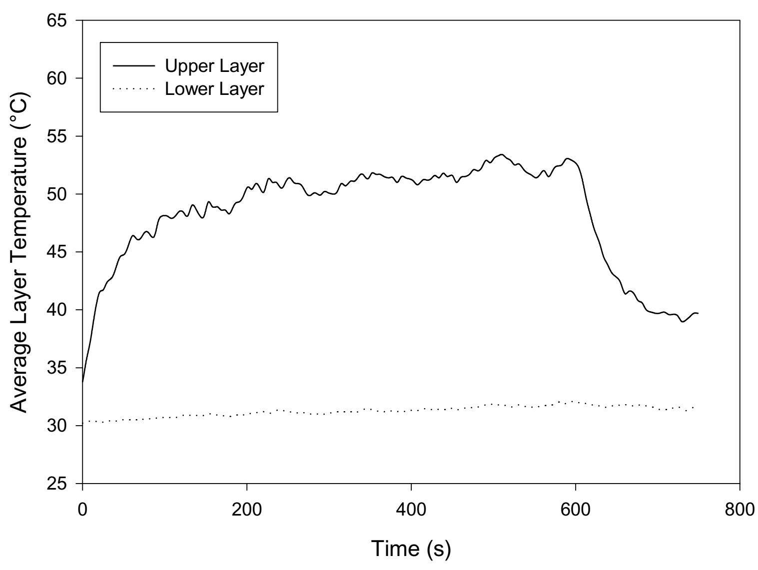


Figure 16. Amfleet I Test Car - Window Drape: Gas Temperature

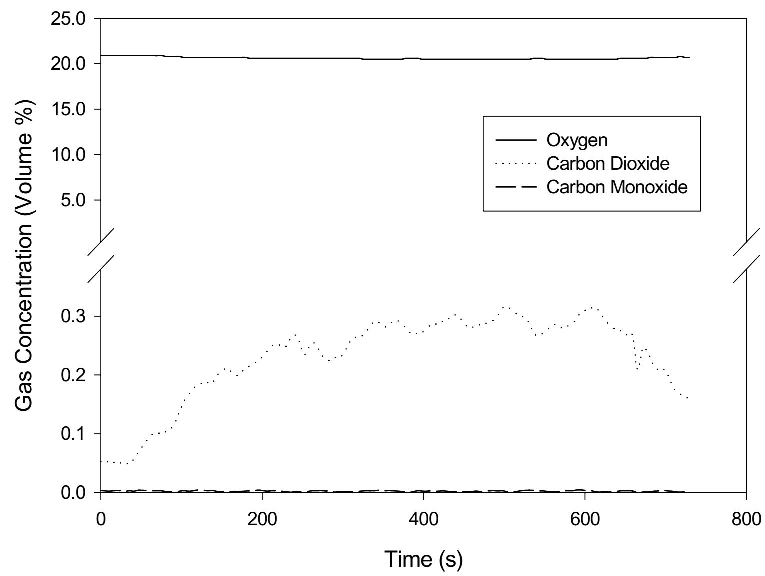


Figure 17. Amfleet I Test Car - Window Drape Test: Gas Concentrations

3.3.2 Corner Test with Trash Bag Ignition

To investigate fire growth with a larger ignition source, the trash bag, ignited by the 25 kW gas sand burner, was used as an ignition source for a fire in one corner of the car adjacent to a FRP and carpeted wall surface. The test lasted 540 s. Figure 18a shows the test configuration. (It should be noted that unlike the Phase II tests, the trash bag was not wrapped in chicken wire.)

(a) Before test (b) During test (c) After test

Figure 18. Amfleet I Test Car - Corner Test with Trash Bag / Sand Burner

While this increased the uncertainty in the HRR of the trash bag ignition source for the current tests compared to the more carefully controlled Phase II tests, this was done to insure the current tests best represented typical use in a rail car. Without the chicken wire wrapping, peak HRR is likely to be somewhat higher for the trash bag compared to the Phase II test results. Specific comparisons were not made.

The fire resulted in a peak average upper layer temperature of 361 ºF (183 ºC) while the average lower layer reached a peak of 142 ºF (61 ºC). The heat flux gauge facing the fire measured a peak of 9 kW/m^2. The concentration of oxygen dropped to a level of 17 percent by volume, carbon monoxide measured a peak value of 0.2 percent by volume, and carbon dioxide peaked at a value of 3.7 percent by volume. Smoke obscuration reached 100 percent for all the measurement positions.

Examination of the rail car after the test showed significant fire spread along the underside of the luggage rack sufficient to expose the metal structure of the rack for approximately 10 ft (3 m) from the ignition source. Burning of the wall carpet was limited to the area directly above the trash bag up to the underside of the luggage rack. The adjacent FRP wall panel sustained extensive damage. Figures 19 to 21 show the gas temperature, heat flux, gas concentrations, and smoke obscuration during the test. In contrast to the drape and sand burner test, the more severe corner test with the trash bag ignition source reached a temperature of 150 °F (65 °C) within the rail car after about 50 s.

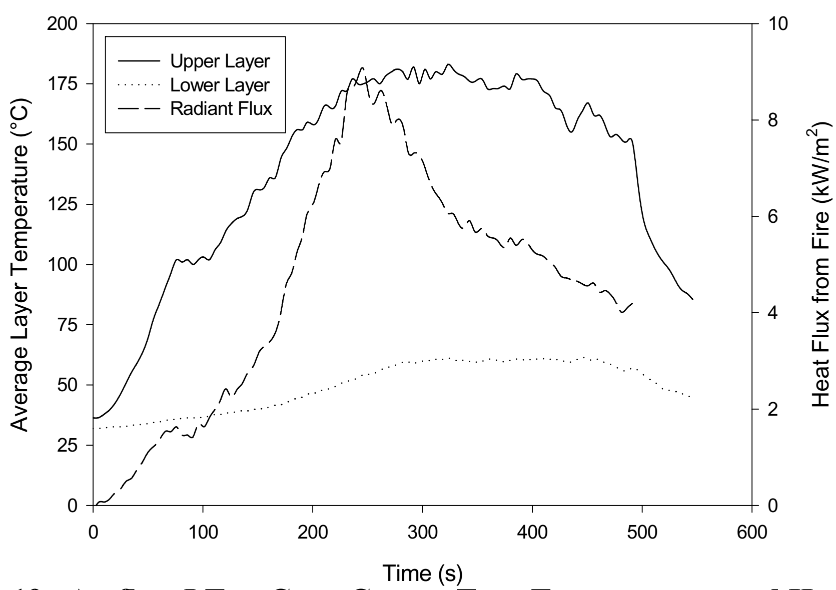


Figure 19. Amfleet I Test Car - Corner Test: Temperatures and Heat Flux

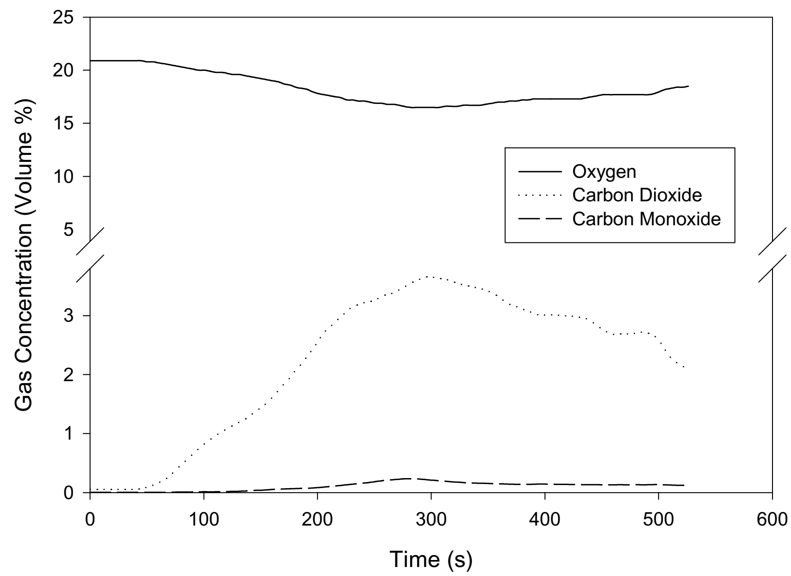


Figure 20. Amfleet I Test Car - Corner Test: Gas Concentrations

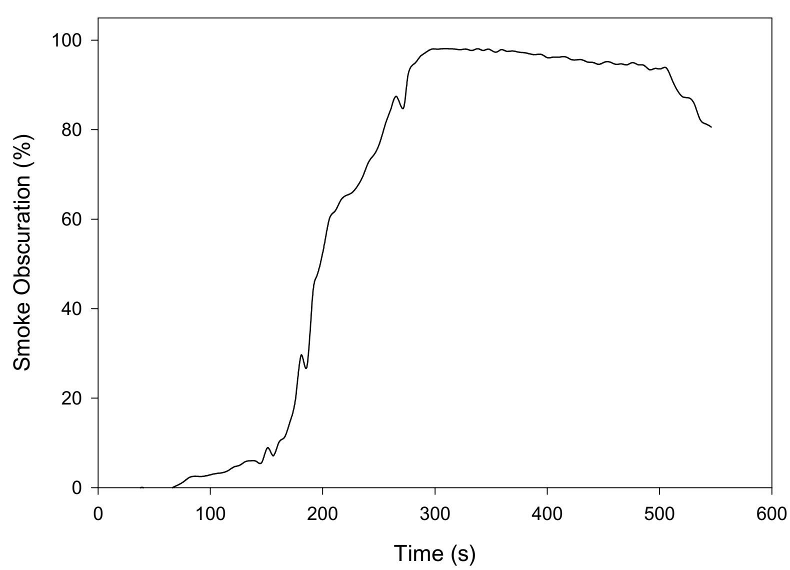


Figure 21. Amfleet I Test Car - Corner Test: Smoke Obscuration

3.3.3 Seat Tests

A series of seat tests was conducted with three ignition sources, the TB 133 gas burner, the square gas sand burner, and a trash bag. Each of these seat tests is described below.

3.3.3.1 TB 133 Burner Ignition on Seat

The TB 133 gas burner ignition source placement is shown in Figure 22a. The HRR of the TB 133 burner was approximately 17 kW and was run for 10 minutes. Peak upper layer temperature reached 117 °F (47 °C) at the conclusion of the test. The lower layer never rose above ambient values. The peak heat flux from the fire was 0.24 kW/m^2. Carbon monoxide levels were near ambient, carbon dioxide levels rose to 0.2 percent by volume, while oxygen levels did not vary significantly from ambient. Figures 22b and 22c show the seat during and after the TB 133 test while Figures 23 and 24 show the gas temperature and gas concentration results.

(a) Before Test (b) During Test (c) After Test

Figure 22. Amfleet I Test Car - Seat Cushion with TB 133 Burner Ignition

3.3.3.2 Gas Sand Burner Ignition Under Seat

Similarly, the 25 kW gas sand burner (see Figure 25) raised the peak upper layer temperature to 127 °F (53 °C) and the peak heat flux from the fire measured 0.46 kW/m^2. All other values remained at ambient levels. While the peak values were marginally higher for the 25 kW sand burner scenario, neither the TB 133 burner nor the 25 kW sand burner exhibited significant flame spread to any rail car materials. For both these tests, damage was limited to the area of the seat cushion in direct contact with the burner flame. Figures 26 and 27 show the sand burner gas temperature and concentration test results.

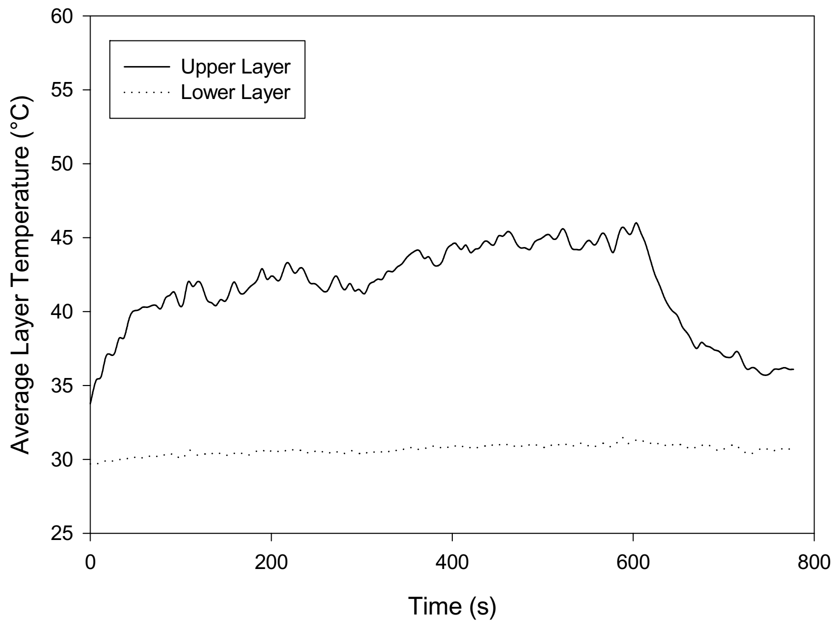


Figure 23. Amfleet I Test Car - Seat Cushion / TB 133 Burner: Gas Temperatures

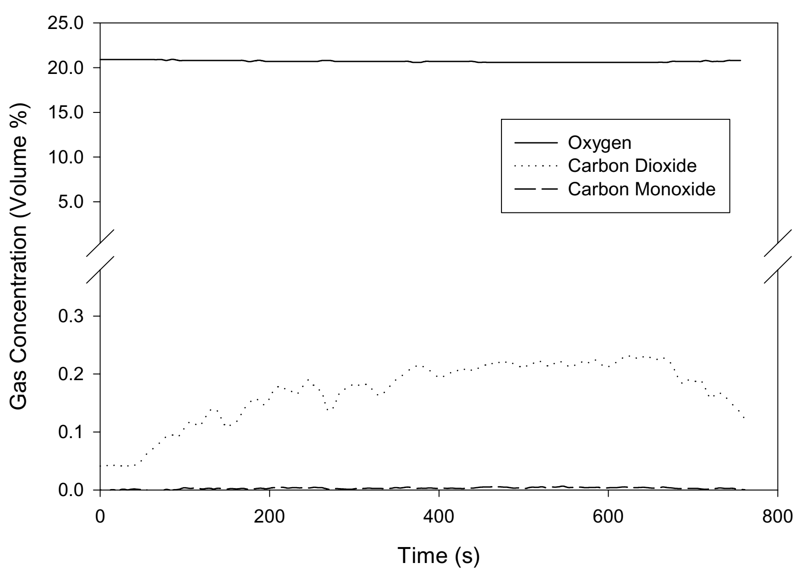


Figure 24. Amfleet I Test Car - Seat Cushion / TB 133 Burner: Gas Concentrations

(a) Before Test (b) During Test (c) After Test

Figure 25. Amfleet I Test Car - Seat Cushion with Gas Sand Burner

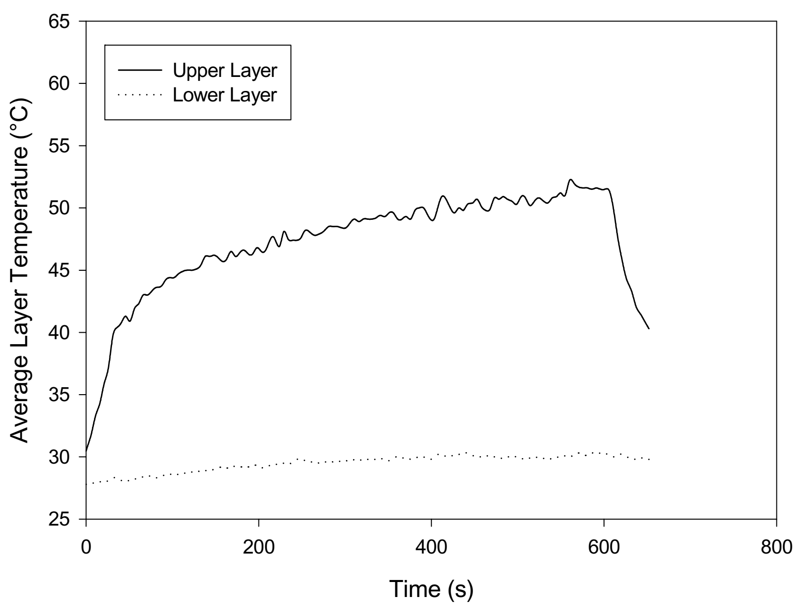


Figure 26. Amfleet I Test Car - Seat Cushion / Sand Burner: Gas Temperatures

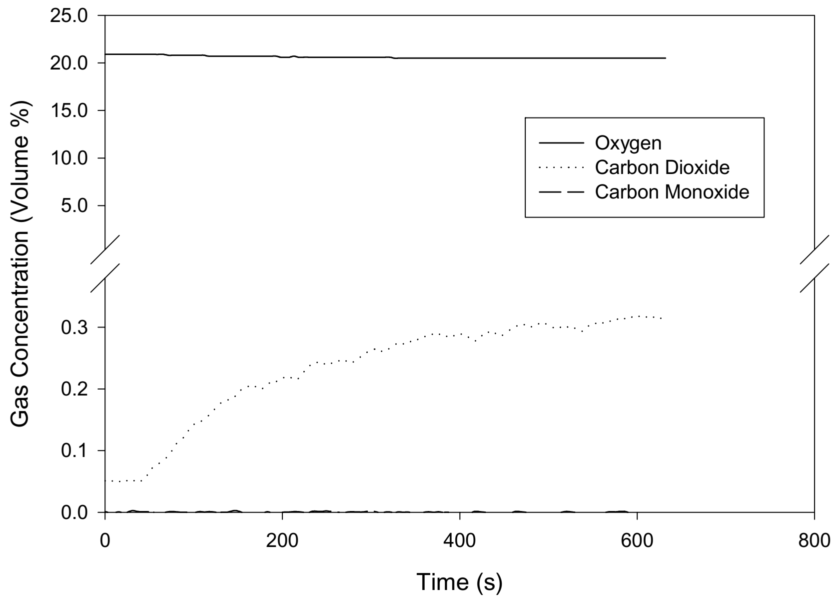


Figure 27. Amfleet I Test Car - Seat Cushion / Sand Burner: Gas Concentrations

3.3.3.3 Trash Bag Ignition on Seat

The trash bag / 25 kW sand burner configuration exhibited significant flame spread. Seat cushions, overhead materials, windows, tray tables, curtains, and wall linings were each involved in flame propagation to some extent. Figure 28 shows the interior of the test car before, during, and after the test. Again, unlike in Phase II tests, the trash bag was not wrapped in chicken wire.

(a) Before test (b) During test (c) After test

Figure 28. Amfleet I Test Car - Seating Area with Trash Bag Ignition

The peak upper layer temperature was 671 °F (341 °C) and the peak lower layer temperature was 342 °F (158 °C). The peak heat flux from the fire was 27 kW/m^2. The oxygen level was reduced to a volume fraction of 12 percent. Carbon dioxide and carbon monoxide reached peak volume fractions of 6.6 percent and 1.4 percent, respectively. Smoke obscuration reached 100 percent. Peak values were attained between 260 s to 300 s after ignition. Figures 29 to 31 show the gas temperatures, heat flux, gas concentrations, and smoke obscuration during the test.

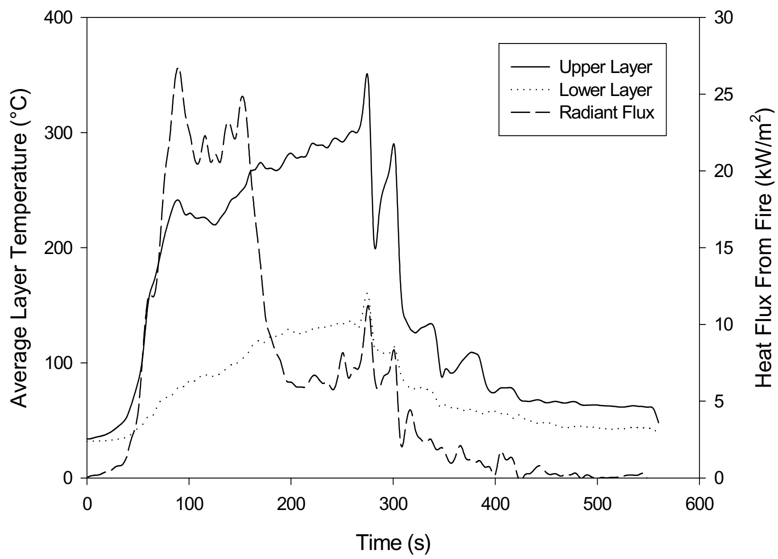


Figure 29. Amfleet I Test Car - Seating Area / Trash Bag: Gas Temperatures and Heat Flux

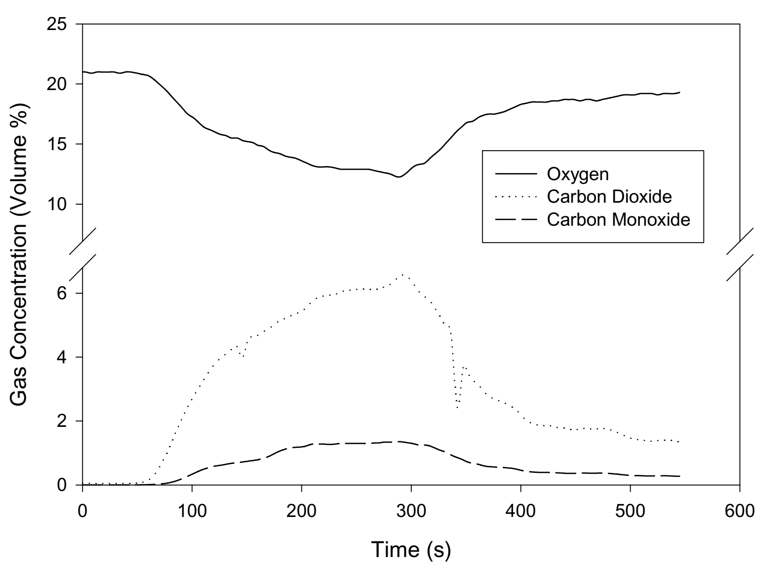


Figure 30. Amfleet I Test Car - Seating Area / Trash Bag: Gas Concentrations

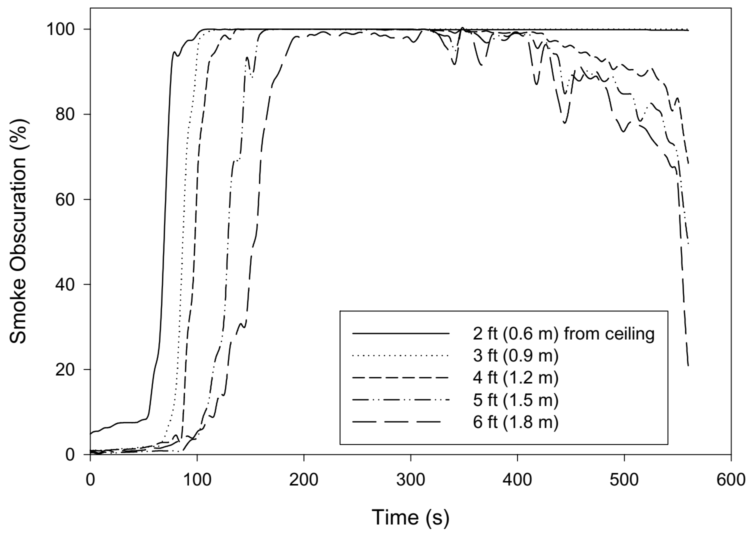
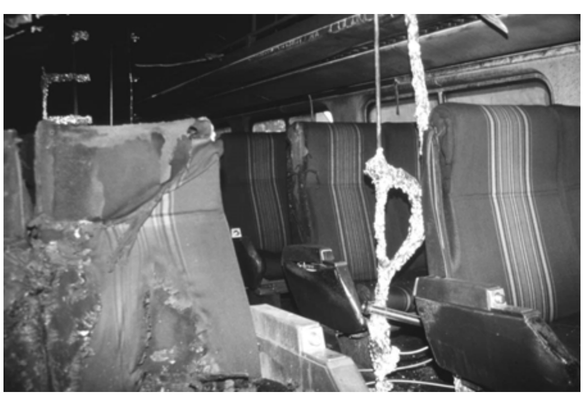


Figure 31. Amfleet I Test Car - Seating Area / Trash Bag: Smoke Obscuration

The test was terminated at 560 s to allow additional tests to be conducted in the rail car. Examination of the car compartment after the trash bag test and examination of photographs taken during the fire show significant flame extension (see Figure 32). Ignition of the trash bag resulted in direct flame impingement upon the seat cushions, seat back of the seat in front, window, wall linings, and underside of the luggage rack. The primary items contributing to the growth of the fire include the ignition source (trash bag with 25 kW sand burner), fabric covering the seat cushions, seat foam, tray table from the back of the seat in front of the primary seat, fabric and foam from the seat in front, wall lining materials, the window, and plastic from the underside of the luggage rack.



(a) Fire spread to front seat area

(b) Fire spread in rear of seat

Figure 32. Amfleet I Test Car - Seating Area After Trash Bag Ignition

The primary seat exhibited significant thermal damage, while the back of the seat in front of the primary seat also exhibited significant thermal damage and flame propagation (see Figure 32a). The wall lining materials and the window material supported vertical flame spread. The inner pane of the two-pane window showed significant melting and flame propagation. The underside of the luggage rack exhibited severe thermal damage and supported flame spread for approximately 15 ft (4.5 m). Across the aisle, the fabric covering the seat cushions pyrolyzed at the surface nearest the flames in two of the three rows (see Figure 32b). This suggests potential flame spread across the aisle. The primary methods of flame spread were along the underside of the luggage rack, along the wall linings, as well as seat-to-seat spread, both on one side of the aisle, as well as potential spread across the aisle through radiative thermal damage. Untenable conditions existed within the rail car after about 50 s.

3.4 COMPARISON OF SMALL- AND FULL-SCALE TEST DATA

Phases I – III of this project included testing of the same set of passenger rail car materials in small-scale, full-scale assembly tests, and full-scale tests in an actual rail coach car. In addition, earlier research included testing of similar materials and train car geometries in small- and full-scale. This section compares the various test results for passenger rail car materials in small- and full-scale. The comparison discussed in this section is intended to aid in the development of appropriate criteria for material screening and to place the current test results in context with earlier research.

3.4.1 Use of Small-Scale Test Data for Material Screening

To realize the maximum benefits of performance-based designs, a low-cost method to screen materials is an important complement to an overall system fire safety analysis. As small-scale tests are significantly cheaper than full-scale tests, use of a small-scale screening method would minimize costs to both the manufacturer, as well as the end-user.

Table 4 and Figure 33 show a comparison of passenger rail car materials tested in the cone calorimeter in Phase I of this project with assembly test results from Phase II. With the exception of the seat cushion assembly, the relative ranking of materials in the cone calorimeter is similar to the rank order in the furniture calorimeter. For the seat cushion assembly, the cone calorimeter result ranks higher than the furniture calorimeter result. This is likely a result of testing with several different ignition sources in the furniture calorimeter, ranging from the small TB 133 burner to a 400 kW gas burner. In contrast, the cone calorimeter results with a

50 kW/m^2 incident flux represents only more severe ignition scenarios. Considering only the most severe ignition source in the furniture calorimeter data would bring this result in line. It is important to note that this comparison was limited to only five different materials. Additional material data would help refine the comparison.

Table 4. Cone Calorimeter and Furniture Calorimeter Material Rankings

Increasing Fire Hazard ⇧	CONE CALORIMETER RANKING	FURNITURE CALORIMETER RANKING
	Wall Carpet	Wall Carpet
	Window components	Window components
	Privacy Door Curtains	Seat Assembly
	Drapes	Privacy Door Curtains
	Seat Assembly	Drapes

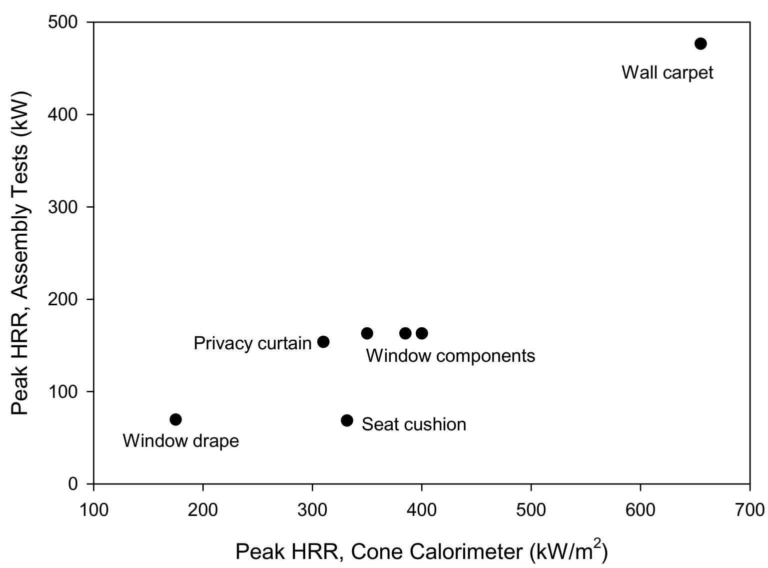


Figure 33. Comparison of Small-Scale (Cone Calorimeter) and Full-scale (Furniture Calorimeter) Test Results for Several Passenger Rail Car Materials

However, it is important to understand the limitations of the comparisons. The comparisons support a fire protection engineer's intuition: low HRR materials are inherently less hazardous than high HRR materials which ignite easily and facilitate flame spread. However, physical phenomena that are not evaluated using the simple peak HRR comparison, such as geometry, burnout time, or smoke and toxic gas production may have a significant impact upon actual burning behavior of passenger rail car materials. Additional research is appropriate to fully understand the comparison between small- and full-scale testing. For example, Janssens has developed a simple flame spread model for application of cone calorimeter data in fire hazard analysis of commuter rail vehicles [29]. Thus, small-scale testing is most appropriate as a screening tool for alternate material selection.

3.4.2 Comparison with Earlier Research

Several previous studies summarized in section 1.3 describe the results of passenger rail car full-scale tests. The 1984 FRA/Amtrak study includes test results on several mock-up configurations of Amtrak passenger cars [12]. That study includes several of the same materials used in this current study. The Eureka tests included temperature measurements inside rail vehicles in several tests [21]. Fire growth in WMATA subway vehicles have been previously studied by NBS (now NIST) [24]. Table 5 shows test data from these three studies along with comparable data from derived from Table 3 of this study.

Table 5. Comparison of Selected Full-scale Test Results from Several Test Series

TEST SERIES	PEAK UPPER GAS TEMPERATURE	
	(°F)	(°C)
Current Study	120 – 685	50 – 360
1984 FRA/Amtrak Study [12]	240 – 1520	114 – 825
Eureka Study [21]	520 – 1650	270 – 900
WMATA Subway Study [24]	130 – 550	55 – 290

In Table 5, results from each test series show a considerable range of values due to different materials and configurations included in the tests. The three earlier studies all included older materials such as untreated urethane foam seating that would not meet current FRA requirements. In these three studies, the higher peak temperatures are noted for configurations including these older materials. The Eureka study shows particularly high temperatures since the tests were full burnout tests intended to study the fire environment inside a tunnel, rather than in the car. The WMATA data show lower temperatures for one of the tests compared to the fully-furnished intercity rail cars. This may be due to either the more limited furnishing of the subway car mockup tests or the small 1 oz (28 g) ignition source for the test (by comparison, the trash bag ignition source was approximately 4 lb (1.8 kg)). The expected high performance of FRA-compliant materials is evident in the lower peak temperatures from the current study compared to other fully-furnished rail cars in the 1984 FRA/Amtrak and Eureka tests.

3.5 TEST RESULT UNCERTAINTY

Uncertainty in test results from full-scale fire tests comes from several sources: random uncertainty in the actual measurements taken during the tests, random variation in the burning behavior of materials in the test, and systematic variation in the tests due to measurement techniques, geometry or other effects. For measurements in this test series, uncertainties typical of full-scale fire tests were observed, with test repeatability within 5 percent for the gas burner tests and 17 percent for the fire growth and spread tests. Additional details for individual measurements are discussed below.

The computer controlled t-squared gas burner tests provide a demonstration of the repeatability of full-scale fire tests with a known and controllable fire source. These provide a measure of the random uncertainty inherent in the measurements collected during the tests. With the replicate tests at each fire growth rate, this random uncertainty can be quantified. For all of the t-squared gas burner tests, average uncertainty for peak gas temperature, heat flux, oxygen concentration, carbon dioxide concentration, and carbon monoxide concentration was ± 29 °F (± 16 °C), ± 1.0 kW/m^2, ± 0.6 percent by volume, ± 0.4 percent by volume, and ± 0.06 percent by volume, respectively. These uncertainties are expressed as the standard deviation of the peak values for the 12 tests.

For the computer-controlled t-squared gas burner tests, variation in the burning behavior of materials in the test is small, averaging ± 16 kW for fire sizes up to 1 MW (2 percent). For the fire growth and spread tests, these uncertainties are harder to judge since replicate tests are impractical. From earlier tests of the trash bag ignition source, measured uncertainty is approximately ± 35 kW for an average peak fire size of 203 kW (17 percent). It is expected that the uncertainty for the fire growth and spread tests is bounded by these two representative values of 2 percent to 17 percent.

Gas temperature measurement is subject to systematic variation due to radiative heating or cooling of the thermocouples by the surroundings. This effect is most noticeable for measurements in the lower gas layer where the measured temperature can be as much as a factor of two underestimated for large fires in small enclosures [30]. For smaller fires, the effect is small. Since all the comparisons of the experimental data to model predictions were based on upper layer values, this systematic effect is not important for this study.

3.6 KEY OBSERVATIONS FROM FULL-SCALE TESTS

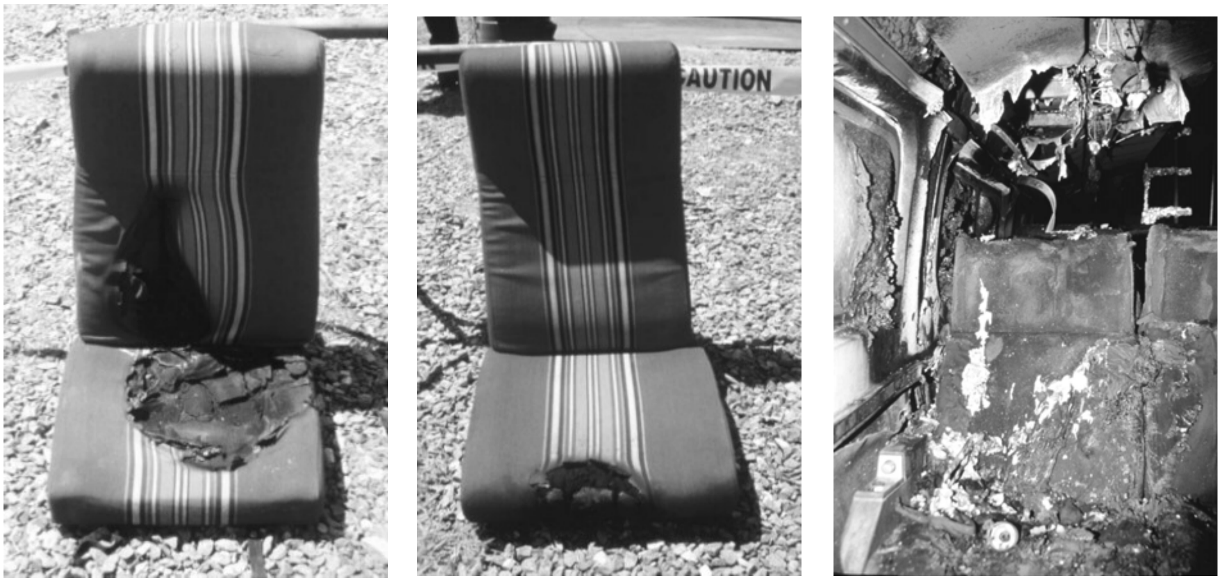
The gas burner tests served two primary purposes: verification of the fire modeling results obtained from the Phase II hazard analysis of this study and estimation of the uncertainty of the measurements. The verification issue will be discussed in the following chapter. The replicate measurements from 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 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 drapes), each yielded temperature and species levels near to slightly above ambient after 6 minutes. 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 in about 100 s. Tenability will be discussed further in the following chapter.

3.7 SUMMARY

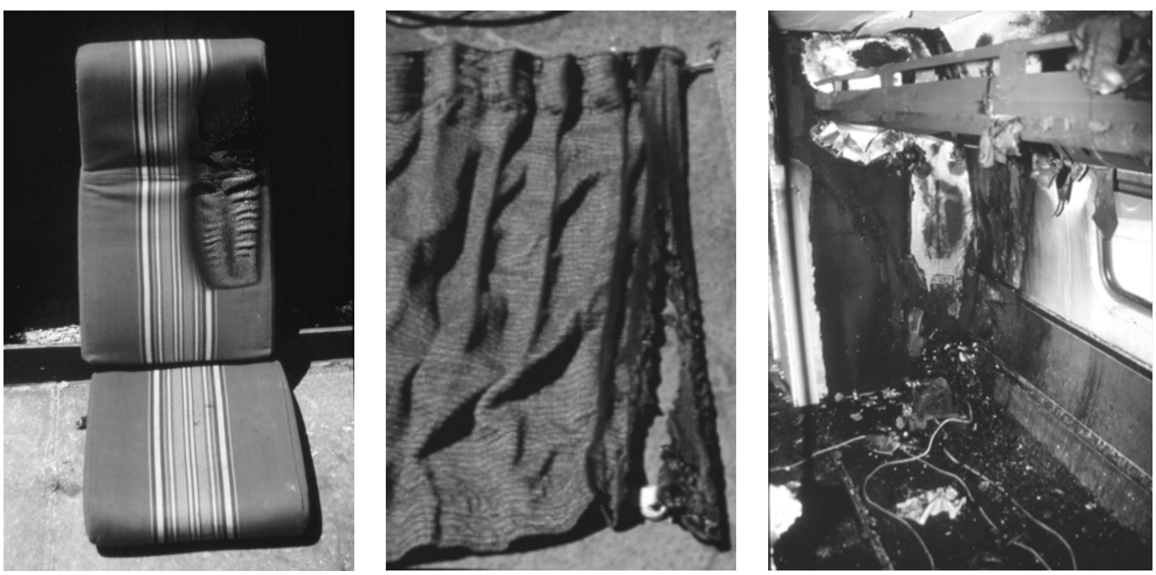
Seventeen fire tests were conducted in an Amtrak Amfleet I passenger rail coach car. Three replicates for each representative t-squared fire growth rate (slow, medium, fast, and ultra-fast) provided an estimate of measurement uncertainty. The uncertainties for all measured quantities were reasonable and suggest that the data will provide the appropriate baseline for verification of the computer modeling performed during Phase II.

For the five flame spread and growth tests, the range of ignition source strengths indicated that an ignition source size between 25 kW and approximately 200 kW is necessary to promote significant fire spread, which is consistent with the conclusions from the Phase II report that the ignition source strength of passenger rail car materials is 2 to 10 times greater than those of typical office furnishings. Given an ignition source of the magnitude of a large trash bag, however, significant flame spread is observed. Figures 34 and 35 show the fire damage after representative tests with various ignition sources. For the largest ignition source tests, conditions within the rail car can become untenable. This issue is further analyzed in the next chapter.



(a) Seat - TB 133 burner (b) Seat - 25 kW sand burner (c) Seat - trash bag

Figure 34. Amfleet I Test Car - Observed Fire Damage to Seats



(a) Seat / drape test - 25 kW sand burner (b) Corner test - trash bag

Figure 35. Observed Fire Damage to Seat/Drape and Car Corner

4. PREDICTIVE CAPABILITY OF FIRE HAZARD ANALYSIS TECHNIQUES APPLIED TO PASSENGER RAIL CARS

Phase II of this study focused on the application of fire hazard analysis techniques to three types of passenger rail cars. That analysis used data from Phase I cone calorimeter tests and data obtained from full-scale rail car component tests. Using fire modeling, the relative importance of material, geometry and other system design parameters was quantified.

Sample fire hazard analyses were described for three different types of passenger rail cars: a coach car, a bi-level dining car, and a bi-level sleeping car. A detailed analysis was presented for the coach car. The Phase II analysis involved four steps:

- Step 1 defines the performance objectives and passenger rail car design. For the analyses presented in this report, the specific objective was to ensure safe egress for all the passengers and crew from the car. In other applications, structural failure or other criteria may be appropriate.

- Step 2 uses the specific performance criterion of *minimum necessary egress time*. The passenger rail car fire performance was calculated in terms of available egress time and compared with that criterion. This calculation involves the creation of fire performance graphs for the single level coach and bi-level dining and sleeping cars to show when the occupied compartment space examined reaches untenability, as well as the minimum time necessary for safe occupant egress.

- Step 3 evaluates specific composite fire scenarios for each of the passenger rail car designs to determine representative HRRs. The HRR curve generated for the individual scenarios is compared to the design fires to come up with a representative design fire.

- Finally, Step 4 examines the sensitivity of the fire performance curves and the HRR curves for the given scenarios. This sensitivity, expert judgement, common practice, and regulatory rules are used to define a safety factor.

Key to the application of fire hazard analysis is a verified computer model to provide accurate predictions of the fire hazards within a passenger rail car. This chapter describes the results of a fire hazard analysis conducted for the full-scale coach test car and compares these results to the experimental data presented in Chapter 3.

4.1 FIRE HAZARD ANALYSIS RESULTS FOR THE TEST CAR

This section presents the fire hazard analysis results of the experimental test car. It should be noted that this section represents summary analyses derived from the more detailed coach car hazard analysis described in the Phase II interim report.

4.1.1 Important Materials

Figure 36 illustrates coach car interior furnishings. The materials that must be considered in this fire hazard analysis focus on the seating compartment. While the ignition source may vary, the method of flame spread and the relative importance of each material remain constant. The seat cushions are the most obvious material to consider as they represent the largest mass of combustible material. A secondary fuel source is the plastic tray table attached to the back of the seat and the arm-rest. In the assembly tests described in the Phase II interim report, the tray table released from the back of the seat in front of the fire, exposing a larger surface area to the growing fire. This phenomenon was not observed in the Phase III tests.

Figure 36. Typical Passenger Rail Car Interior Furnishings

Window drapes could be a source of vertical fire spread and can serve to increase the heat flux applied to the window.

The window glazing has one of the highest rates of heat release of any material tested in the coach car. Due to the fact that most radiant energy from an exposure fire is transmitted through the material, the window glazing is slow to ignite, often taking several minutes depending upon the incident flux exposure. However, the window glazing, once ignited, has a rapid growth rate and a significant peak HRR.

The wall carpet also exhibited delayed ignition and fast growth rates, attributable to melting of the glue that holds the wall lining to the wall surface. The wall carpet has the highest HRR of any material in the passenger rail coach car and represents a significant fuel load once ignited. The wall and FRP ceiling linings represent a large surface area of combustible material together with a moderate HRR. The combination of the large quantity and HRR makes the wall and ceiling lining a potentially serious contributor to a coach car fire. Finally, the greatest unknown with respect to the materials in the coach car is baggage brought onto the train, presumably stored in either the overhead racks, underneath the seat in front of each passenger, or in the small luggage closet at one end of the train. Luggage can contain many materials, varying dramatically in composition, density, quantity, and flammability. Recent tests of luggage have show it to have HRR values similar to those of the trash bags used as an ignition source for this project [31].

4.1.2 Analysis Results

Figure 37 shows the fire performance graph for the experimental test car geometry, with curves indicating incapacitation and lethality. This graph varies from the coach car analysis in Phase II, since the interior of the coach car used in the experiments was half the length due to accident damage at one end. For a medium growth rate t-squared fire (which reaches 1 MW in 300 s), the time to incapacitation (when a person is subjected to upper layer conditions (layer height ≤5 ft (1.5 m)) <u>and</u> the average air temperature exceeds 150 °F (65 °C)) was 129 s and the time to lethality (using a temperature of 212 °F (100 °C)) was 176 s. For other growth rate fires, the time to impaired evacuation ranged from 43 s to 230 s. These calculated times are compared to the ones determined from the gas burner tests in the next section.

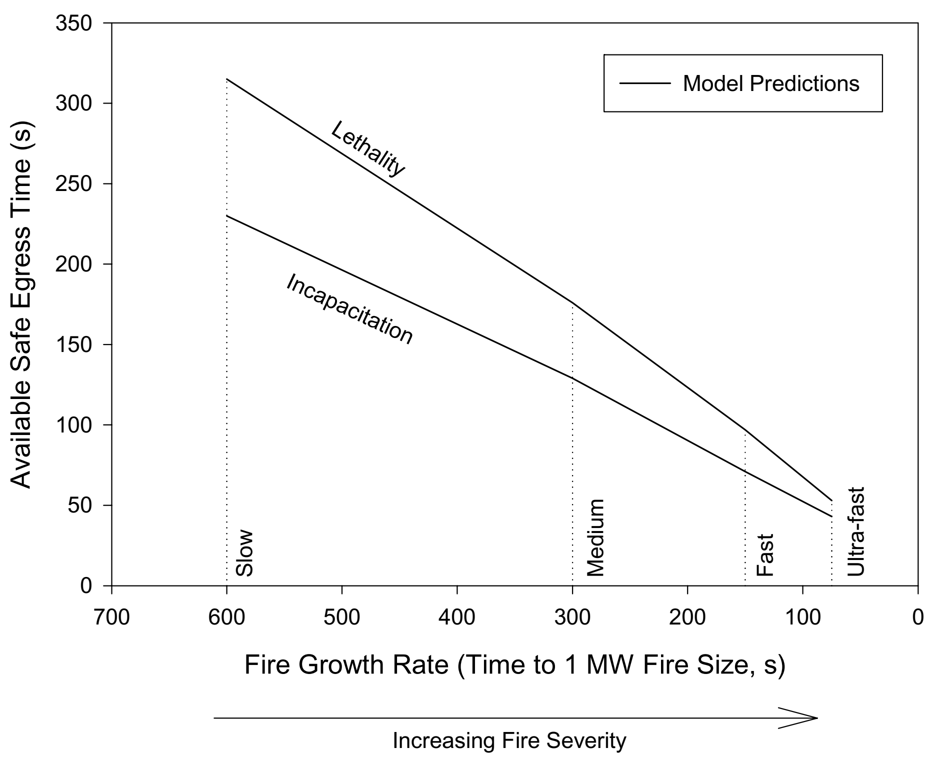


Figure 37. Amfleet I Test Car - Predicted Fire Performance Graph

4.2 COMPARISON OF FIRE HAZARD ANALYSIS PREDICTIONS WITH TEST DATA

Figure 38 includes fire performance graphs determined from experimental measurements in the gas burner tests described in Chapter 3 along with the fire model predicted curves from Figure 37. For a medium growth t-squared fire, the time to incapacitation determined from the replicate gas burner tests was (126 ± 9) s. For other growth rate fires, the time to incapacitation ranged from (40 ± 2) s for the ultra-fast growth rate fire to (231 ± 12) s for the slow growth rate fire. On average, the uncertainty of the experimentally determined times to untenable conditions was less than 7 percent (based on one standard deviation).

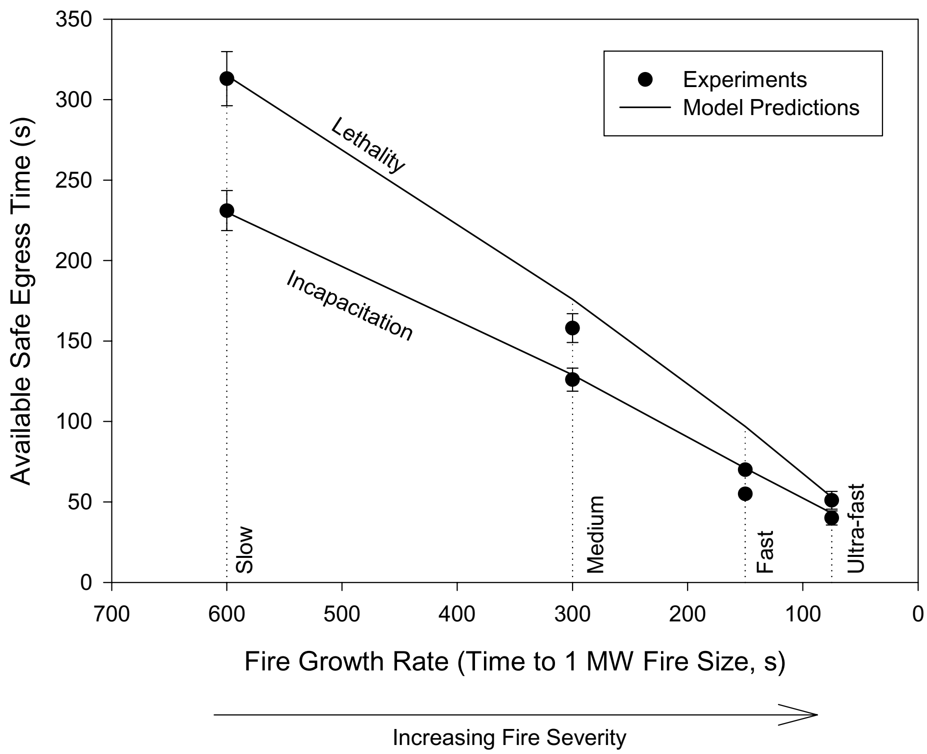


Figure 38. Amfleet I Test Car - Comparison of Measured and Predicted Fire Performance

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

13 percent should be considered excellent. It is important to note that this comparison was based on carefully controlled gas-burner experiments in a single car geometry. It does not include uncertainty due to fire growth in other sources (for example, the repeatability of the fire growth and spread tests is estimated to be within 17 percent) or other car designs.

4.3 SUMMARY

Key to the application of fire hazard analysis is a verified fire model to provide accurate predictions of the fire hazards within a passenger rail car. Comparison of times to untenable conditions for a range of fire sizes determined from experimental measurements with those calculated by the CFAST fire model showed agreement that averaged approximately 13 percent. With experimental uncertainty in the measurements typically less than 10 percent and typical agreement between fire model predictions and experiments of 20 to 25 percent, the average agreement for these calculations of 13 percent should be considered excellent.

Determining whether or not a hazard exists requires an estimate of the time necessary for passengers and crew to reach a point of safety. For buildings, the prediction of the reaction and movement of people in fires is well established. An emergency evacuation model for commercial aircraft also has been developed using similar techniques. Substantial modifications for the unique conditions of aircraft are required based on the large data base produced in the 90 second evacuation certification tests required by the FAA. No such model or data resource exists for passenger trains.

The full-scale car tests verified that the current high performance materials used in passenger rail cars require a significant and sustained initiating fire to produce hazardous conditions. For these large ignition sources, resulting hazards can still be reduced with appropriate modifications in design or procedures. For example, the potential of trash bags to represent such an initiating fire was identified, and Amtrak has taken steps to address that situation. Such a proactive approach to fire safety results in the reduction of significant fire hazards to factors beyond the control of the system operator, such as materials brought onboard by passengers and collision accidents. By identifying and addressing hazard scenarios, the risk of passenger and crew injury from fire can be minimized.

5. SUMMARY

Considerable advances in fire safety engineering have been made in the decades since the original development of the current fire safety requirements for passenger train material selection. Better understanding of the underlying phenomena governing fire initiation and growth has led to the development of advanced engineering analysis techniques. These techniques have gained worldwide credibility for the regulation of building fire safety and have recently been examined for a range of transportation vehicles. This Phase III interim report documents full-scale fire tests conducted in an actual passenger rail coach car and compares the test results with calculations from a fire hazard analysis using the Hazard I CFAST computer model.

5.1 FULL-SCALE RAIL CAR TESTS

Seventeen tests were conducted within an Amtrak passenger rail coach car. Three replicates for each representative t-squared fire growth rate provided an estimate of measurement uncertainty. The uncertainties for all measured quantities were reasonable and suggest that the data will provide the appropriate baseline for verification of the modeling from Phase II of the study. The range of ignition source strengths indicated that an ignition source size between 25 kW and approximately 200 kW is necessary to promote significant fire spread, which is consistent with the conclusions from the Phase II interim report that the ignition source strength of passenger rail car materials is 2 to 10 times greater than typical office furnishings. However, given an ignition source of the magnitude of a large trash bag, significant flame spread may be observed and resulting conditions within the rail car could become untenable. The ignition scenario where all components are ignited by a large trash bag has been addressed by Amtrak through a redesign of trash containers and modification of operational procedures to ensure that large accumulations of trash are removed from the cars.

5.2 COMPARISON OF FULL-SCALE TEST RESULTS TO EARLIER RESEARCH

A comparison of small-scale cone calorimeter material test results with full-scale component material assembly tests and full-scale tests using a passenger rail coach car shows similar ranking of materials from low HRR to high HRR. For the materials studied, small-scale tests in the cone calorimeter provide an appropriate tool for material screening for heat release. In practice, a major advantage of HRR data from a device like the cone calorimeter is the ability to use these data in an appropriate model to predict full-scale performance. Although not within the scope of this report, the data developed in Phases I – III of this project provide the necessary data for an analysis to develop such a predictive ability.

Comparison of the results from the current study to earlier rail vehicle tests was consistent with expected high performance of FRA-compliant materials. Peak temperatures in the current tests were lower than comparable fully-furnished rail vehicle tests with older materials.

5.3 IMPLICATIONS OF FULL-SCALE TESTS ON FIRE HAZARD ANALYSIS

Key to the application of fire hazard analysis is a verified fire model to provide accurate predictions of the fire hazards within a passenger rail car. Comparison of times to untenable conditions for a range of fire sizes determined from experimental measurements with those calculated by the CFAST fire model showed agreement which averaged approximately 13 percent. With experimental uncertainty in the measurements typically less than 10 percent and typical agreement between fire model predictions and experiments of 20 to 25 percent, the average agreement for these calculations of 13 percent should be considered excellent.

5.4 FUTURE WORK

Phase I of this study described the successful use of the cone calorimeter for evaluating the fire performance of component materials used in passenger rail cars. Using data from Phase I and additional HRR tests of full-scale component material assemblies, Phase II provided examples of the application of fire hazard analysis techniques to the passenger rail car interior environment. Finally, this Phase III interim report demonstrates that fire hazard analysis using computer modeling is sufficiently accurate to be used as a tool in evaluating passenger rail car fire safety.

It is important to note that this report did not address several areas important to the successful application of fire hazard analysis techniques for passenger rail cars:

- Accurate estimation of passenger rail car conditions and evacuation in an actual emergency situation. No verification of the calculation of the time necessary for passenger egress in the event of a passenger rail car fire was included.

- Development of appropriate HRR performance criteria. Appropriate small-scale (cone calorimeter) and full-scale (furniture calorimeter) test acceptance criteria for materials and component assemblies were not determined.

- Evaluation of unique characteristics of fabrics, structural flooring, and electrical wire and cable. The fire endurance of floor or wall partitions and the impact of electrical wire and cable were not considered.

These areas are suggested for further research and would provide additional resources for the application of fire hazard analysis techniques to passenger rail cars and rail transit vehicles.

The current FRA tests and performance criteria required by 49 CFR, Part 238, Subpart 238.103, were adapted from those that FTA first published in 1984 for rail transit vehicle materials. Due to the use of many similar interior materials, the FTA is interested in the potential application of fire hazard analyses as evaluated in Phases I-III of this FRA-sponsored study to rail transit vehicles. Accordingly, the FTA has contributed funding to the Volpe Center-directed fire safety research program.

6. REFERENCES

1. Peacock, R. D. and E. Braun. *Fire Safety of Passenger Trains Phase I: Material Evaluation (Cone Calorimeter)*. National Institute of Standards and Technology (NIST). Prepared for Federal Railroad Administration (FRA), U.S. Department of Transportation (USDOT). Washington, DC. Interim Report. Report No. DOT/FRA/ORD-99/01, January 1999. (Natl. Inst. Stand. Technol. Report NISTIR 6132, March 1999.)

2. Peacock, R. D., et al. *Fire Safety of Passenger Trains: Phase II Application of Fire Hazard Analysis Techniques*. NIST. Prepared for FRA/USDOT. Washington, DC. Interim Report. Report No. DOT/FRA/ORD-01/16. December 2001. (Natl. Inst. Stand. Technol. Report NISTIR 6525, December 2002.)

3. ASTM International. *Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter*. ASTM E-1354. Annual Book of ASTM Standards. Volume 04.07, 2000.

4. FRA. Code of Federal Regulations, Title 49, Transportation (49 CFR), *Part 238: Passenger Equipment Safety Standards. Subpart 238.103, Fire Safety and Appendix B*. National Archives and Records Administration, Washington, DC. Revised as of October 1, 2002.

5. FRA. 49 CFR, Transportation, Part 238: "Passenger Equipment Safety Standards; Final Rule." *Federal Register*, Vol. 64, No. 91, May 12, 1999. 25540-25705. National Archives and Records Administration, Washington, DC.

6. FRA. 49 CFR, Transportation, Part 238: "Passenger Equipment Safety Standards; Final Rule." *Federal Register*, Vol. 67, No.122, June 25, 2002. Response to Petitions for Reconsideration. 42892-42912. National Archives and Records Administration, Washington, DC.

7. FRA. "Rail Passenger Equipment; Guidelines for Selecting Materials to Improve Their Fire Safety Characteristics." *Federal Register*, Vol. 49, No. 62, 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.

8. 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. USDOT. National Archives and Records Administration, Washington, DC.

9. Federal Transit Administration (then 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.

10. Peacock, R. D., et al. *Fire Safety of Passenger Trains: A Review of U.S. and Foreign Approaches*. Natl. Inst. Stand. Technol. Prepared for FRA/USDOT. Washington, DC. Final Report. Report No. DOT/FRA/ORD-93/23, December 1993.

11. ASTM International. *Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using a Furniture Calorimeter.* ASTM E-1357. Annual Book of ASTM Standards. Volume 04.07. 2000.

12. Peacock, R. D. and E. Braun. *Fire Tests of Amtrak Passenger Rail Vehicle Interiors*. Performed for FRA/USDOT. Natl. Bur. Stand. (U.S.). Technical Note 1183, 1984.

13. ERRI. Working Party B 106.2. *Coaches; Reasons for Undertaking Supplementary Studies on Improvement of Protection of Coaches Against Fire.* ERRI B 106 RP 22. Utrecht, Netherlands. July 1992.

14. ERRI. Working Party B 106.2. *Coaches; Feasibility Study of Computer Modeling of Fires in Railway Vehicles with a View to Improving Passenger Safety.* ERRI B 106 RP 25. Utrecht, Netherlands. November 1992.

15. ERRI. Young, R. and S. Metral. Edited by A. Kaminski, ERRI Technical Advisor. *Improvement of the Protection 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, Netherlands. June 1994.

16. ERRI. *Improvement of the Fire Protection of Passenger Rolling Stock;Progress Report on the Tests Carried Out Using A Cone Calorimeter and the Furniture Calorimeter and on the Calculation with the HAZARD 1.1. Software Package.* ERRI C 204/RP 2. Utrecht, Netherlands. 1995.

17. ERRI. *Improvement of Fire Protection Against Fire of Passenger Rolling Stock; Final Report on the Feasibility Study into Computer Modelling of Fire in a Railway Vehicle.* ERRI C204.1/RP3. Utrecht, Netherlands. June 1997.

18. ERRI. Metral, S., J. Wolinska, and G. Barbu. *Improvement of the Protection Against Fire of Passenger Rolling Stock; Results of Laboratory Tests using a Cone Calorimeter to Provide Data for Computation.* ERRI C204.1/DT301. Utrecht, Netherlands. 1994.

19. ERRI. Young, R. Scientifics/British Railway Board. Edited by A. Kaminski, ERRI Technical 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, Netherlands. June 1995.

20. ERRI. Metral, S., J. Wolinska, and G. Barbu. *Improvement of Fire Protection of Passenger Rolling Stock; Computer Simulation of the Fire Process Within Railway Passenger Coaches Using the HAZARD 1.2 Software.* ERRI C204.1/DT358. Utrecht,

Netherlands. November 1997.

21. *Fires in Transport Tunnels, Report on Full-Scale Tests, EUREKA Project 499:FIRETUN*. editor Studiengesellschaft Stahlanwendung e.V., D-40213 Dusseldorf, Germany, November 1995.

22. Le Tallec, Y., A. Sainrat,, and V. Le Sant. *The FIRESTARR Project – Fire Protection of Railway Vehicles.* Fire and Materials 2001. 7th International Conference and Exhibition. Proceedings. Interscience Communications Limited. January 22-24, 2001, San Antonio, TX, 53-66 pp, 2001.

23. *Final Report,* Report C/SNCF/01001, SNCF, Direction Matérial et de la Traction, Paris. April 2001.

24. Braun, E. *Fire Hazard Evaluation of the Interior of WMATA Metrorail Cars*. Prepared for Washington Metropolitan Area Transit Authority. Natl. Bur. Stand. (U.S.). NBSIR 75-971, December 1975.

25. Braun, E. *Fire Hazard Evaluation of BART Vehicles*. NBS. Prepared for UMTA, USDOT. Natl. Bur. Stand. (U.S.). NBSIR 78-1421, March 1978.

26. Schifiliti, R.P. "Design of Detection Systems," Section 3/Chapter 1, *SFPE Handbook of Fire Protection Engineering*, Third Edition, Phillip J. DiNenno, P.E., editor-in-chief, Society of Fire Protection Engineers, Boston, MA. March 2002.

27. Ohlemiller, T. J. and Villa, K. "Characterization of the California Technical Bulletin 133 Ignition Source and a Comparable Gas Burner," *Fire Safety Journal*, Vol.18, No. 4, pp 325-354, 1992.

28. State of California. *Technical Bulletin (CAL TB 133) Flammability Test Procedure for Seating Furniture for Use in Public Occupancies*, North Highlands, CA. 1991.

29. Janssens, M. and J. Huczek, "Fire Hazard Assessment of Commuter Rail Equipment", *Fire Risk & Hazard Assessment Research Application Symposium*, Baltimore, MD, July 24-26, 2002, pp. 404-433.

30. Blevins, L. G., and W. M. Pitts. *Modeling of Bare and Aspirated Thermocouples in Compartment Fires*. Natl. Inst. Stand. Technol. Report NISTIR 6310, April 1999.

31. Messa, S. L. S. F. Fire Laboratories, *Designing Fires for Firestarr*, Draft Report March 2000." L.S.F. srl Laboratorio di Studi e Ricerche sul Fuoco, Italy, 2000.

APPENDIX A. FRA Regulations: 49 CFR, Part 238

Passenger Rail Car and Locomotive Fire Safety-
Subpart 238.103 and Appendix B

(As of June 25, 2002; effective August 25, 2002)

- Incorporating June 25, 2002 revisions to May 12, 1999 Federal Register Notice -

238.103 Fire Safety

(a) *Materials.* (1) Materials used in constructing a passenger car or a cab of a locomotive ordered on or after September 8, 2000, or placed in service for the first time on or after September 9, 2002, shall meet the test performance criteria for flammability and smoke emission characteristics as specified in Appendix B to this part, or alternative standards issued or recognized by an expert consensus organization after special approval of FRA under Sec. 238.21.

(2) On or after November 8, 1999, materials introduced in a passenger car or a locomotive cab, as part of any kind of rebuild, refurbishment, or overhaul of the car or cab, shall meet the test performance criteria for flammability and smoke emission characteristics as specified in Appendix B to this part, or alternative standards issued or recognized by an expert consensus organization after special approval of FRA under Sec. 238.21.

(3) For purposes of complying with the requirements of this paragraph, a railroad may rely on the results of tests of material conducted in accordance with the standards and performance criteria for flammabilitiy and smoke emission characteristics as specified in Appendix B to this part in effect on July 12, 1999 (see 49 CFR parts 200-399, revised as of October 1, 1999), if prior to June 25, 2002 the material is–

(i) Installed in a passenger car or locomotive;

(ii) Held in inventory by the railroad; or

(iii) Ordered by the railroad.

(b) *Certification*. A railroad shall require certification that a representative sample of combustible materials to be--

(1) Used in constructing a passenger car or a locomotive cab, or

(2) Introduced in a passenger car or a locomotive cab, as part of any kind of rebuild, refurbishment, or overhaul of the car or cab, has been tested by a recognized independent testing laboratory and that the results show the representative sample complies with the requirements of paragraph (a) of this section at the time it was tested.

(c) Fire safety analysis for procuring new passenger cars and locomotives. In procuring new passenger cars and locomotives, each railroad shall ensure that fire safety considerations and features in the design of this equipment reduce the risk of personal injury caused by fire to an acceptable level in its operating environment using a formal safety methodology such as MIL-STD-882. To this end, each railroad shall complete a written fire safety analysis for the passenger equipment being procured. In conducting the analysis, the railroad shall--

(1) Identify, analyze, and prioritize the fire hazards inherent in the design of the equipment.

(2) Take effective steps to design the equipment and select materials which help provide sufficient fire resistance to reasonably ensure adequate time to detect a fire and safely evacuate the passengers and crewmembers, if a fire cannot be prevented. Factors to consider include potential ignition sources; the type, quantity, and location of the materials; and availability of rapid and safe egress to the exterior of the equipment under conditions secure from fire, smoke, and other hazards.

(3) Reasonably ensure that a ventilation system in the equipment does not contribute to the lethality of a fire.

(4) Identify in writing any train component that is a risk of initiating fire and which requires overheat protection. An overheat detector shall be installed in any component when the analysis determines that an overheat detector is necessary.

(5) Identify in writing any unoccupied train compartment that contains equipment or material that poses a fire hazard, and analyze the benefit provided by including a fire or smoke detection system in each compartment so identified. A fire or smoke detector shall be installed in any unoccupied compartment when the analysis determines that such equipment is necessary to ensure sufficient time for the safe evacuation of passengers and crewmembers from the train. For purposes of this section, an unoccupied train compartment means

any part of the equipment structure that is not normally occupied during operation of the train, including a closet, baggage compartment, food pantry, etc.

(6) Determine whether any occupied or unoccupied space requires a portable fire extinguisher and, if so, the proper type and size of the fire extinguisher for each location. As required by Sec. 239.101 of this chapter, each passenger car is required to have a minimum of one portable fire extinguisher. If the analysis performed indicates that one or more additional portable fire extinguishers are needed, such shall be installed.

(7) On a case-by-case basis, analyze the benefit provided by including a fixed, automatic fire-suppression system in any unoccupied train compartment that contains equipment or material that poses a fire hazard, and determine the proper type and size of the automatic fire suppression system for each such location. A fixed, automatic fire-suppression system shall be installed in any unoccupied compartment when the analysis determines that such equipment is practical and necessary to ensure sufficient time for the safe evacuation of passengers and crewmembers from the train.

(8) Explain how safety issues are resolved in the design of the equipment and selection of materials to reduce the risk of each fire hazard.

(9) Describe the analysis and testing necessary to demonstrate that the fire protection approach taken in the design of the equipment and selection of materials meets the fire protection requirements of this part.

(d) *Fire safety analysis for existing passenger equipment*.

(1) Not later than January 10, 2001, each passenger railroad shall complete a preliminary fire safety analysis for each category of existing passenger cars and locomotives and rail service.

(2) Not later than July 10, 2001, each such railroad shall--

(i) Complete a final fire safety analysis for any category of existing passenger cars and locomotives and rail service evaluated during the preliminary fire safety analysis as likely presenting an unacceptable risk of personal injury. In conducting the analysis, the railroad shall consider the extent to which materials comply with the test performance criteria for flammability and smoke emission characteristics as specified in Appendix B to this part or alternative standards approved by FRA under this part.

(ii) Take remedial action to reduce the risk of personal injuries to an acceptable level in any such category, if the railroad finds the risk to be unacceptable. In considering remedial action, a railroad is not required to replace material found not to comply with the test performance criteria for flammability and smoke emission characteristics required by this part, if:

(A) The risk of personal injuries from the material is negligible based on the railroad's operating environment and the material's size, or location, or both; or

(B) The railroad takes alternative action which reduces the risk of personal injuries to an acceptable level.

(3) Not later than July 10, 2003, each such railroad shall--

(i) Complete a final fire safety analysis for all categories of existing passenger cars and locomotives and rail service. In completing this analysis, the railroad shall, as far as practicable, determine the extent to which remaining materials comply with the test performance criteria for flammability and smoke emission characteristics as specified in Appendix B to this part or alternative standards approved by FRA under this part.

(ii) Take remedial action to reduce the risk of personal injuries to an acceptable level in any such category, if the railroad finds the risk to be unacceptable. In considering remedial action, a railroad is not required to replace material found not to comply with the test performance criteria for flammability and smoke emission characteristics required by this part, if:

(A) The risk of personal injuries from the material is negligible based on the railroad's operating environment and the material's size, or location, or both; or

(B) The railroad takes alternative action which reduces the risk of personal injuries to an acceptable level.

(4) Where possible prior to transferring existing passenger cars and locomotives to a new category of rail service, but in no case more than 90 days following such a transfer, the passenger railroad shall complete a new fire safety analysis taking into consideration the change in railroad operations and shall effect prompt action to reduce any identified risk to an acceptable level.

(5) As used in this paragraph, a "category of existing passenger cars and locomotives and rail service" shall be determined by the railroad based on relevant fire safety risks, including available ignition sources, presence or absence of heat/smoke detection systems, known variations from the required material test performance criteria or alternative standards approved by FRA, and availability of rapid and safe egress to the exterior of the vehicle under conditions secure from fire, smoke, and other hazards.

(e) Inspection, testing, and maintenance. Each railroad shall develop and adopt written procedures for the inspection, testing, and maintenance of all fire safety systems and fire safety equipment on the passenger equipment it operates. The railroad shall comply with these procedures that it designates as mandatory for the safety of the equipment and its occupants.

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 Sec. 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 Office of the Federal Register, 800 North Capitol Street, N.W., Suite 700, Washington, D.C. 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 (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 (Is) means, as defined in ASTM E 162-98, a factor derived from the rate of progress of the flame front (Fs) and the rate of heat liberation by the material under test (Q), such that Is = Fs x 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 (Ds) 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/cm2 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:

NOTES TO TABLE

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 California Technical Bulletin 133, and testing of a complete mattress assembly (including foam and ticking) according to ASTM E 1590-01 using the pass/fail criteria of California Technical Bulletin 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.

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 ≤ 10 seconds Burn length ≤ 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. ≥ 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 < 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

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 (including equipment carrying portions of a vehicle's roof and interior floors separating lower level of a bi-level car, but not including a flooring assembly subject to Note 16) 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. A railroad is not required to use the ASTM E 119 test method.

APPENDIX B. PASSENGER RAIL CAR FULL-SCALE TEST DATA

A series of passenger rail car full-scale fire tests was performed in August 1999 at the Army Test Center, Aberdeen, MD.

Two different types of full-scale tests were conducted to evaluate the accuracy of the results of the passenger rail car fire hazard analyses conducted in Phase II of this research study: 1) a series of gas burner tests conducted to evaluate the accuracy of the baseline analysis fire growth rates for an actual coach car geometry, and 2) a smaller series of fire tests to evaluate fire spread and growth for actual passenger rail car furnishings exposed to a range of initial fire sources.
Table B-1 lists full-scale the tests conducted in the Amfleet I passenger rail coach test car.

Table B-1. Full-Scale Tests Conducted in Amfleet I Test Car

TEST NUMBERS	TEST TYPE AND IGNITION SOURCE	
1-3	Slow t^2 gas burner (3 replicates)	
4-6	Medium t^2 gas burner (3 replicates)	
7-9	Fast t^2 gas burner (3 replicates)	
10-12	Ultra-fast t^2 gas burner (3 replicates	
13	Window Drape	25 kW gas burner on lower edge
14	Corner Test	Trash Bag in corner next to wall carpet and FRP Panel
15		25 kW gas burner below seat
16	Seating Area	TB 133 gas burner on seat
17		Trash bag on seat

This appendix contains the data results from the 17 tests.

The test instrumentation used in the test experiments consisted of thermocouples; heat flux gauges; smoke obscuration meters; and oxygen, carbon dioxide and carbon monoxide analyzers. The installed locations of the instrument arrays and the gas sampling points are shown in Figure B-1.

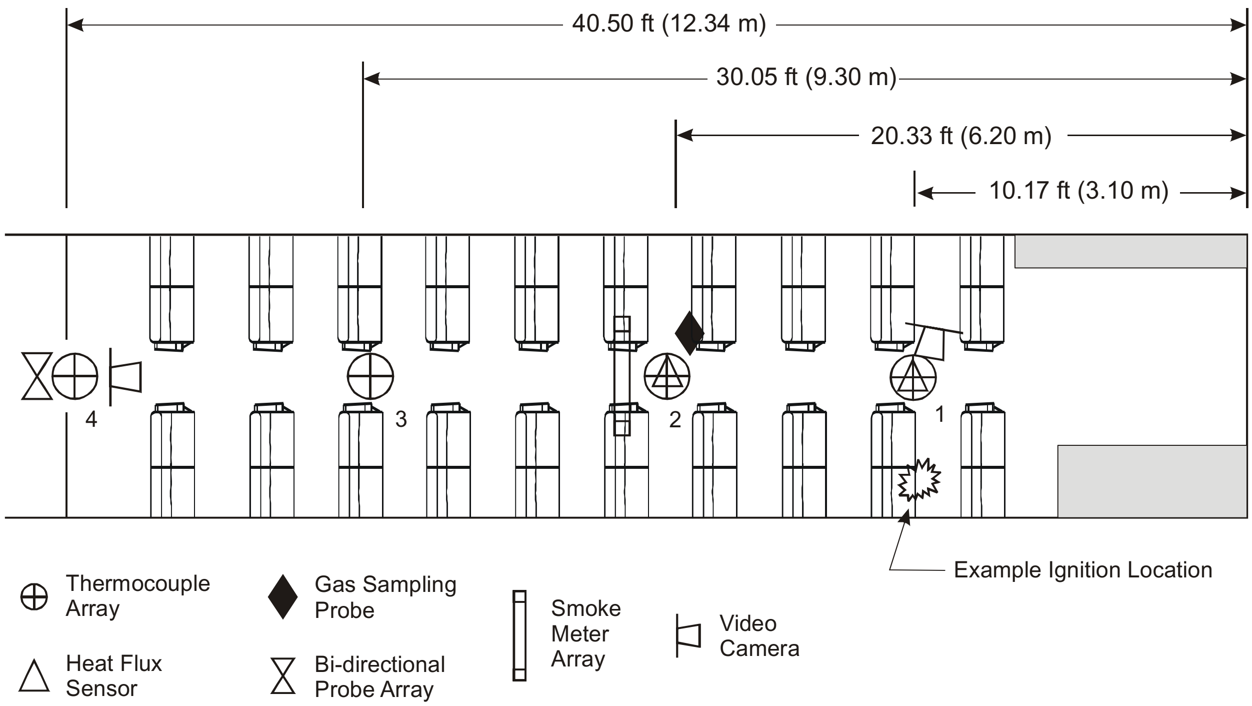


Figure B-1. Amfleet I Test Car - Interior "A" End Instrumentation

B. 2 TEST RESULTS

Figures B-2 through B-142 show the measured test results for all instrument locations. The following data are included for each test:

- Gas temperatures at various locations throughout the passenger rail car,
- Carbon monoxide, carbon dioxide, and oxygen concentrations in the center of the rail car,
- Heat flux measured at two locations in the rail car,
- Smoke obscuration at several positions in the rail car, and
- Heat release rate of the fire measured in the rail car stack.

In some experiments, one or more of these measurements was not available. These are noted in the graphs, as appropriate. Uncertainty in these measurements are discussed in Section 3.5 of this report.

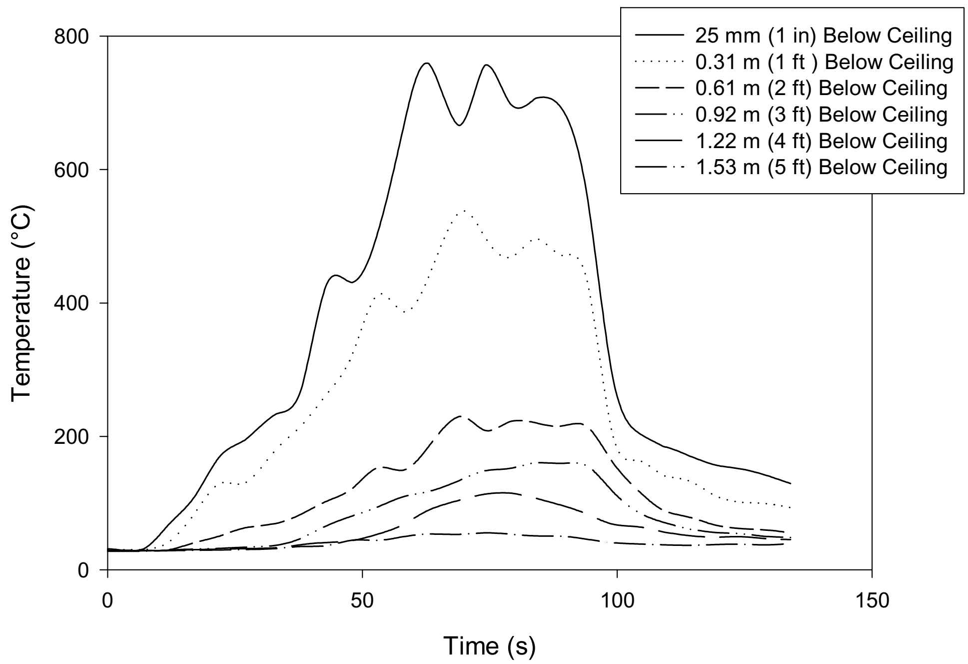


Figure B-2. Test 1 (Slow Gas Burner), Thermocouple Array 1 Data

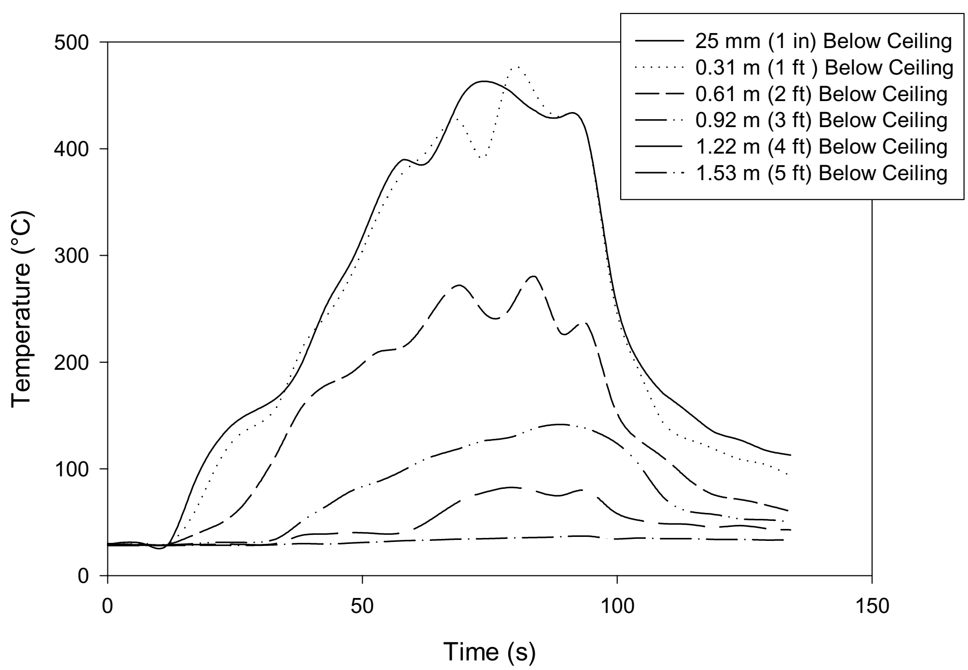


Figure B-3. Test 1 (Slow Gas Burner), Thermocouple Array 2 Data

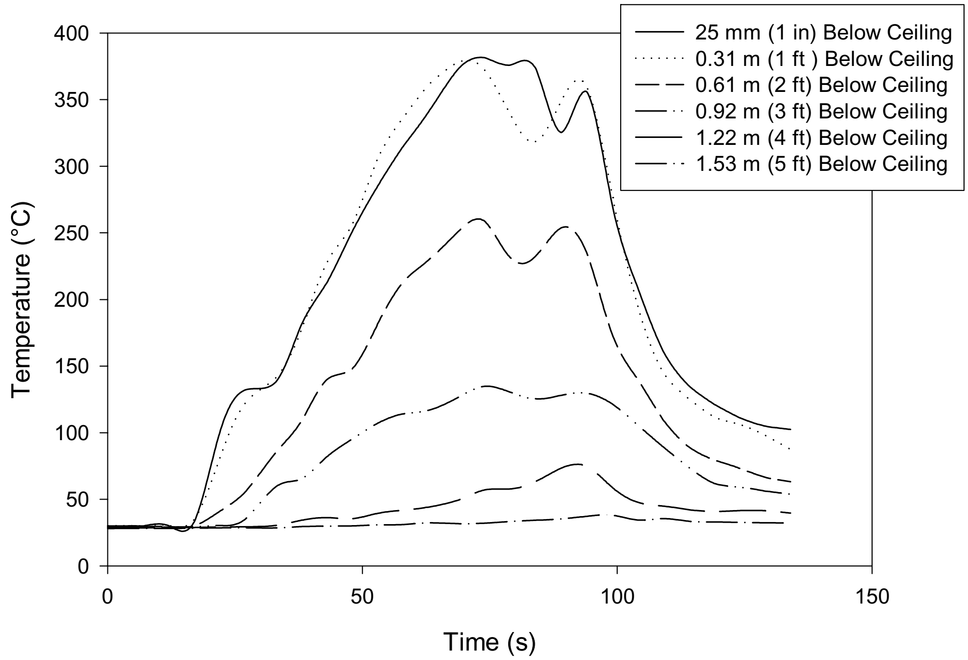


Figure B-4. Test 1 (Slow Gas Burner), Thermocouple Array 3 Data

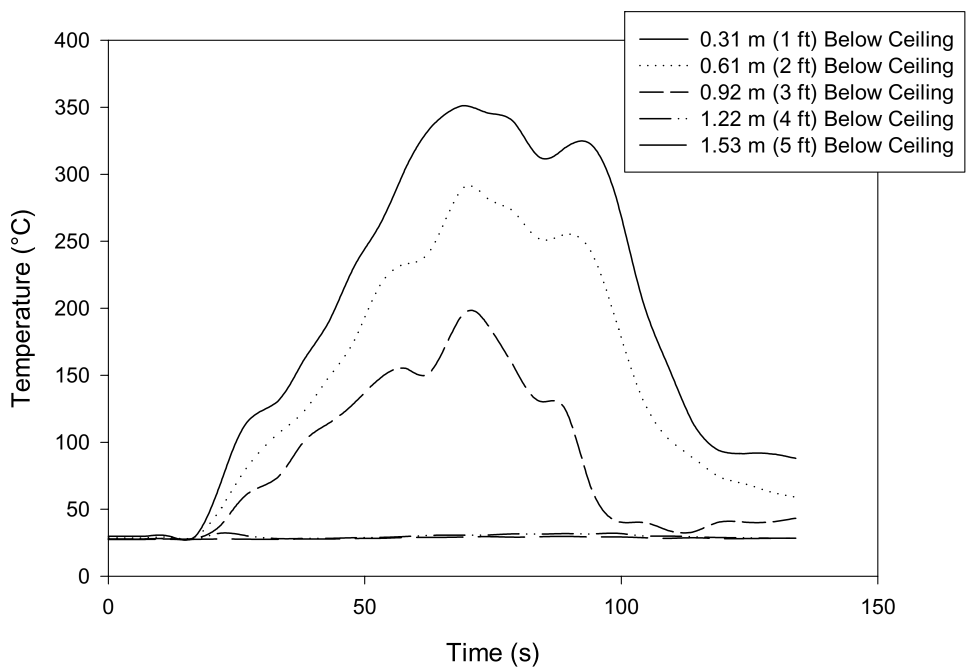


Figure B-5. Test 1 (Slow Gas Burner), Thermocouple Array 4 Data

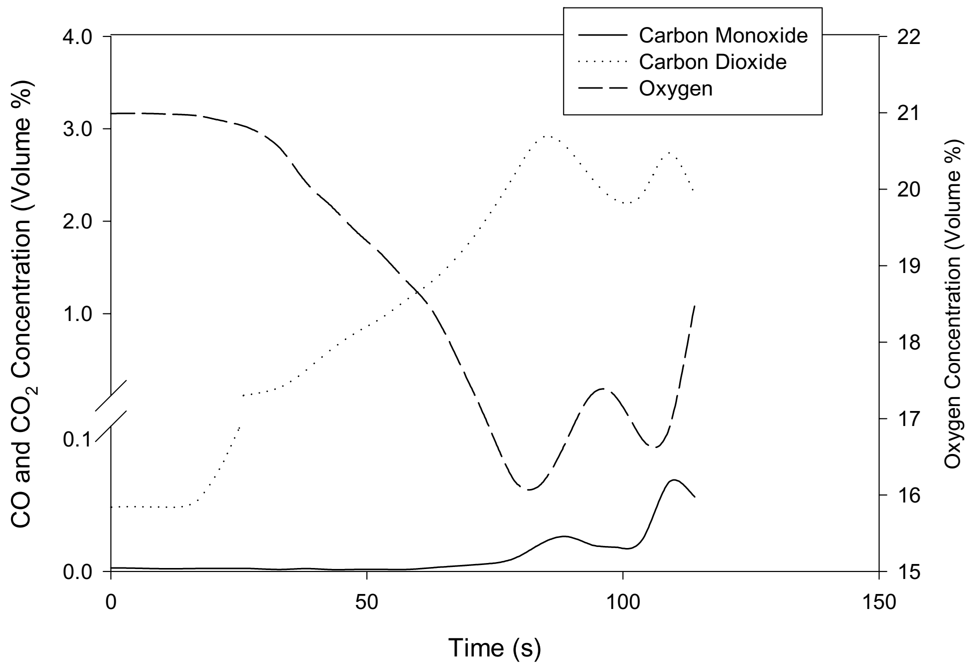


Figure B-6. Test 1 (Slow Gas Burner), Gas Concentration Data

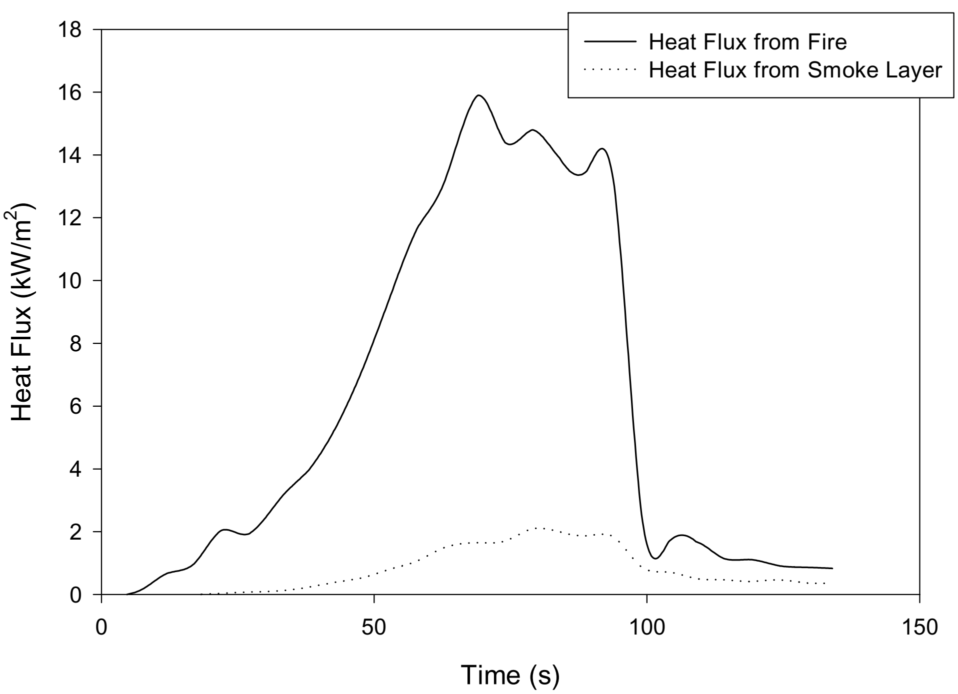


Figure B-7. Test 1 (Slow Gas Burner), Heat Flux Data

Figure B-8. Test 1 (Slow Gas Burner), Heat Release Rate Data

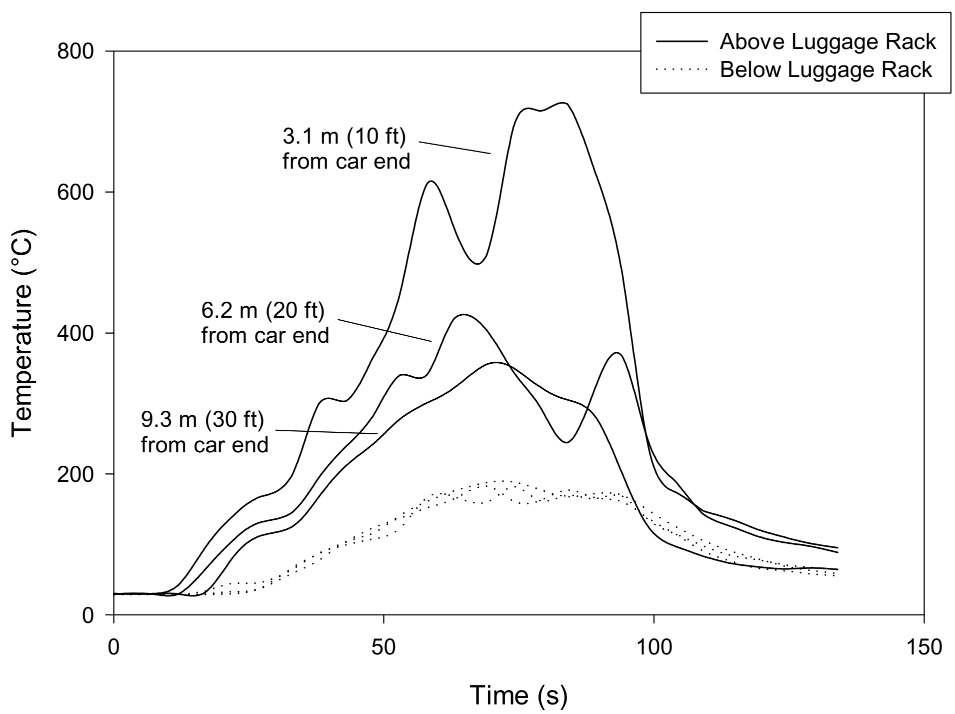


Figure B-9. Test 1 (Slow Gas Burner), Luggage Rack Temperature Data

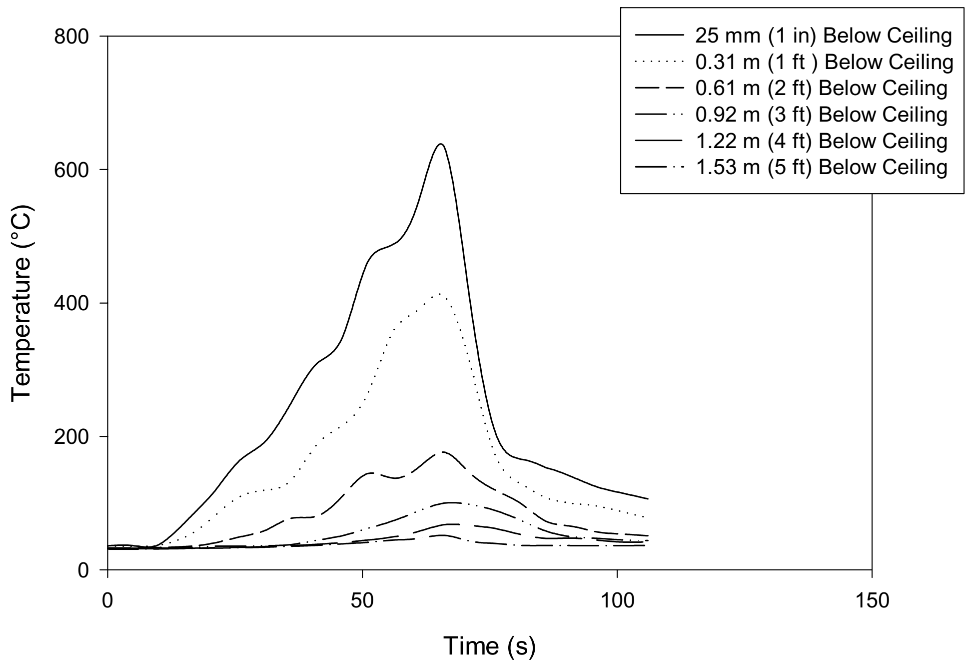


Figure B-10. Test 2 (Slow Gas Burner), Thermocouple Array 1 Data

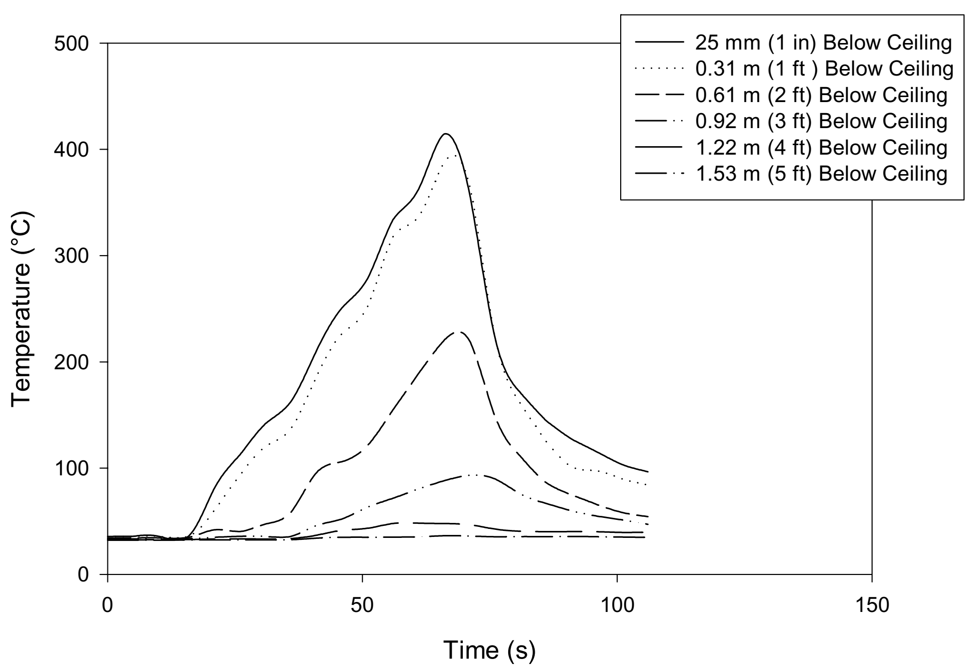


Figure B-11. Test 2 (Slow Gas Burner), Thermocouple Array 2 Data

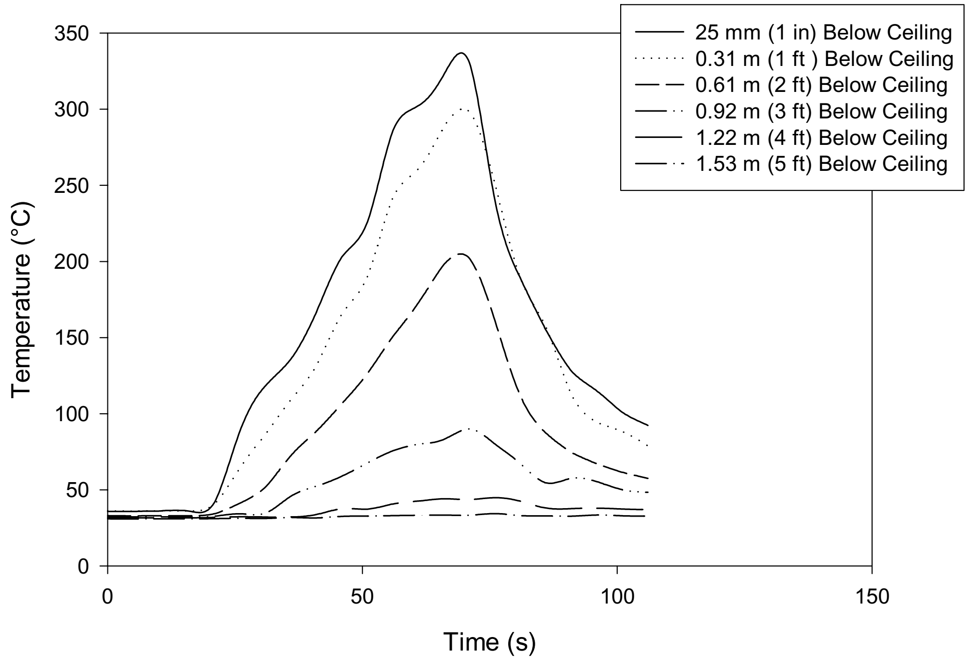


Figure B-12. Test 2 (Slow Gas Burner), Thermocouple Array 3 Data

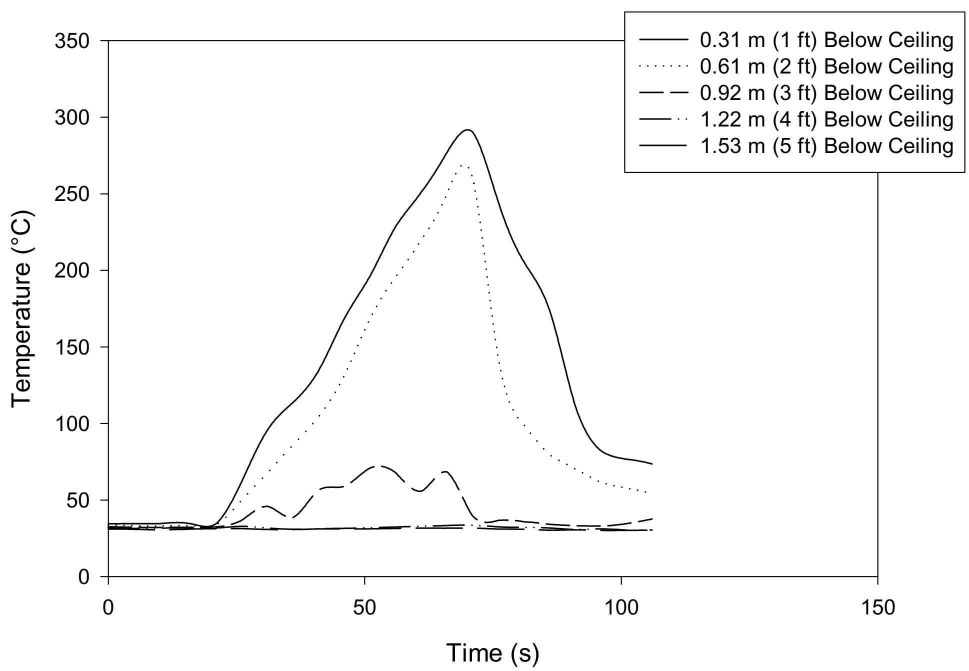


Figure B-13. Test 2 (Slow Gas Burner), Thermocouple Array 4 Data

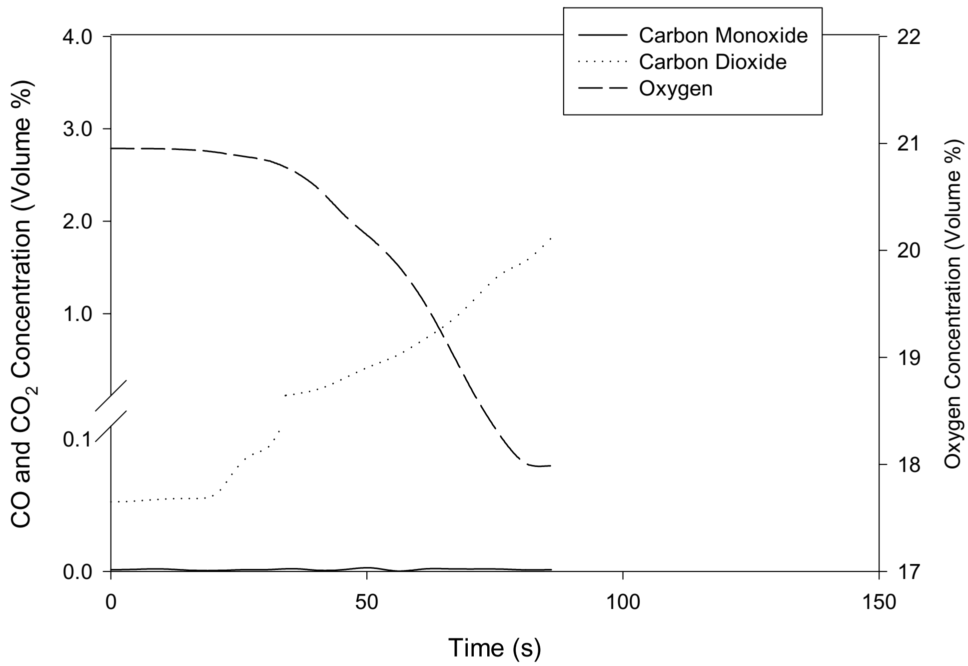


Figure B-14. Test 2 (Slow Gas Burner), Gas Concentration Data

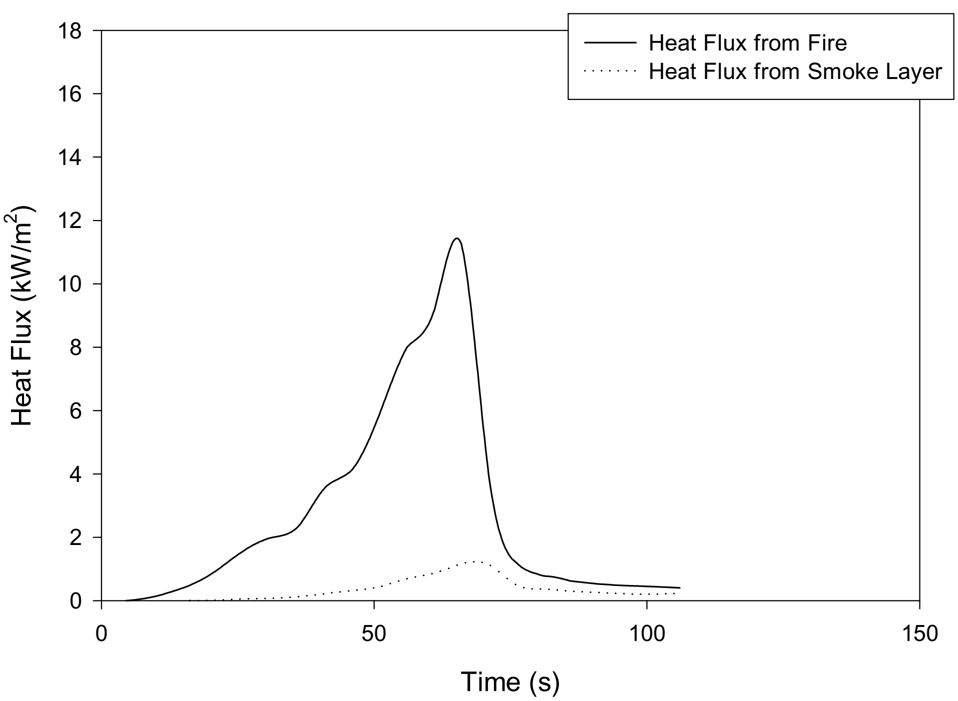


Figure B-15. Test 2 (Slow Gas Burner), Heat Flux Data

Figure B-16. Test 2 (Slow Gas Burner), Heat Release Rate Data

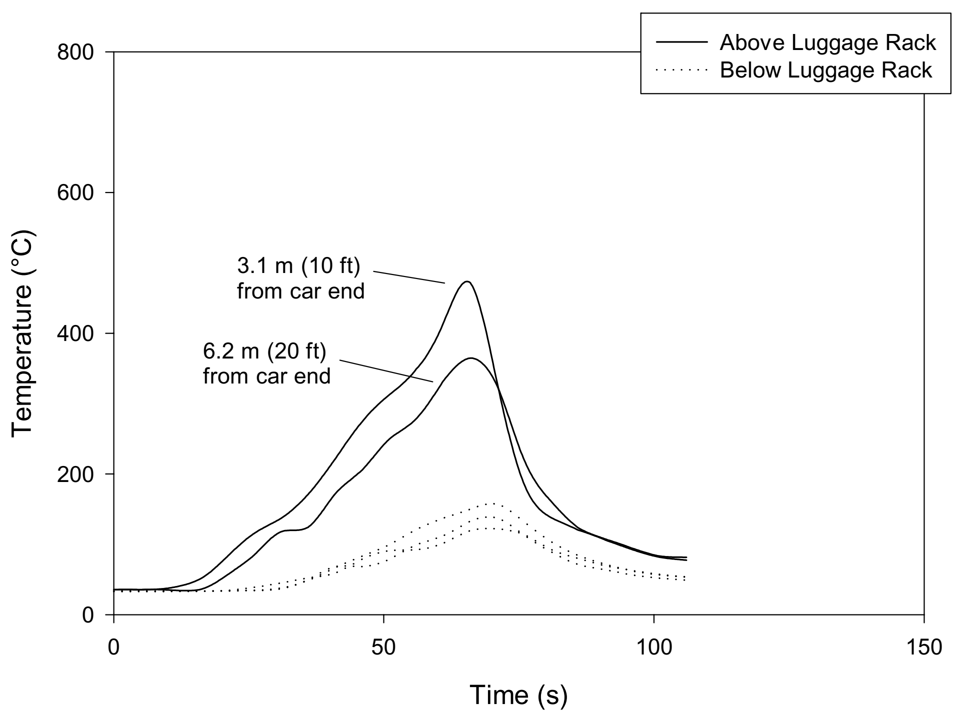


Figure B-17. Test 2 (Slow Gas Burner), Luggage Rack Temperature Data

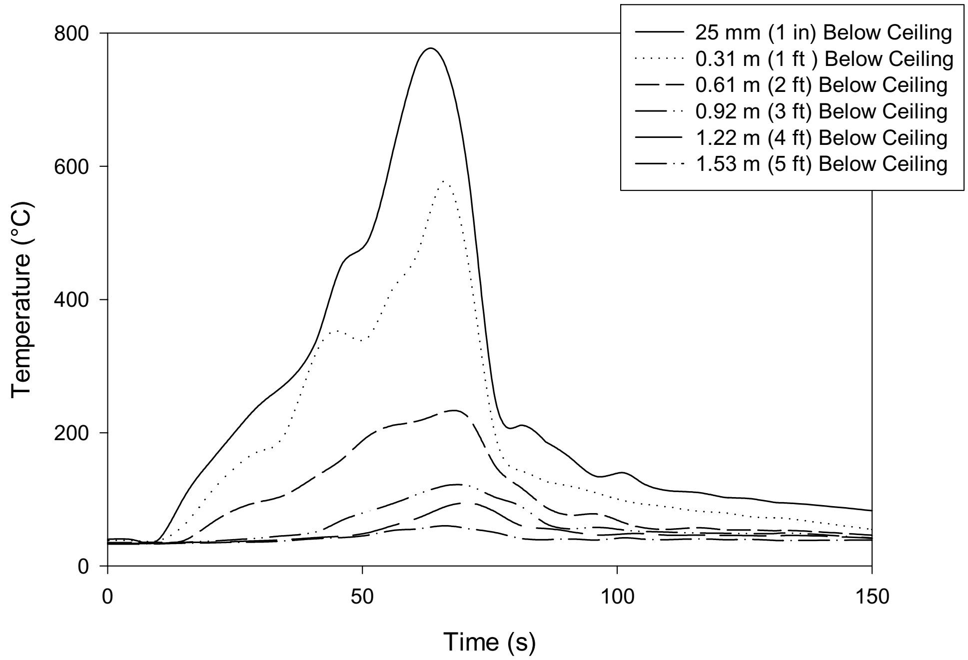


Figure B-18. Test 3 (Slow Gas Burner), Thermocouple Array 1 Data

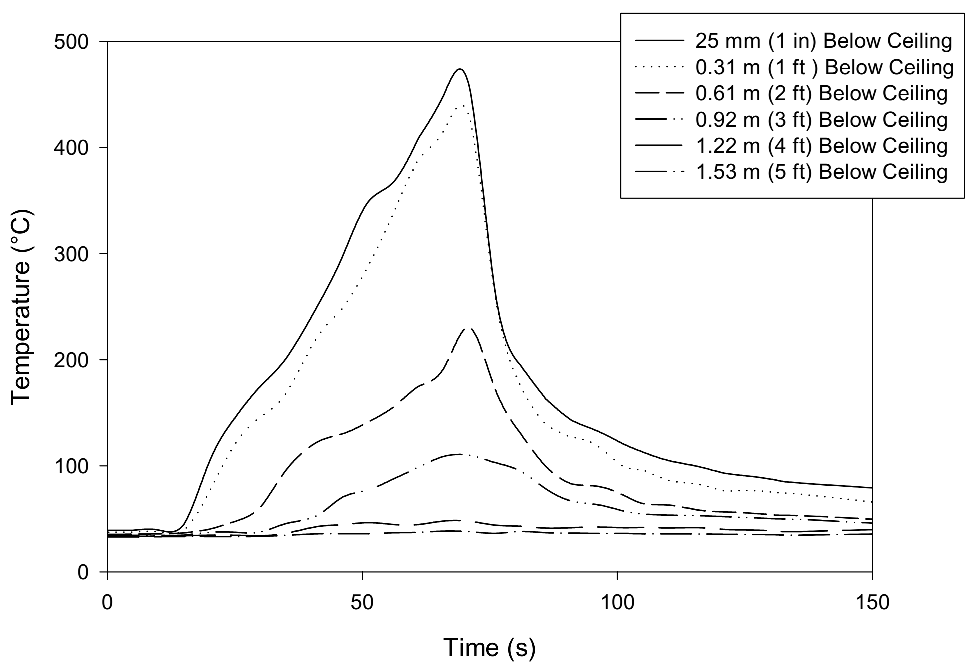


Figure B-19. Test 3 (Slow Gas Burner), Thermocouple Array 2 Data

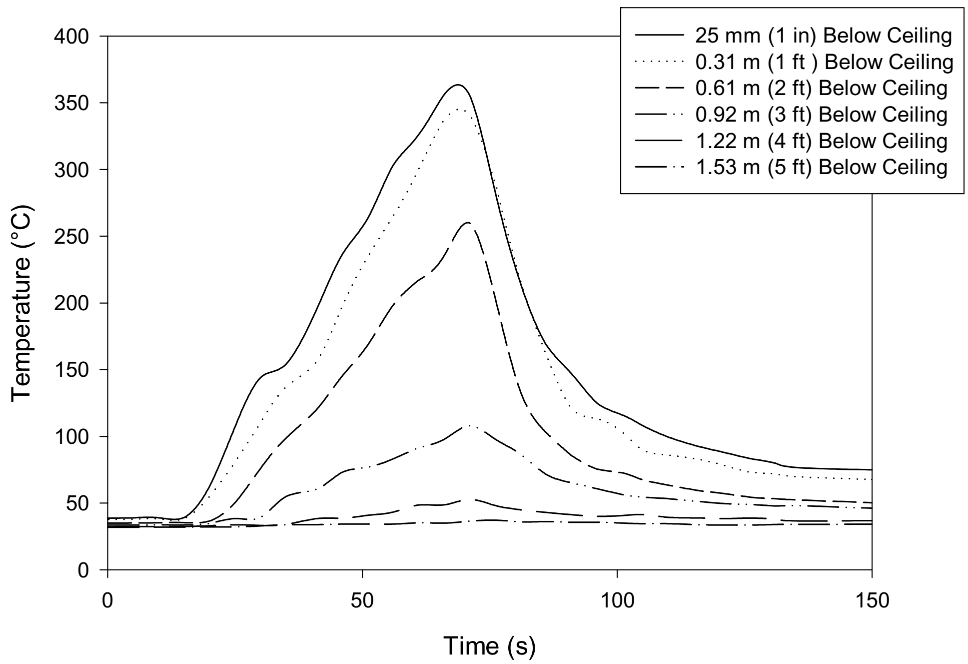


Figure B-20. Test 3 (Slow Gas Burner), Thermocouple Array 3 Data

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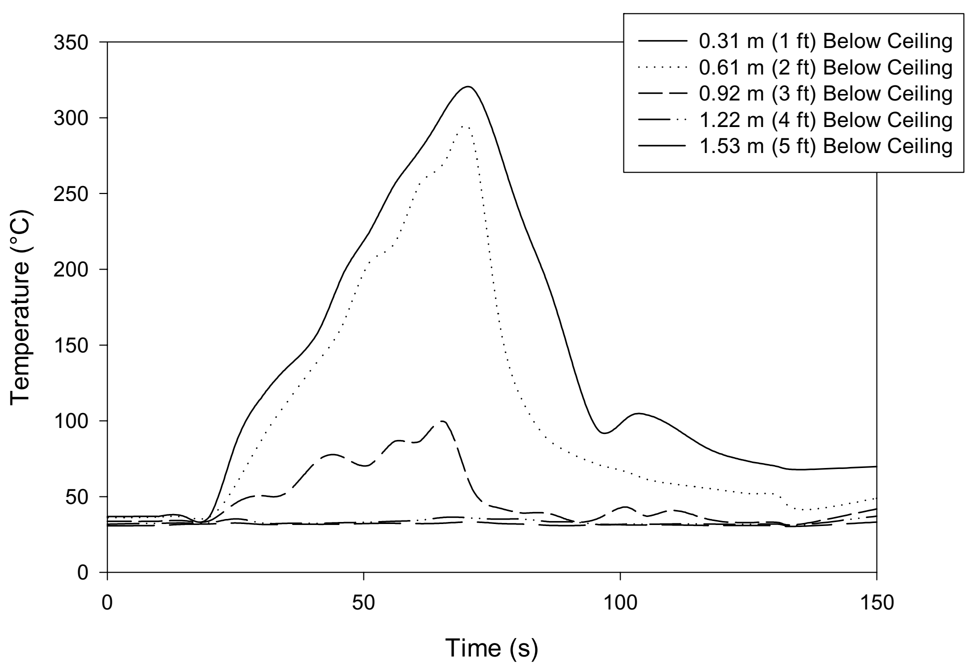

Figure B-21. Test 3 (Slow Gas Burner), Thermocouple Array 4 Data

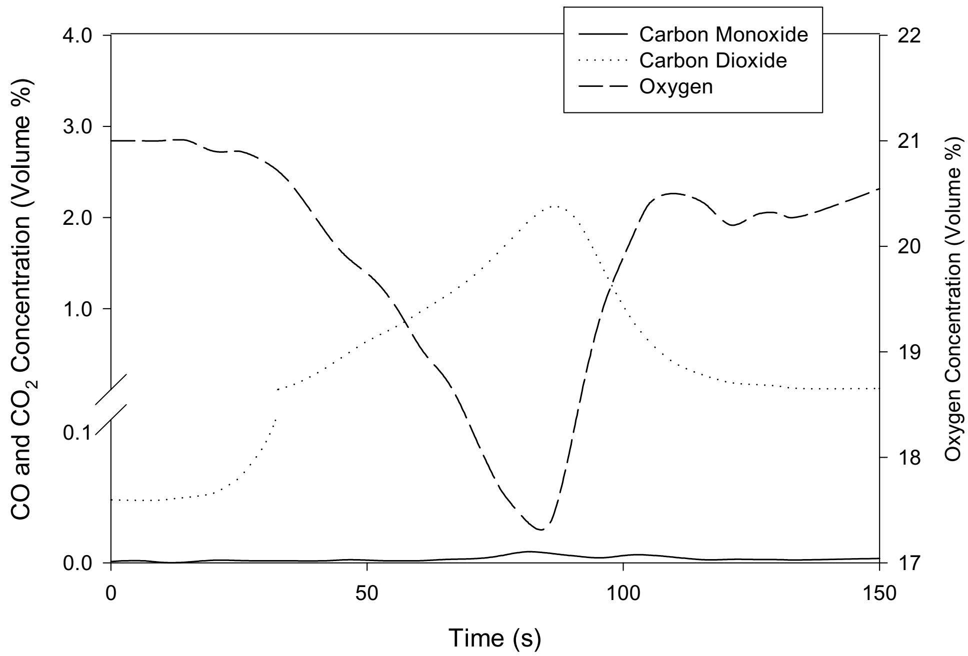

Figure B-22. Test 3 (Slow Gas Burner), Gas Concentration Data

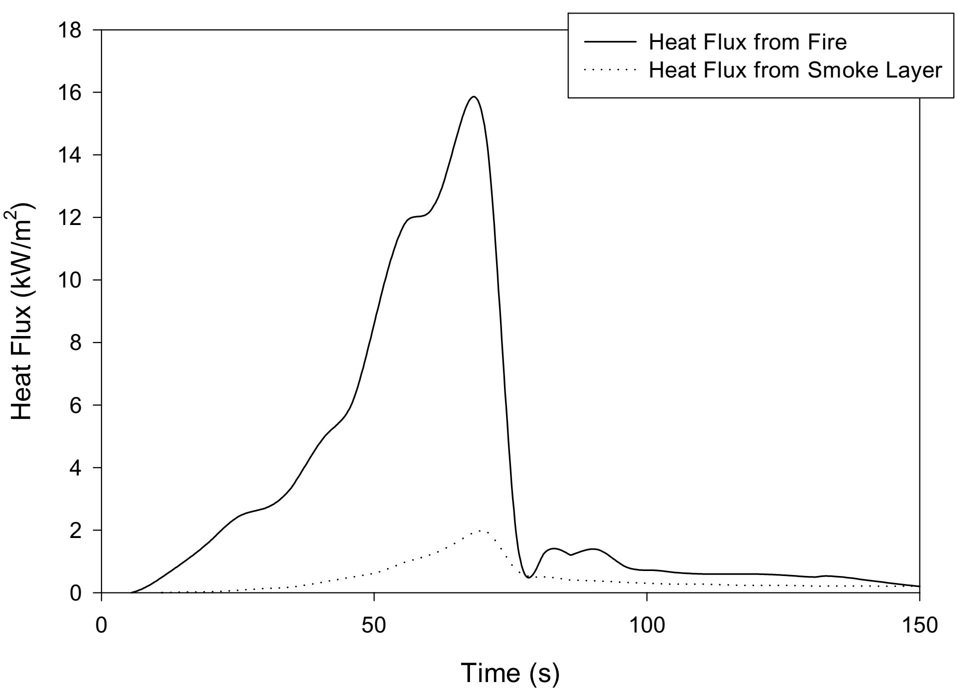

Figure B-23. Test 3 (Slow Gas Burner), Heat Flux Data

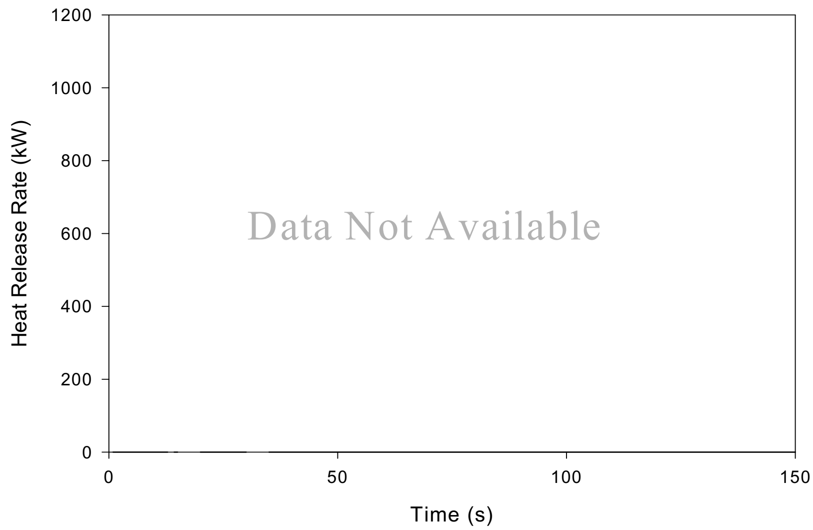

Figure B-24. Test 3 (Slow Gas Burner), Heat Release Rate Data

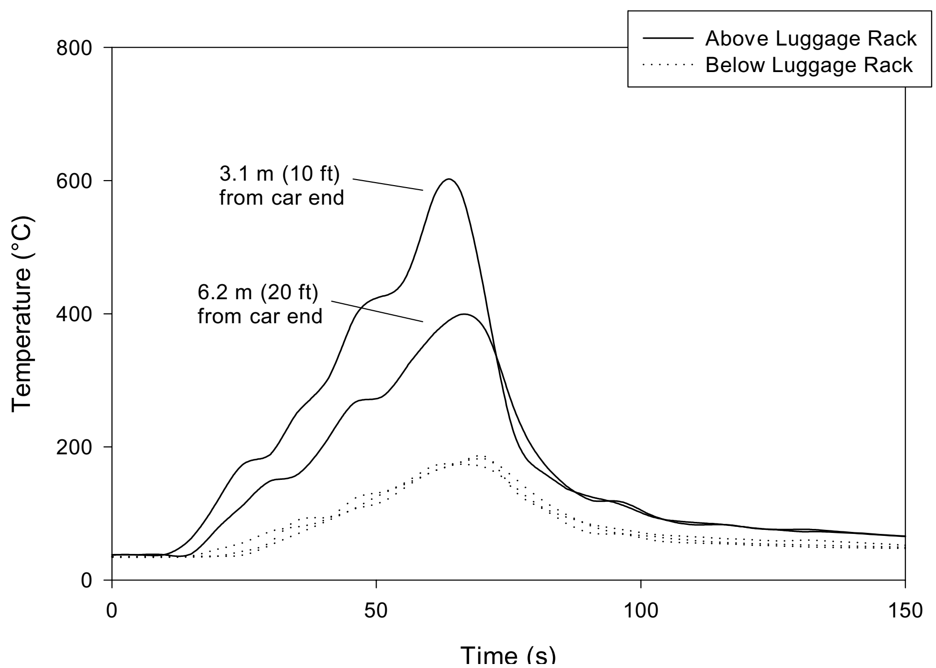

Figure B-25. Test 3 (Slow Gas Burner), Luggage Rack Temperature Data

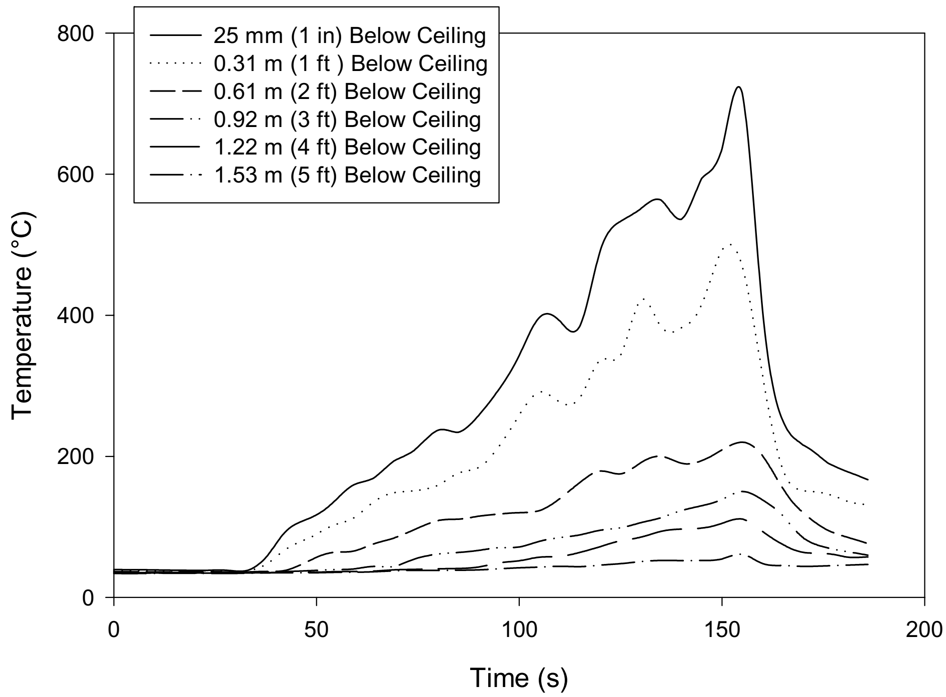

Figure B-26. Test 4 (Medium Gas Burner), Thermocouple Array 1 Data

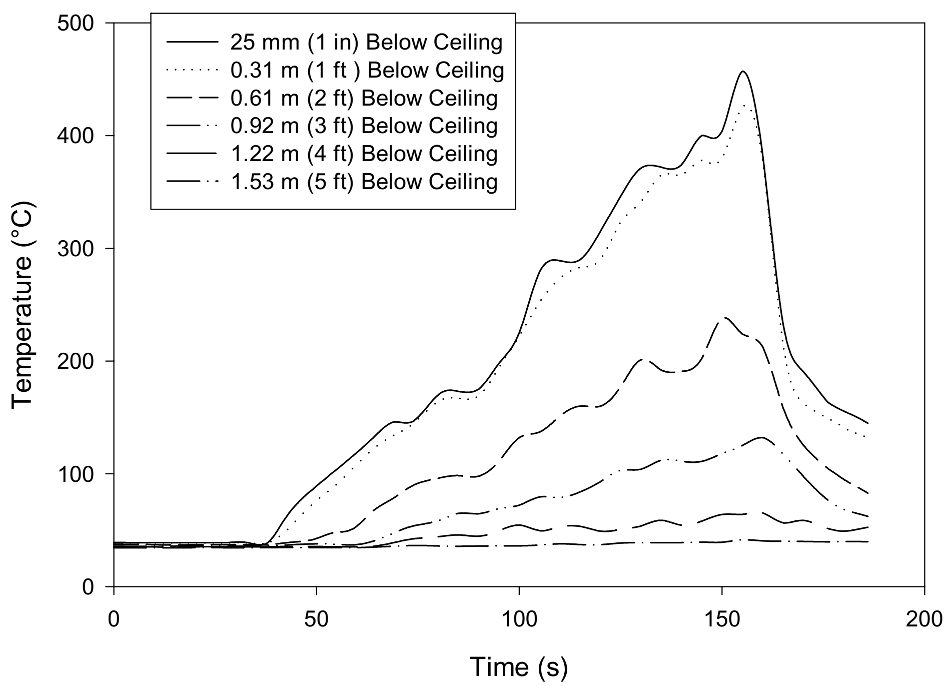

Figure B-27. Test 4 (Medium Gas Burner), Thermocouple Array 2 Data

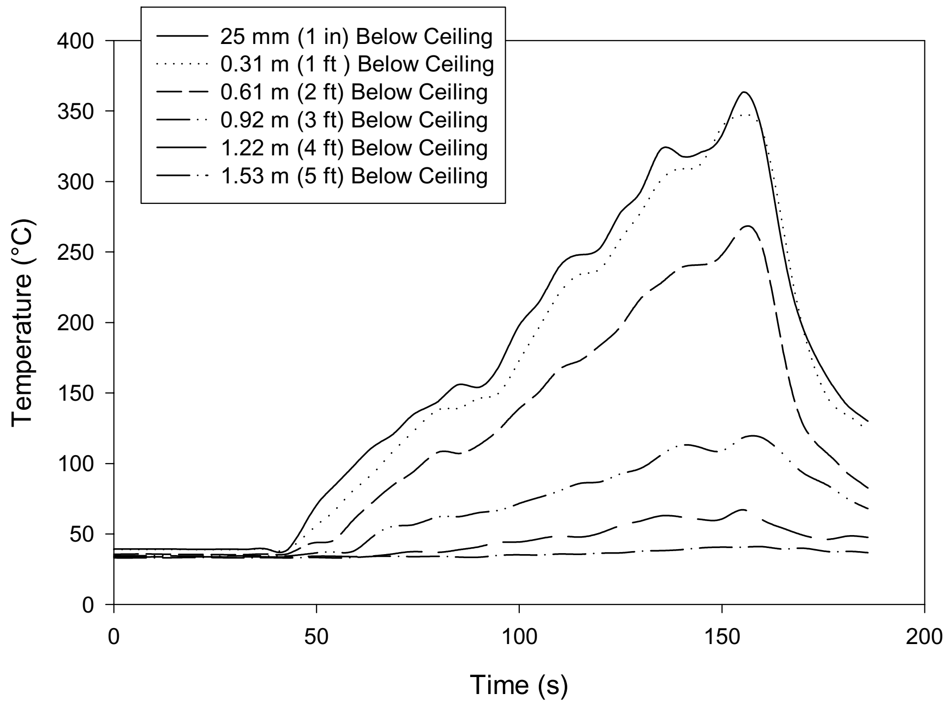

Figure B-28. Test 4 (Medium Gas Burner), Thermocouple Array 3 Data

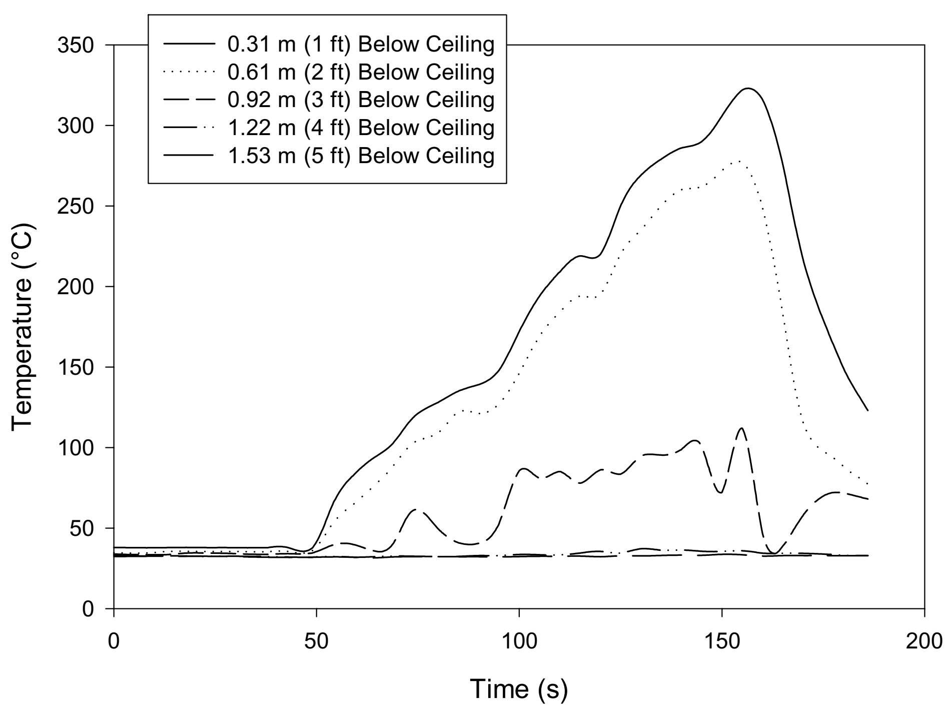

Figure B-29. Test 4 (Medium Gas Burner), Thermocouple Array 4 Data

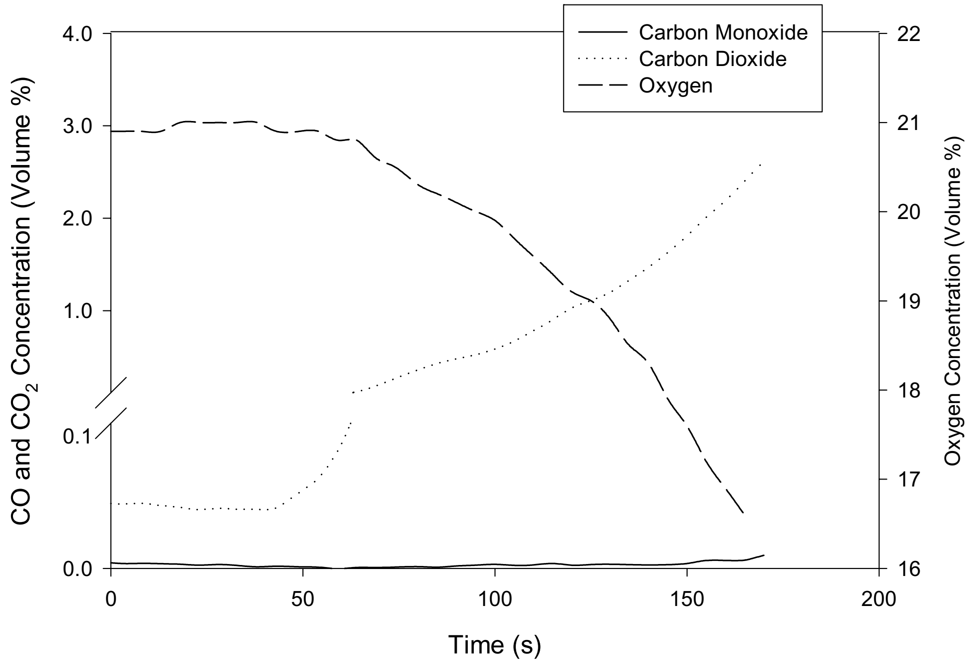

Figure B-30. Test 4 (Medium Gas Burner), Gas Concentration Data

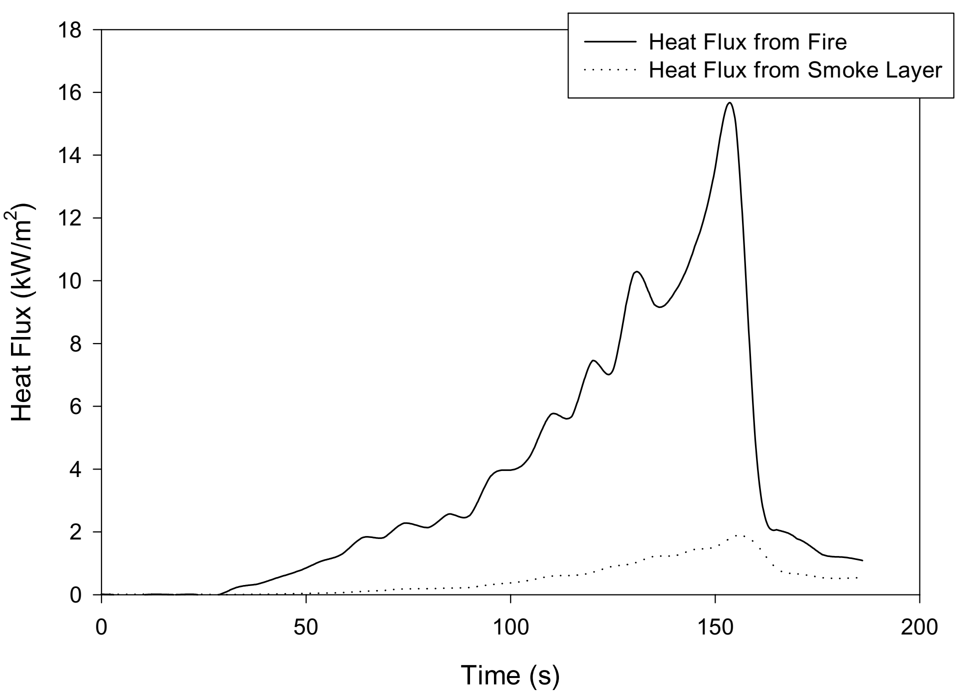

Figure B-31. Test 4 (Medium Gas Burner), Heat Flux Data

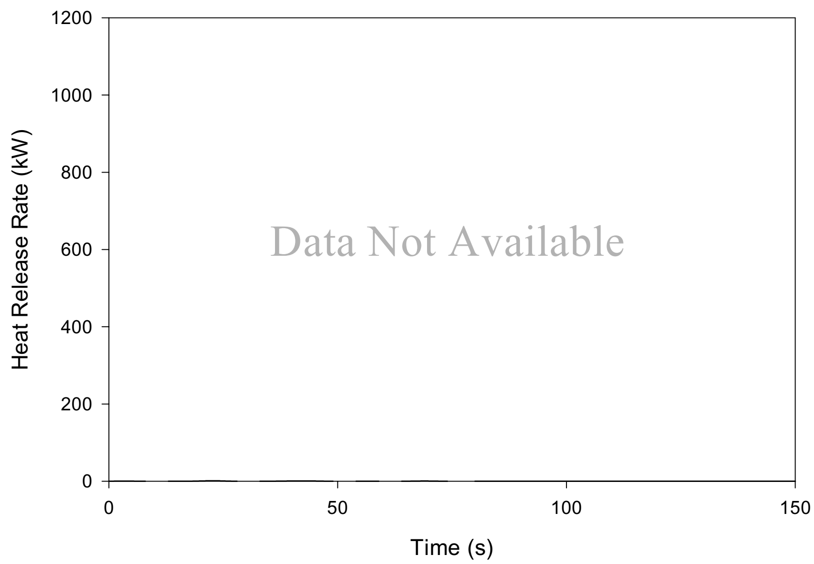

Figure B-32. Test 4 (Medium Gas Burner), Heat Release Rate Data

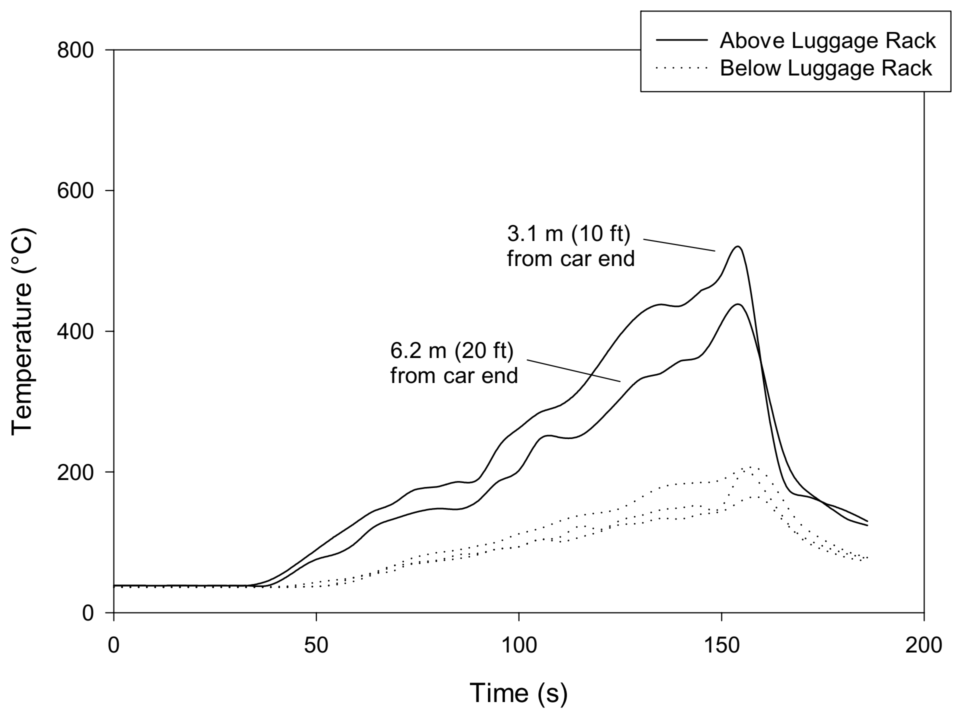

Figure B-33. Test 4 (Medium Gas Burner), Luggage Rack Temperature Data

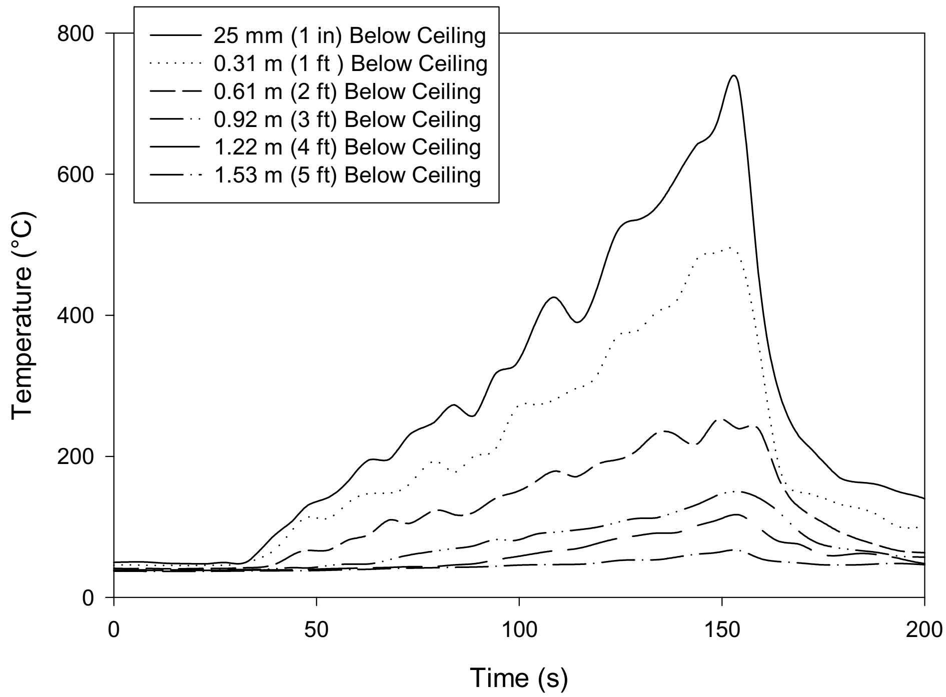

Figure B-34. Test 5 (Medium Gas Burner), Thermocouple Array 1 Data

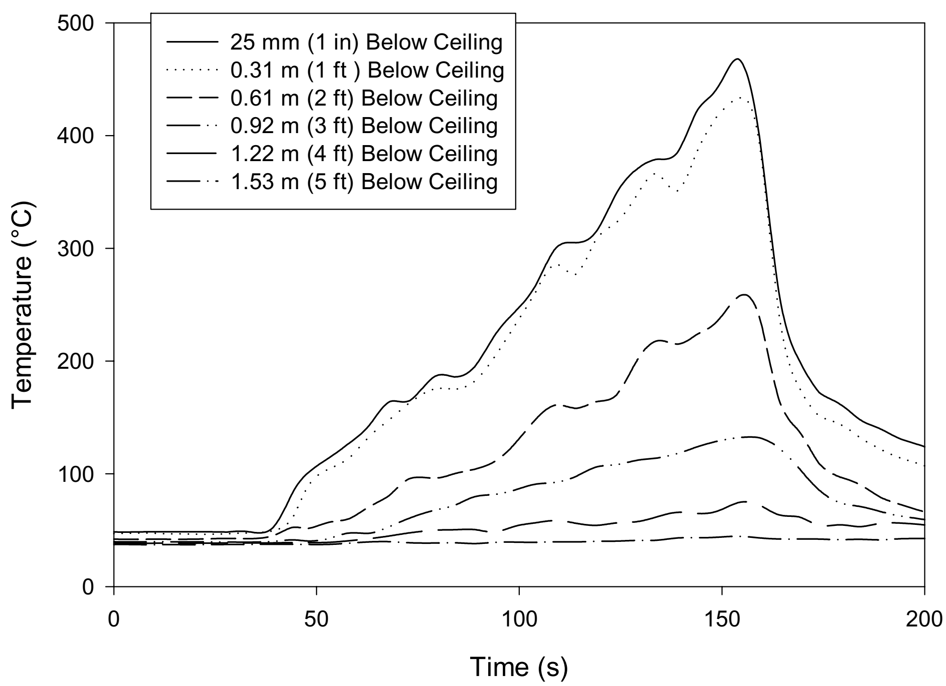

Figure B-35. Test 5 (Medium Gas Burner), Thermocouple Array 2 Data

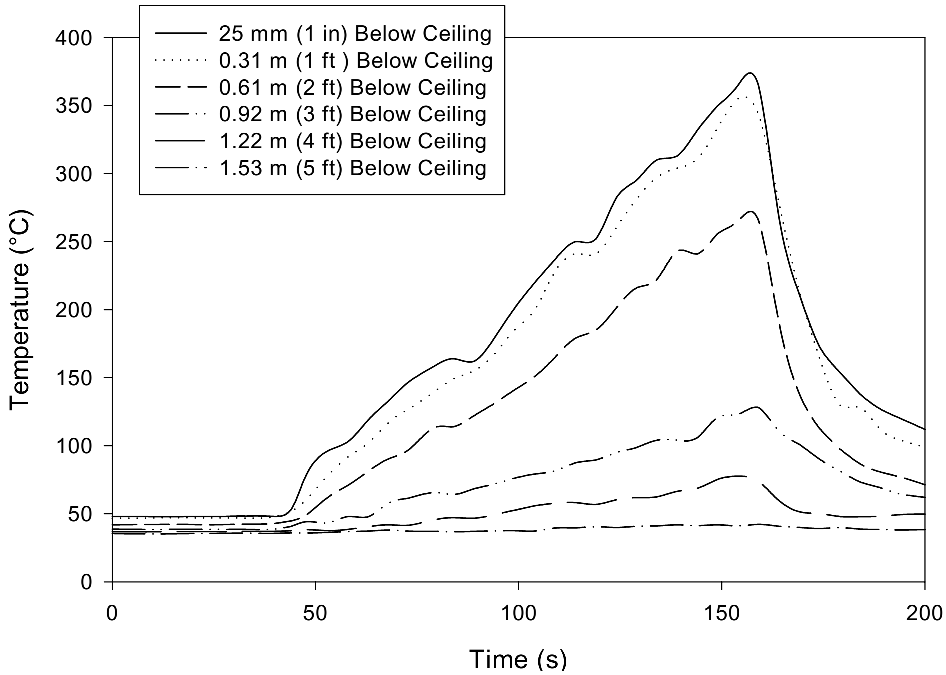

Figure B-36. Test 5 (Medium Gas Burner), Thermocouple Array 3 Data

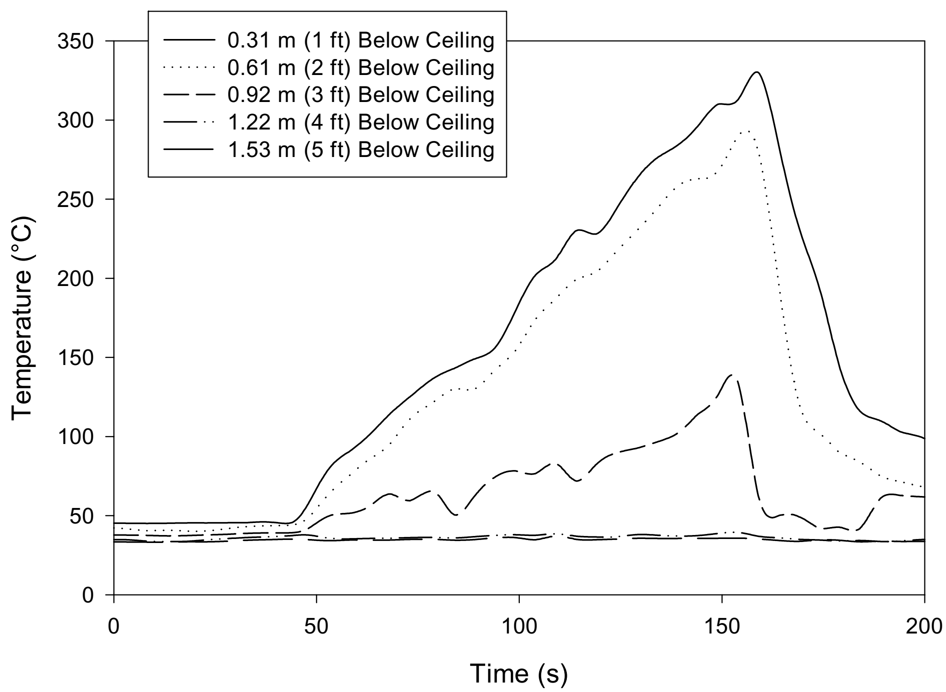

Figure B-37. Test 5, (Medium Gas Burner) Thermocouple Array 4 Data

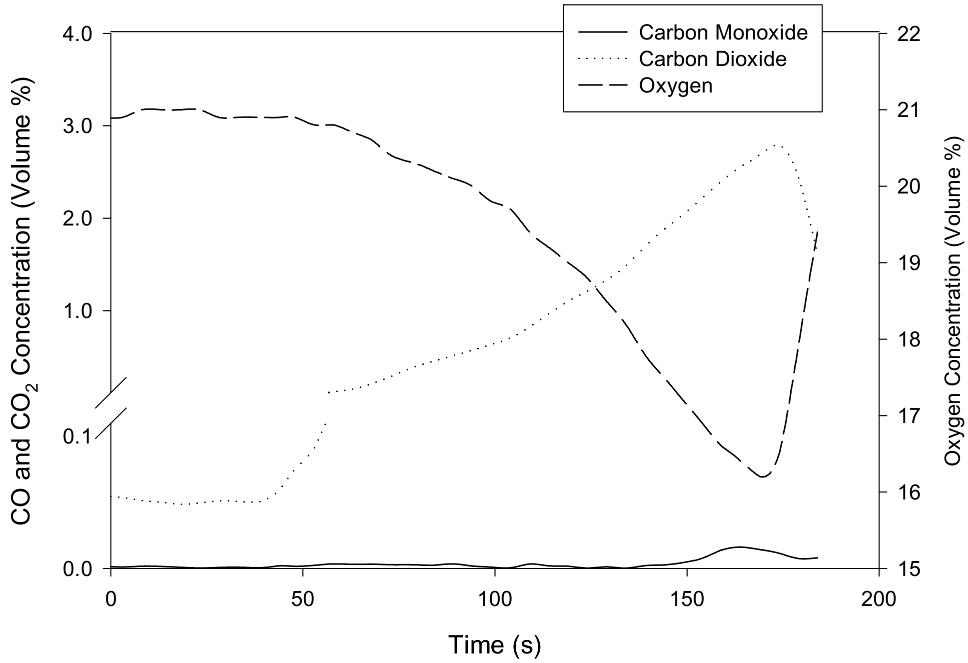

Figure B-38. Test 5 (Medium Gas Burner), Gas Concentration Data

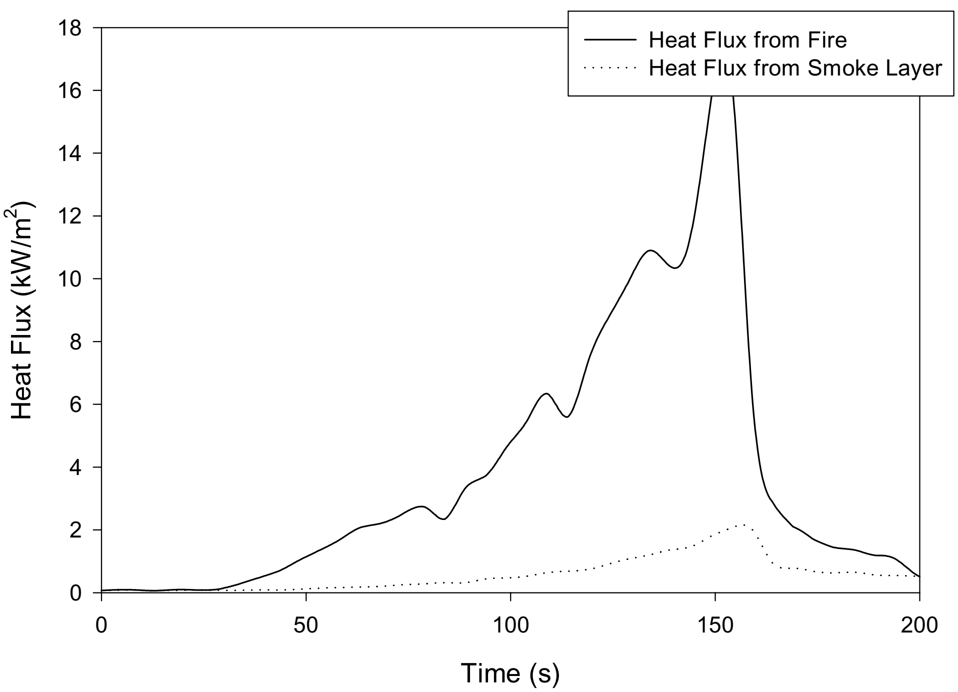

Figure B-39. Test 5 (Medium Gas Burner), Heat Flux Data

Figure B-40. Test 5 (Medium Gas Burner), Heat Release Rate Data

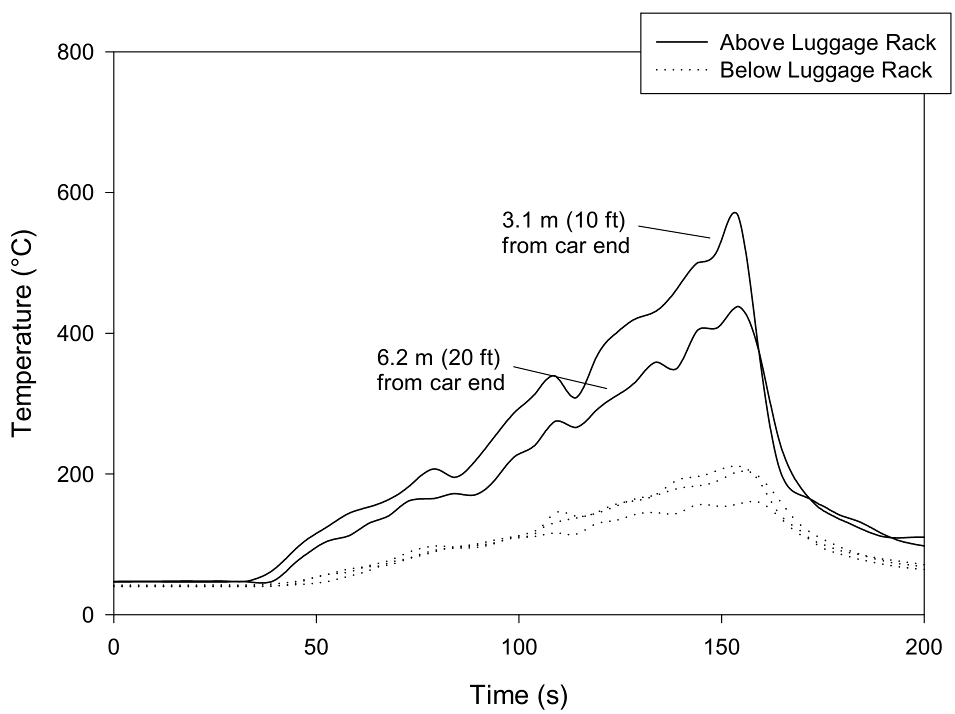

Figure B-41. Test 5 (Medium Gas Burner), Luggage Rack Temperature Data

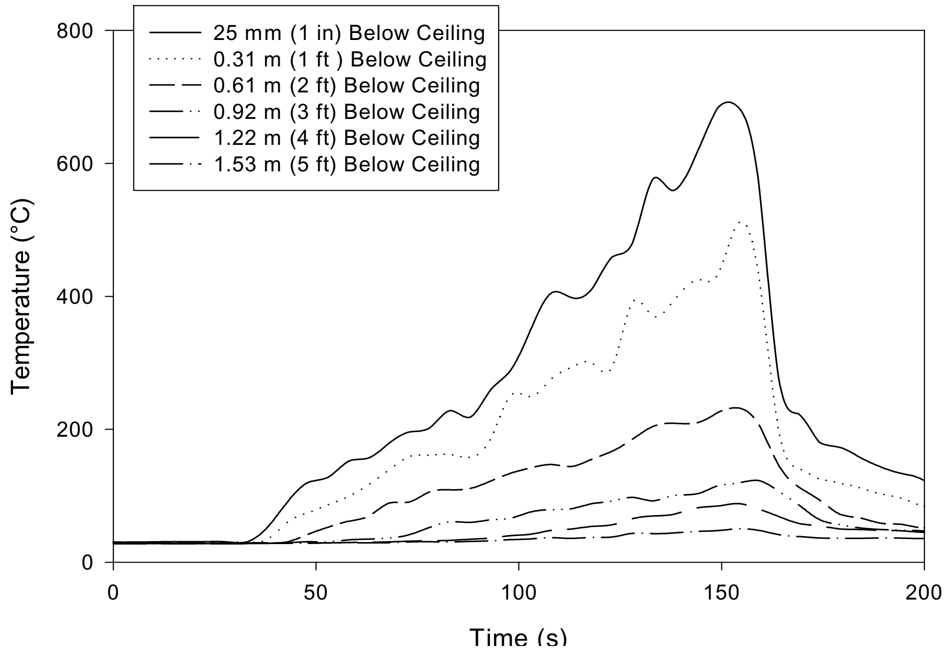

Figure B-42. Test 6 (Medium Gas Burner), Thermocouple Array 1 Data

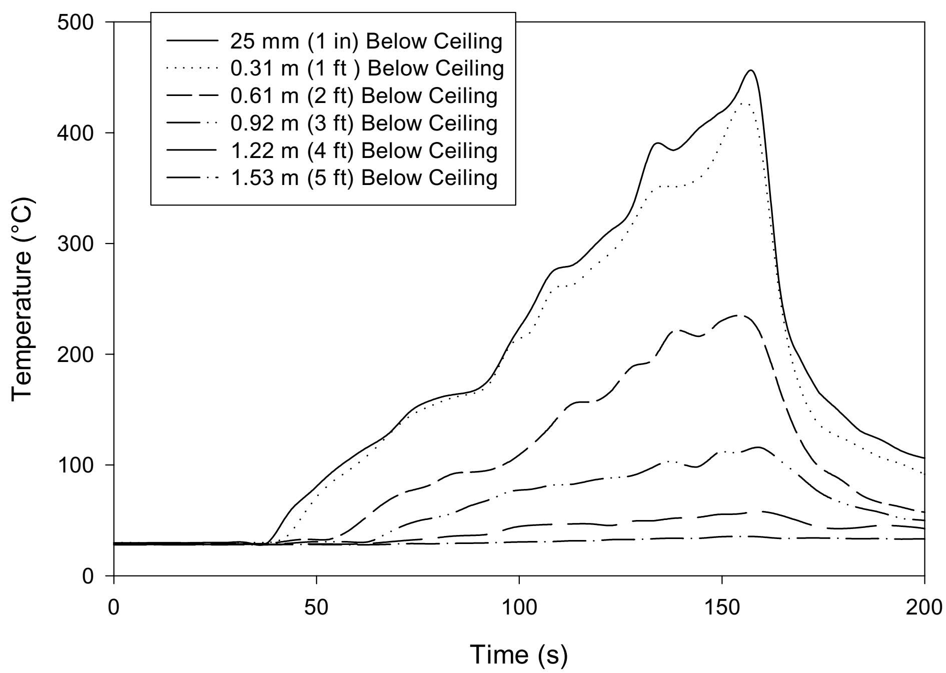

Figure B-43. Test 6 (Medium Gas Burner), Thermocouple Array 2 Data

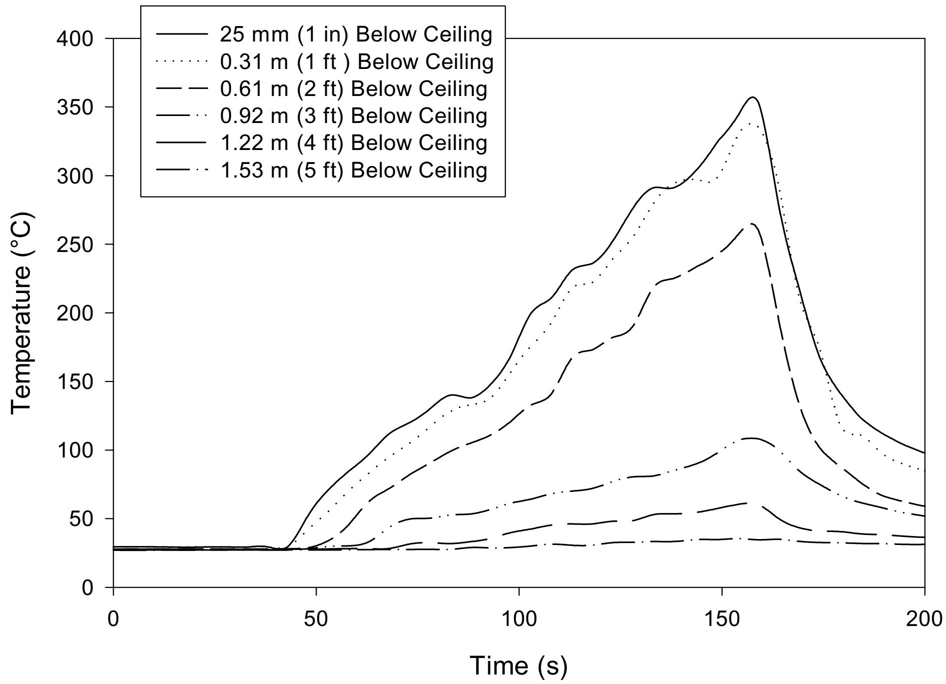

Figure B-44. Test 6 (Medium Gas Burner), Thermocouple Array 3 Data

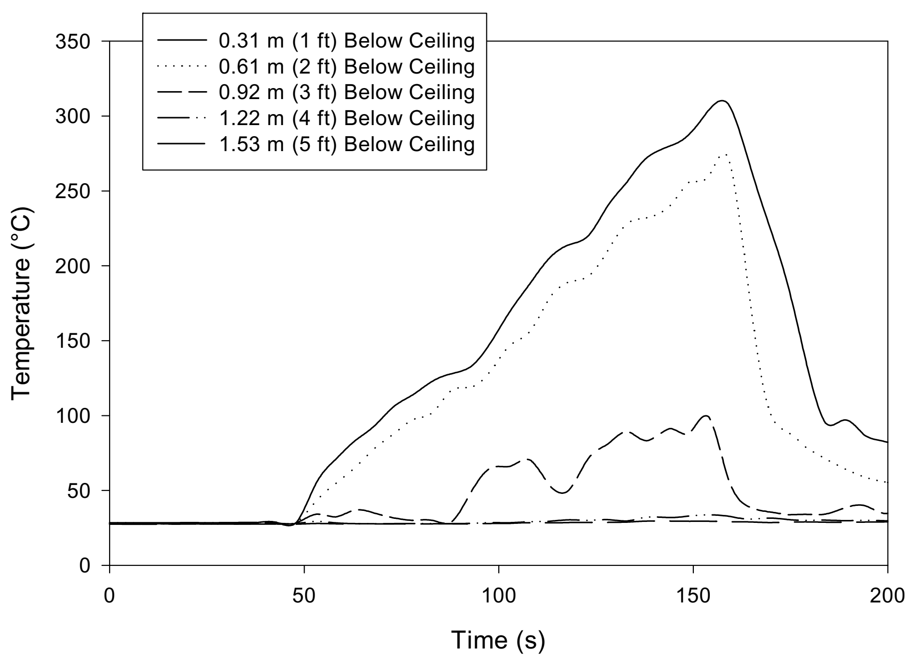

Figure B-45. Test 6 (Medium Gas Burner), Thermocouple Array 4 Data

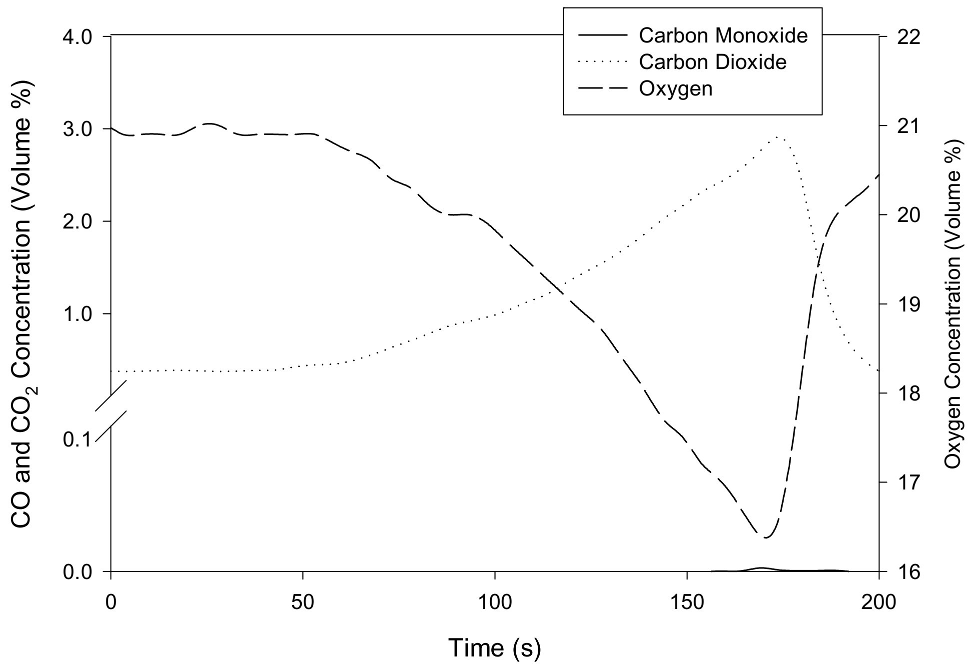

Figure B-46. Test 6 (Medium Gas Burner), Gas Concentration Data

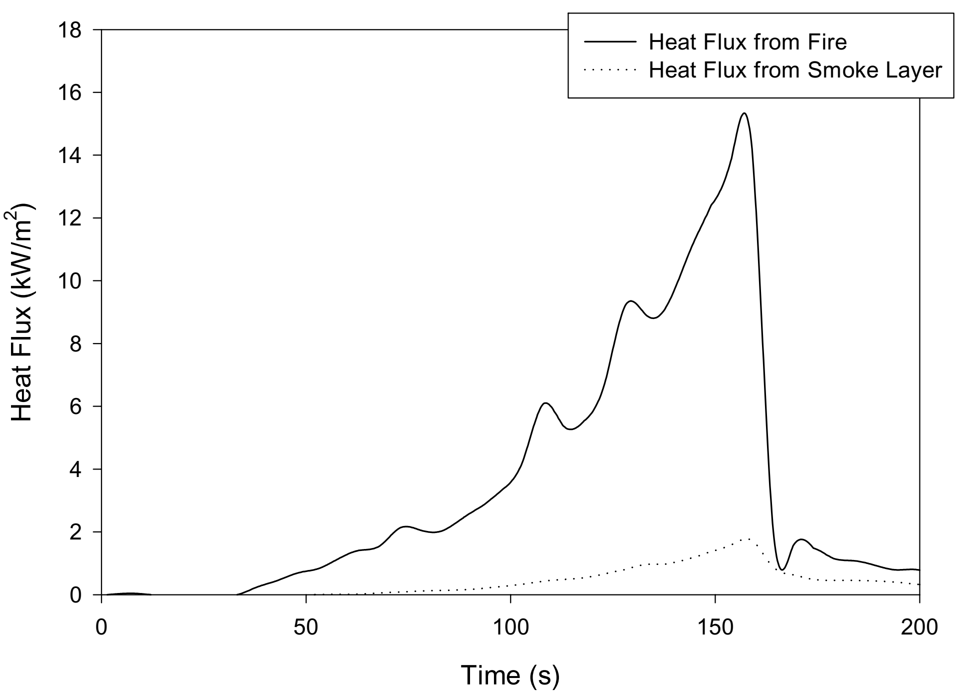

Figure B-47. Test 6 (Medium Gas Burner), Heat Flux Data

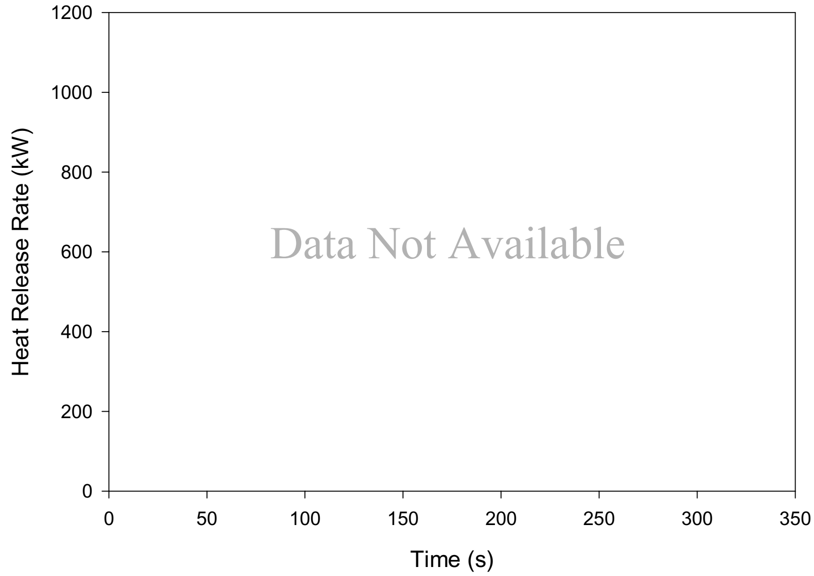

Figure B-48. Test 6 (Medium Gas Burner), Heat Release Rate Data

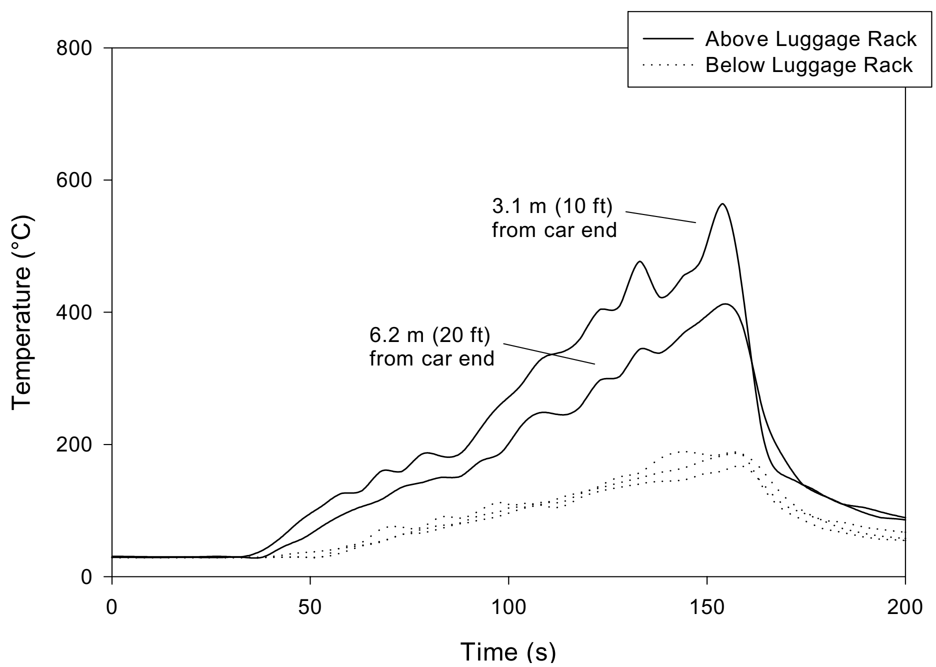

Figure B-49. Test 6 (Medium Gas Burner), Luggage Rack Temperature Data

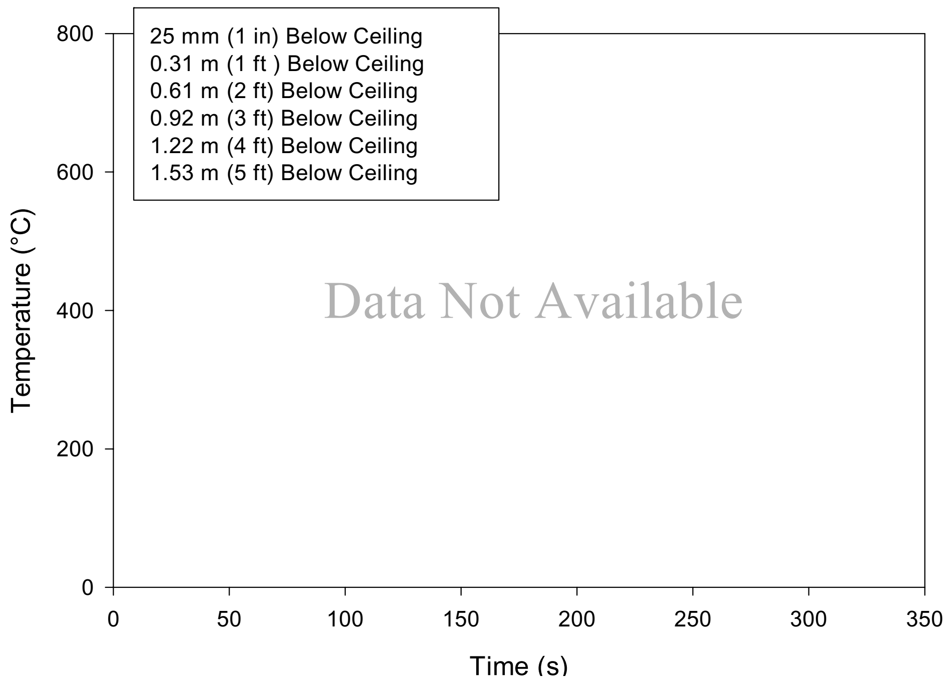

Figure B-50. Test 7 (Fast Gas Burner), Thermocouple Array 1 Data

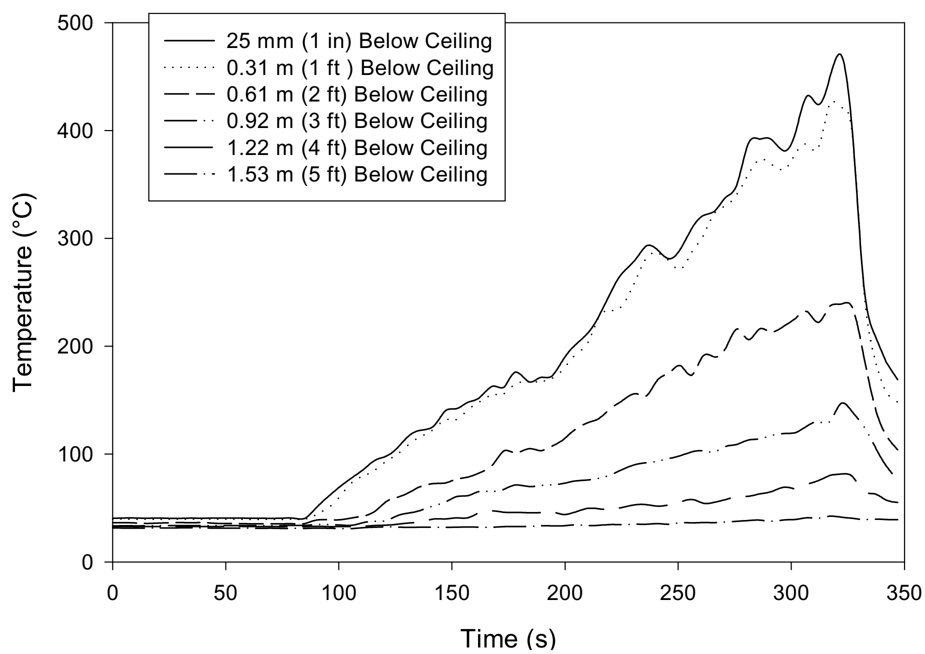

Figure B-51. Test 7 (Fast Gas Burner), Thermocouple Array 2 Data

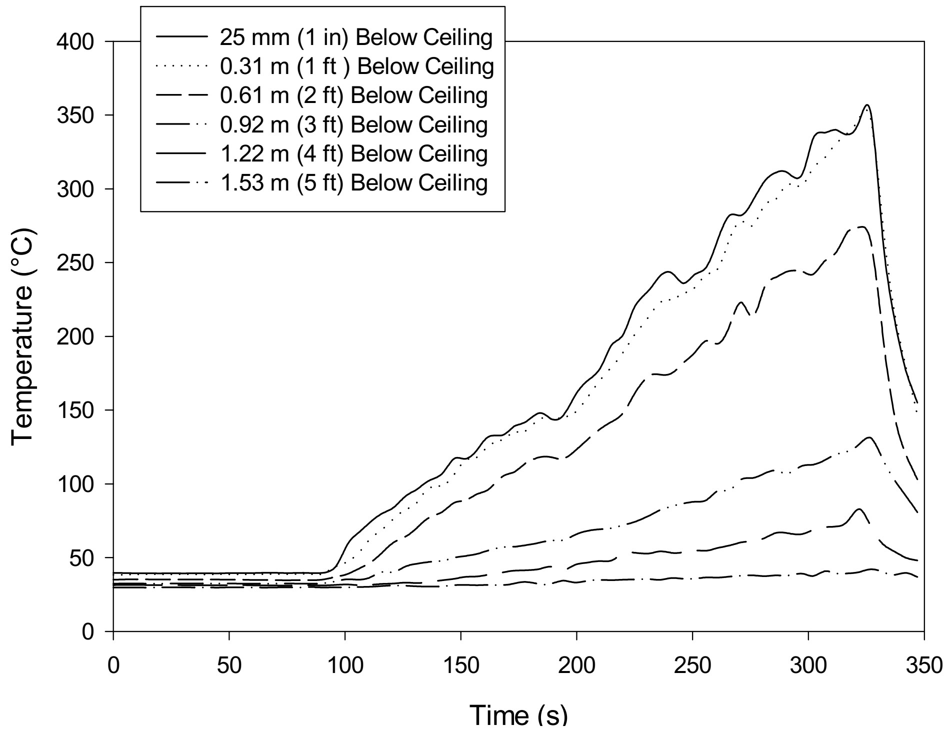

Figure B-52. Test 7 (Fast Gas Burner), Thermocouple Array 3 Data

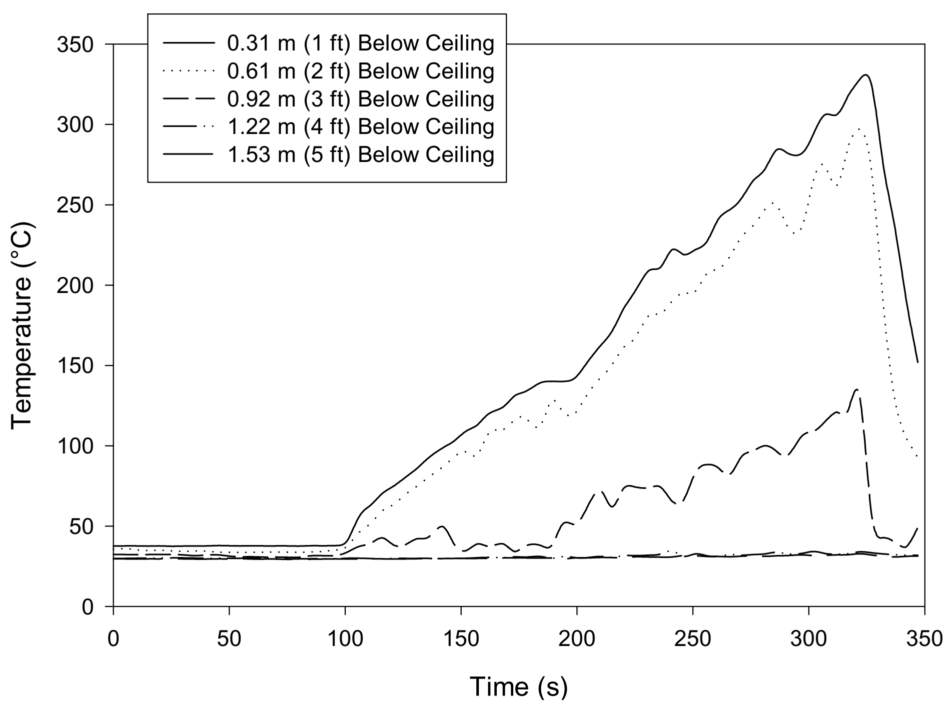

Figure B-53. Test 7 (Fast Gas Burner), Thermocouple Array 4 Data

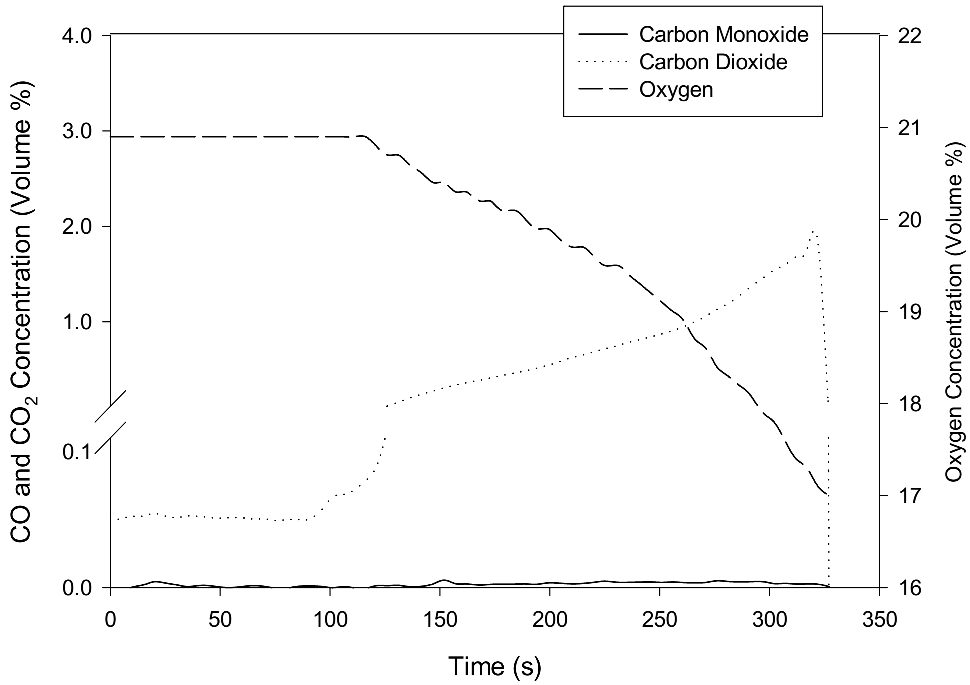

Figure B-54. Test 7 (Fast Gas Burner), Gas Concentration Data

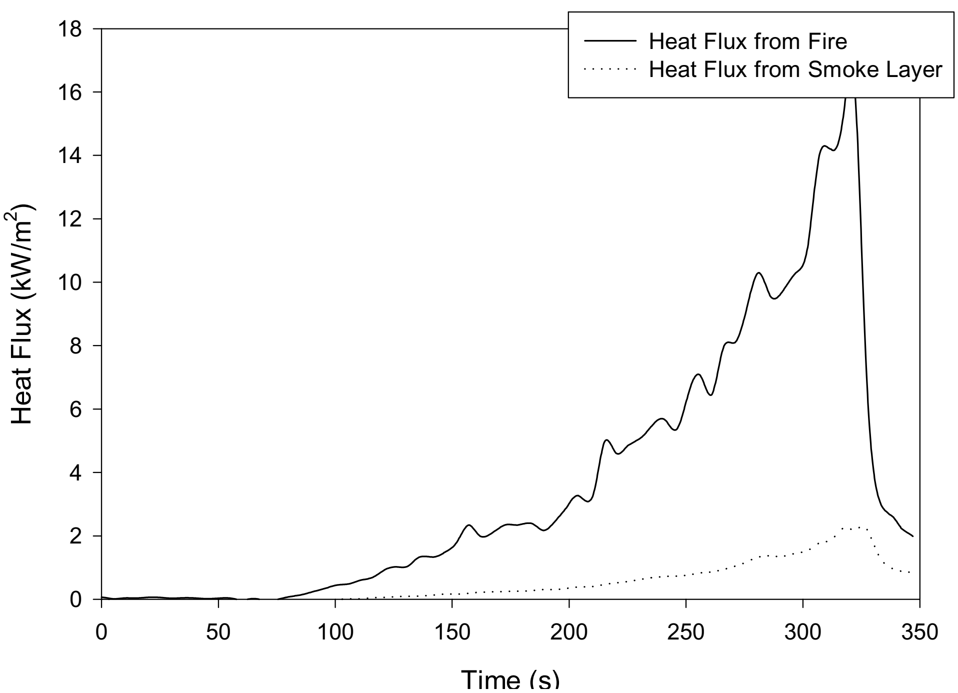

Figure B-55. Test 7 (Fast Gas Burner), Heat Flux Data

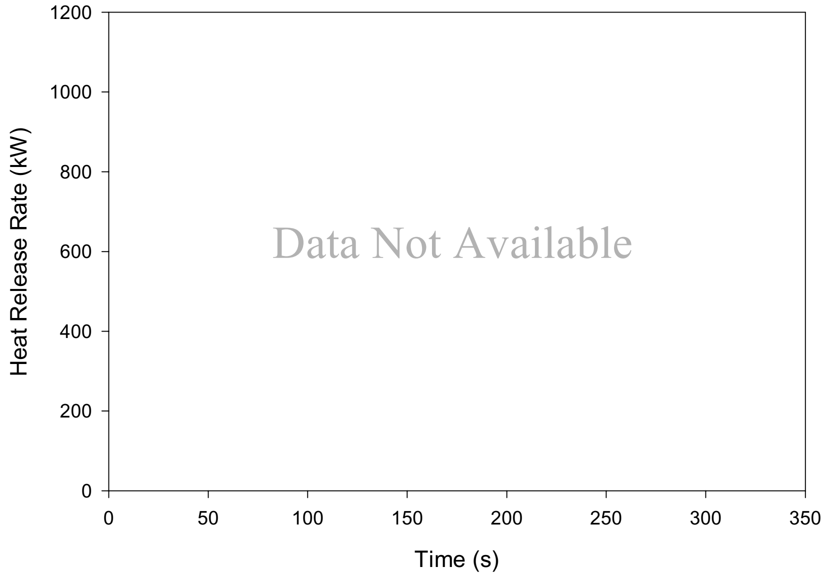

Figure B-56. Test 7 (Fast Gas Burner), Heat Release Rate Data

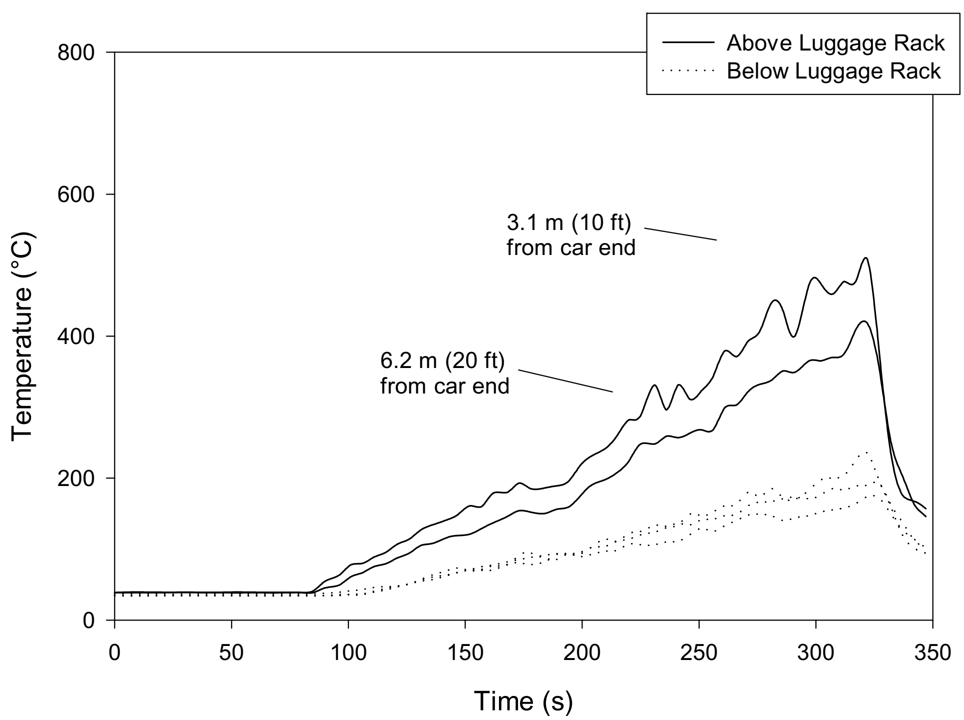

Figure B-57. Test 7 (Fast Gas Burner), Luggage Rack Temperature Data

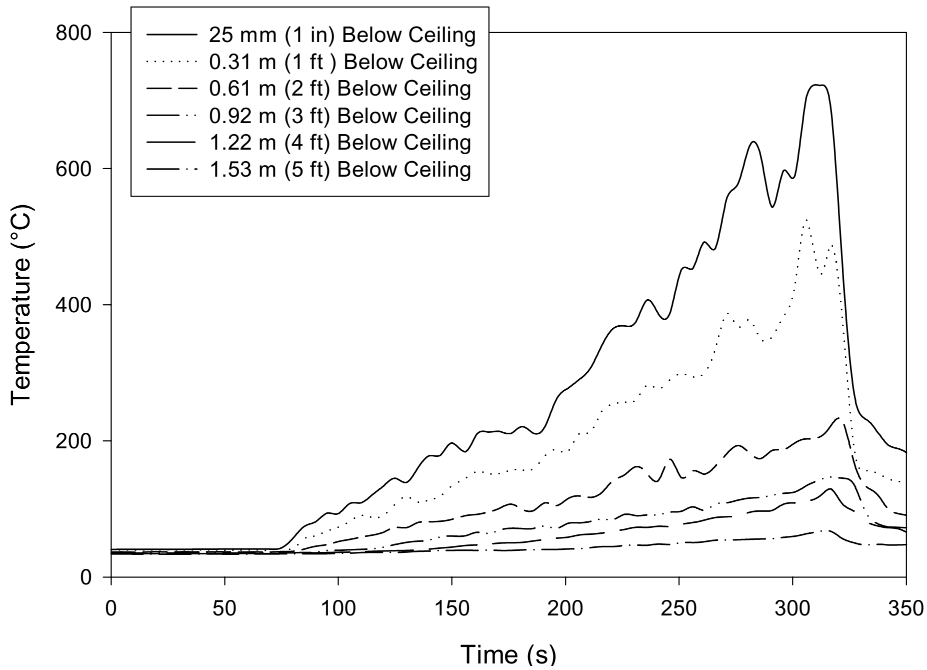

Figure B-58. Test 8 (Fast Gas Burner), Thermocouple Array 1 Data

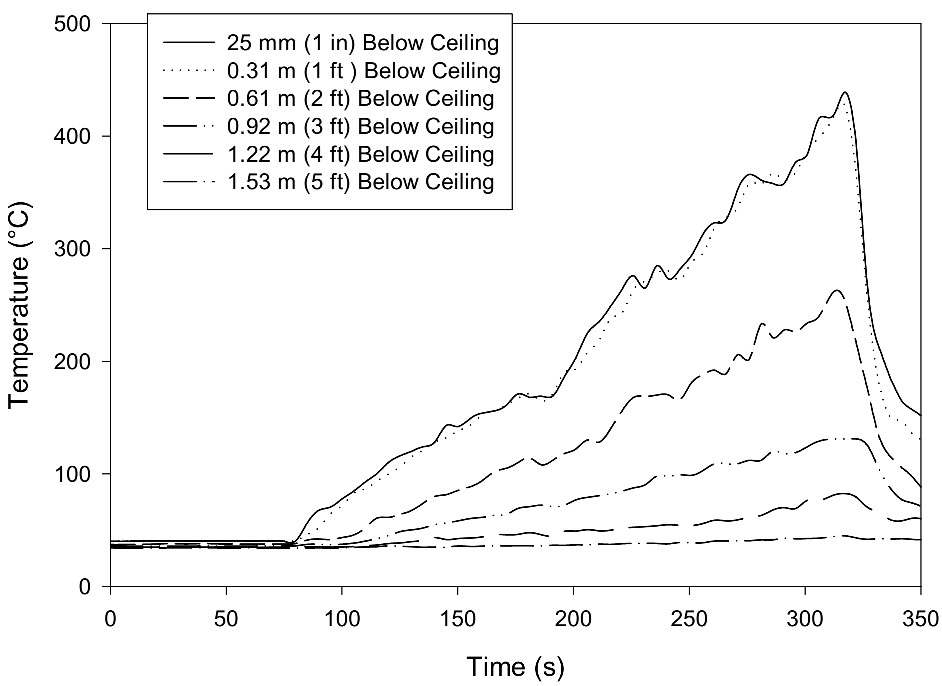

Figure B-59. Test 8 (Fast Gas Burner), Thermocouple Array 2 Data

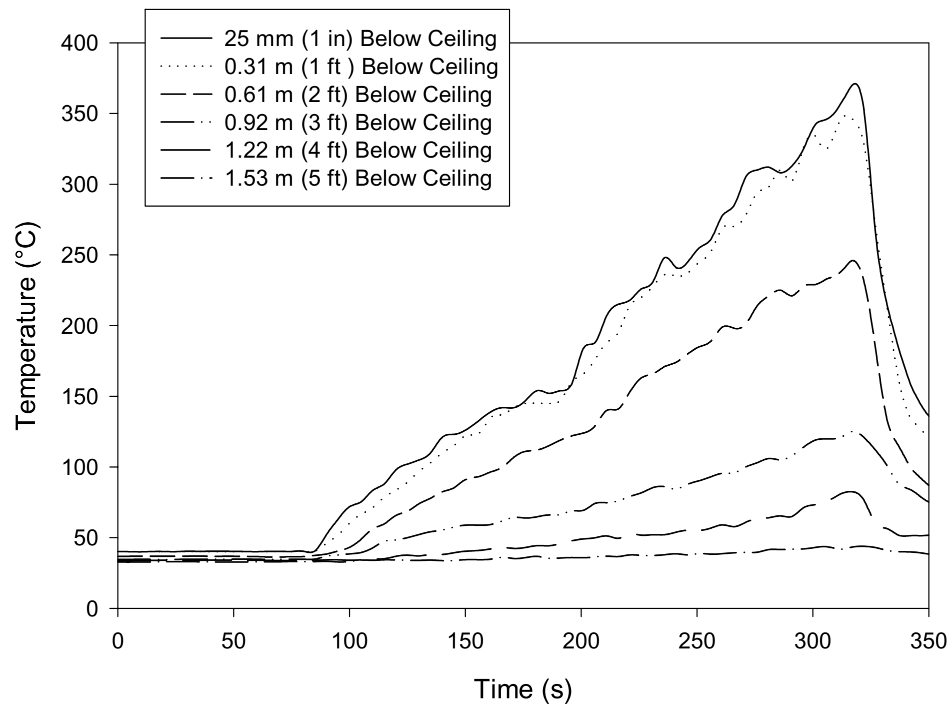

Figure B-60. Test 8 (Fast Gas Burner), Thermocouple Array 3 Data

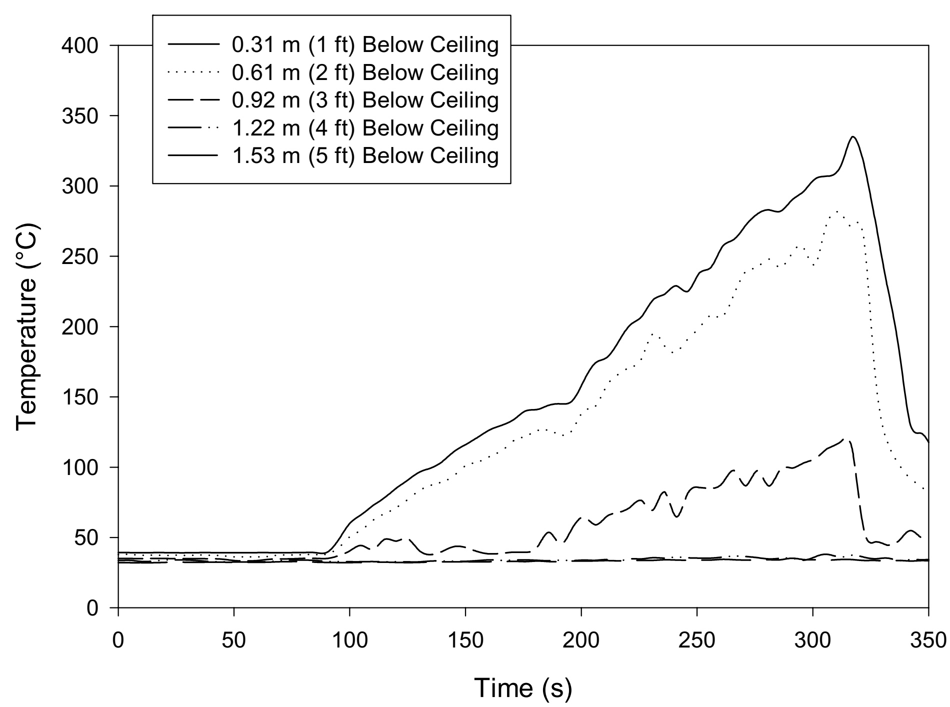

Figure B-61. Test 8 (Fast Gas Burner), Thermocouple Array 4 Data

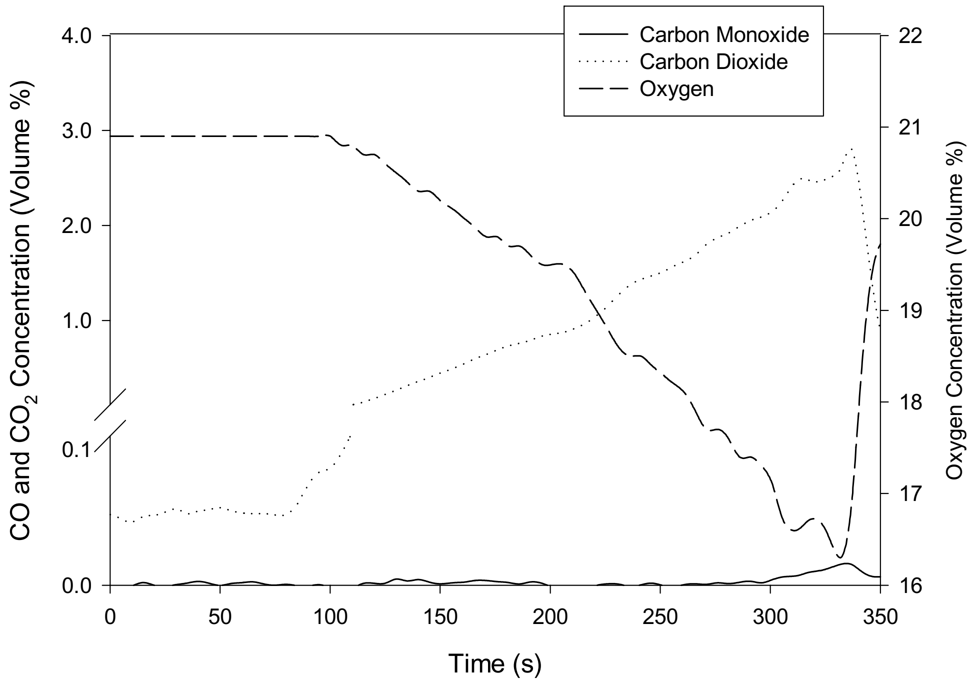

Figure B-62. Test 8 (Fast Gas Burner), Gas Concentration Data

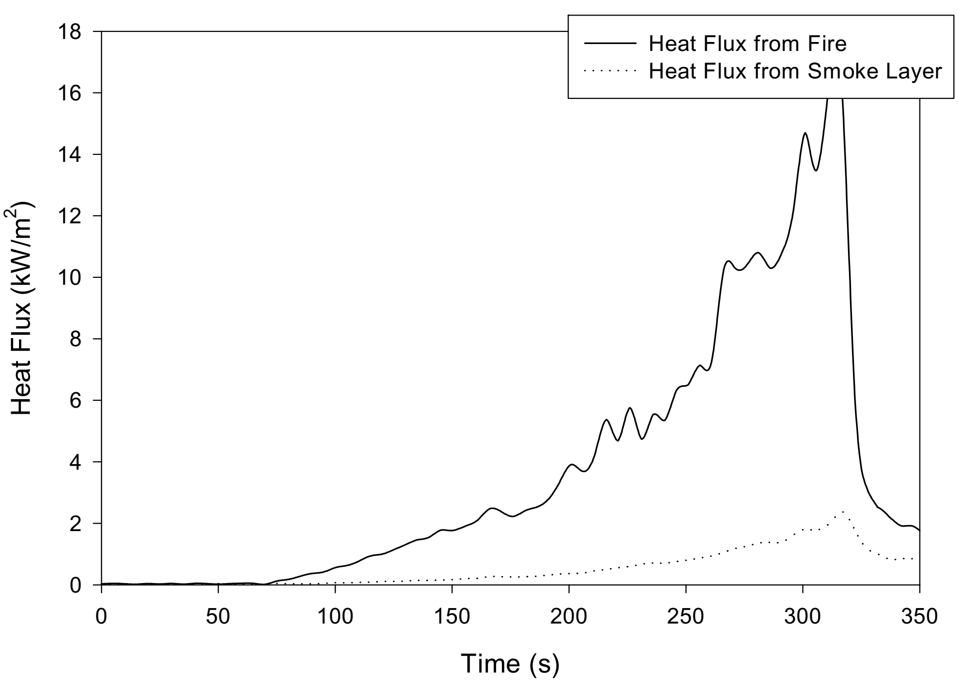

Figure B-63. Test 8 (Fast Gas Burner), Heat Flux Data

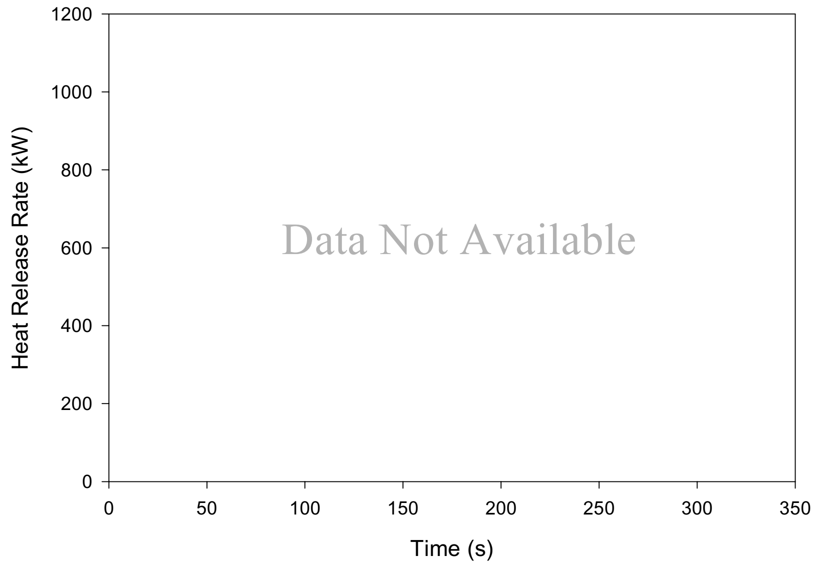

Figure B-64. Test 8 (Fast Gas Burner), Heat Release Rate Data

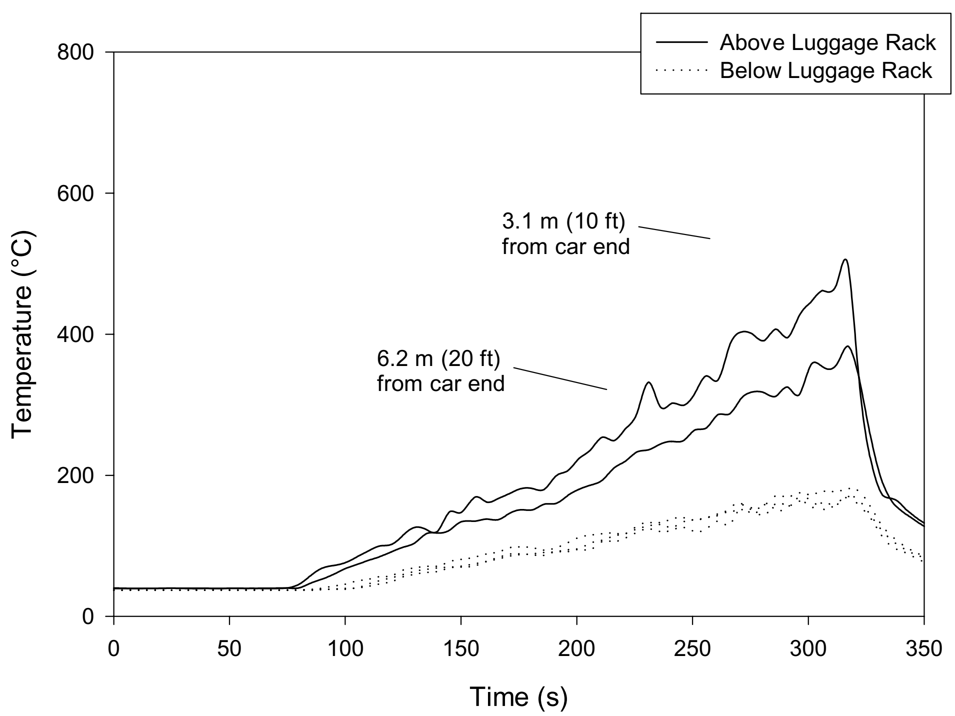

Figure B-65. Test 8 (Fast Gas Burner), Luggage Rack Temperature Data

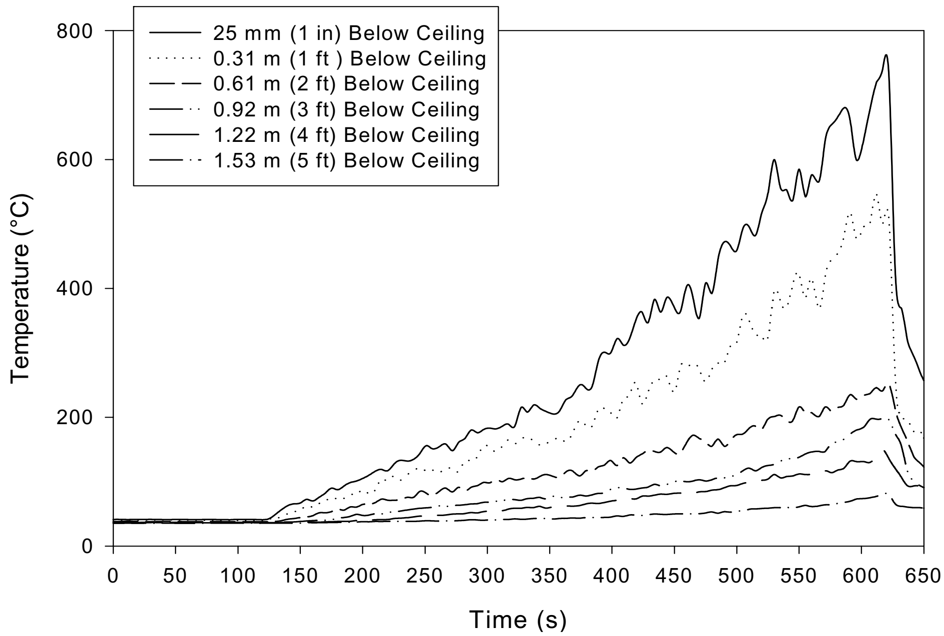

Figure B-66. Test 9 (Fast Gas Burner), Thermocouple Array 1 Data

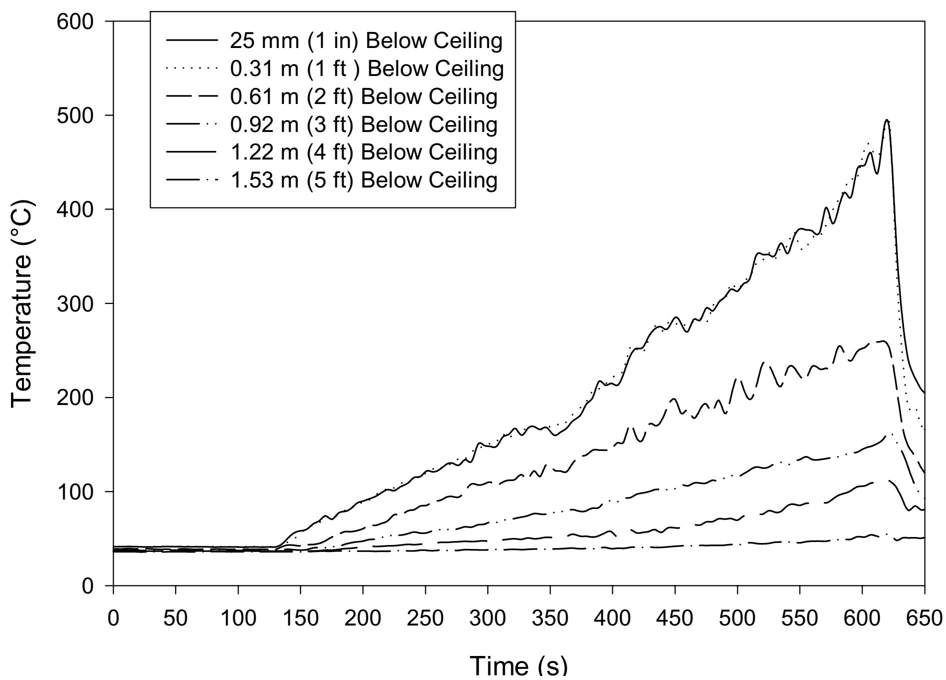

Figure B-67. Test 9 (Fast Gas Burner), Thermocouple Array 2 Data

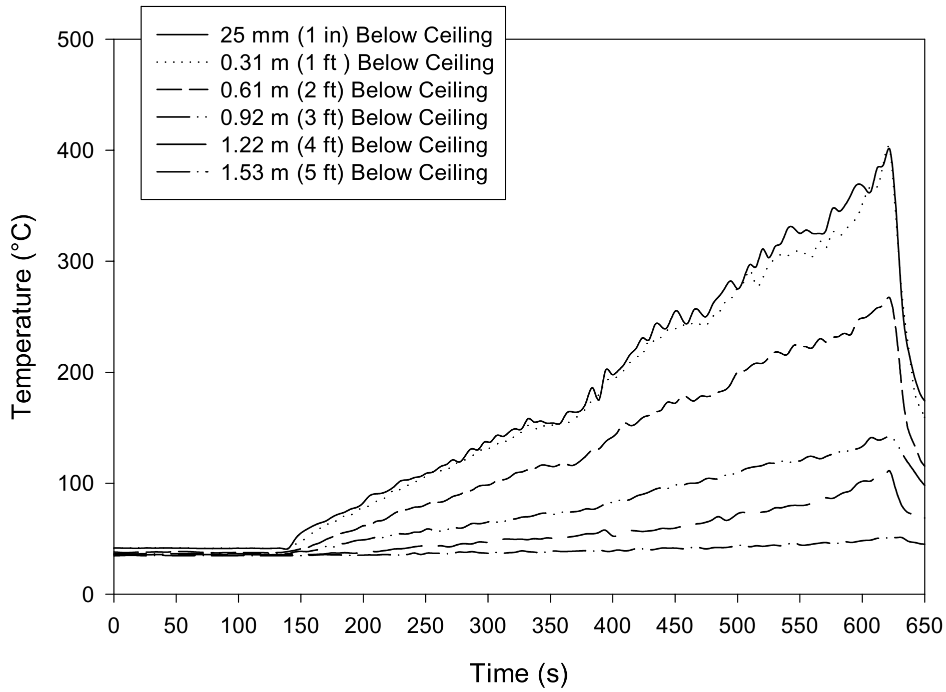

Figure B-68. Test 9 (Fast Gas Burner), Thermocouple Array 3 Data

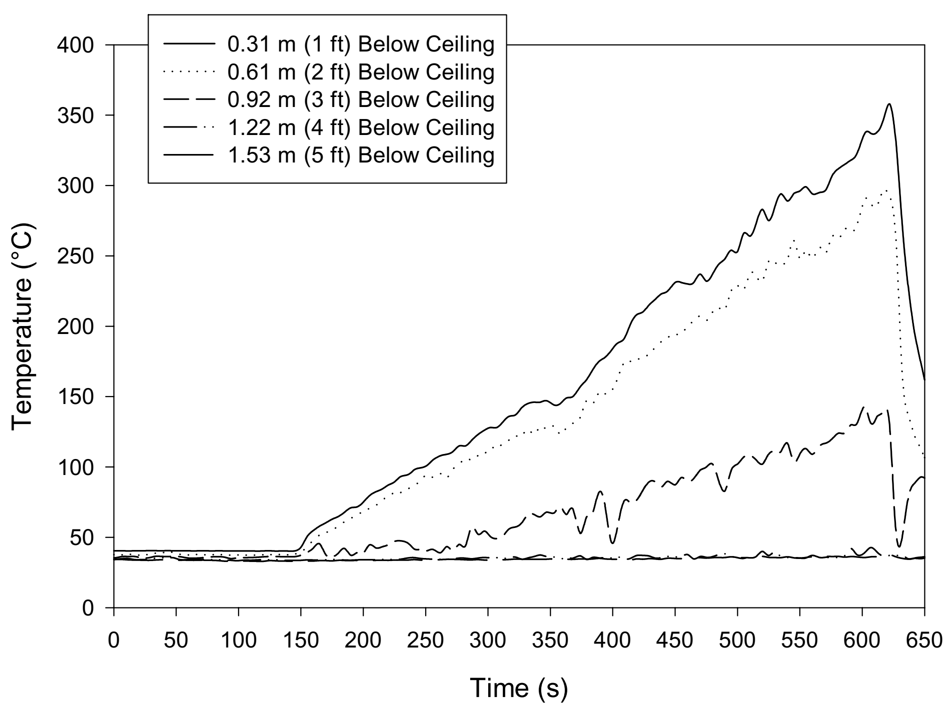

Figure B-69. Test 9 (Fast Gas Burner), Thermocouple Array 2 Data

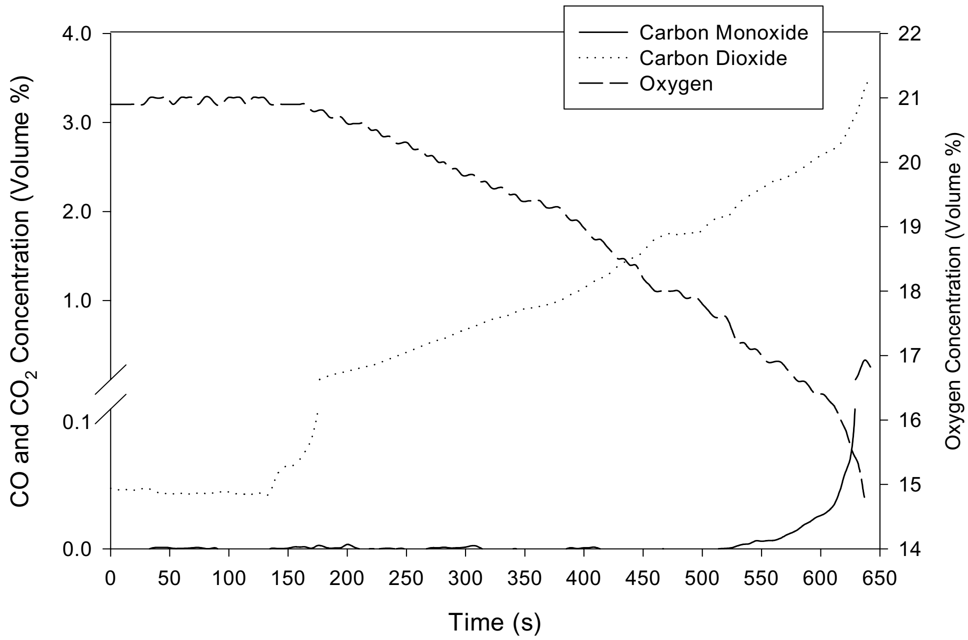

Figure B-70. Test 9 (Fast Gas Burner), Gas Concentration Data

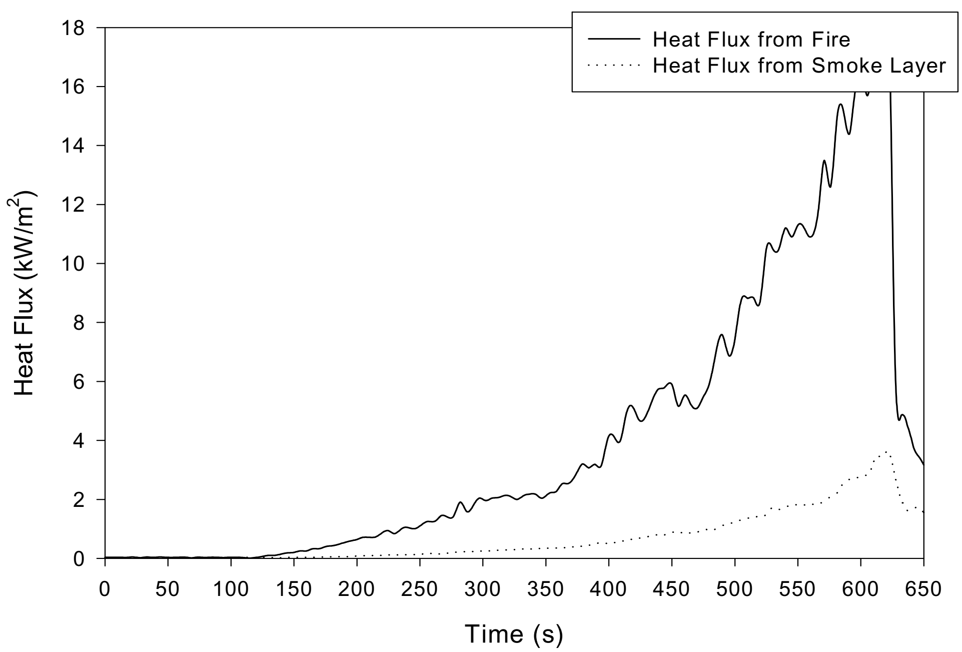

Figure B-71. Test 9 (Fast Gas Burner), Heat Flux Data

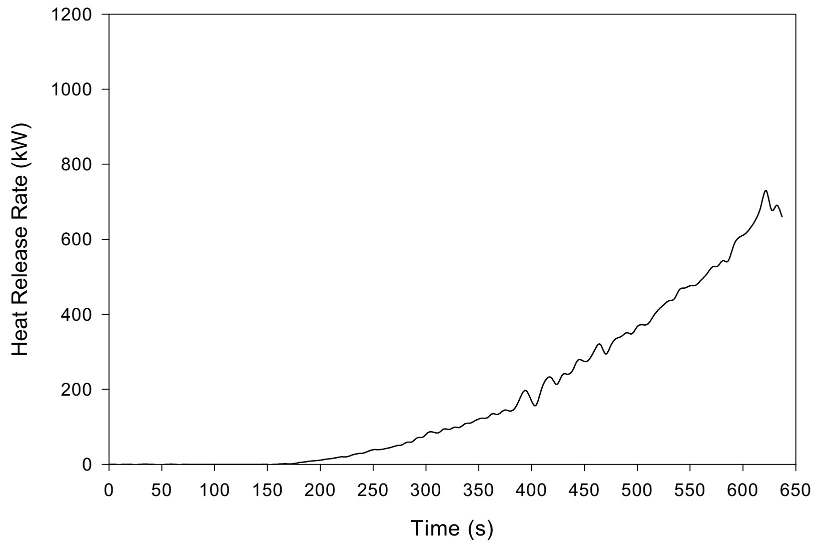

Figure B-72. Test 9 (Fast Gas Burner), Heat Release Rate Data

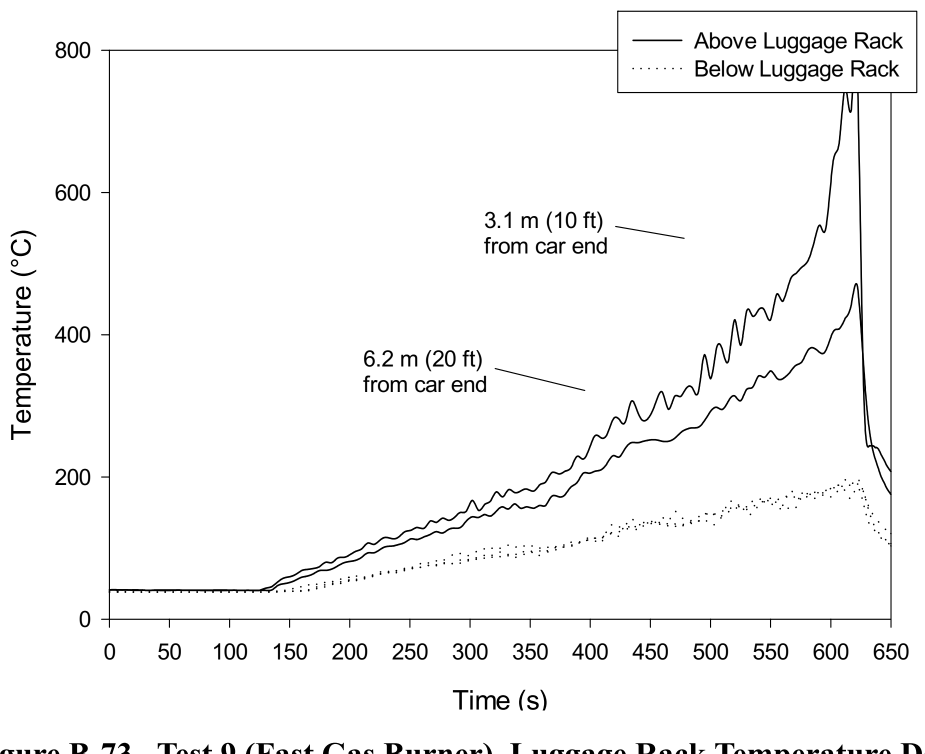

Figure B-73. Test 9 (Fast Gas Burner), Luggage Rack Temperature Data

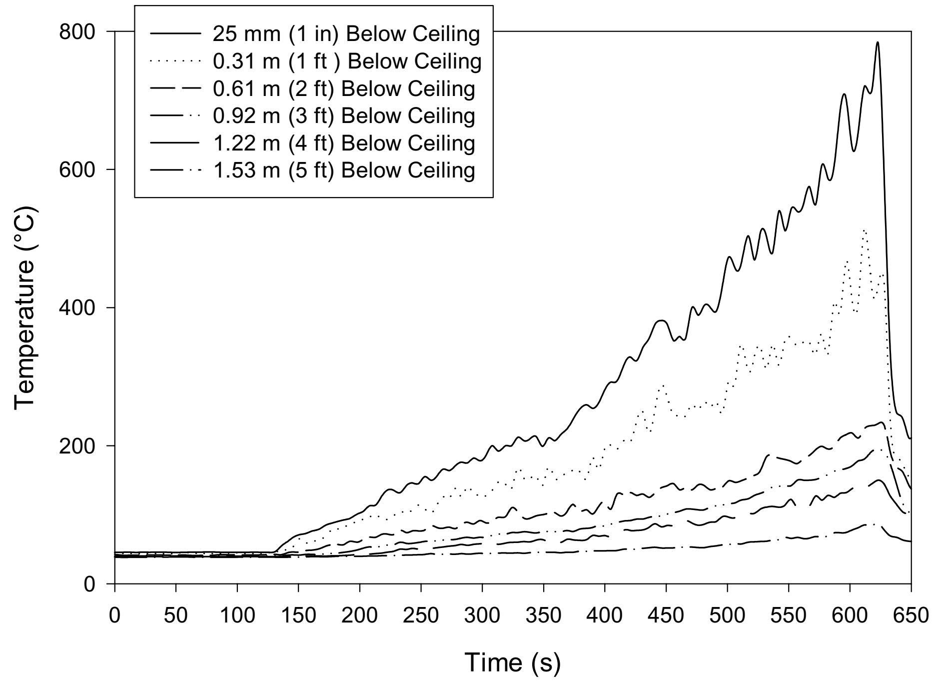

Figure B-74. Test 10 (Ultra-fast Gas Burner), Thermocouple Array 1 Data

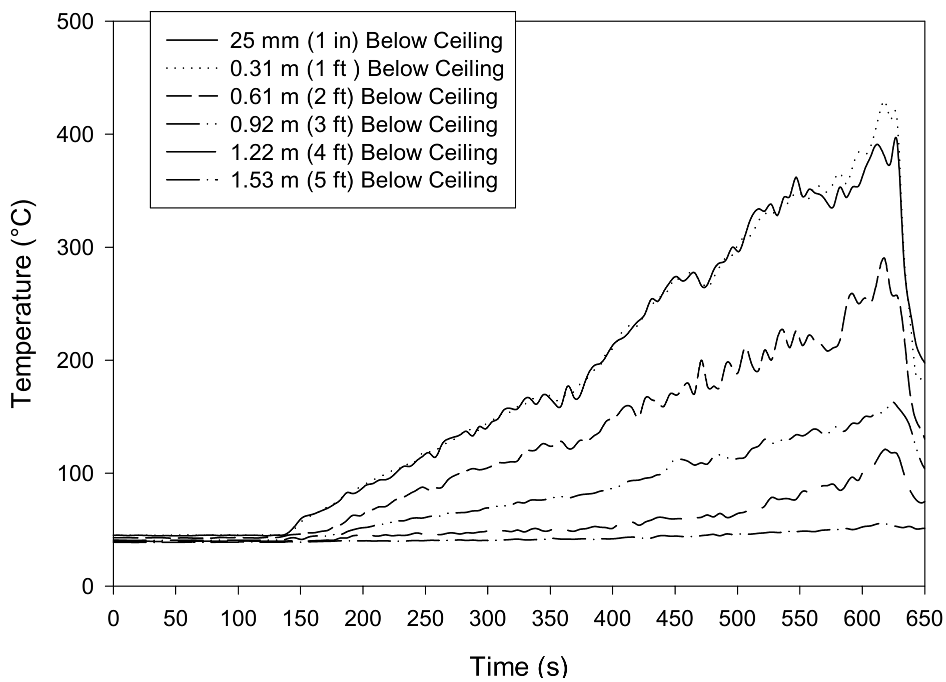

Figure B-75. Test 10 (Ultra-fast Gas Burner), Thermocouple Array 2 Data

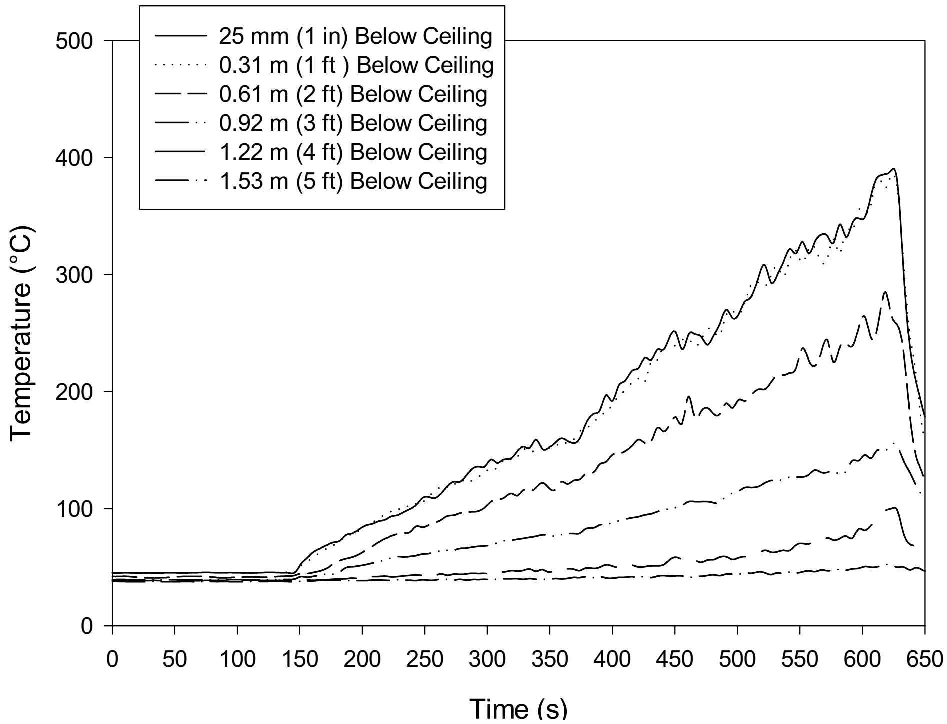

Figure B-76. Test 10 (Ultra-fast Gas Burner), Thermocouple Array 3 Data

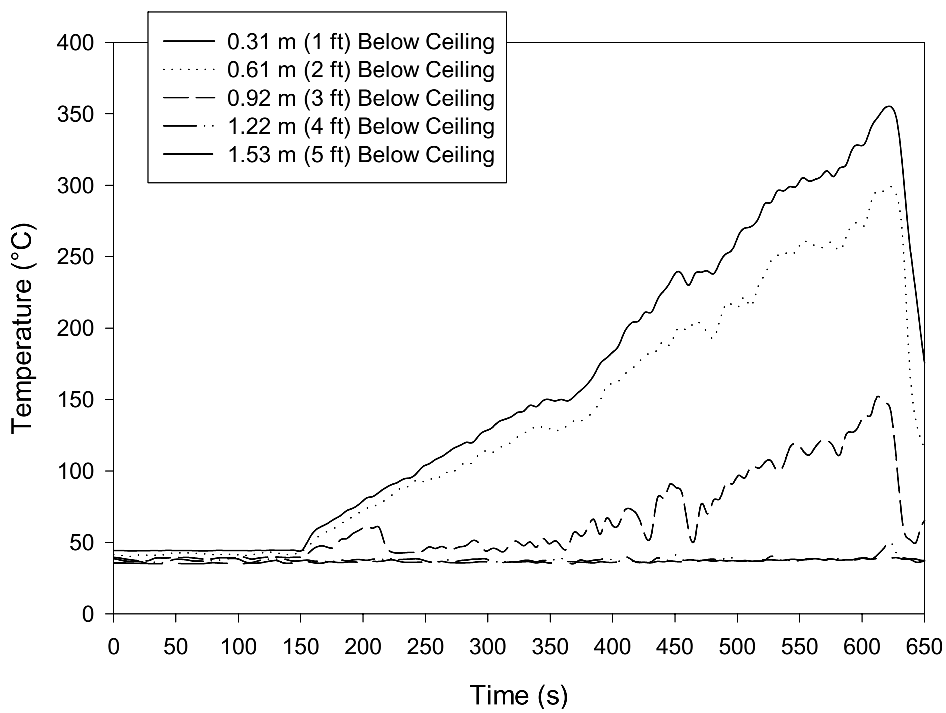

Figure B-77. Test 10 (Ultra-fast Gas Burner), Thermocouple Array 4 Data

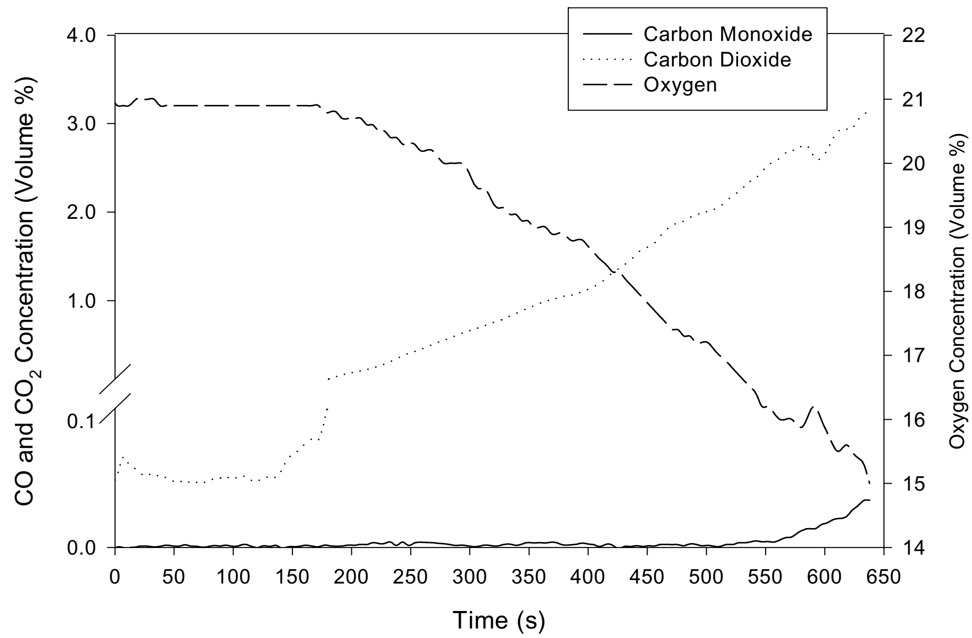

Figure B-78. Test 10 (Ultra-fast Gas Burner), Gas Concentration Data

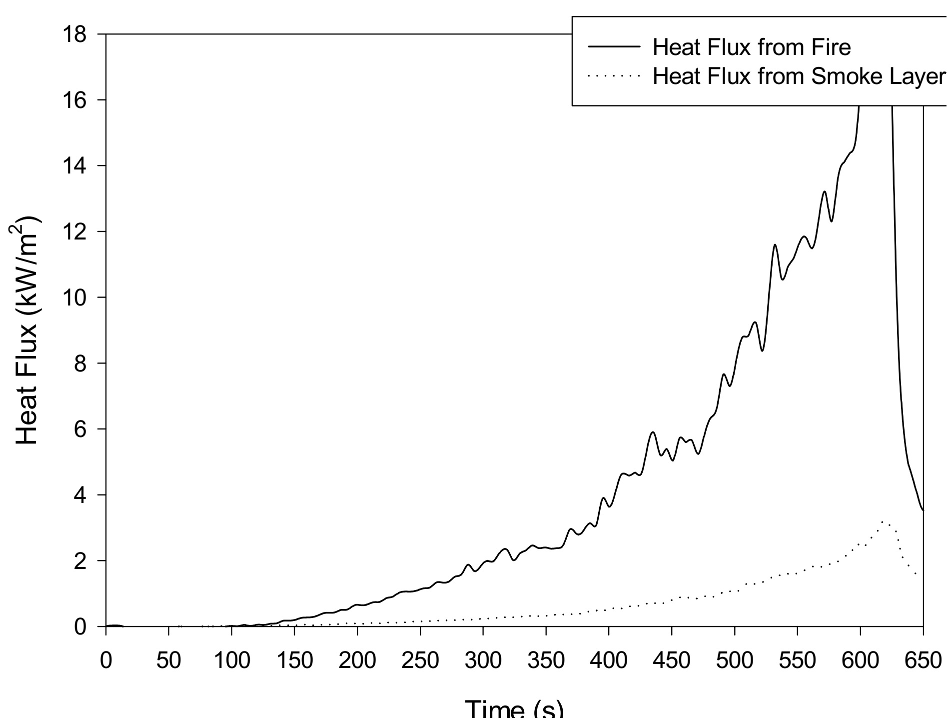

Figure B-79. Test 10 (Ultra-fast Gas Burner), Heat Flux Data

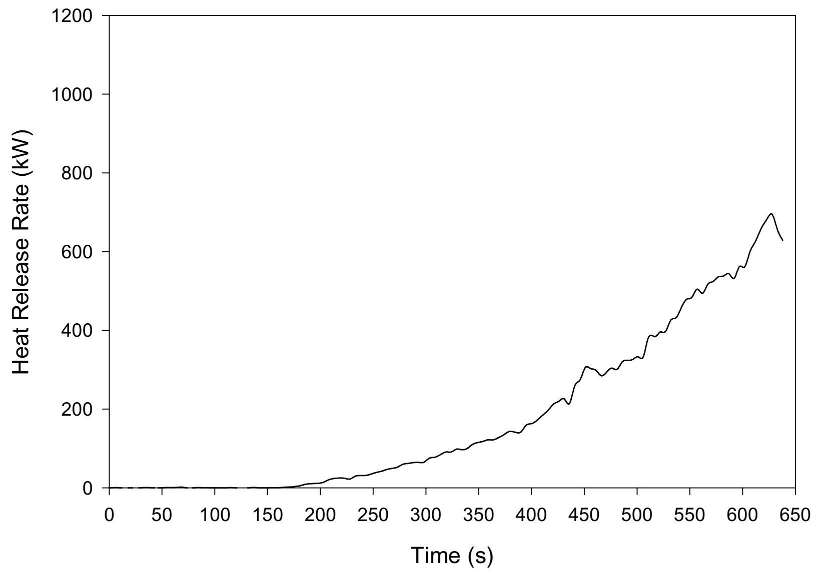

Figure B-80. Test 10 (Ultra-fast Gas Burner), Heat Release Rate Data

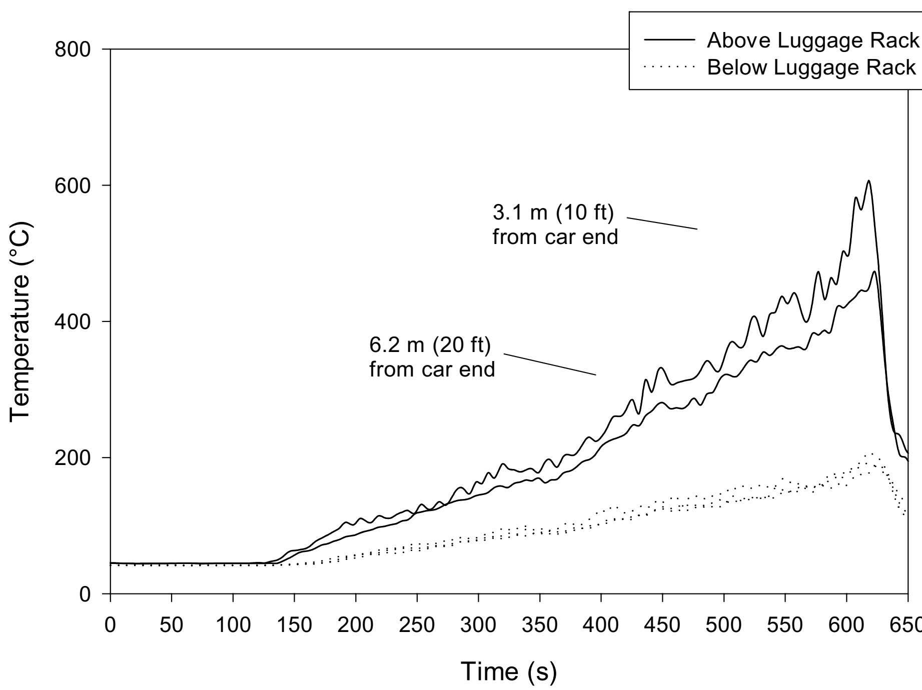

Figure B-81. Test 10 (Ultra-fast Gas Burner), Luggage Rack Temperature Data

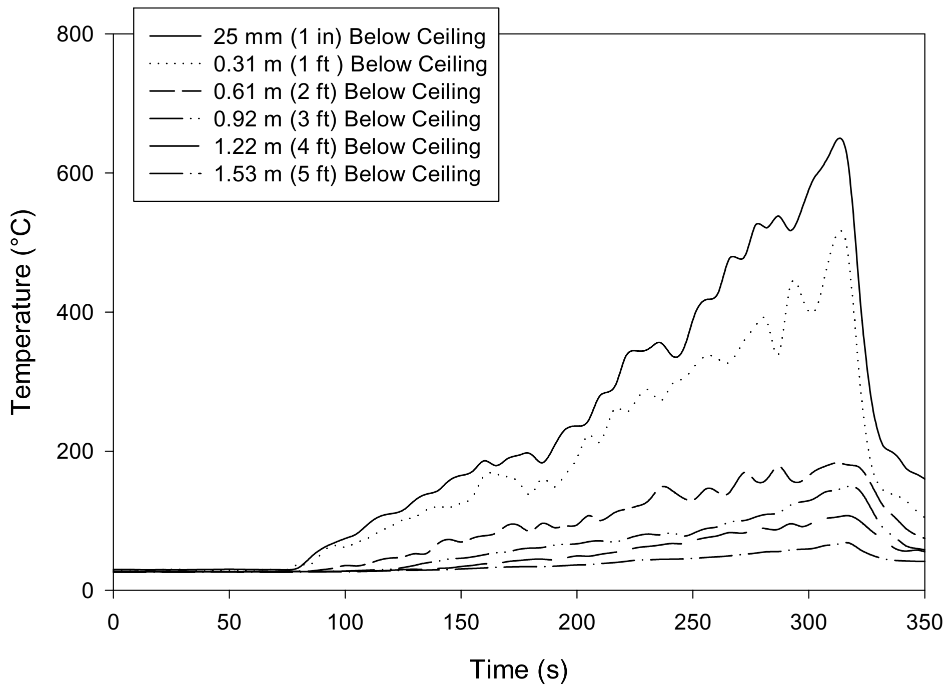

Figure B-82. Test 11 (Ultra-fast Gas Burner), Thermocouple Array 1 Data

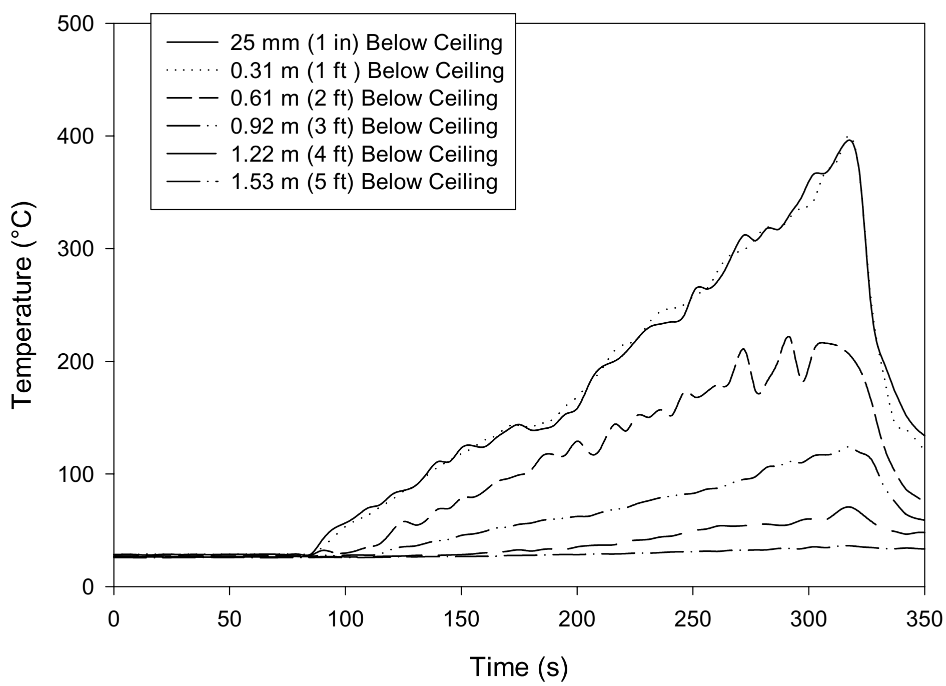

Figure B-83. Test 11 (Ultra-fast Gas Burner), Thermocouple Array 2 Data

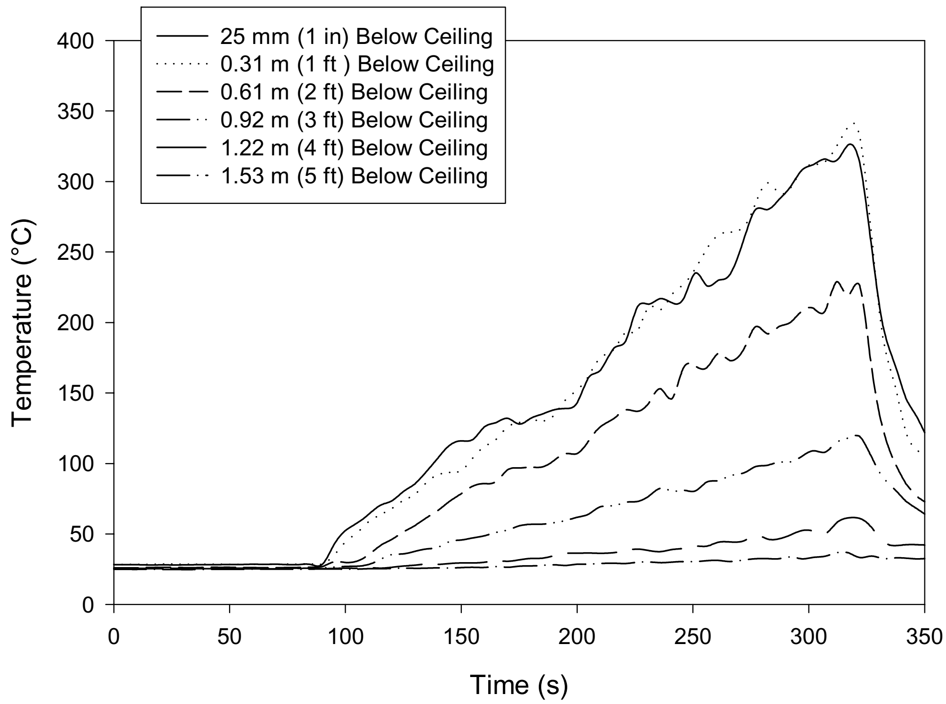

Figure B-84. Test 11 (Ultra-fast Gas Burner), Thermocouple Array 3 Data

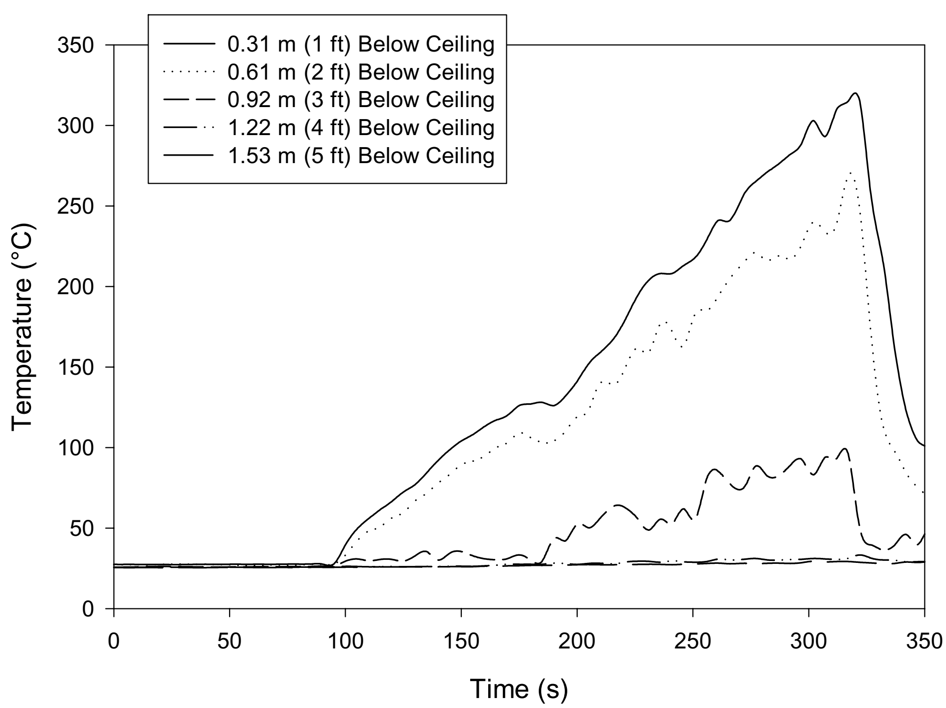

Figure B-85. Test 11 (Ultra-fast Gas Burner), Thermocouple Array 4 Data

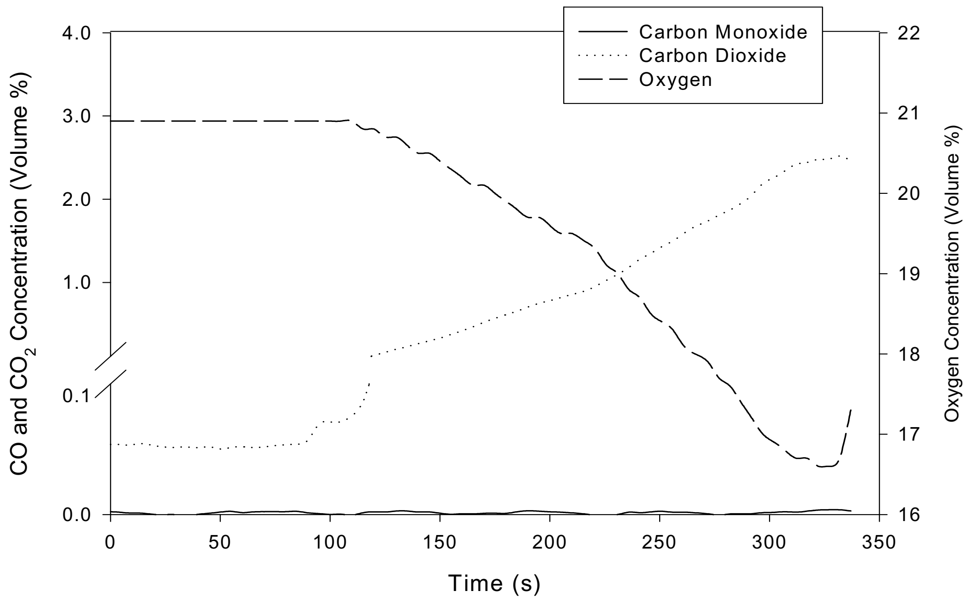

Figure B-86. Test 11 (Ultra-fast Gas Burner), Gas Concentration Data

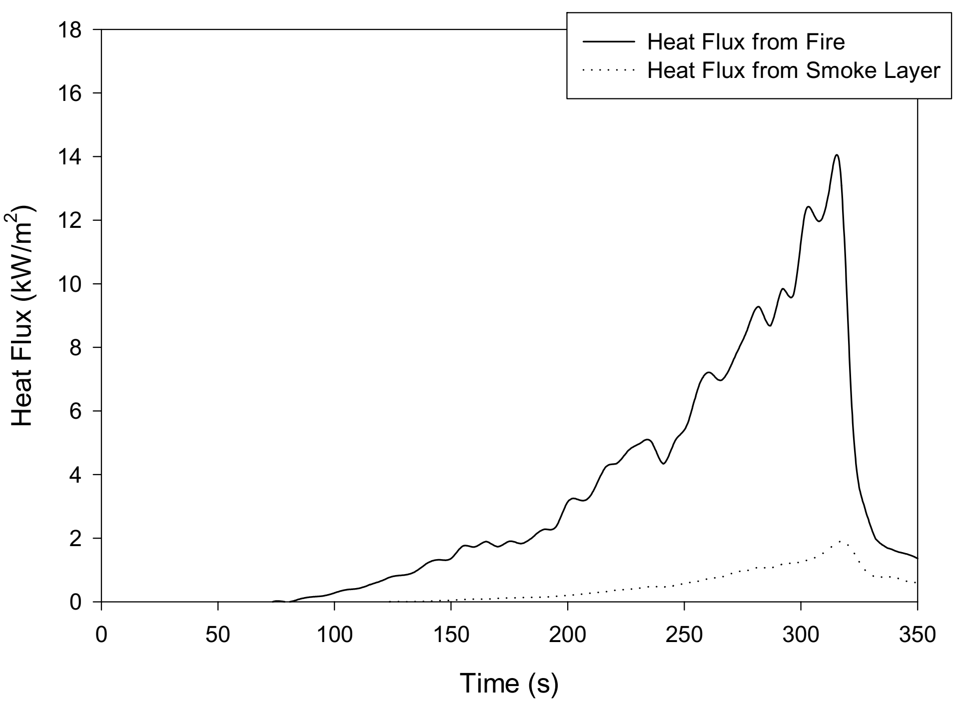

Figure B-87. Test 11 (Ultra-fast Gas Burner), Heat Flux Data

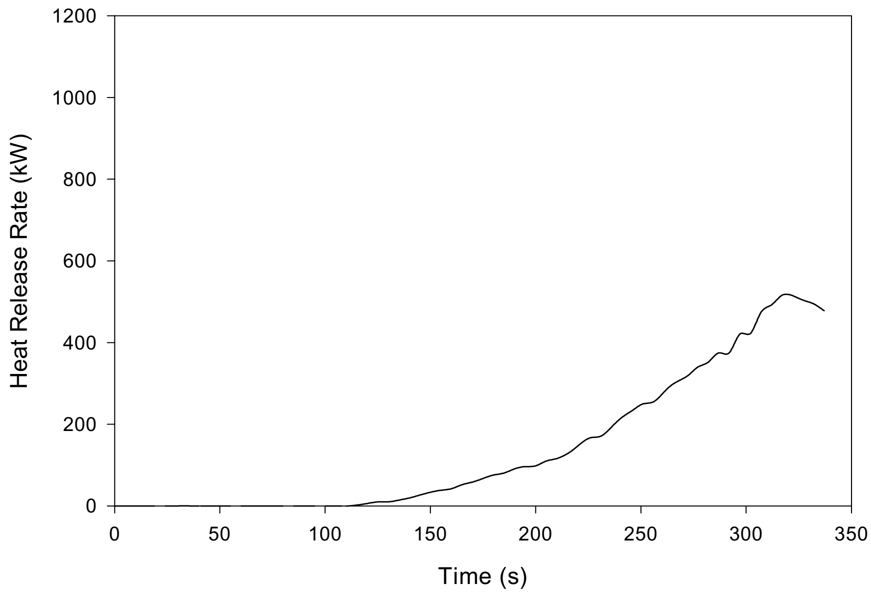

Figure B-88. Test 11 (Ultra-fast Gas Burner), Heat Release Rate Data

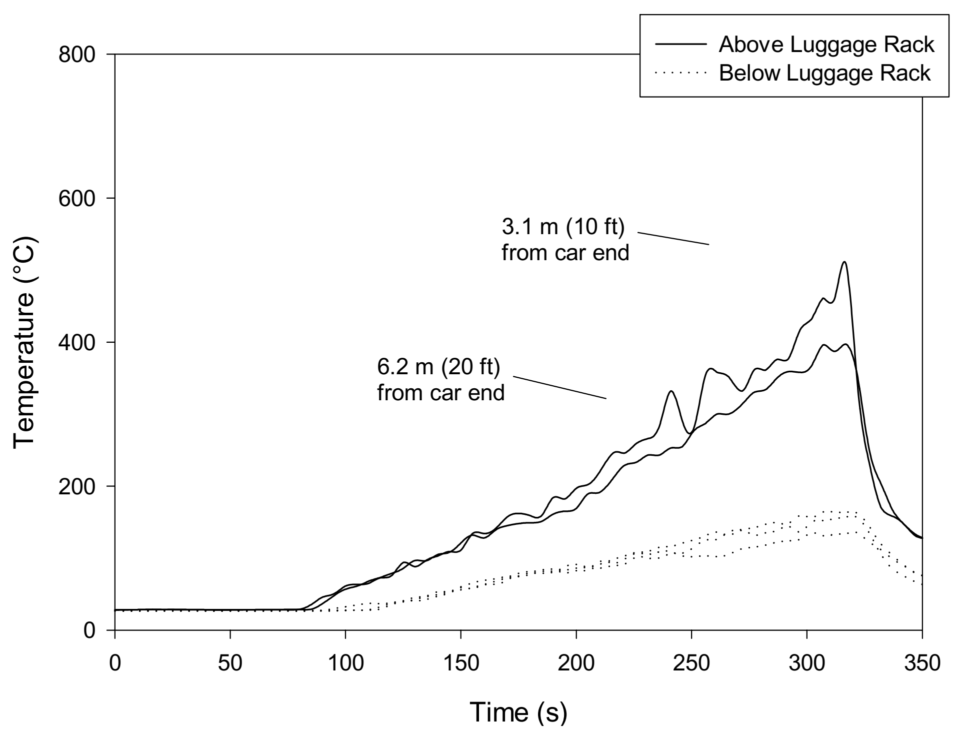

Figure B-89. Test 11 (Ultra-fast Gas Burner), Luggage Rack Temperature Data

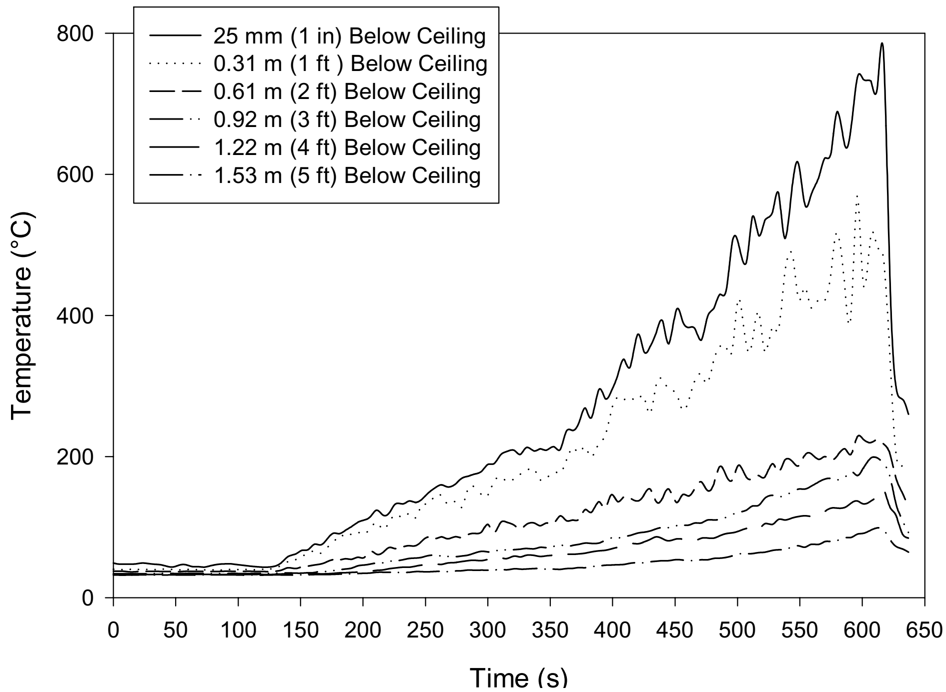

Figure B-90. Test 12 (Ultra-fast Gas Burner), Thermocouple Array 1 Data

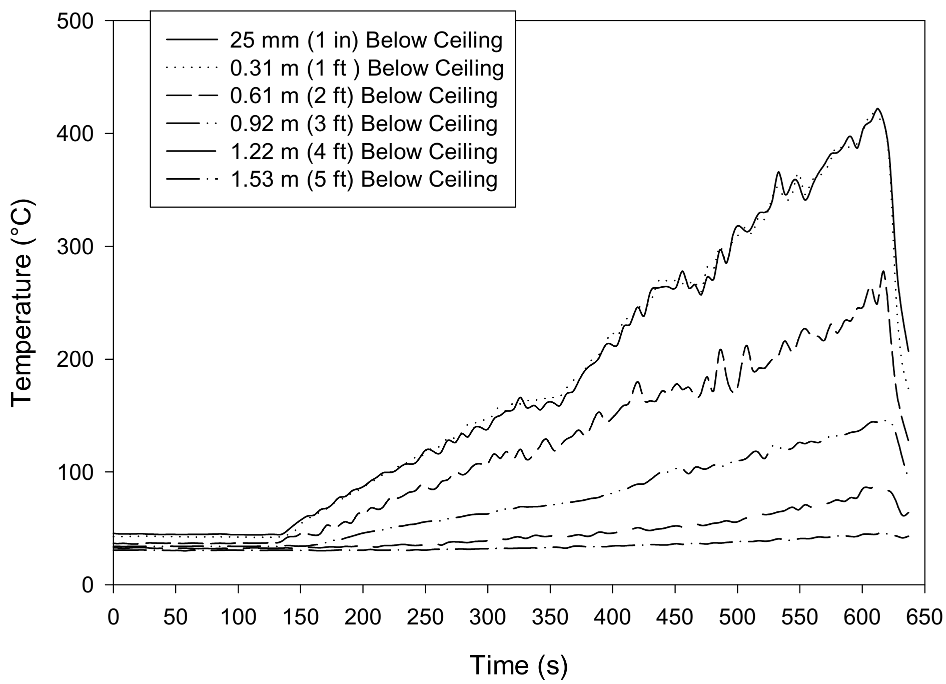

Figure B-91. Test 12 (Ultra-fast Gas Burner), Thermocouple Array 2 Data

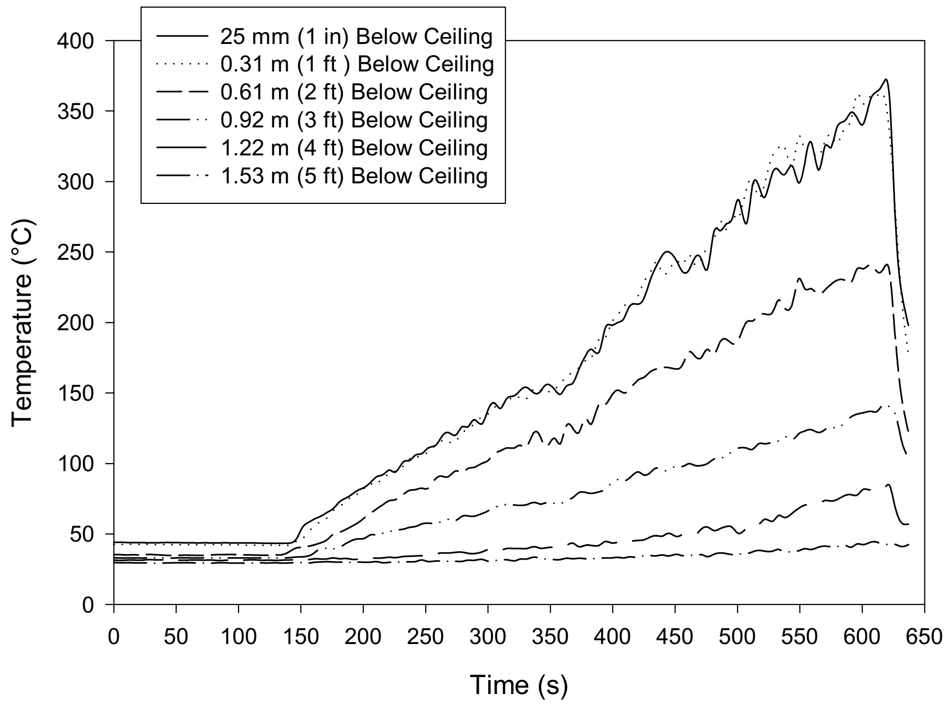

Figure B-92. Test 12 (Ultra-fast Gas Burner), Thermocouple Array 3 Data

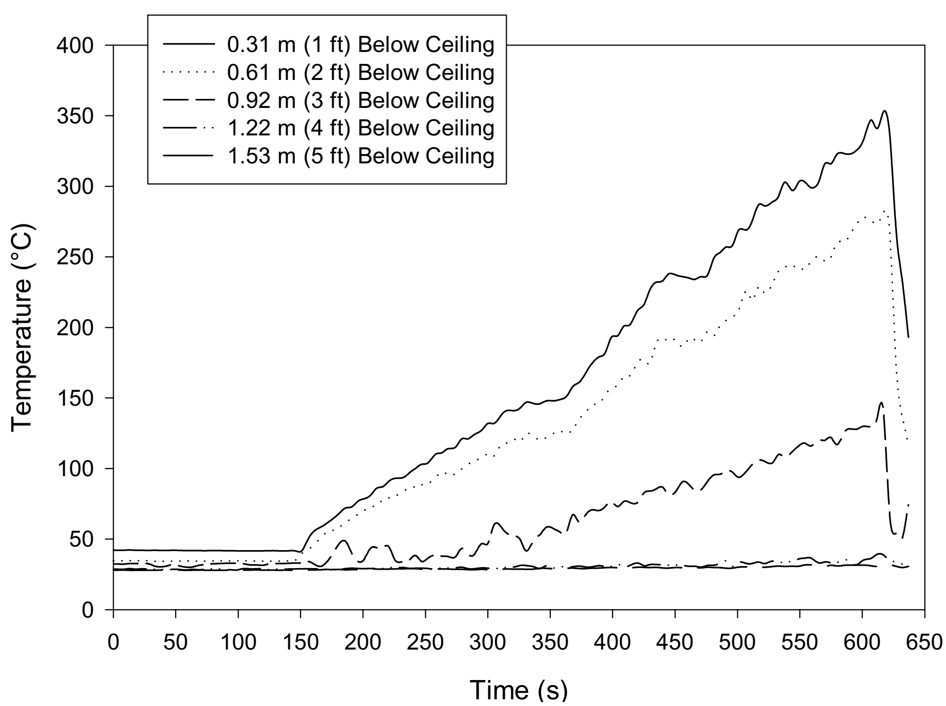

Figure B-93. Test 12 (Ultra-fast Gas Burner), Thermocouple Array 4 Data

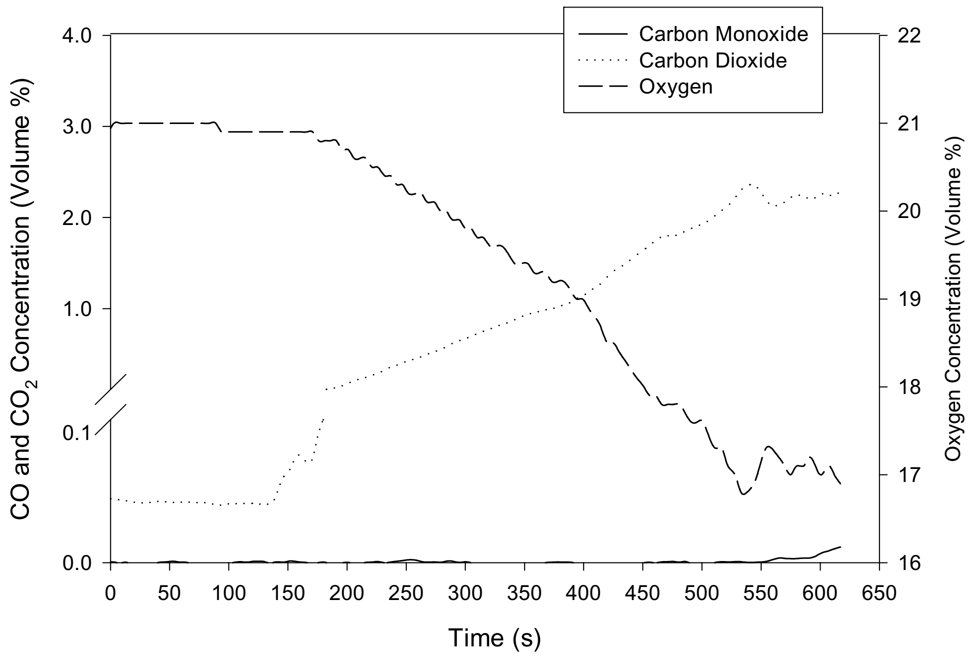

Figure B-94. Test 12 (Ultra-fast Gas Burner), Gas Concentration Data

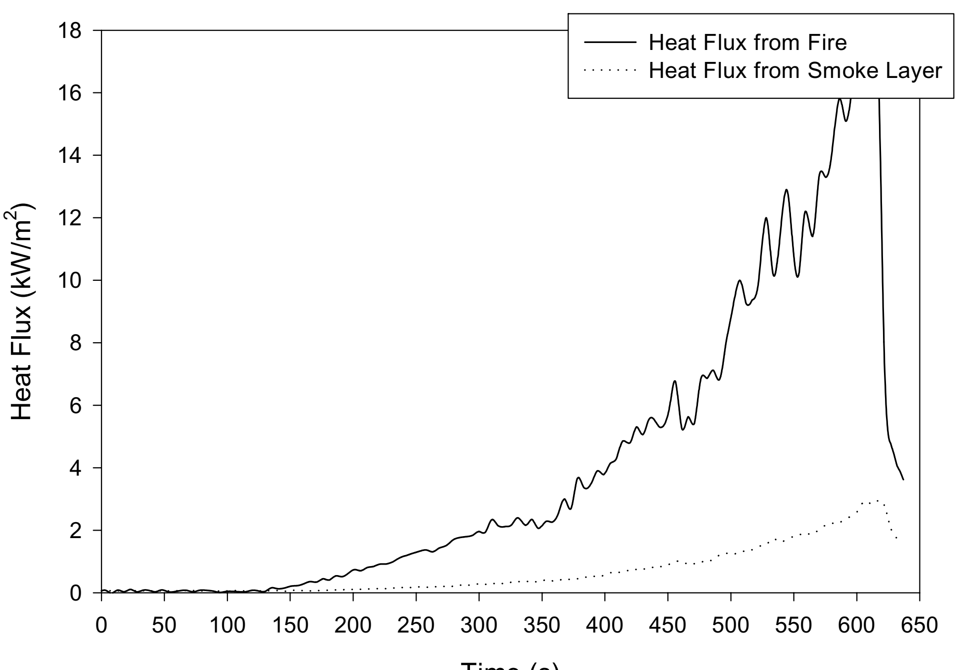

Figure B-95. Test 12 (Ultra-fast Gas Burner), Heat Flux Data

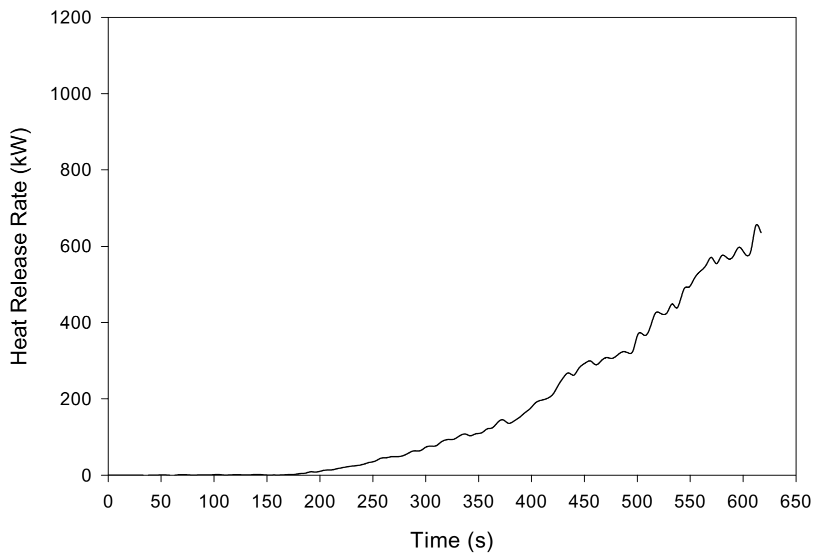

Figure B-96. Test 12 (Ultra-fast Gas Burner), Heat Release Rate Data

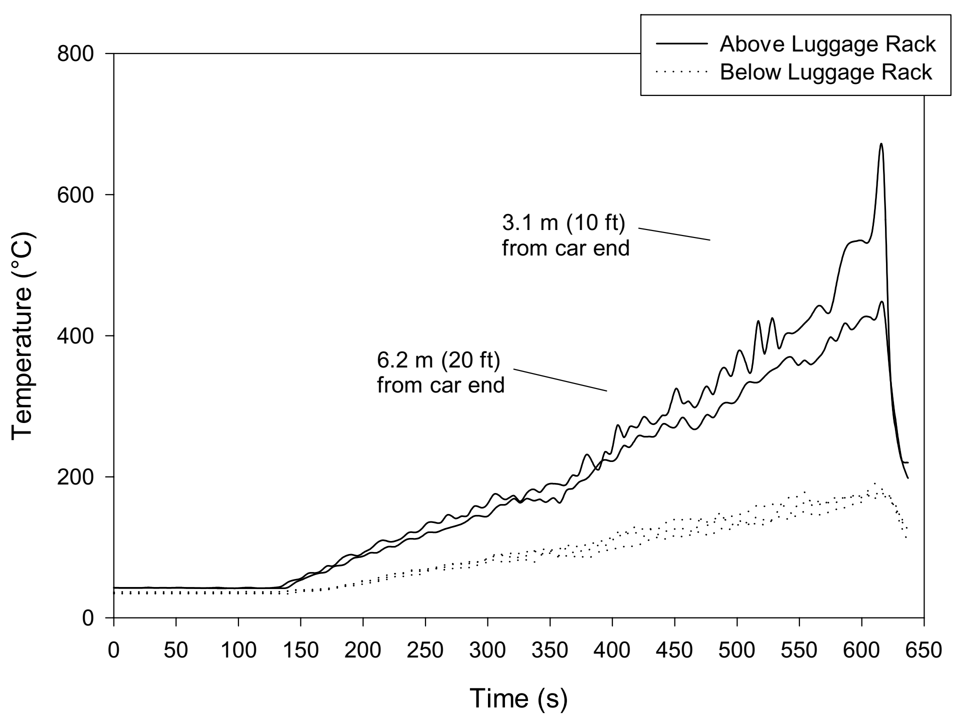

Figure B-97. Test 12 (Ultra-fast Gas Burner), Luggage Rack Temperature Data

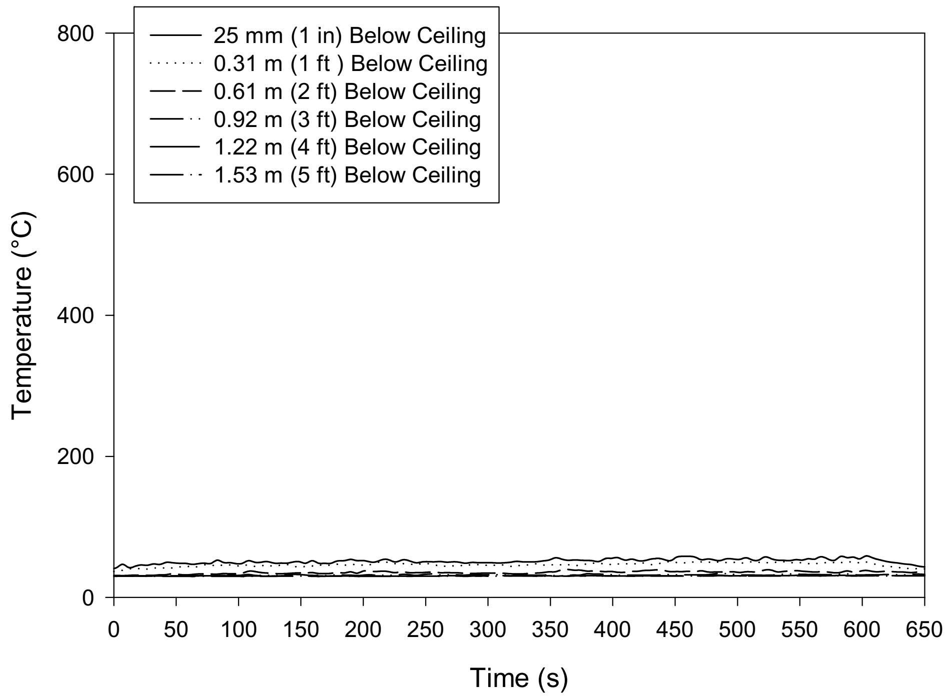

Figure B-98. Test 13 (Drape with 25 kW Sand Burner), Thermocouple Array 1 Data

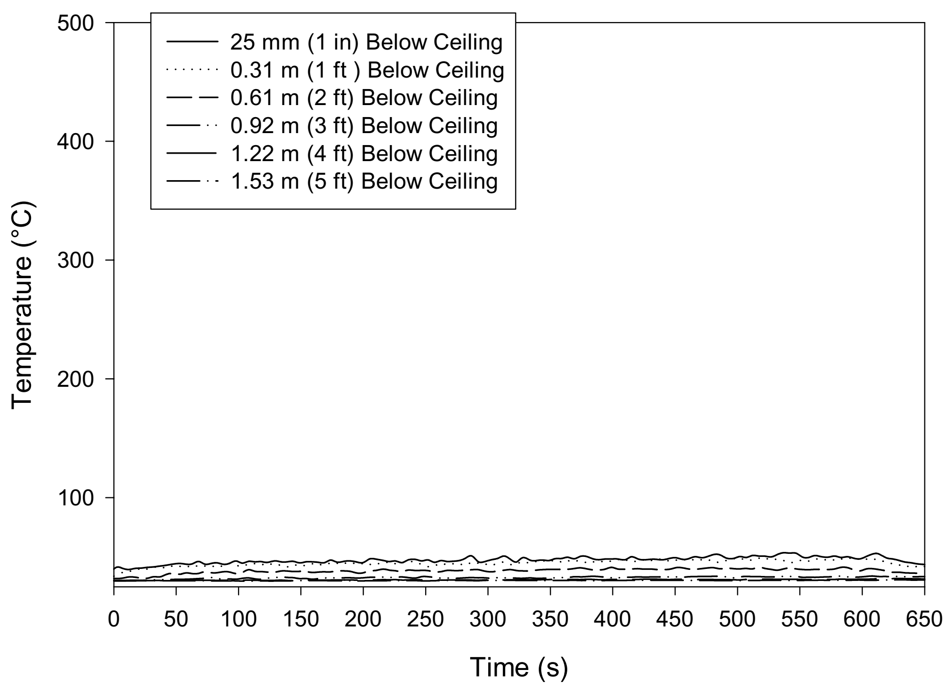

Figure B-99. Test 13 (Drape with 25 kW Sand Burner), Thermocouple Array 2 Data

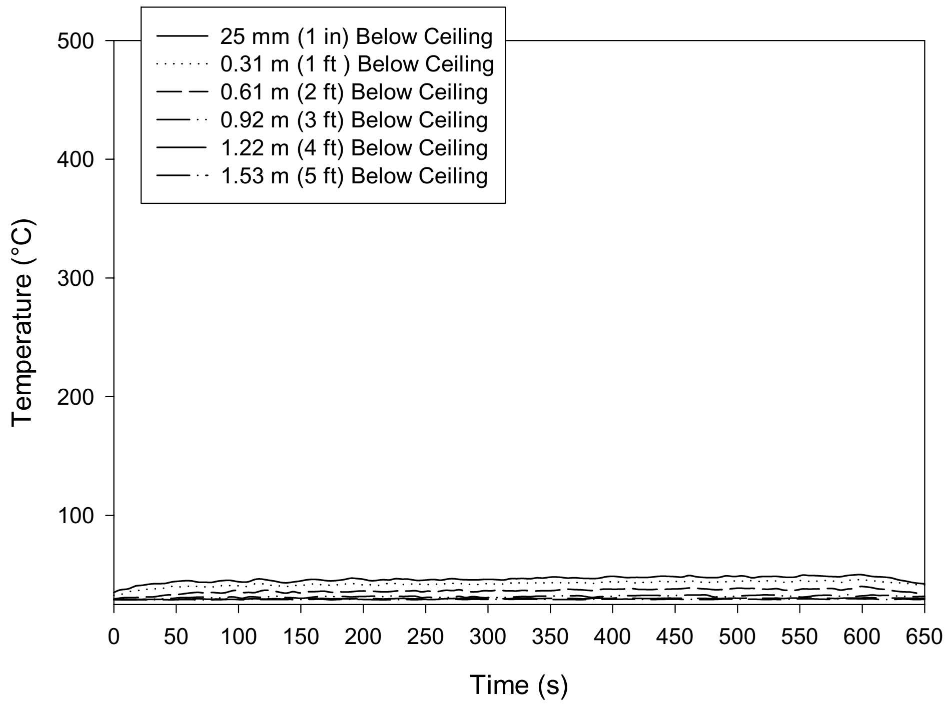

Figure B-100. Test 13 (Drape with 25 kW Sand Burner), Thermocouple Array 3 Data

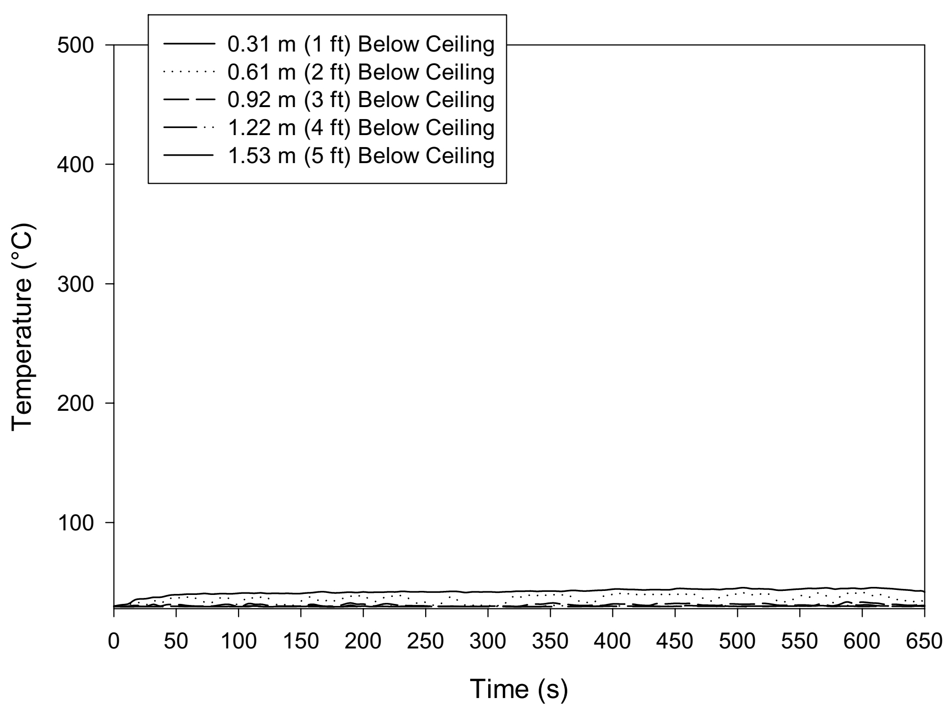

Figure B-101. Test 13 (Drape with 25 kW Sand Burner), Thermocouple Array 4 Data

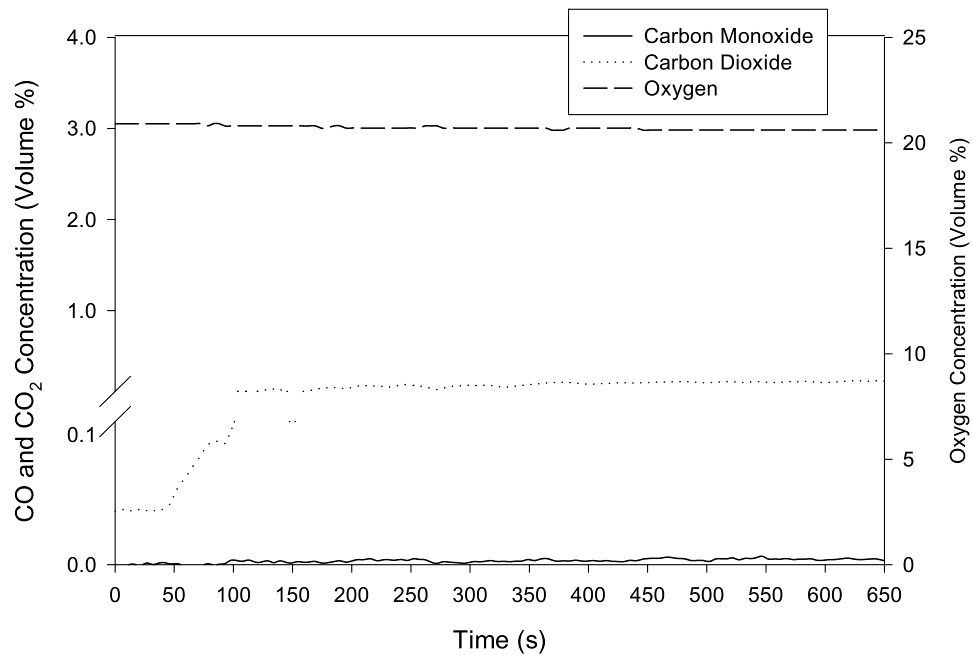

Figure B-102. Test 13 (Drape with 25 kW Sand Burner), Gas Concentration Data

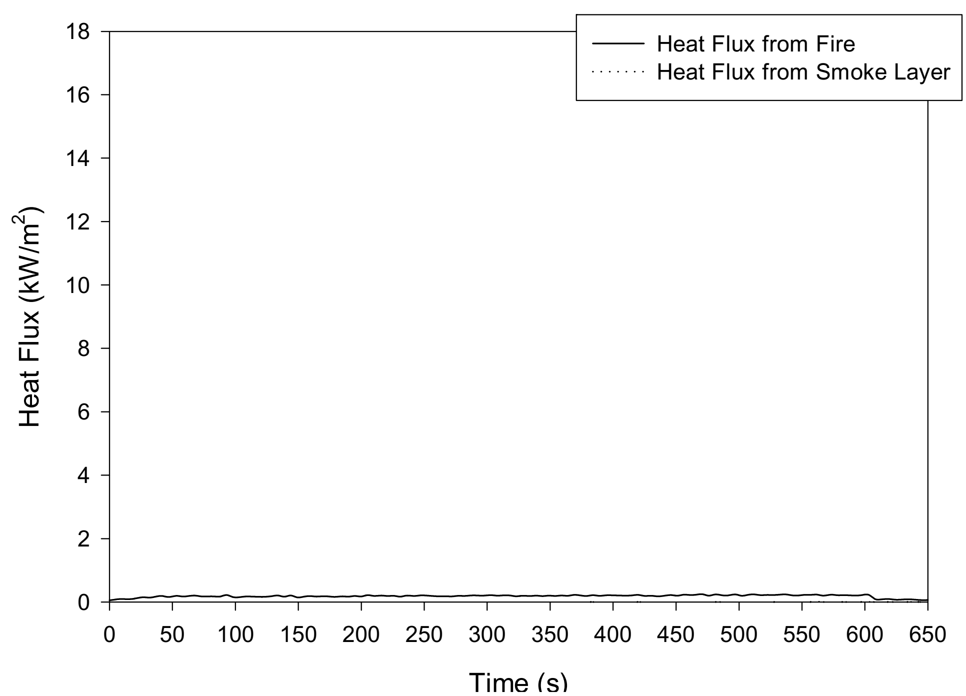

Figure B-103. Test 13 (Drape with 25 kW Sand Burner), Heat Flux Data

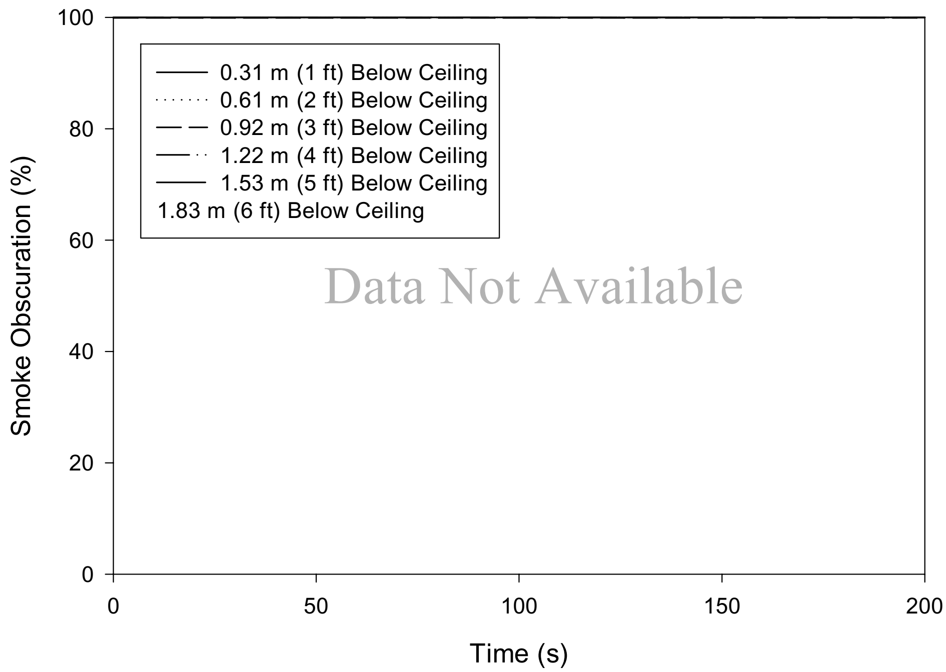

Figure B-104. Test 13 (Drape with 25 kW Sand Burner), Smoke Obscuration Data

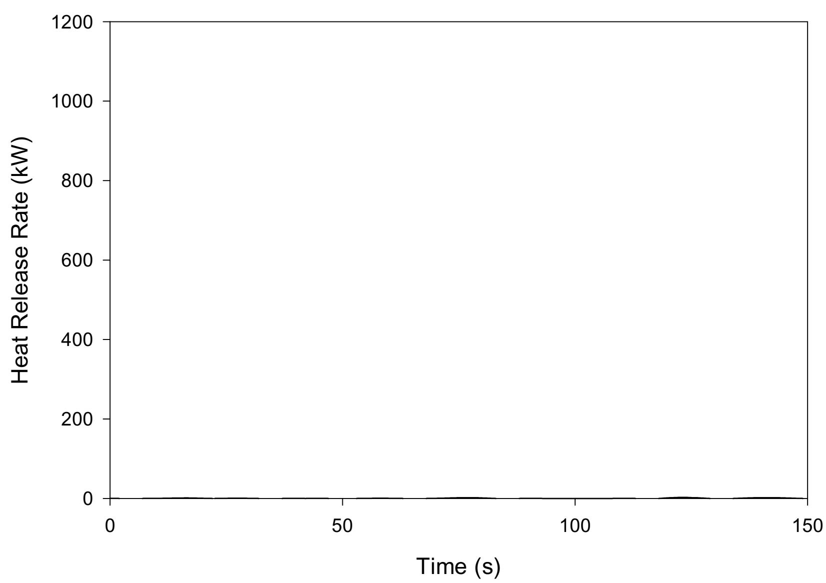

Figure B-105. Test 13 (Drape with 25 kW Sand Burner), Heat Release Rate Data

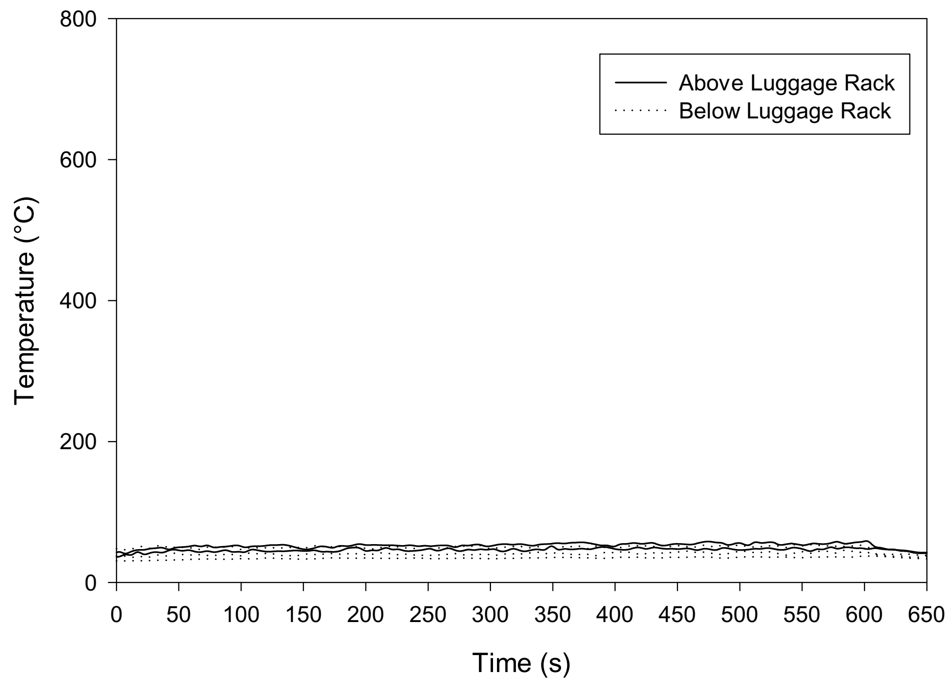

Figure B-106. Test 13 (Drape with 25 kW Sand Burner), Luggage Rack Temperature Data

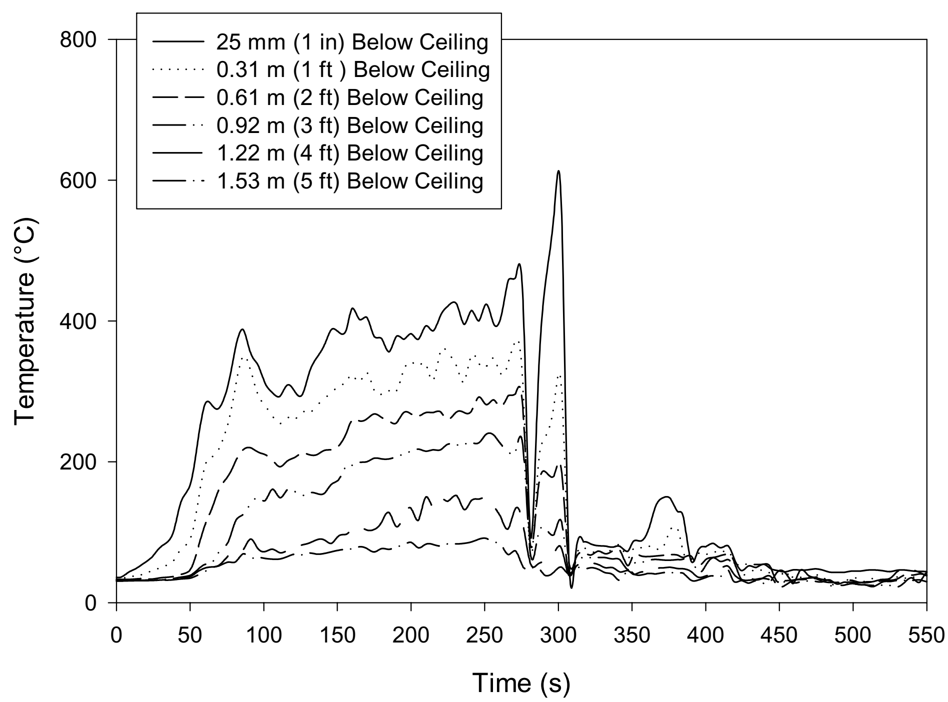

Figure B-107. Test 14 (Corner with 25 kW Sand Burner), Thermocouple Array 1 Data

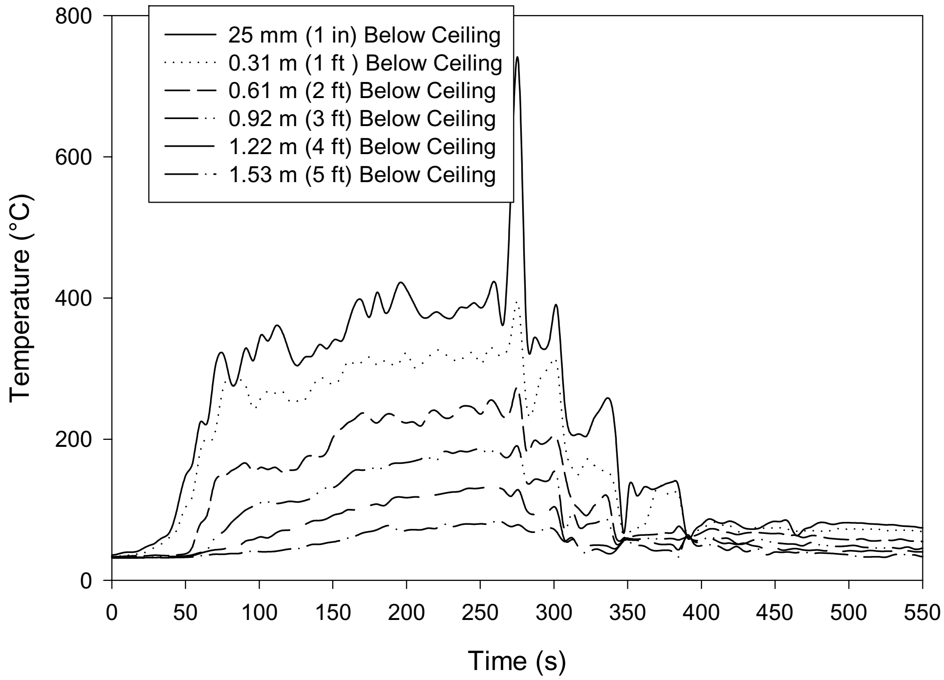

Figure B-108. Test 14 (Corner with 25 kW Sand Burner), Thermocouple Array 2 Data

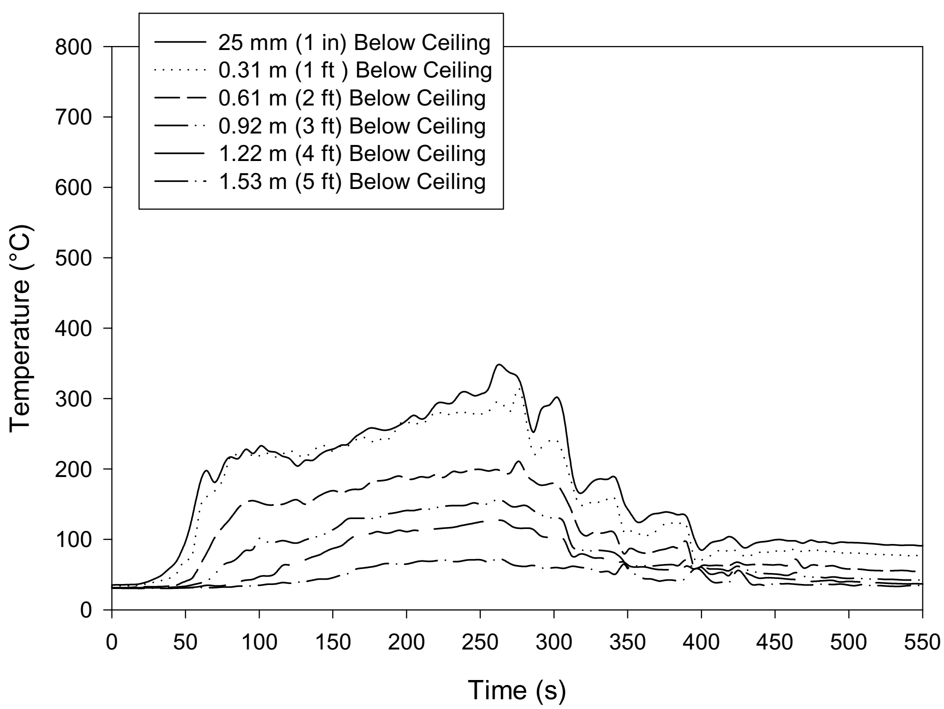

Figure B-109. Test 14 (Corner with 25 kW Sand Burner), Thermocouple Array 3 Data

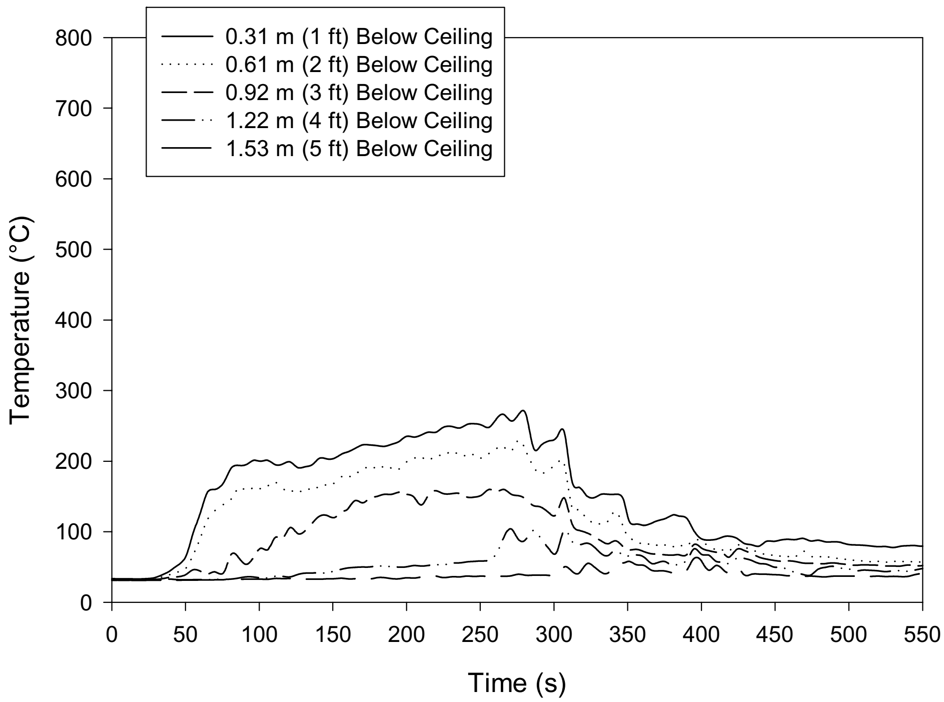

Figure B-110. Test 14 (Corner with 25 kW Sand Burner), Thermocouple Array 4 Data

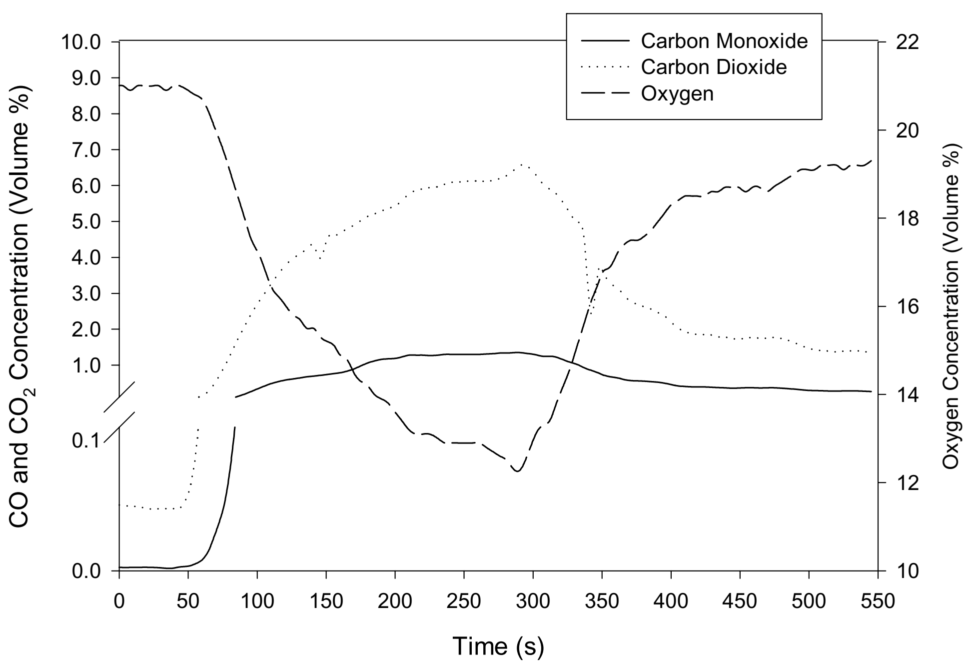

Figure B-111. Test 14 (Seat with TB 133 Burner), Gas Concentration Data

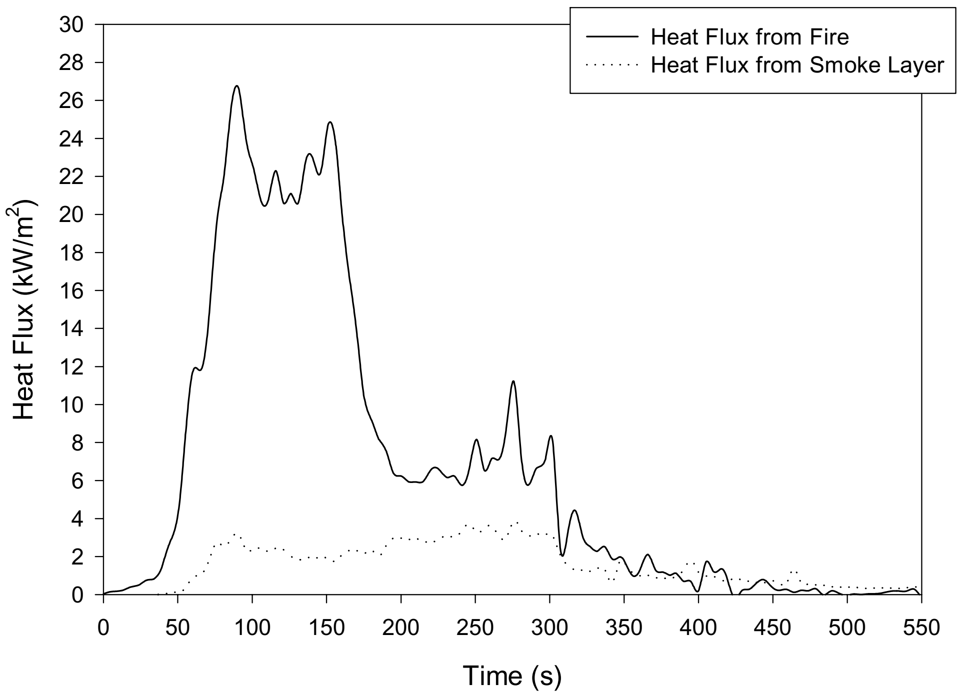

Figure B-112. Test 14 (Corner with 25 kW Sand Burner), Heat Flux Data

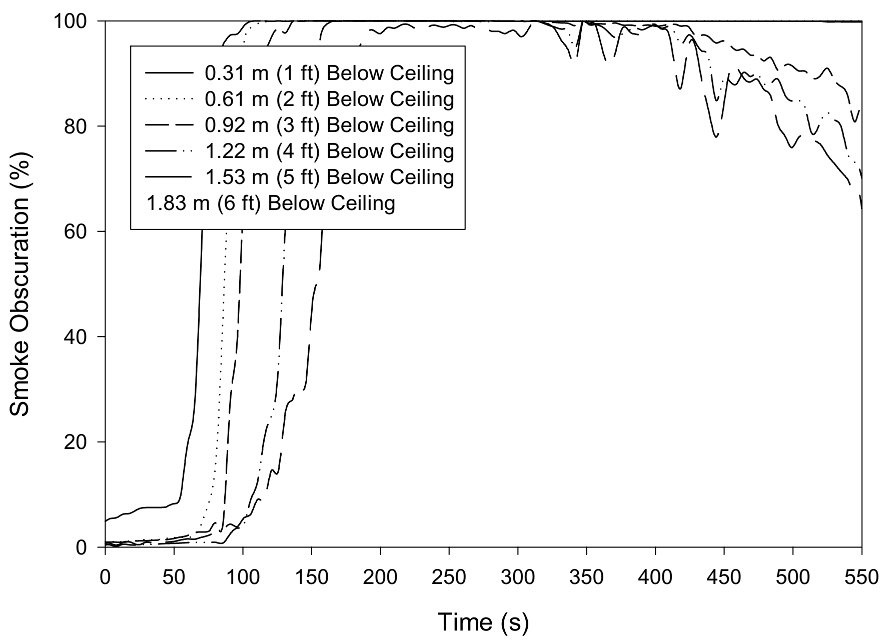

Figure B-113. Test 14 (Corner with 25 kW Sand Burner), Smoke Obscuration Data

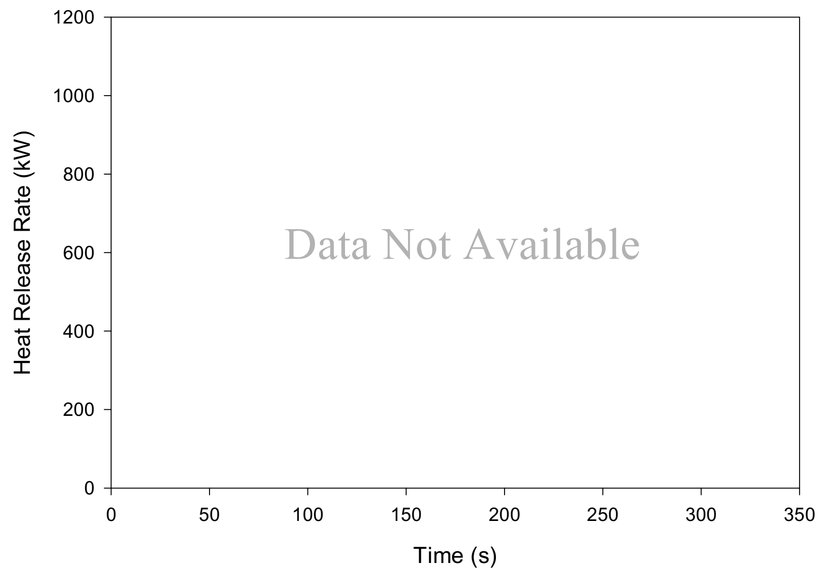

Figure B-114. Test 14 (Corner with 25 kW Sand Burner), Heat Release Rate Data

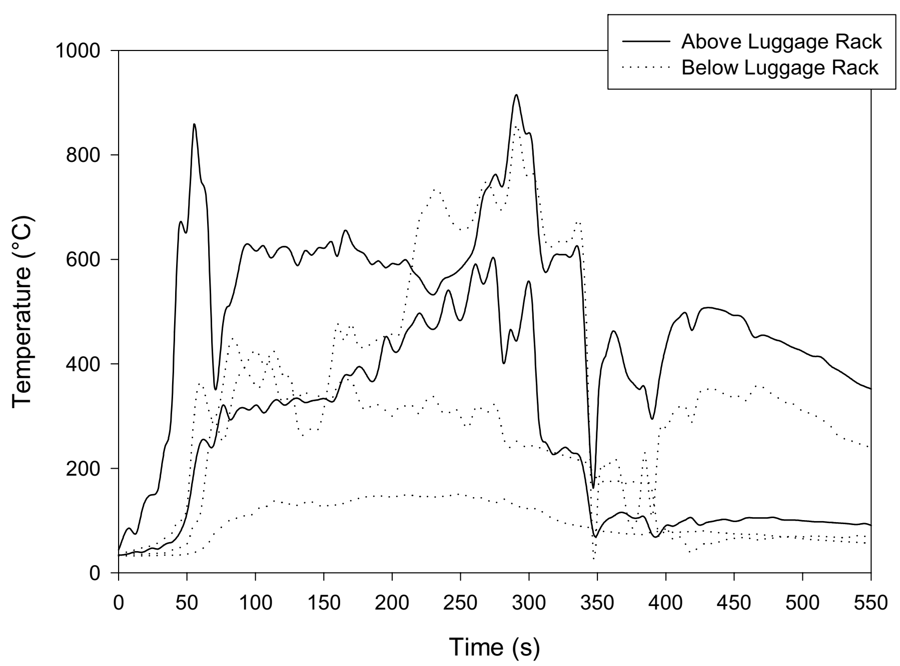

Figure B-115. Test 14 (Corner with 25 kW Sand Burner), Luggage Rack Temperature Data

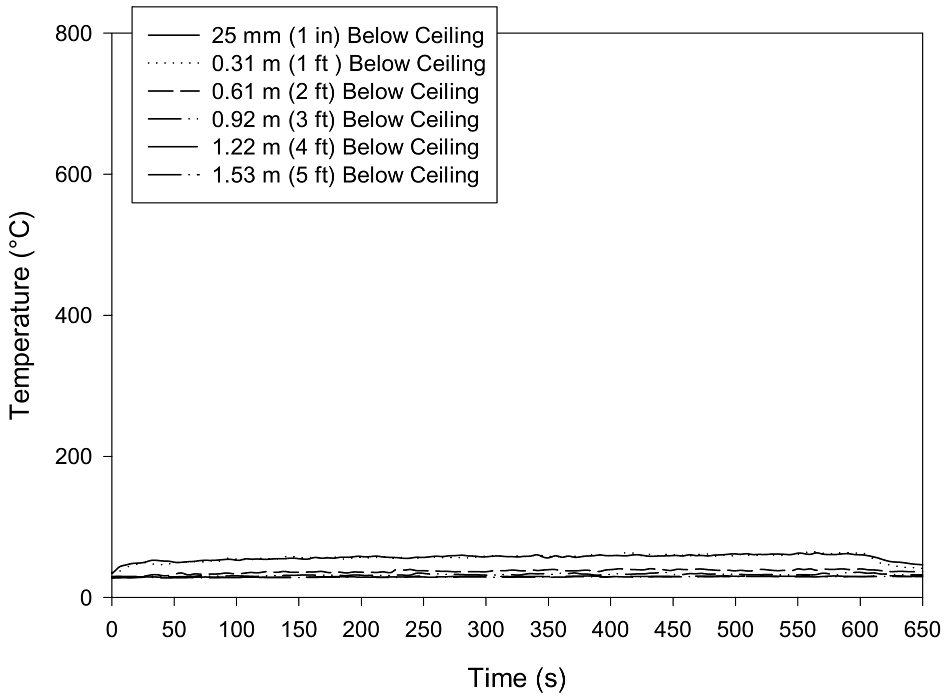

Figure B-116. Test 15 (Seat with 25 kW Sand Burner), Thermocouple Array 1 Data

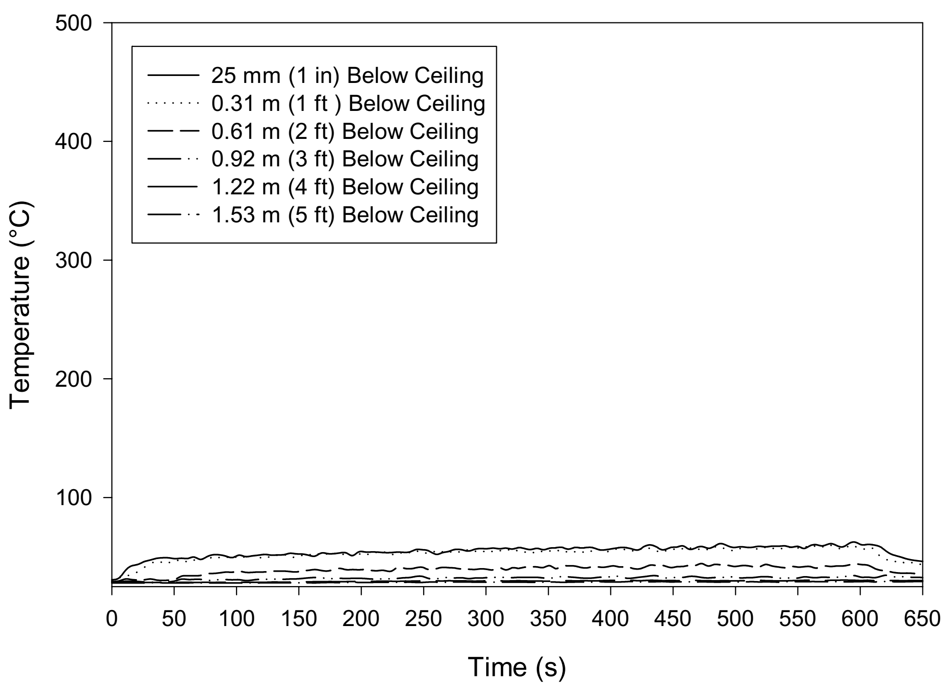

Figure B-117. Test 15 (Seat with 25 kW Sand Burner), Thermocouple Array 2 Data

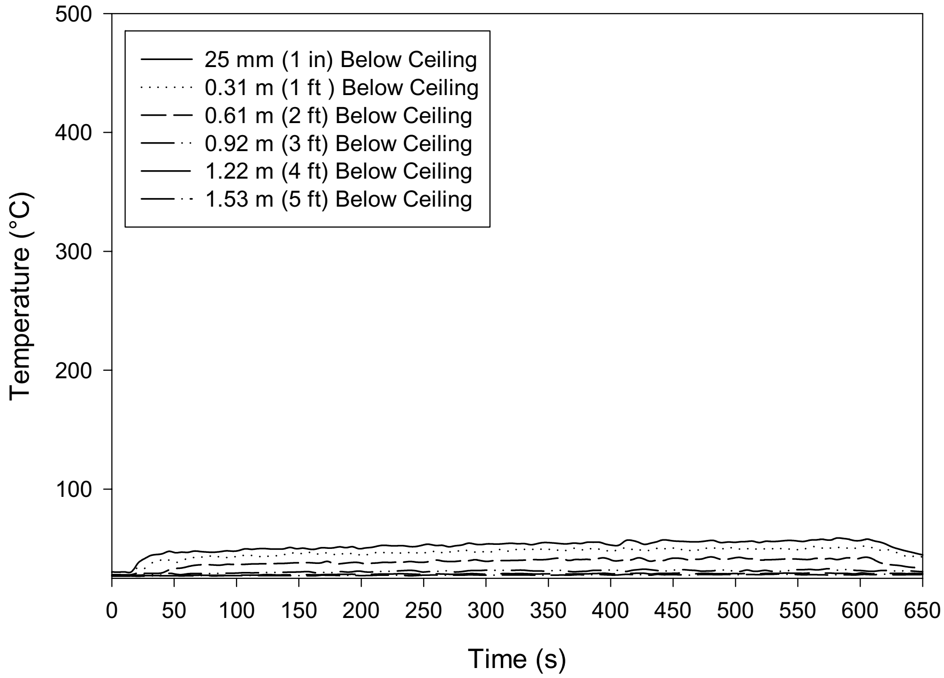

Figure B-118. Test 15 (Seat with 25 kW Sand Burner), Thermocouple Array 3 Data

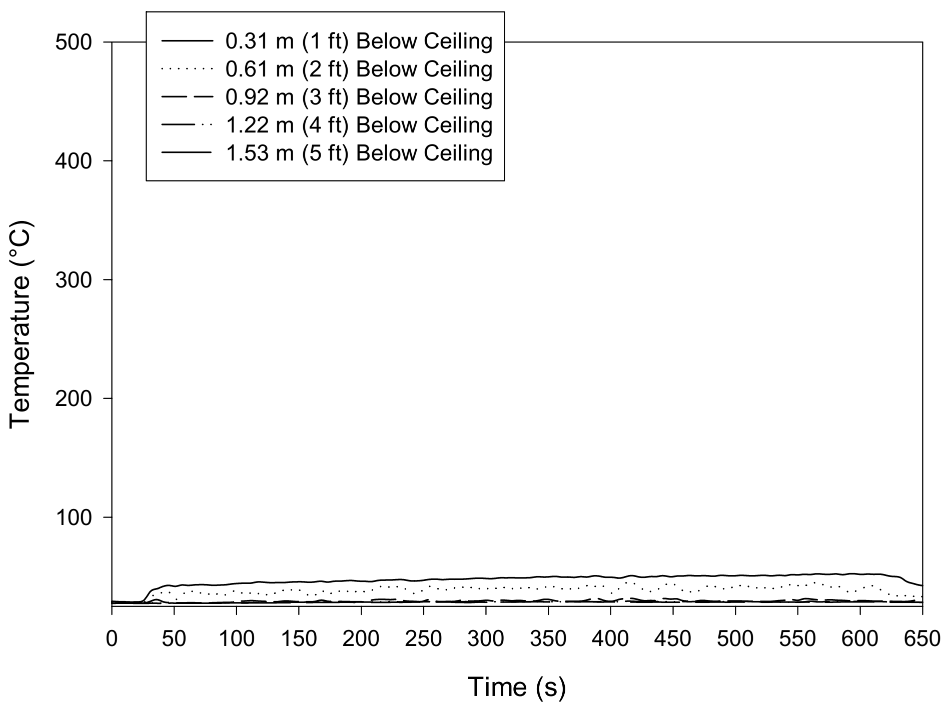

Figure B-119. Test 15 (Seat with 25 kW Sand Burner), Thermocouple Array 4 Data

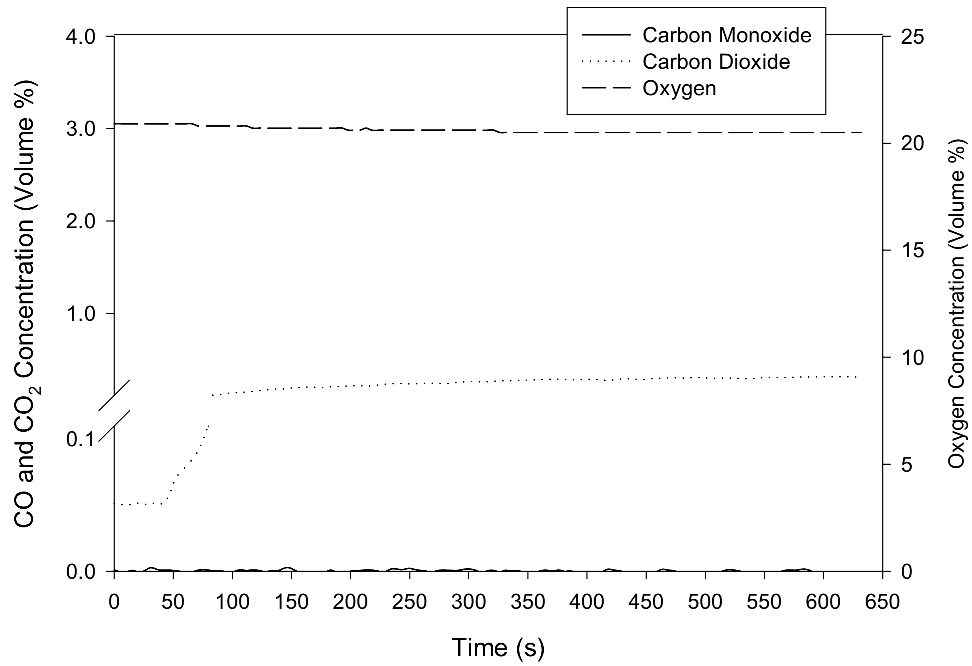

Figure B-120. Test 15 (Seat with 25 kW Sand Burner), Gas Concentration Data

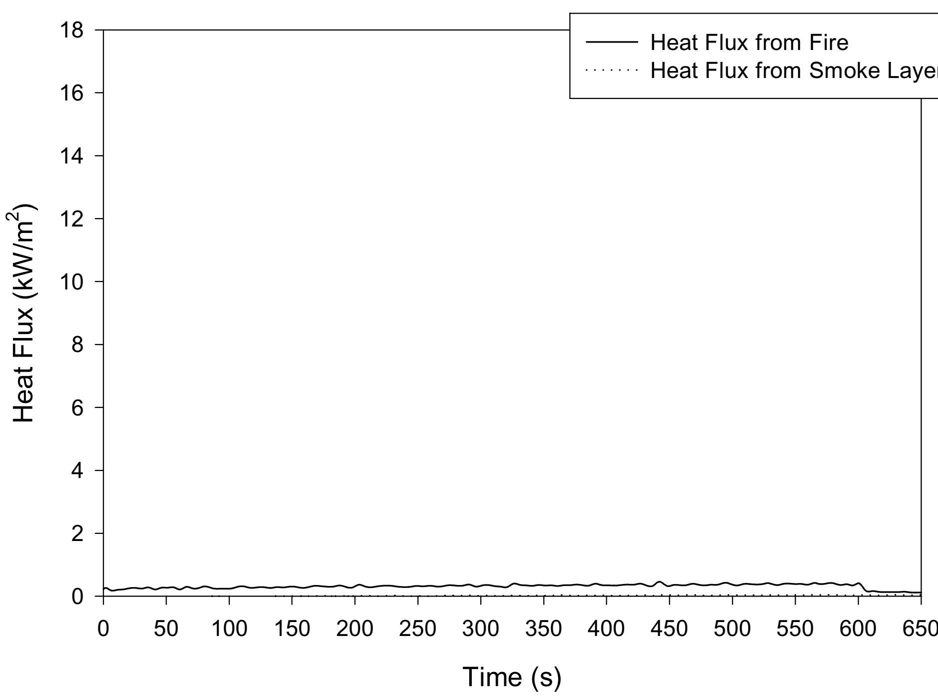

Figure B-121. Test 15 (Seat with 25 kW Sand Burner), Heat Flux Data

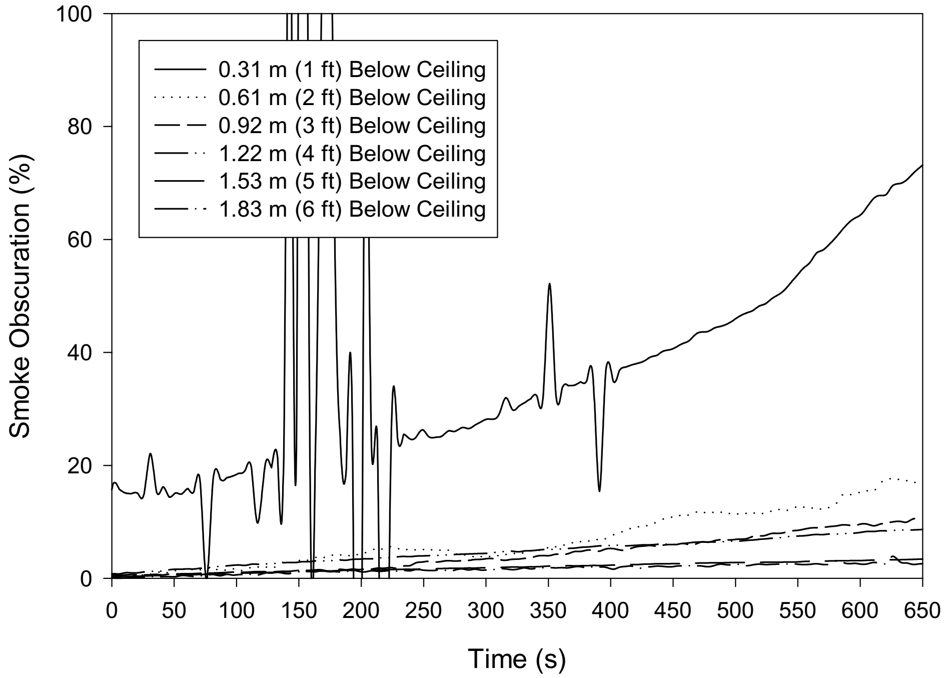

Figure B-122. Test 15 (Seat with 25 kW Sand Burner), Smoke Obscuration Data

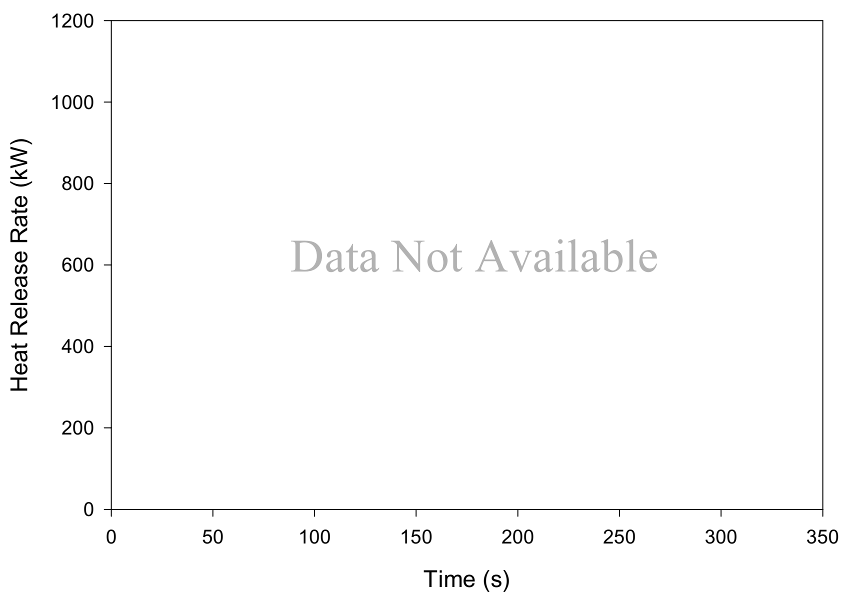

Figure B-123. Test 14 (Seat with 25 kW Sand Burner), Heat Release Rate Data

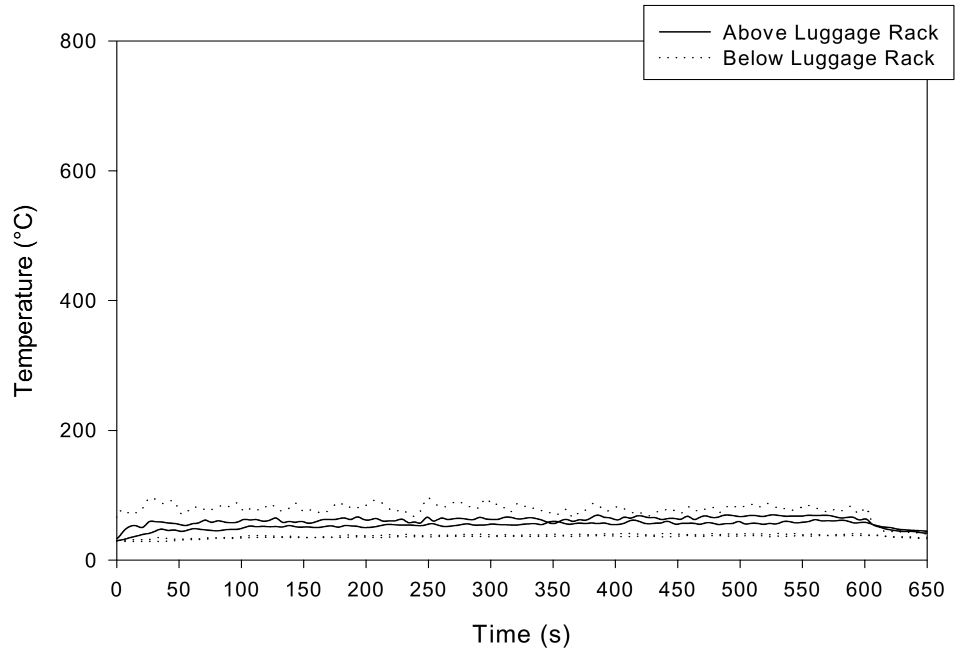

Figure B-124. Test 15 (Seat with 25 kW Sand Burner), Luggage Rack Temperature Data

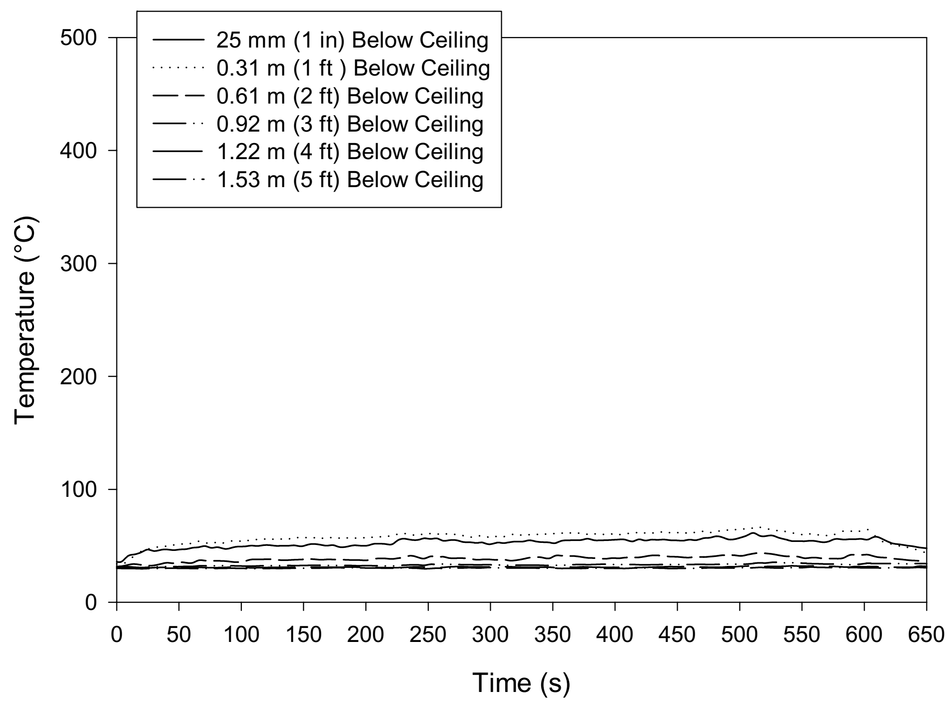

Figure B-125. Test 16 (Seat with TB 133 Burner), Thermocouple Array 1 Data

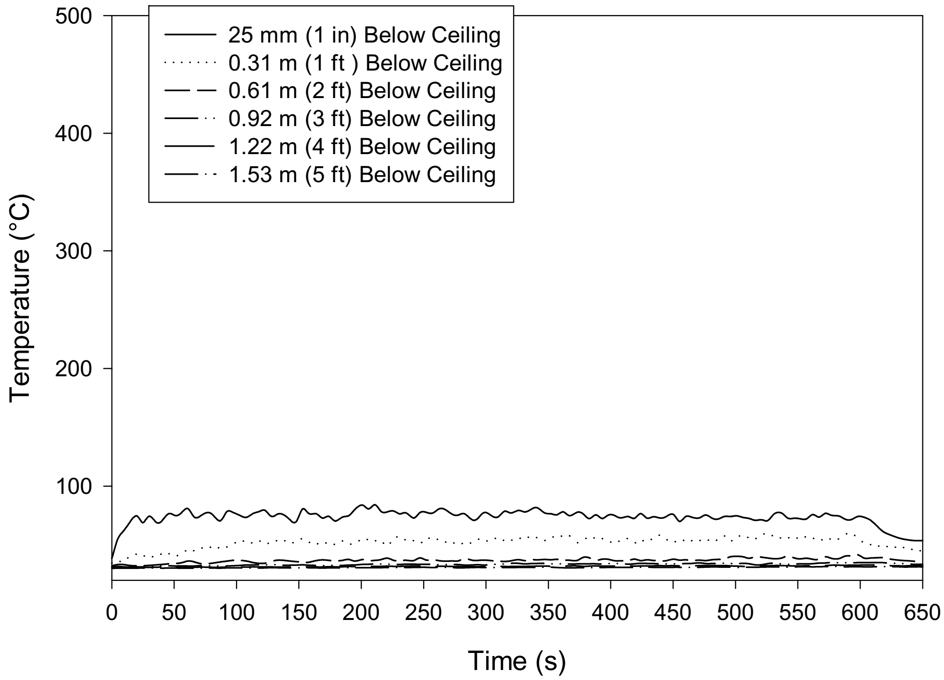

Figure B-126. Test 16 (Seat with TB 133 Burner), Thermocouple Array 2 Data

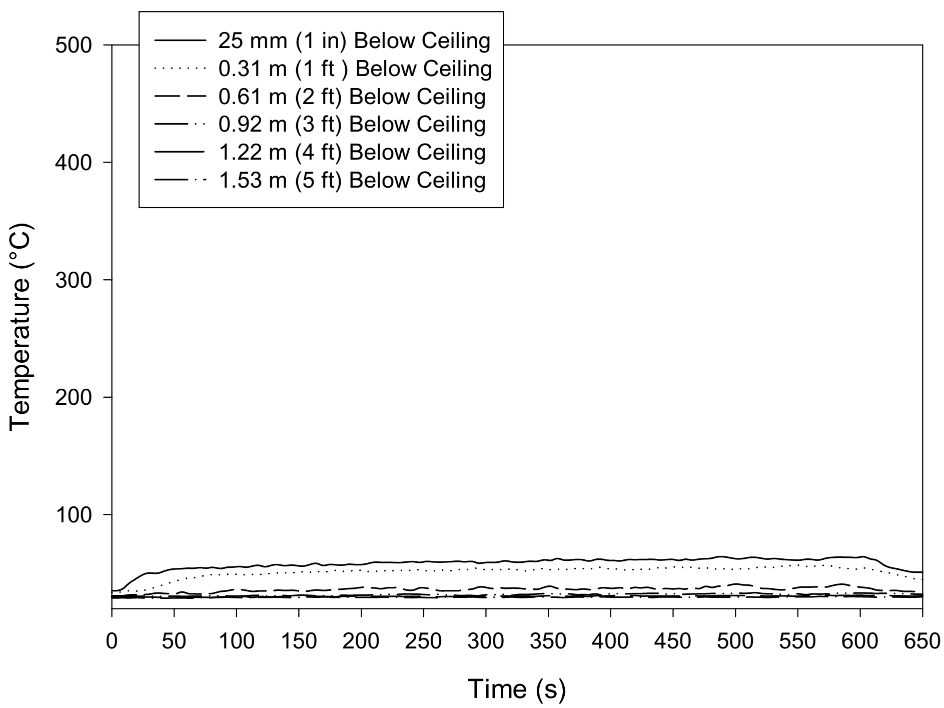

Figure B-127. Test 16 (Seat with TB 133 Burner), Thermocouple Array 3 Data

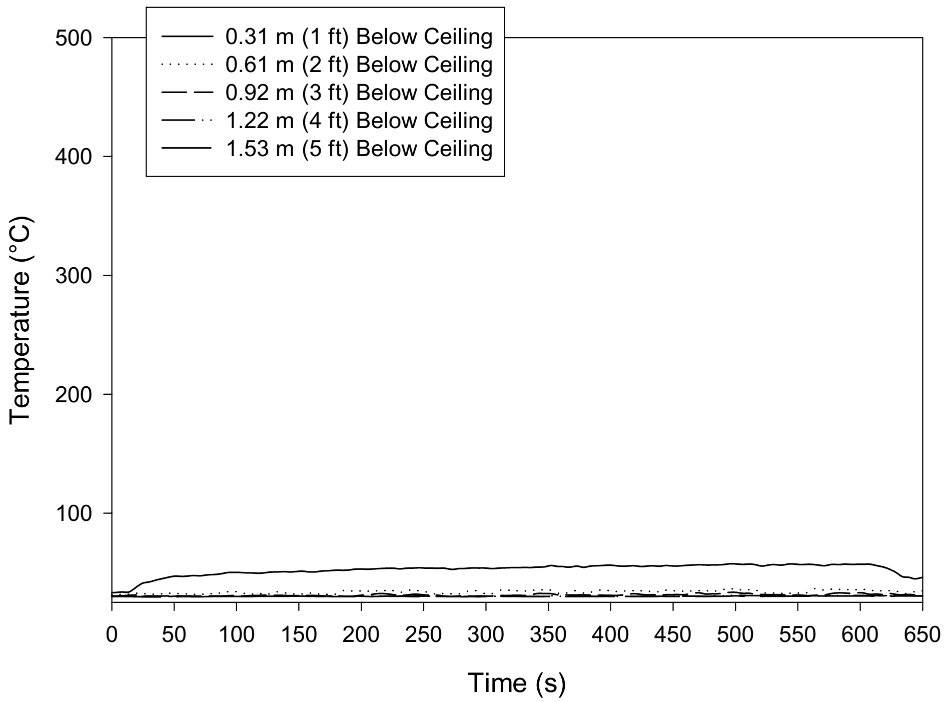

Figure B-128. Test 16 (Seat with TB 133 Burner), Thermocouple Array 4 Data

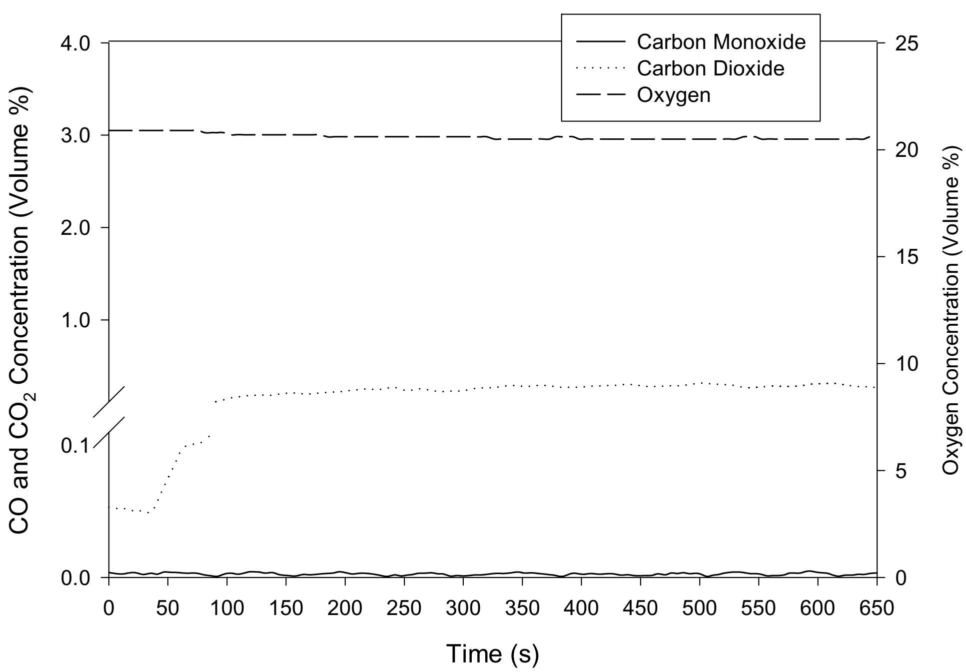

Figure B-129. Test 16 (Seat with TB 133 Burner), Gas Concentration Data

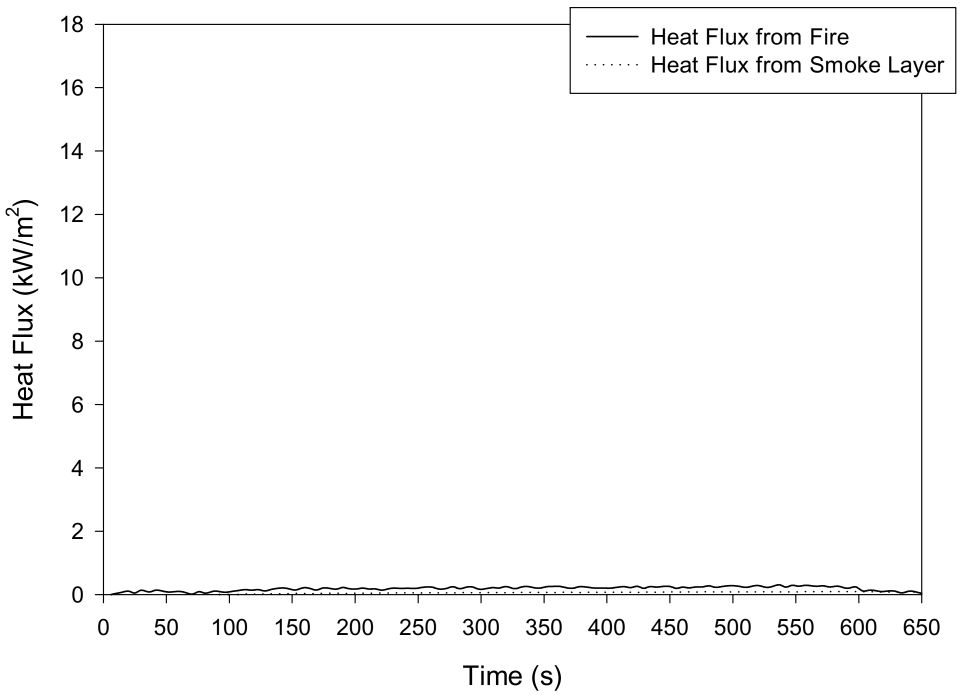

Figure B-130. Test 16 (Seat with TB 133 Burner), Heat Flux Data

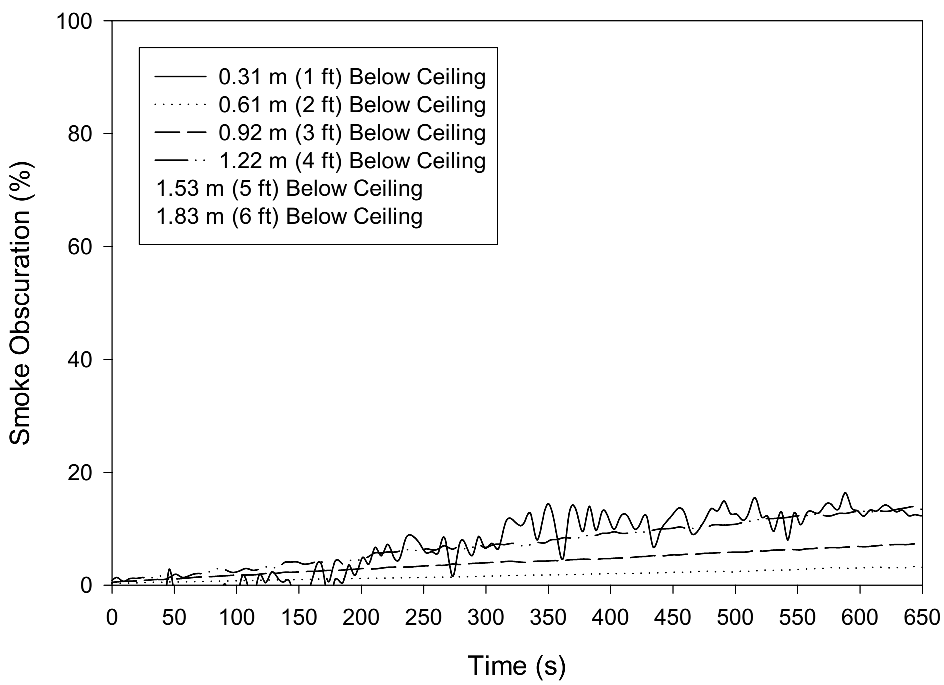

Figure B-131. Test 16 (Seat with TB 133 Burner), Smoke Obscuration Data

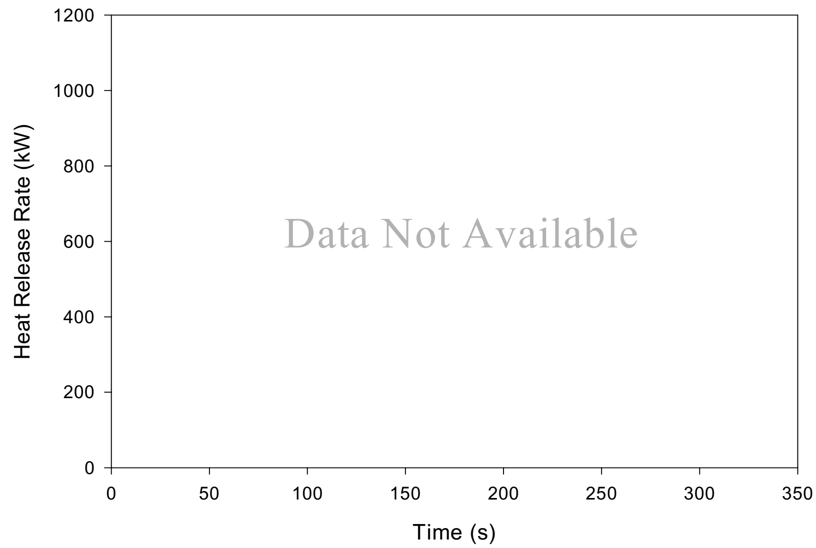

Figure B-132. Test 16 (Seat with TB 133 Burner), Heat Release Rate Data

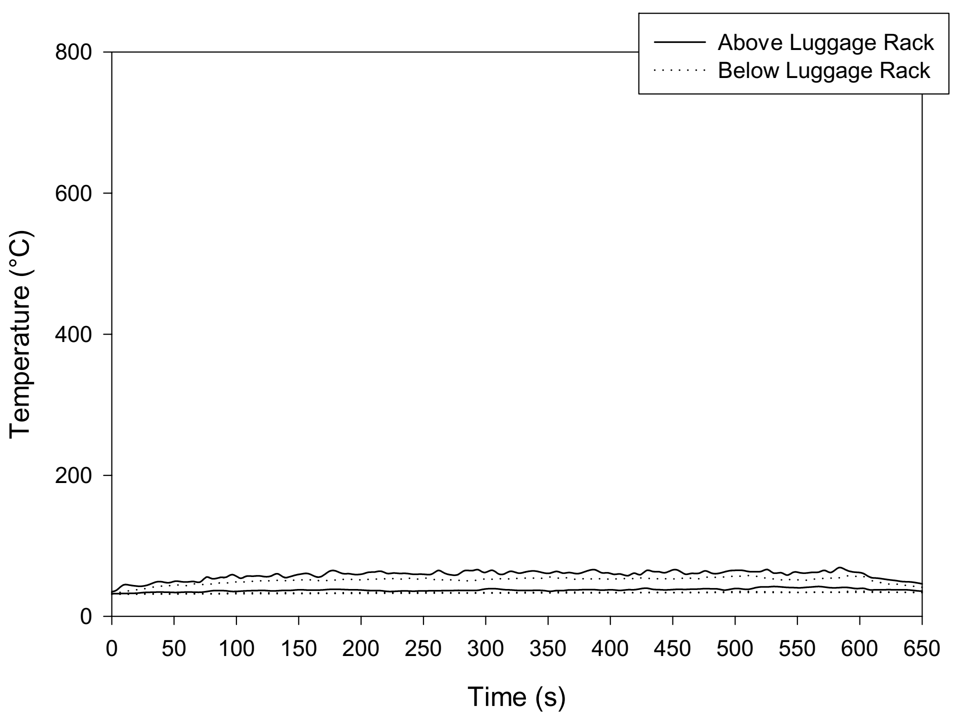

Figure B-133. Test 16 (Seat with TB 133 Burner), Luggage Rack Temperature Data

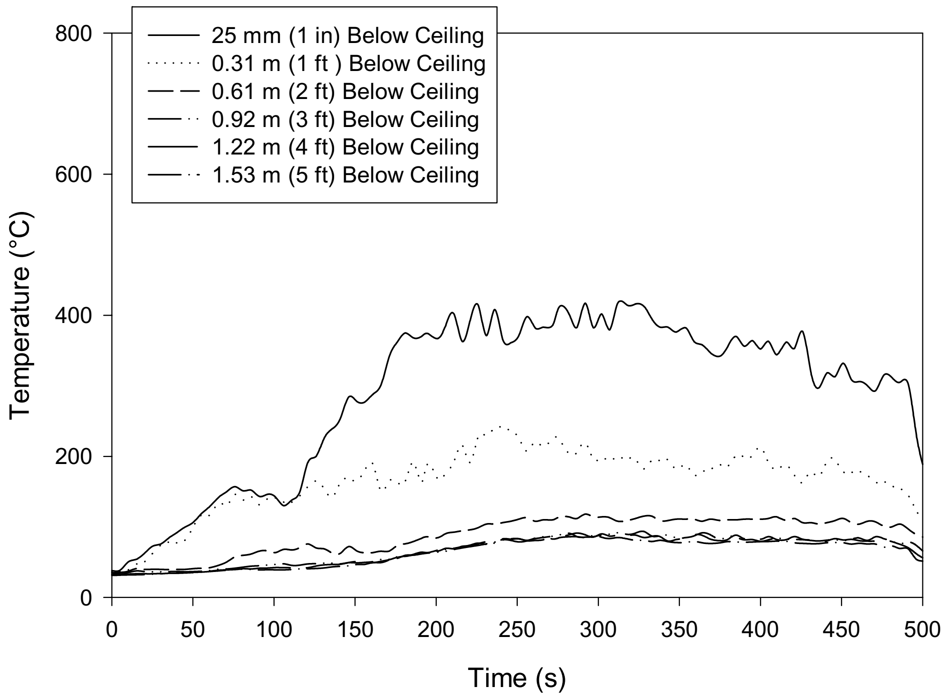

Figure B-134. Test 17 (Seat with Trash Bag), Thermocouple Array 1 Data

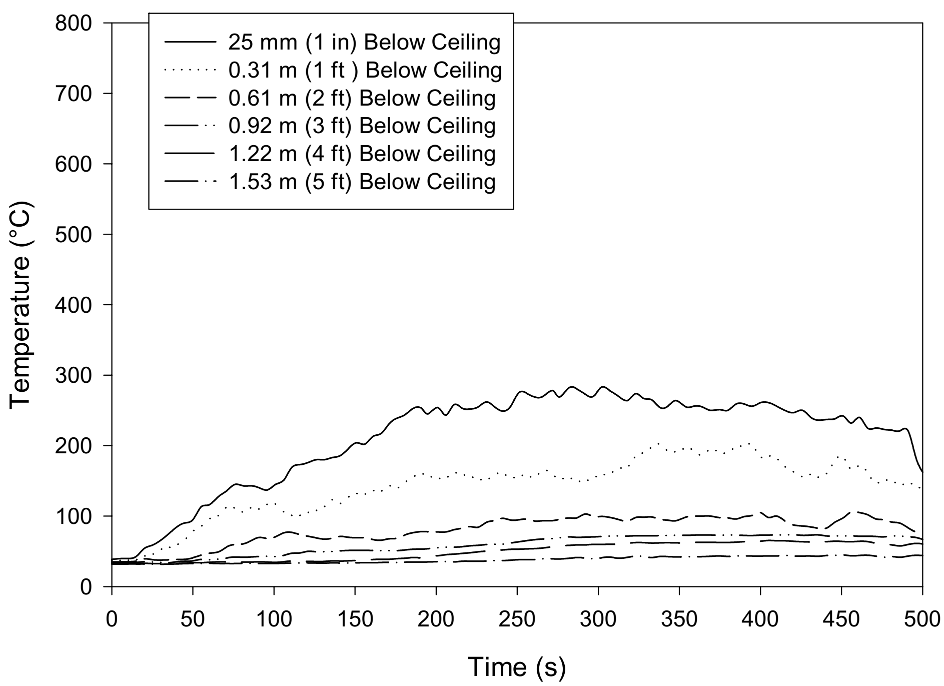

Figure B-135. Test 17 (Seat with Trash Bag), Thermocouple Array 2 Data

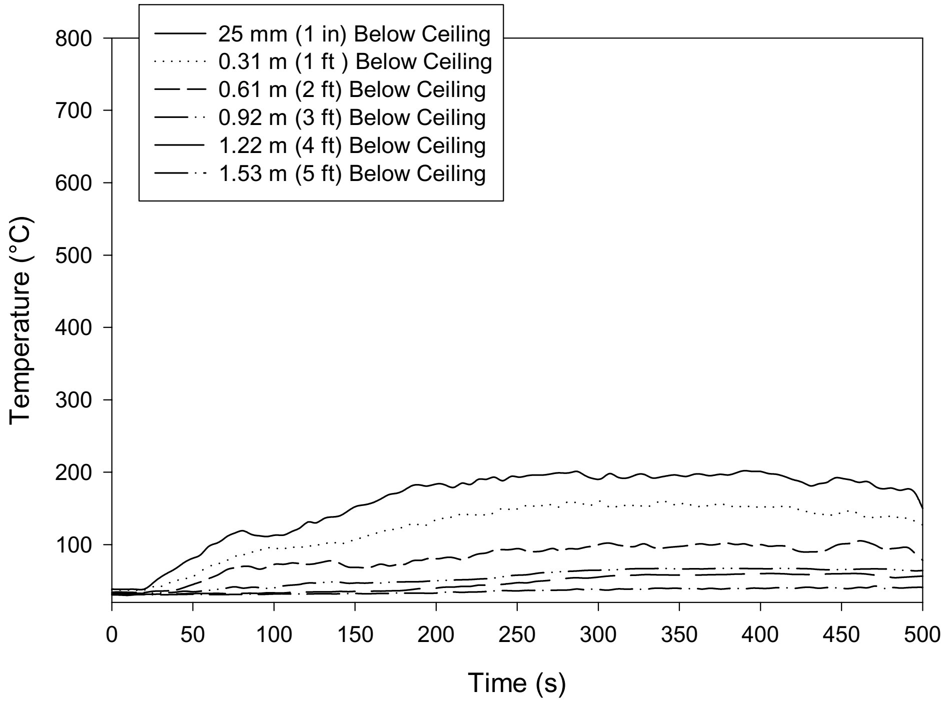

Figure B-136. Test 17 (Seat with Trash Bag), Thermocouple Array 3 Data

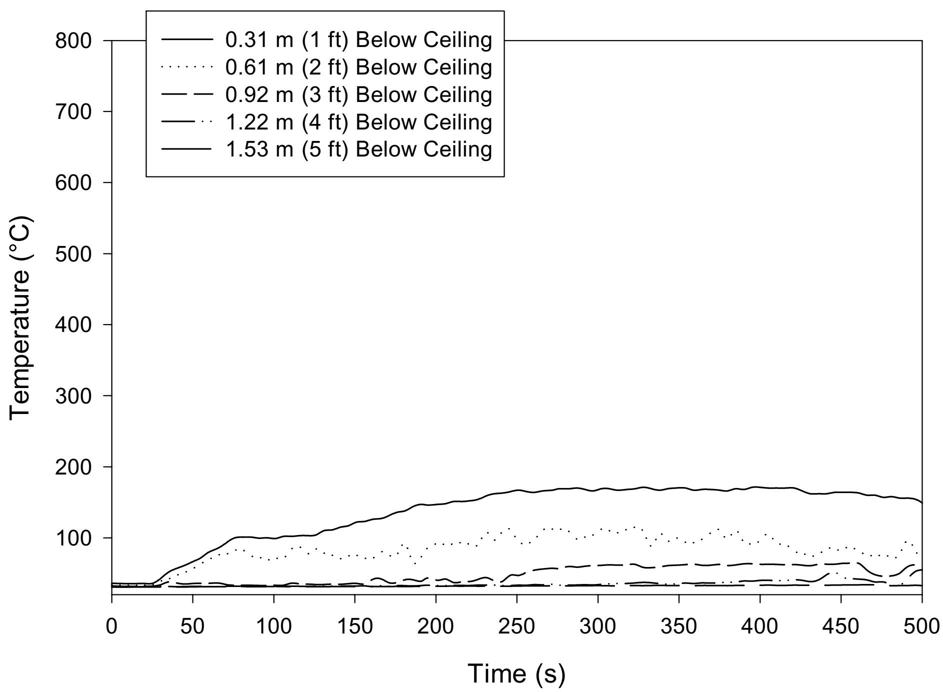

Figure B-137. Test 17 (Seat with Trash Bag), Thermocouple Array 4 Data

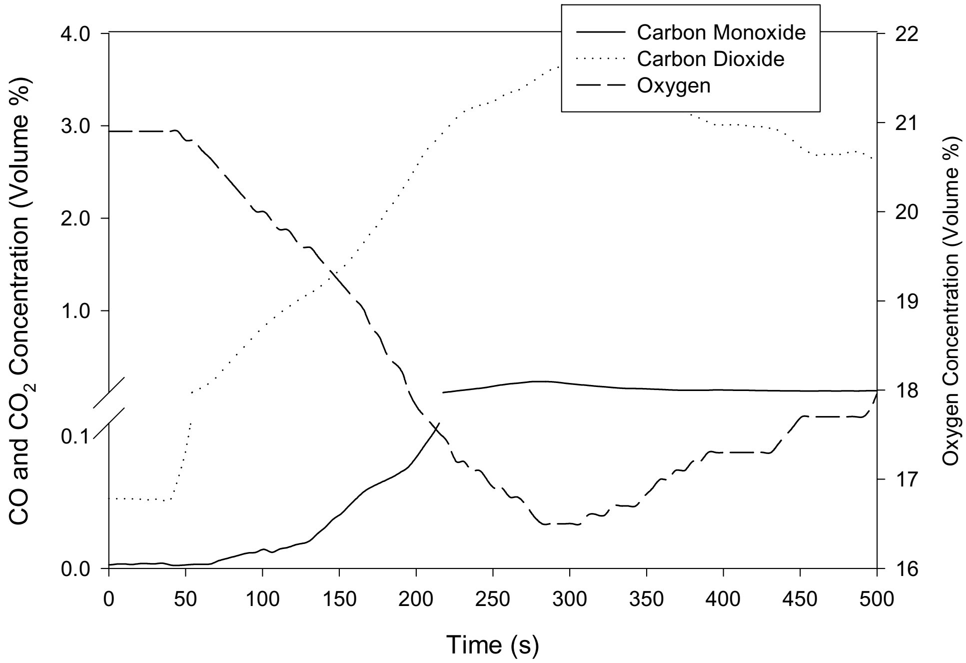

Figure B-138. Test 17 (Seat with Trash Bag), Gas Concentration Data

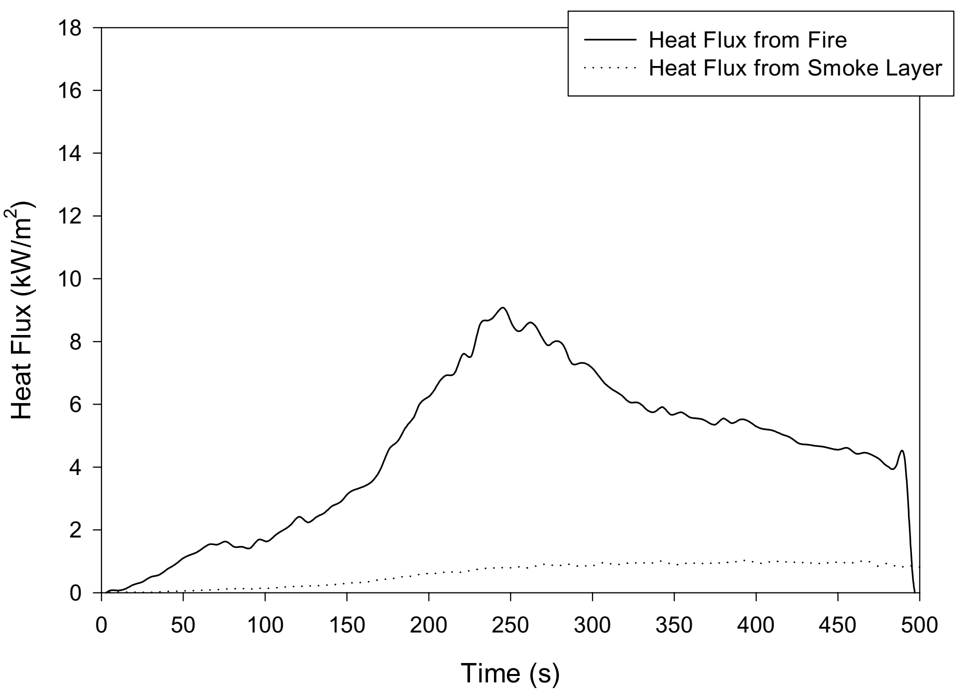

Figure B-139. Test 17 (Seat with Trash Bag), Heat Flux Data

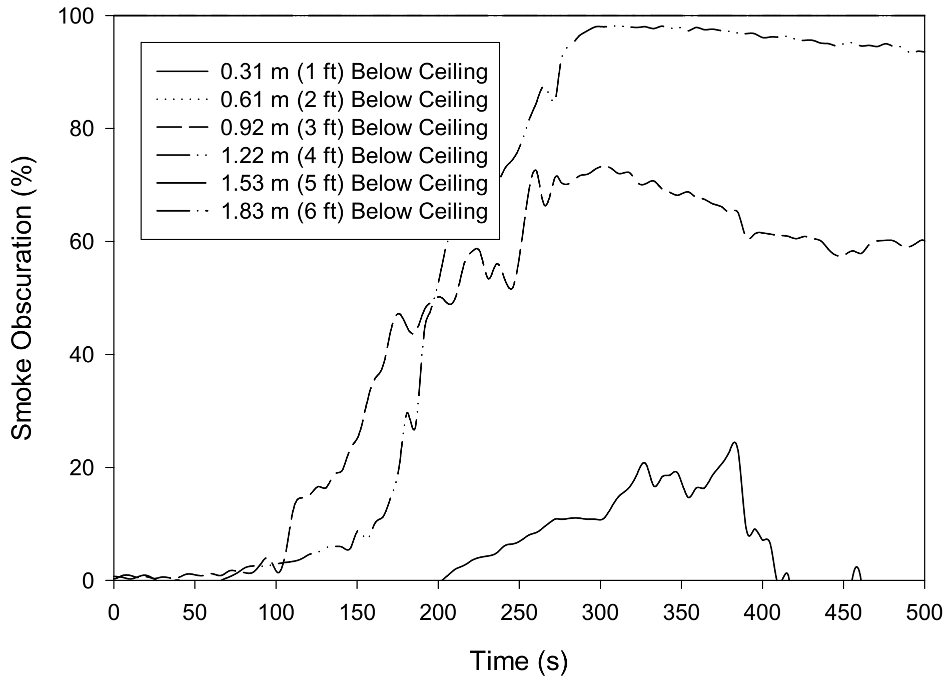

Figure B-140. Test 17 (Seat with Trash Bag), Smoke Obscuration Data

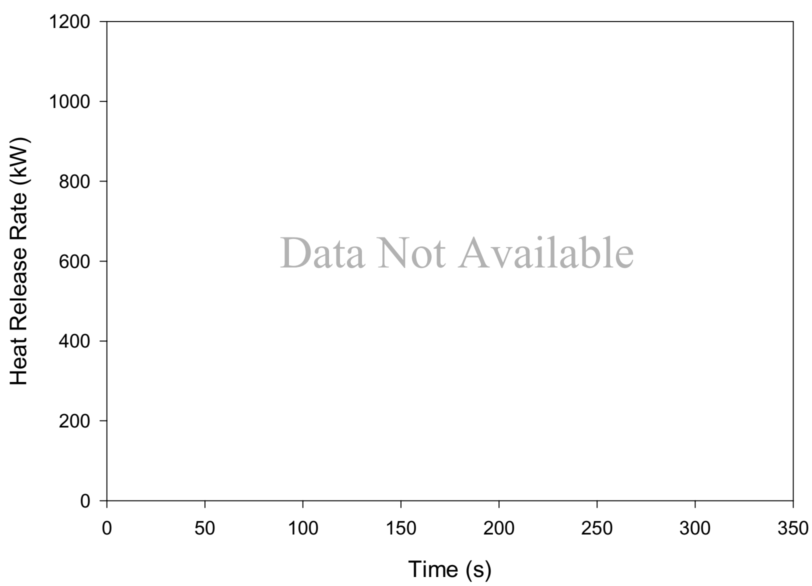

Figure B-141. Test 17 (Seat with Trash Bag), Heat Release Rate Data

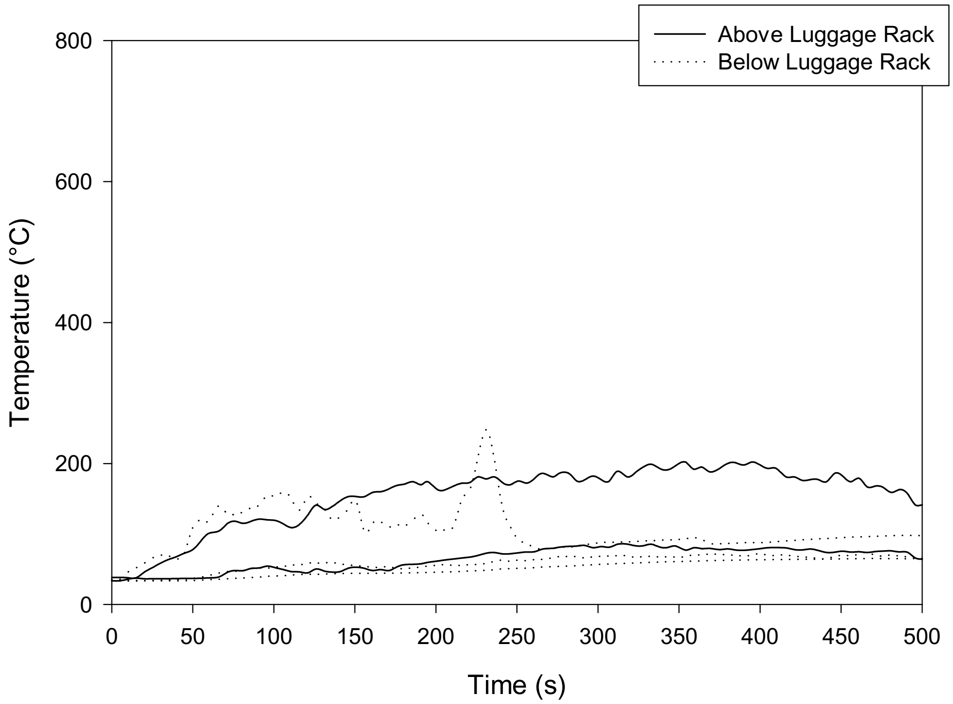

Figure B-142. Test 17 (Seat with Trash Bag), Luggage Rack Temperature Data