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Passenger Minivan Fire Tests

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Abstract

Two fire tests were conducted using a passenger minivan. The fire test scenarios were selected as part of a fire investigation being conducted by the U.S. Department of Treasury's Bureau of Alcohol, Tobacco, and Firearms. Heat release rate was determined as a function of time from ignition under a large calorimeter using the oxygen depletion principle. In addition, the temperatures and gas concentrations inside the passenger compartment were measured. For the first test, approximately 0.317 kg (0.697 lb) of paper was ignited in the passenger compartment with the windows closed. This fire extinguished itself due to lack of oxygen within the passenger compartment. A second test was conducted using 2 L (0.53 gal) of gasoline in the passenger compartment with the driver and passenger windows open. This fire did not extinguish itself; it was extinguished manually with hose lines.

Key Words:
arson; fire data; fire models; fire tests; gas analysis; heat release rate; motor vehicle fires; temperature measurements

Introduction

Measurement of the rate at which a burning item releases heat is a critical parameter in fire protection engineering. The heat release rate can be used in the characterization of the hazard represented by a given fuel package. Heat release rate can provide information on fire size and fire growth rate. When used as input to a computer fire model, the heat release rate can be used to estimate available egress time and determine detection or suppression system activation time. Temperature and gas concentration measurements in an enclosed space can be used to estimate potential hazard for occupants of the space.

As part of a fire investigation, the U.S. Department of Treasury's Bureau of Alcohol, Tobacco and Firearms (ATF) was interested in determining the likelihood and hazard associated with a fire in a passenger minivan. Figure 1 presents a photograph of the test arrangement showing the minivan placed under the main calorimetry hood in the Large Fire Research Facility at the National Institute of Standards and Technology. Figure 2 presents the test arrangement in plan and elevation views with dimensions.

Experimental Configuration

The experiments were conducted on December 7, 1999, under the main calorimetry hood in the NIST Large Fire Research Facility. The main hood is 4 m by 5 m (13.1 ft by 16.4 ft) and slopes upward to a 1.2 m (3.9 ft) square duct. During a fire test, data from various sensors are acquired using a computer-based data acquisition system. The fire test data is recorded on magnetic media for further data reduction and interpretation after the test. Data acquisition and reduction in the Large Fire Research Facility are accomplished using in-house developed computer software [1].

Using the principle of oxygen consumption, it is possible to calculate the heat release rate of burning materials when the products of combustion are collected in an exhaust hood. Parker [2, 3] presents several sets of equations for calculating heat release rate using oxygen consumption. The appropriateness of each set of equations depends on the combustion products being measured. A paper by Janssens [4] proposes a form of the equations for calculating heat release rate specifically for full-scale fire test applications. The equation for determining heat release rate when oxygen, carbon dioxide and carbon monoxide are measured is used for the main calorimeter hood at NIST.

Heat release rate is determined in the NIST Large Fire Research Facility using the equations from reference 3 together with data obtained from instruments in the exhaust hood. The measured heat release rate has been shown to be within 20 % of the actual value [5]. Reference 5, page 2 contains details concerning the calculation of heat release rate and its implementation in the Large Fire Research Facility.

Both experiments were conducted with the vehicle centered under the main exhaust hood. A diagram of the test arrangement with dimensions is shown in Figure 2. The vehicle used for these tests was a typical model year 1995 passenger minivan. The minivan had exterior damage sufficient for an insurance company to consider the van totally destroyed. The insurance company donated the van for this research effort. Since the tests involved only the passenger compartment, the exterior damage did not impact this research effort.

In addition to heat release rate, temperatures were measured at several locations within the van. Thermocouple arrays were placed above the drivers seat, in between the driver and front passenger seat, and between the two passenger bench seats (see Figure 3). The two thermocouple arrays had thermocouple beads located at the ceiling and at the following distances below the ceiling: 0.15 m, 0.3 m, 0.46 m, 0.61 m, 0.76 m, 0.91 m, 1.07 m, and 1.22m (6 in, 12 in, 18 in, 24 in, 30 in, 36 in, 42 in, and 48 in). The thermocouple beads for the third thermocouple array, above the driver’s seat, stop at the top of the seat cushion 0.91 m (36 in) below the ceiling. Thermocouples were placed at the same three locations on the roof of the van. All of the thermocouples were constructed using 0.25 mm (0.01 in) diameter, Type K thermocouple wire. Based on work presented in references [6] and [7], the temperature measurements are estimated to be within ±5 % of the actual values.

The concentrations of products of combustion were measured at two locations within the passenger compartment of the van. The first location was approximately 0.25 m (10 in) below the ceiling and directly above the center of the driver’s seat cushion. The second was approximately 0.36 m (14 in) below the ceiling and 0.1 m (4 in) from the centerline of the driver’s seat cushion toward the middle of the van (Figure 4). The locations were selected to provide general information concerning the gas concentrations within the van, and, specifically to measure conditions in the breathing zone of an adult driver who could be slumped over toward the center of the van. The gas concentrations were measured using the same procedures and equipment described in reference [5] for use in determining heat release rate. The issues and uncertainties for the gas concentration measurements obtained in these experiments are similar to those described in reference [5].

Experiments

Two passenger minivan fire experiments were conducted in the Large Fire Research Facility at the National Institute of Standards and Technology. The two tests were conducted inside the same minivan. For the first test, approximately 0.317 kg (0.697 lb) of paper was placed on the front passenger seat (Figure 4). All of the doors and windows in the minivan were closed, and the paper was ignited using a butane lighter similar to those used to for charcoal grills. Flames reached the headliner within 3 min after ignition (Figure 5). At 5 min after ignition, the van was completed filled with smoke and no fire could be seen through the windows (Figure 6). The van doors were left closed for an additional 25 min (Total Test Time – 30 min). At the end of 30 min, the passenger side door was opened (Figure 7). The damage resulting from the first fire is shown in Figures 8 and 9.

The second experiment utilized 2 L (0.53 gal) of gasoline distributed throughout the minivan. Gasoline was poured on the driver's seat, front passenger seat, and on the floor and passenger seat behind the front seats (Figure 10). The front driver's side and passenger windows were left fully open; all other doors and windows were closed. For the second fire, the gasoline was ignited with an electric match. Immediately after ignition, the passenger compartment was filled with flames that projected from the open windows (Figure 11). As the fire progressed, closed van windows cracked and fell from their holders (Figure 12). Approximately 4 min after ignition, the fire was extinguished. The damage resulting from the second fire is shown in Figures 13, 14, and 15.

Results

The temperature profiles obtained within the passenger compartment of the minivan during the first test are shown in Figures 16 – 18. Peak temperatures of between 500 °C (932 °F) and 750 °C (1382 °F) are reached at the ceiling within 2 min after ignition. The temperatures peak and decrease rapidly within the first 4 min of the test. After about 5 min, the temperatures within the passenger compartment have decreased to less than 150 °C (302 °F). Roof temperatures at the three thermocouple locations are shown in Figure 19. The temperatures range from 50 °C (122 °F) to 95 °C (203 °F) depending on location. The gas concentrations measured in the passenger compartment during the first test are shown in Figure 20. The oxygen concentration falls to below 5 % within the first 2 min. Correspondingly, the concentrations of carbon dioxide and carbon monoxide increase to 13 % and 2 %, respectively. An equipment failure resulted in no oxygen measurements at the 0.25 m (10 in) location. All of the products of combustion remained inside the minivan until the door was opened. Therefore, no heat release rate information could be obtained during the first test.

The temperature profiles obtained within the passenger compartment of the minivan during the second test are shown in Figures 21 – 23. Peak temperatures of between 600 °C (1112 °F) and 800 °C (1472 °F) are reached at the ceiling within 30 s after ignition. The temperatures peak and remain at high levels for the duration of the test. Roof temperatures at the three thermocouple locations are shown in Figure 24. After about 60 s, the roof temperature has increased to approximately 650 °C (1202 °F) and remains at that level. The gas concentrations measured in the passenger compartment during the second test are shown in Figure 25. Within the first min, the oxygen concentration falls to below 5 %. Correspondingly, the concentrations of carbon dioxide and carbon monoxide increase to 13 % and 2 %, respectively. After the first min, the oxygen concentration begins increasing until it reaches a value of about 10 %. The concentrations of carbon dioxide and carbon monoxide decrease and ultimately stabilize at values of 7.5 % and 0.5 %, respectively. An equipment failure resulted in no oxygen measurements at the 0.25 m (10 in) location. The heat release rate obtained during the second test is presented in Figure 26. The peak heat release rate for this test was 2.4 MW.

References

[1] Peacock, R.D., J.N. Breese, and C.L. Forney, "A Users Guide for RAPID, Version 2.3," NIST Special Publication 798, National Institute of Standards and Technology, Gaithersburg, MD, January 1991.

[2] Parker, W., "Calculations of the Heat Release Rate by Oxygen Consumption for Various Applications," NBSIR 81-2427, National Bureau of Standards, Gaithersburg, MD, March 1982.

[3] Parker, W., "Calculations of the Heat Release Rate by Oxygen Consumption for Various Applications," *J. of Fire Sciences*, **2**, September/October 1984, pp. 380-395, 1982.

[4] Janssens, M.L., "Measuring Rate of Heat Release by Oxygen Consumption," *Fire Technol.*, **27**, pp. 234-249, 1991.

[5] Stroup, D.W., et. al., "Large Fire Research Facility (Building 205) Heat Release Rate Measurement System," NISTIR 6509, National Institute of Standards and Technology, Gaithersburg, MD, July 2000.

[6] Luo, M., “Effects of Radiation on Temperature Measurement in a Fire Environment,” *Journal of Fire Sciences*, **15**, pp. 443-461, 1997.

[7] Blevins, L.G. and Pitts, W.M., “Modeling Bare and Aspirated Thermocouples in Compartment Fires”, NISTIR 6310, National Institute of Standards and Technology, Gaithersburg, MD, April 1999.

Figure 1. Photograph of van from passenger side with open doors

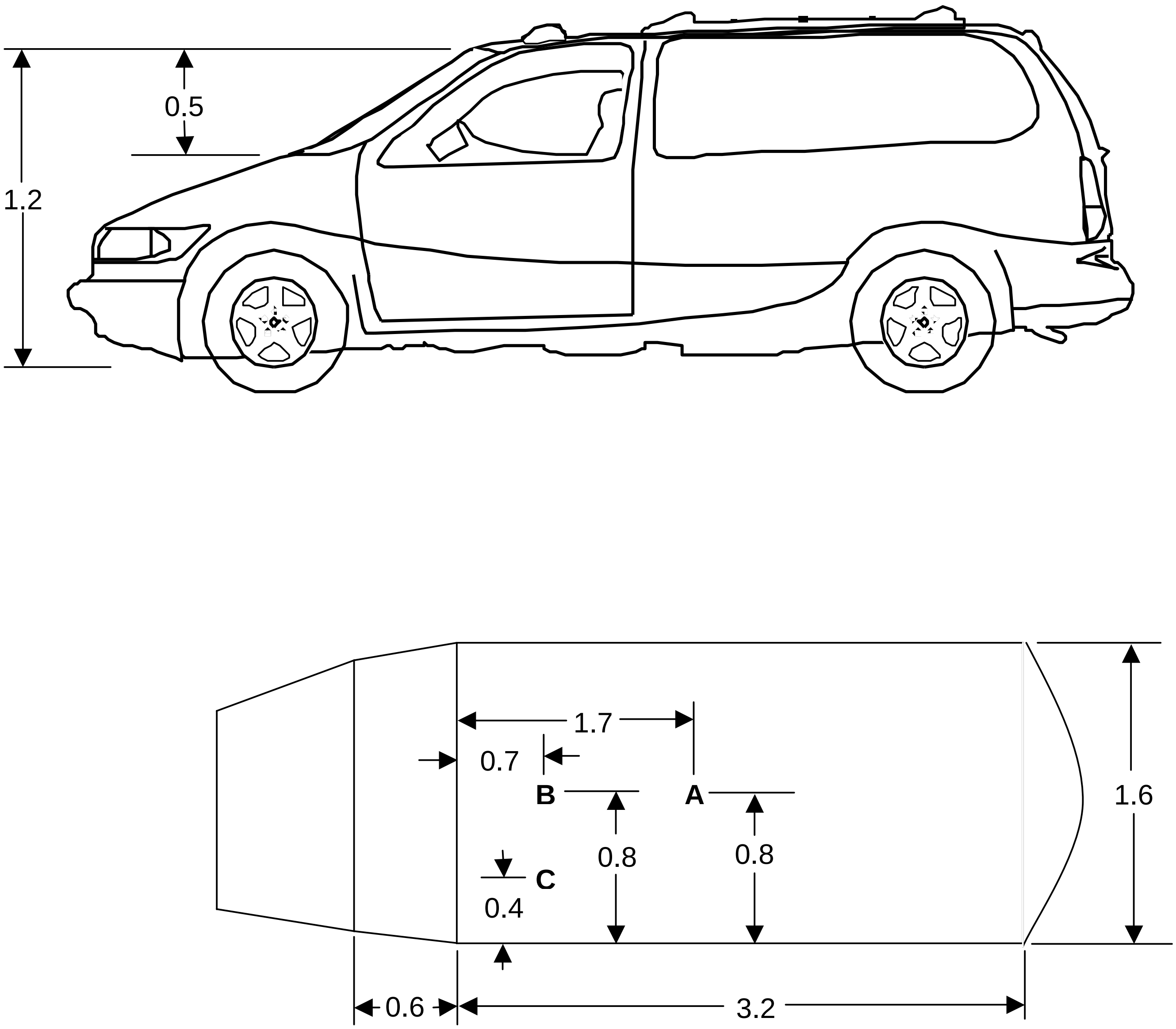

Figure 2. Plan and elevation views of the van showing general dimensions. (A, B, and C represent the three instrumentation locations. All dimensions in meters)

Figure 3. Photograph of van from driver side showing gas sampling probes and thermocouple arrays

Figure 4. Photograph of van from passenger side showing placement of paper in passenger seat for use as ignition source for first test

Figure 5. Photograph of van approximately 1 min after ignition with flames reaching headliner

Figure 6. Photograph of van at 5 min after ignition

Figure 7. Photograph of van at 30 min after ignition just prior to opening of the passenger side door

Figure 8. Photograph of van after passenger side doors were opened

Figure 9. Photograph showing damage to front passenger side seat of van

Figure 10. Photograph showing fire fighter preparing gasoline for ignition of second test

Figure 11. Photograph showing the van immediately after ignition of the gasoline in the van with flames visible extending from both the driver side and passenger side open windows

Figure 12. Photograph showing van after failure of the front window

Figure 13. Photograph showing extinguishment of the second fire

Figure 14. Photograph of the front of the van showing damage resulting from second fire test

Figure 15. Photograph of the passenger side of the van showing damage in the interior resulting from the second fire test

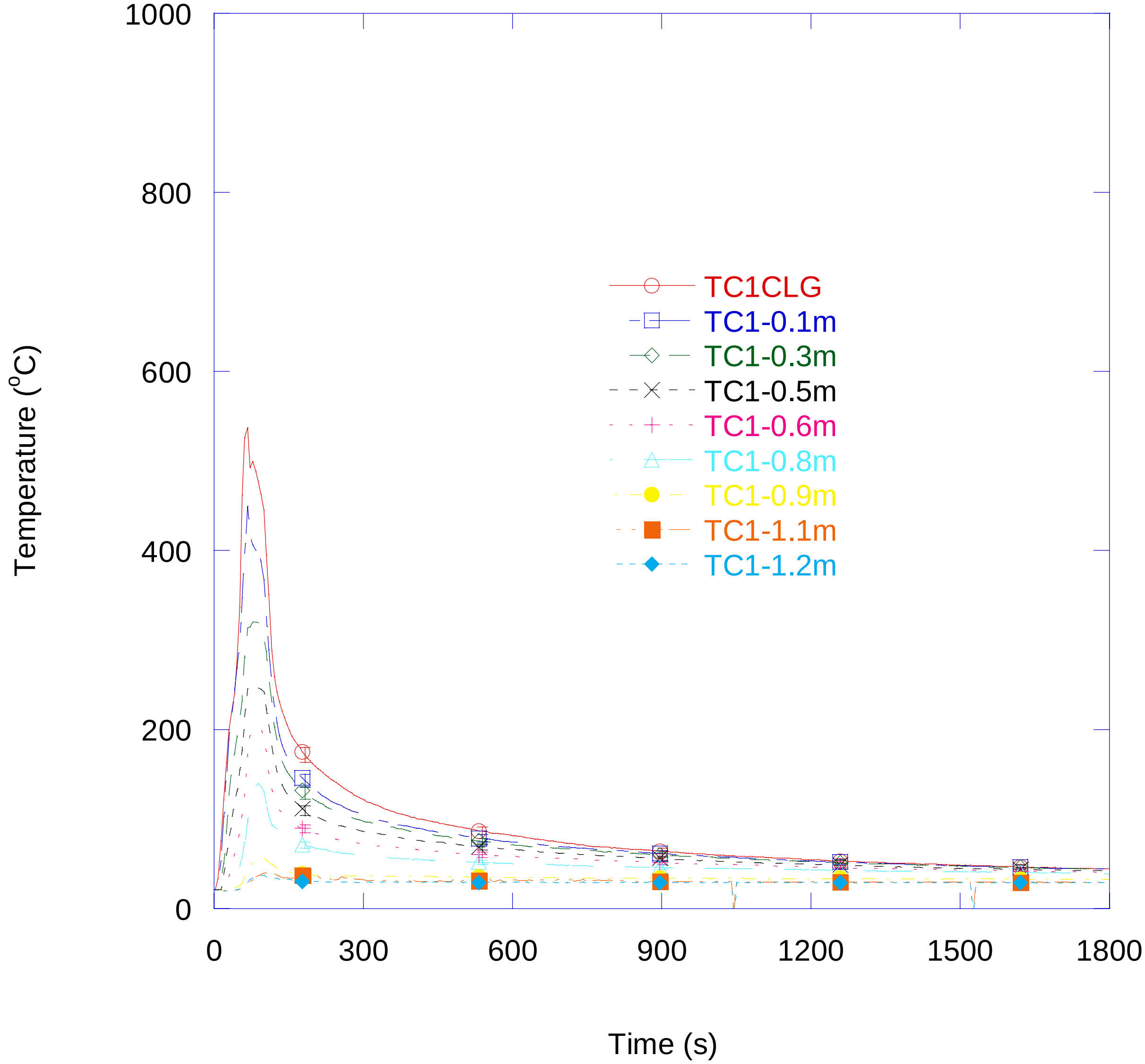

Figure 16. Graph of the temperatures in the center of the van behind the front seat during the first test

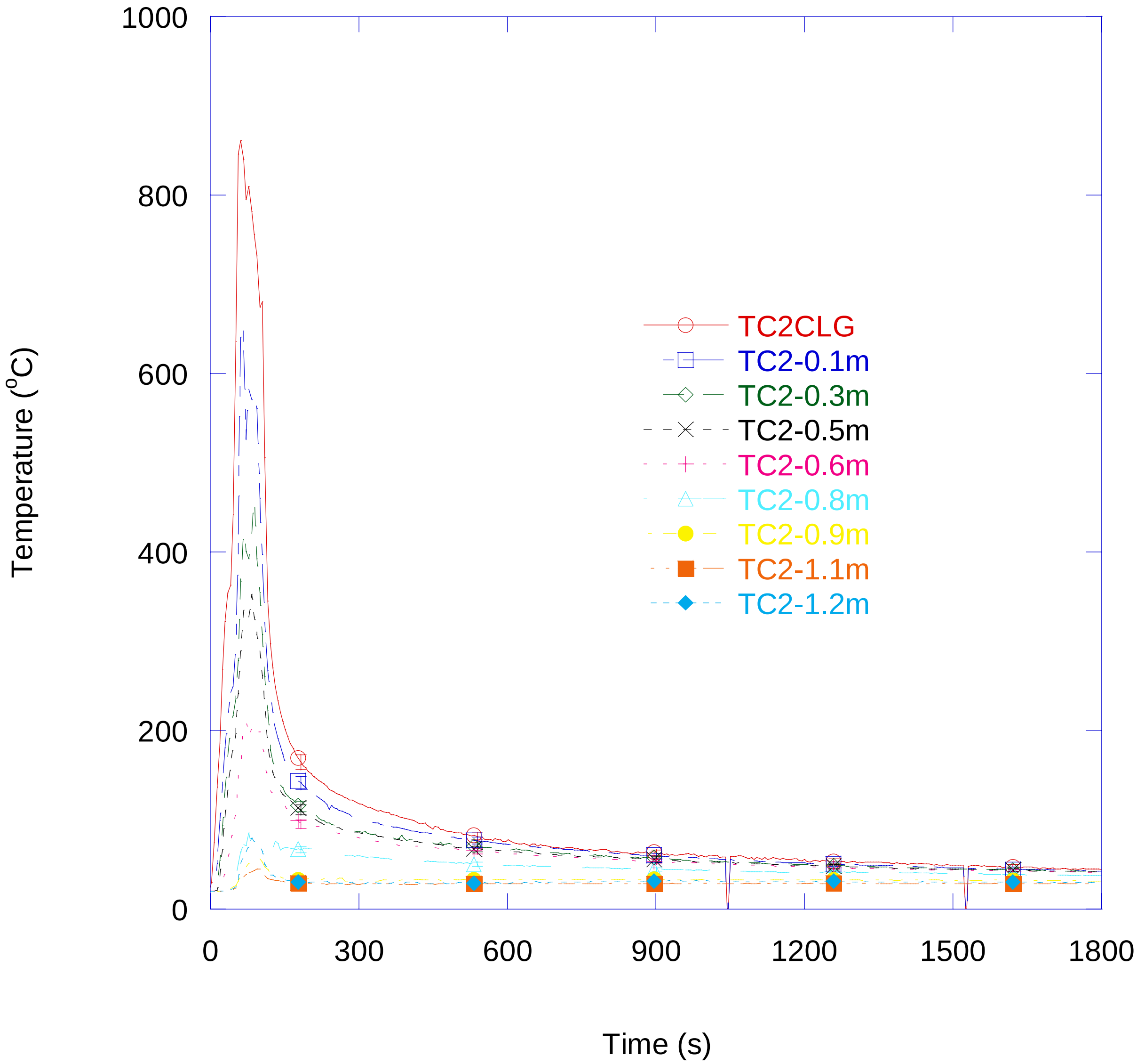

Figure 17. Graph of the temperatures in the center of the van between the two front seats during the first test

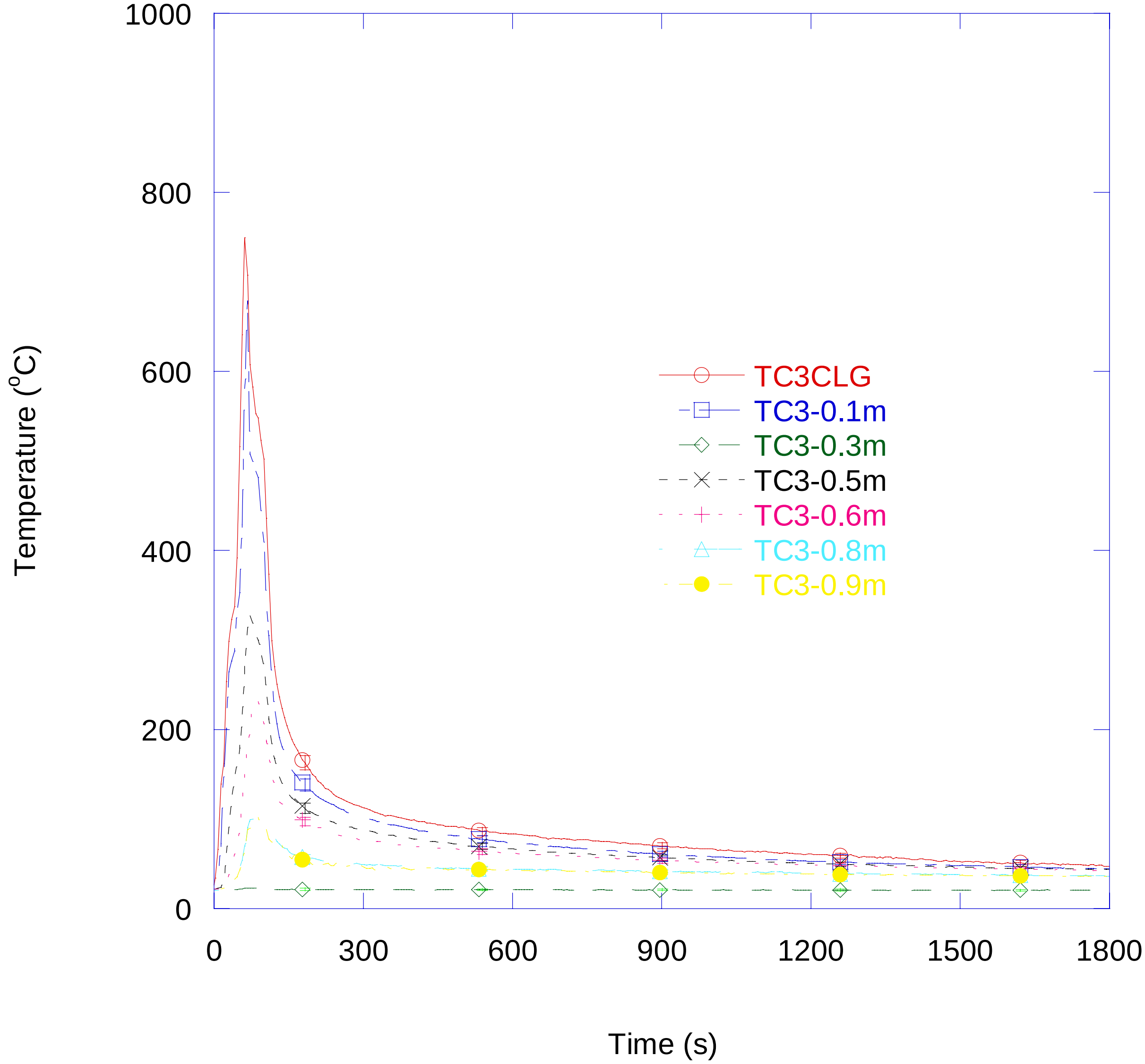

Figure 18. Graph of the temperatures above the drivers seat during the first test

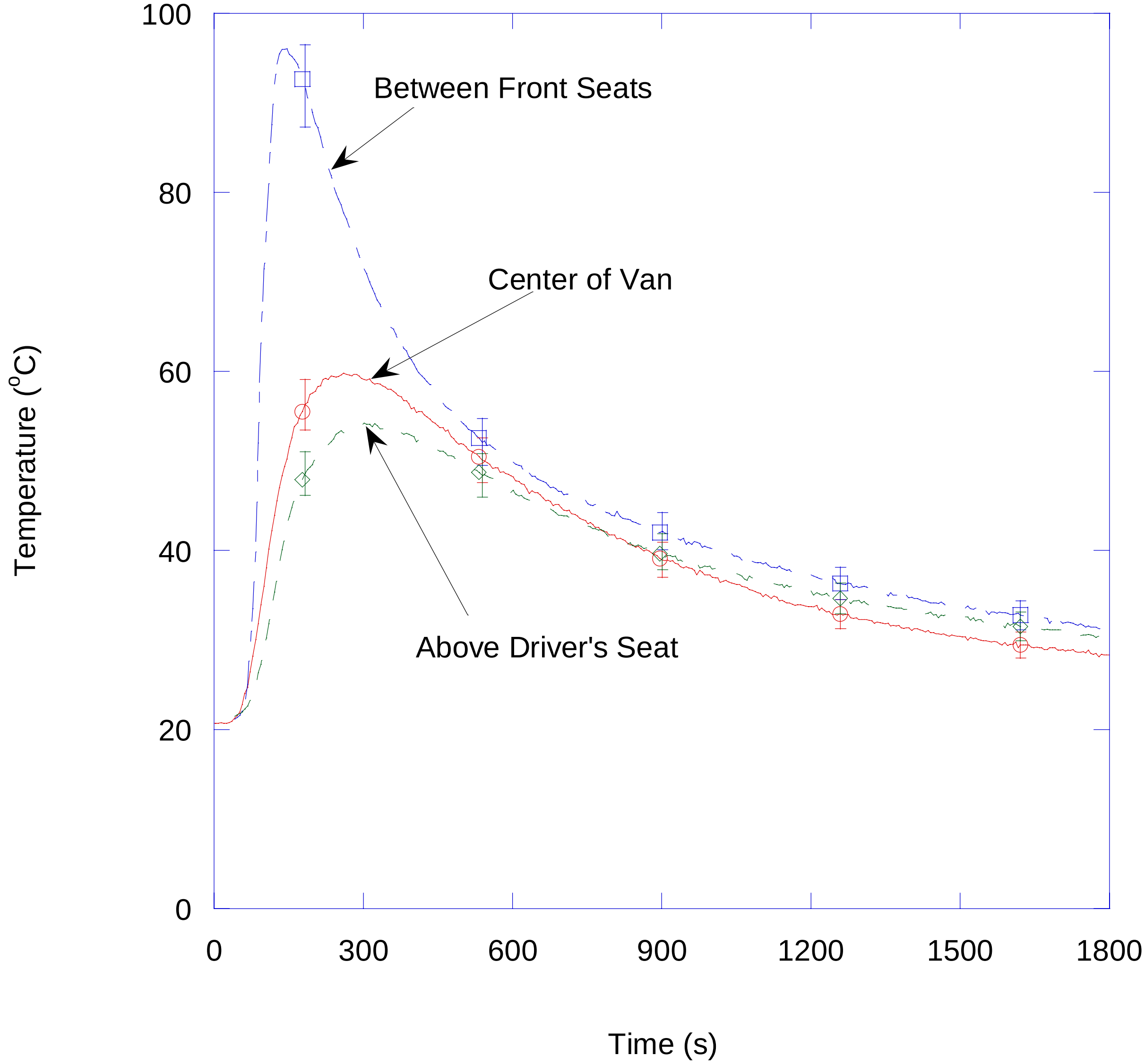

Figure 19. Graph of the temperatures above the roof of the van at the three thermocouple array locations during the first test

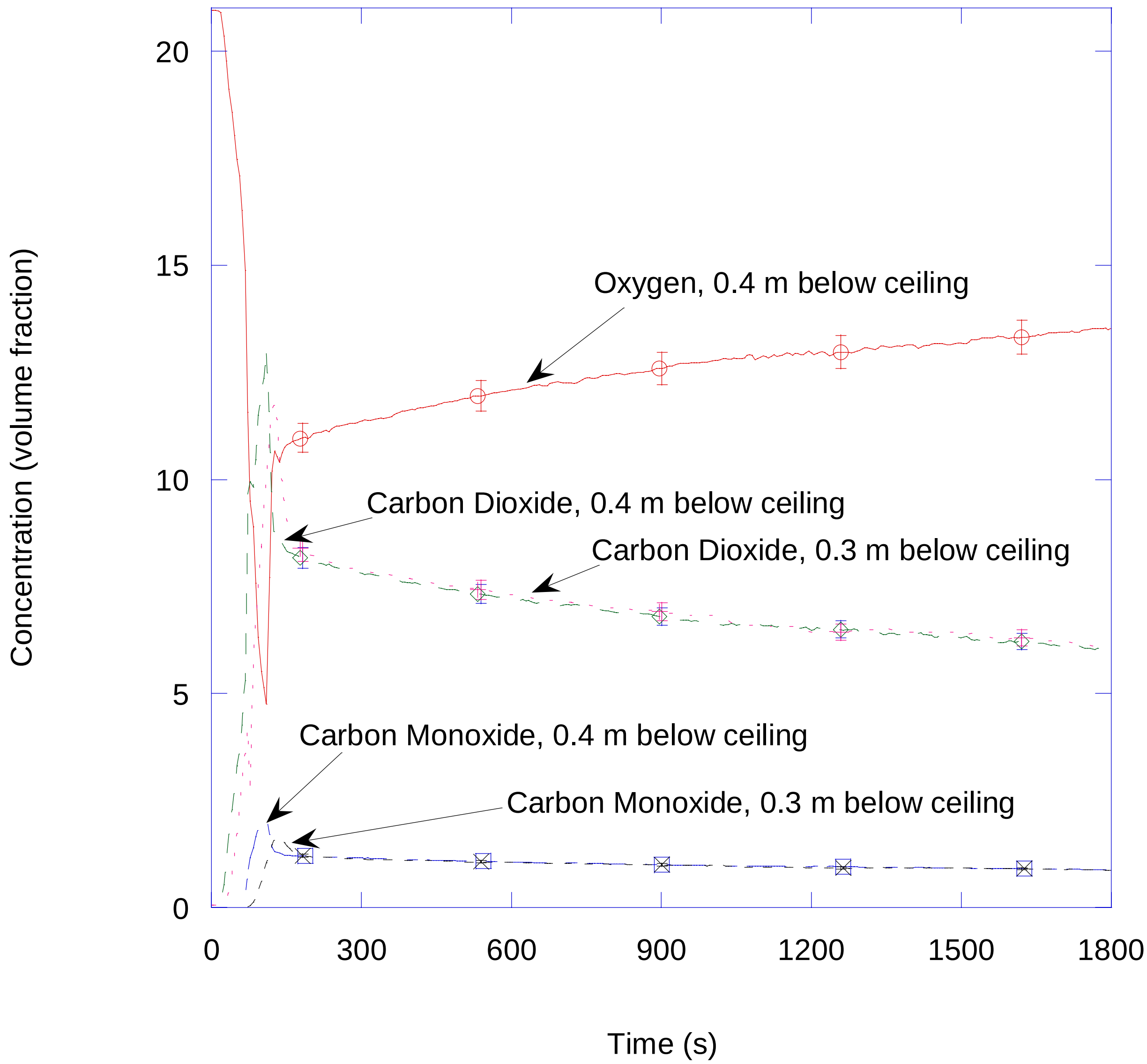

Figure 20. Graph showing concentrations of oxygen, carbon dioxide, and carbon monoxide in van at two locations above center of driver's seat during first test

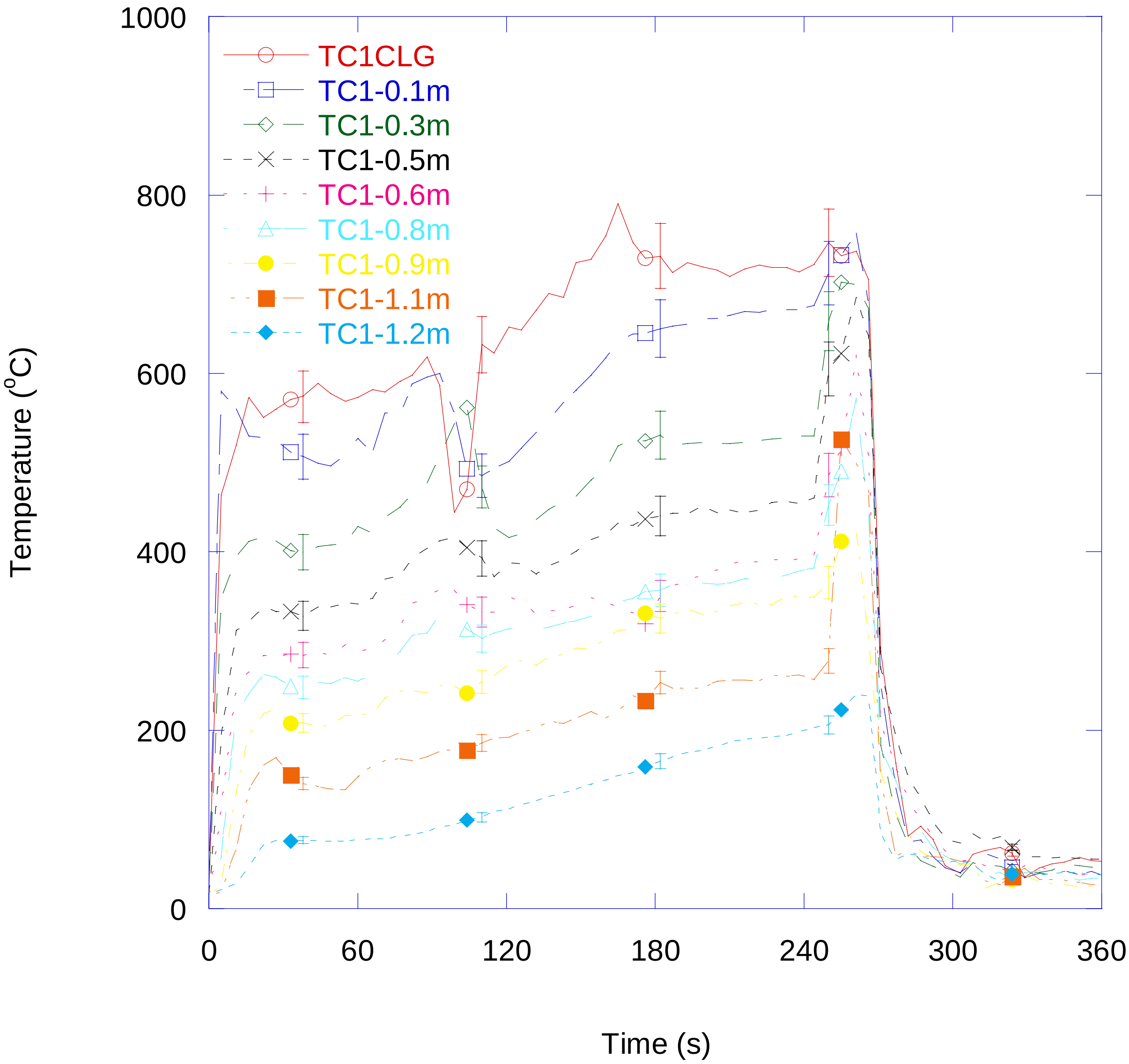

Figure 21. Graph of the temperatures in the center of the van behind the front seat during the second test

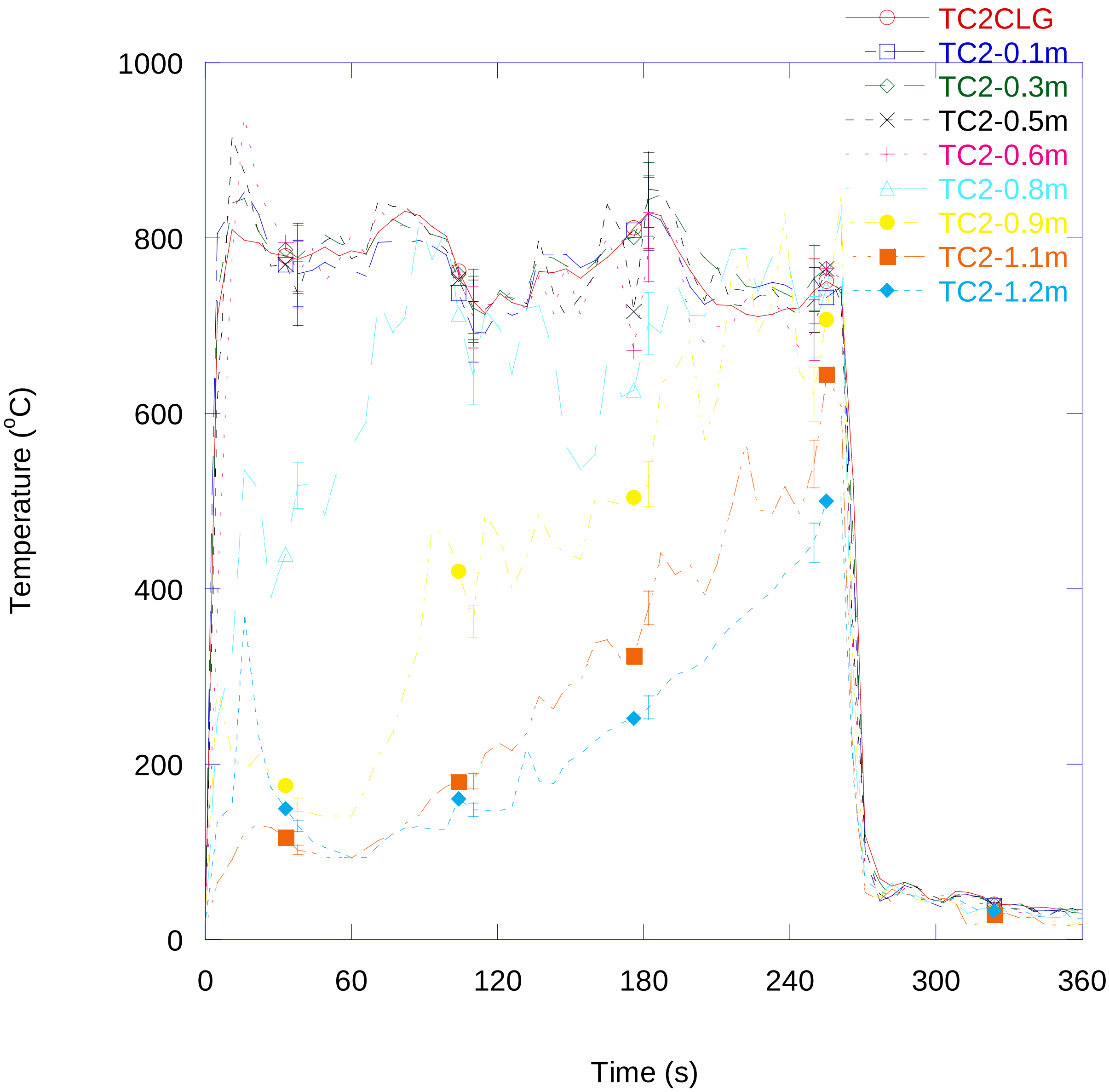

Figure 22. Graph of the temperatures in the center of the van between the two front seats during the second test

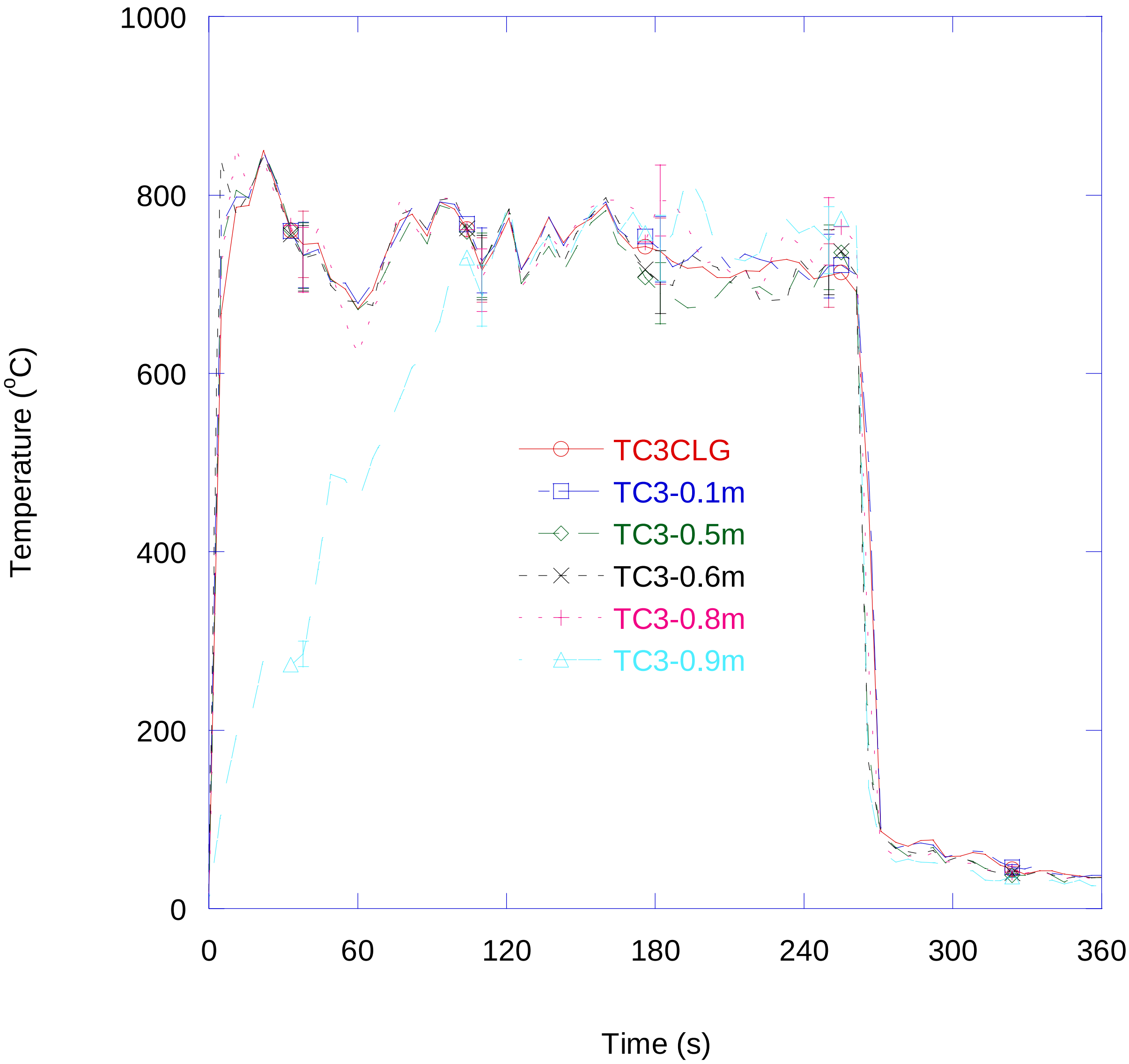

Figure 23. Graph of the temperatures above the drivers seat during the second test

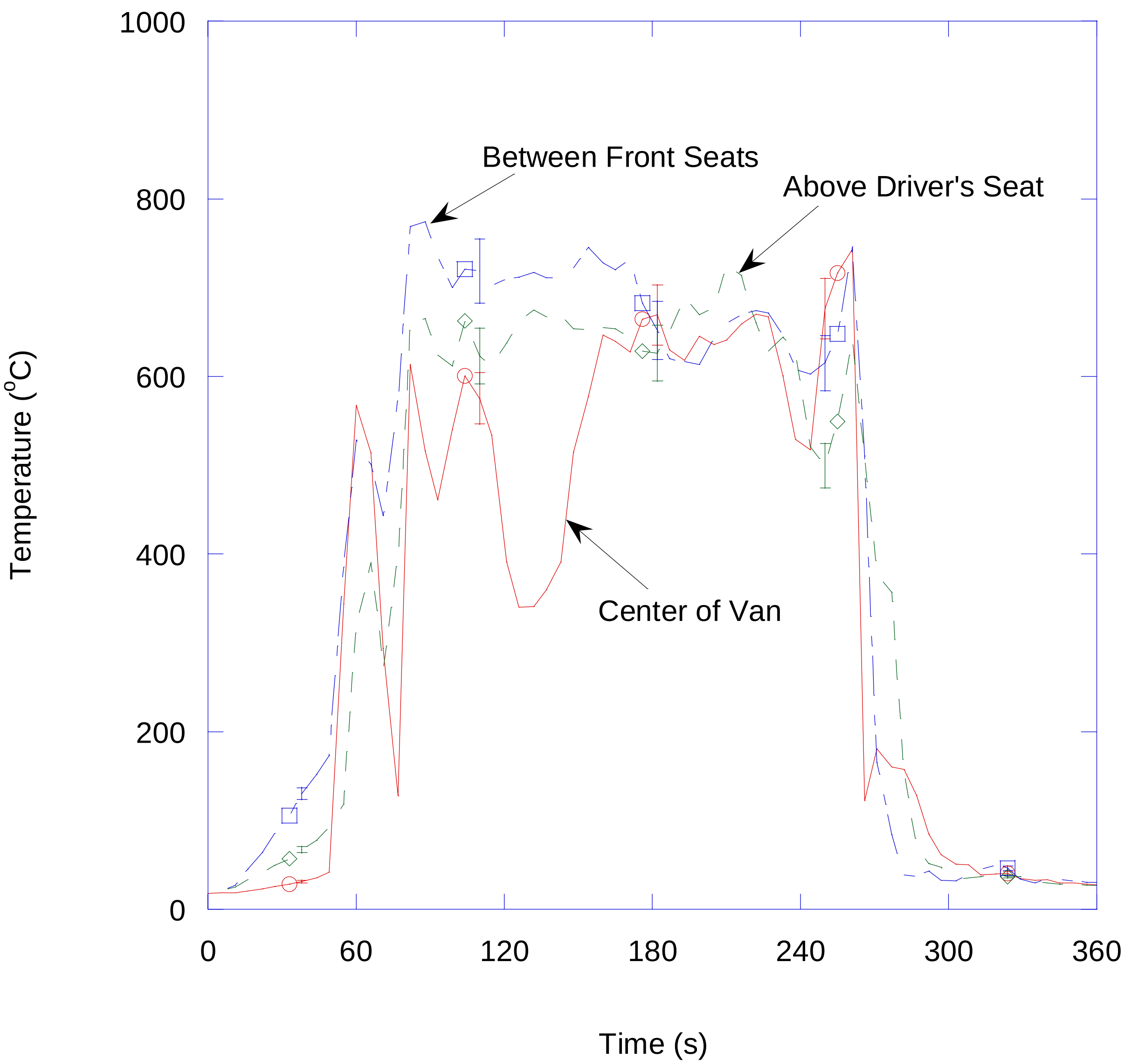

Figure 24. Graph of the temperatures above the roof of the van at the three thermocouple array locations during the second test

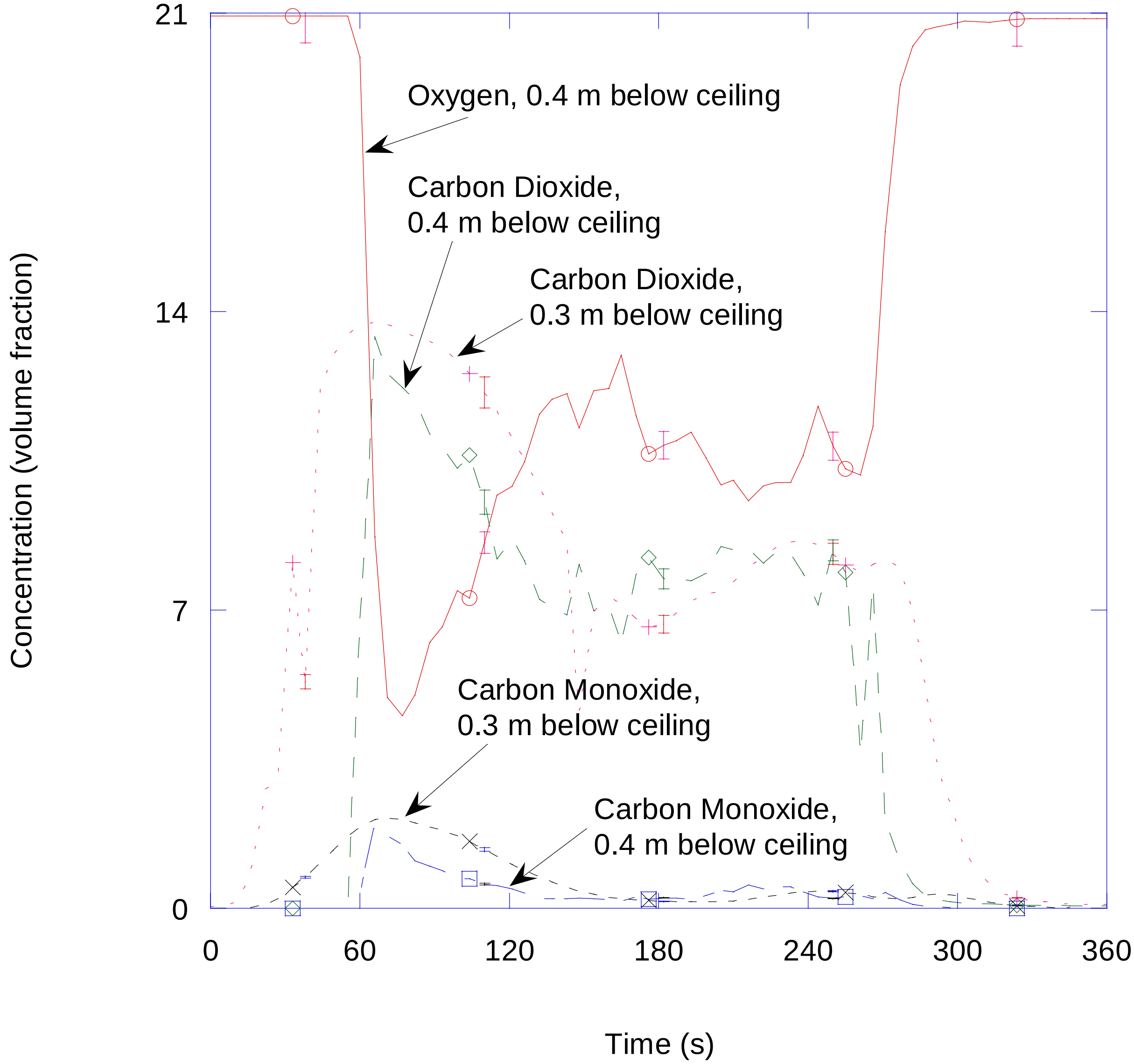

Figure 25. Graph showing concentrations of oxygen, carbon dioxide, and carbon monoxide in van at two locations above center of driver's seat during the second test

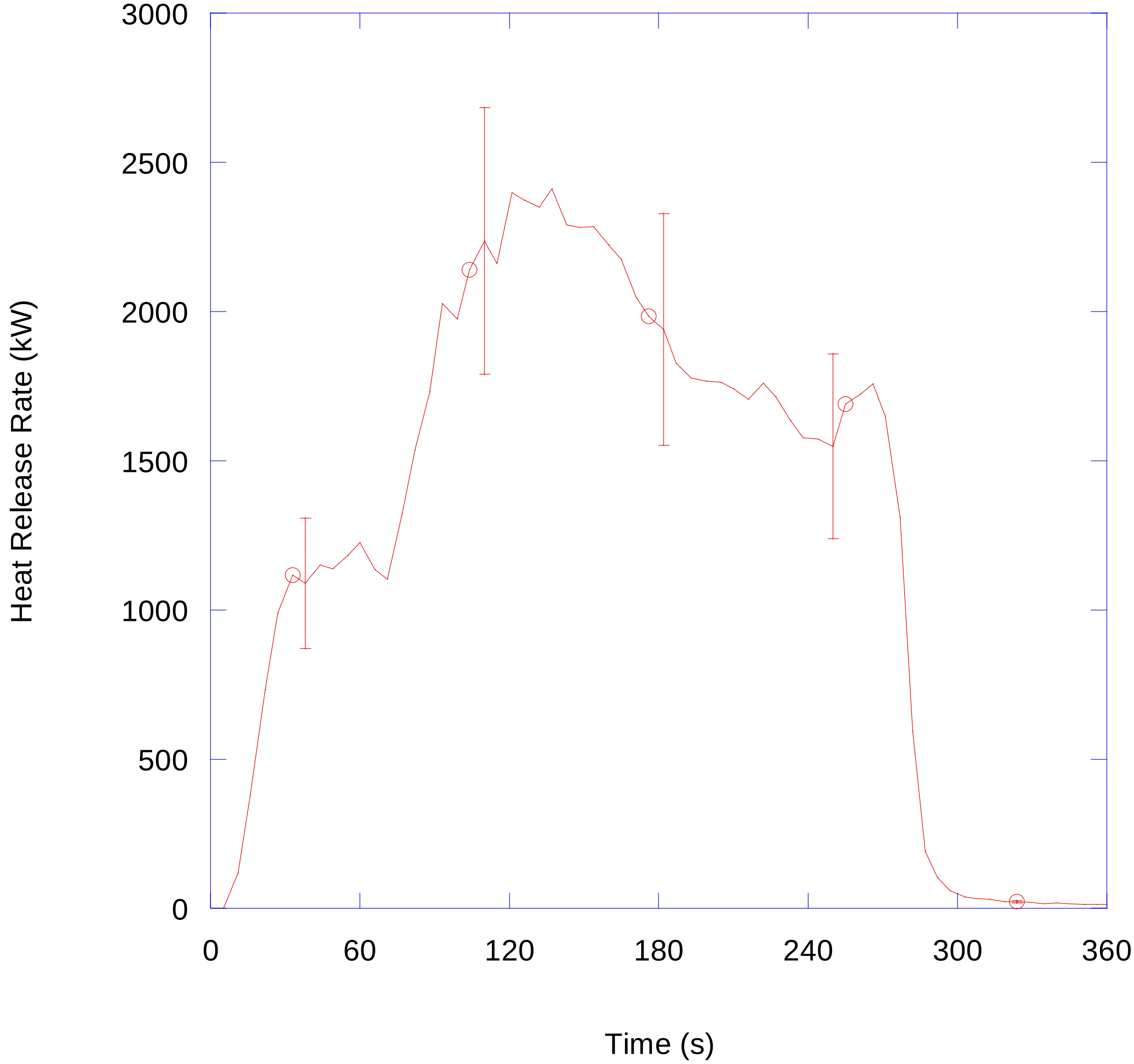

Figure 26. Graph showing heat release rate determined from measurements in the exhaust hood obtained during the second test