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DEVELOPMENT OF A DATABASE OF FULL-SCALE CALORIMETER TESTS OF MOTOR VEHICLE BURNS

FINAL REPORT
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ABSTRACT

This report describes the development of a database of full-scale motor vehicle fire test results. The data were obtained from a careful review of 20 publications[1-20] comprised of: 3 journal articles, 2 conference papers, and 15 reports. To be included in the database, tests had to involve heat release rate measurements. A total of 34 tests in 12 studies were found to meet this requirement. The database consists of four interrelated tables that primarily contain scalar data. The main table includes links to available time-dependent data, e.g., heat release rate, mass loss, interior heat flux, interior temperature and interior CO concentration vs. time. The data may be useful in fire engineering, e.g., fire design of parking garages, fire hazard assessment of automotive materials in post-collision fires, etc. Use of the database is illustrated with two examples.

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1.0 INTRODUCTION

In 2004, the author of this report presented a survey of full-scale motor vehicle burn tests at the Fifth International Conference on Performance-Based Codes and Fire Safety Design Methods in Luxemburg. The objective of the survey was to collect heat release rate data for motor vehicles and provide recommendations for suitable design fires for performance-based fire design of parking garages and similar structures. The survey covered data obtained in 11 studies spanning a period of 10 years between 1994 and 2004. Subsequently, the Motor Vehicle Fire Research Institute (MVFRI) initiated a project to expand the survey with the most recent test results and additional data pertinent to fire-hazard assessment of automotive materials. The database that resulted from this effort forms the subject of this report.

2.0 TEST SERIES

A literature search was conducted to find journal articles, conference papers, and reports describing full-scale motor vehicle burn tests with heat release rate measurements. A total of 12 studies were identified. These studies are briefly described below.

2.1 Series One

In 1994, Mangs and Keski-Rahkonen published the results of three tests.[1] The purpose of the tests was to obtain data for fire engineering of parking garages. Each test involved a single, late-1970s model vehicle. The ignition source in the first test consisted of a burning heptane pan fire placed under the left front seat. The ignition source for the remaining two tests consisted of a heptane pan fire placed under the engine. The vehicle was on a load platform under an open oxygen consumption calorimeter. In addition to heat release rate, mass loss, temperature and heat flux at various locations were measured. The tests were terminated at burnout, i.e., when significant flaming ceased and the heat release rate returned to a negligible level.

2.2 Series Two

In October of 1994, the National Testing and Research Institute in Borås, Sweden organized a major conference on fires in tunnels. Eleven papers covered various aspects of the EUREKA fire tests. The remaining 12 presentations dealt with other tunnel fire experiments and fire protection of tunnels in general. The EUREKA EU-499 FIRETUN project consisted of 20 full-scale fire tests of road and rail transportation vehicles, wood cribs, and heptane pools.[21] The tests were conducted between July 1990 and November 1992 in the abandoned Repparfjord tunnel in Norway. Extensive instrumentation was used to measure gas temperature and velocity profiles, tunnel surface temperatures, heat fluxes, smoke obscuration, and gas composition at various distances in both directions from the location of the fire.[22] Temperatures and mass loss of the burning object were also measured. Several approaches were used to determine the heat release rate of the burning object based on the available temperature, velocity, and gas composition data.[2,23-26] The difficulties were

that there was no single extraction point where flow rate and oxygen concentration could be measured as in an oxygen consumption calorimeter, and that the distribution of temperature, velocity, and oxygen concentration across the section of the tunnel had to be accounted for. The project included two tests on automobiles: one test of a vehicle with a steel body and one test of a vehicle with a plastic body. Heat release rate data are reported for the latter only. All tests were terminated at burnout.

2.3 Series Three

In 1995, Shipp and Spearpoint published the results of two tests on a single motor vehicle to obtain data for fire safety assessment of the Channel tunnel shuttle train.[3] The vehicle was placed under a canopy with insulated side walls simulating a shuttle wagon. Hoods were positioned at both ends of the canopy to capture all products of combustion released in the fire. The first test involved a 1982 model mid-size sedan with a small wood crib ignition source inside the passenger compartment. This test was terminated at 17 min when the heat release rate exceeded 8 MW and smoke started overflowing the hoods. The second test involved a 1986 model mid-size sedan with a burning tray of gasoline placed in the engine compartment. The second test was terminated at burnout. Measurements consisted of heat release rate and temperature and heat flux at various locations.

2.4 Series Four

A series of ten tests was conducted at the Technical Center of the Steel Industry (CTICM) in France as part of a European research project to develop design rules for steel parking structures subjected to fire.[4] Four of the ten tests generated heat release rate data and mass loss data for a single vehicle. Two of the four tests were conducted under a hood in an open calorimeter, and the remaining two tests were conducted in a corner configuration. All tests were terminated at burnout.

2.5 Series Five

The Organization for Applied Scientific Research (TNO) in the Netherlands published a report in 1999 describing 18 fire tests in a parking garage in Amsterdam.[5] All tests involved multiple vehicles. The purpose of this study was to evaluate the effectiveness of different types of ventilation systems in a parking garage fire. The heat release rate of the burning vehicle was determined on the basis of mass loss rate measurements and the assumption that the average heat of combustion is 25 MJ/kg. The assumption was based on data from Series Four.[4] The validity of this assumption was confirmed on the basis of 4 of the 18 tests; these tests included measurements of the enthalpy rise of the gases flowing through the parking garage and an estimate of heat losses to the walls and ceiling of the structure. All tests were terminated at burnout of the vehicle first ignited.

2.6 Series Six

In 1997 and 1998, ten motor vehicle fire tests were conducted at the Materials Research and Testing Institute (MFPA) in Leipzig, Germany.[6] The objectives of the study were to evaluate the

burning behavior of motor vehicles parked next to each other and fire propagation from a burning vehicle to adjacent vehicles. Three of the ten experiments involved a single vehicle. Three types of vehicles were tested:

- a vehicle made in the former East Germany (Trabant);
- a vehicle with a steel body; and
- a vehicle with a plastic body.

The tests were performed in a room calorimeter. Heat release rate was calculated based on oxygen consumption calorimetry. In addition, vehicle mass loss and temperature and heat flux at various locations were also measured. All tests were terminated at burnout.

2.7 Series Seven

In 1999, two fire tests using a passenger minivan were conducted at the National Institute of Standards and Technology (NIST) as part of an investigation by the Bureau of Alcohol, Tobacco, and Firearms (ATF).[7] The tests were conducted under a large open oxygen consumption calorimeter hood. In the first test, 0.3 kg of paper was placed inside the passenger compartment with the windows closed. The fire extinguished due to lack of oxygen. The second test was conducted with 2 L of gasoline in the passenger compartment with the driver and passenger windows open. This test was terminated when the passenger compartment was fully involved, approximately 5 min after ignition. Measurements included temperature and gas composition (O_2, CO_2, and CO) at various locations inside the passenger compartment. Vehicle mass loss was not measured.

2.8 Series Eight

A series of full-scale motor vehicle fire tests was conducted as part of the March 7, 1995, settlement agreement between General Motors Corporation (GM) and the Department of Transportation (DOT). These tests were performed on four different types of motor vehicles representing more than 50% of the sales in the U.S. The vehicles were subjected to a crash test by GM prior to the fire tests in the Combustion Products Collector at Factory Mutual (currently FM Global). A detailed discussion of the objectives and experimental design of these crash and fire tests is provided in the literature[27]. Three types of tests were performed with heat release rate measurements:

- fires initiated in the engine compartment;[8,11,16]
- pool fires under the vehicle;[9,10,12,13,15] and
- comparative tests between a control vehicle and a vehicle with an HVAC system made of FR plastics.[14]

These tests are by far the most extensively instrumented fire experiments on motor vehicles ever conducted. Since the focus was on assessing the fire hazard to occupants, all tests were terminated at or before the time of full involvement of the passenger compartment. Vehicle mass loss

was measured in all except the first two tests; however, the total mass loss was too low and the data too noisy to be useful.

2.9 Series Nine

CTICM in France, ARBED in Luxemburg, and TNO in the Netherlands performed a research project between July 1998 and June 2001 to demonstrate through fire tests and numerical simulations that exposed steel structures can be designed to withstand motor vehicle fires.[17] The final report of this study includes data for two tests on a single vehicle conducted at CTICM. The tests were performed in the open calorimeter used for some of the Series Four tests.

2.10 Series Ten

Five full-scale tests were conducted at the Building Research Institute (BRI) in Japan to obtain data for structural fire design of parking garages.[18] Each test involved a single four-door sedan. The first test was performed outdoors. The remaining four tests were performed under an oxygen consumption calorimeter hood. The ignition source was a piece of cloth soaked in alcohol and placed on the driver seat. Driver and passenger windows were partially rolled down. Although it is stated that heat release rate was measured based on oxygen consumption calorimetry, the heat release rate data reported are based on mass loss measurements and an assumed heat of combustion of 32 MJ/kg. All tests were terminated at burnout.

2.11 Series Eleven

An additional test was conducted recently in a room calorimeter at CTICM to supplement the data obtained in Series Four and Series Nine. The test involved two vehicles side-by-side. The report[19] includes a heat release rate curve for the first vehicle in an open configuration.

2.12 Series Twelve

Finally, a test was conducted at the Technical Research Institute of Sweden (SP) to quantify the emissions from a motor vehicle fire.[20] A 1998 model mid-size sedan was placed under SP's industry calorimeter. The ignition source consisted of 0.3 L of mineral spirits poured on the driver and the front passenger seats. The door on the driver side and one of the doors in the back of the vehicle were partially open to allow sufficient air supply to support combustion. Mass loss was not measured. The test was terminated at burnout.

3.0 DATABASE STRUCTURE

A database was developed in MS Access to facilitate the use of results from full-scale motor vehicle tests for fire engineering. A total of 34 tests were included. The database consists of four interrelated tables that are briefly discussed below. A form was developed for each table to facilitate data entry.

3.1 Vehicle Table

The first table includes important information concerning the vehicle that was tested. Figure 1 shows the corresponding form after entering the data from Series 1, Test 1. The ID field contains the primary key automatically assigned by Access. The remaining fields are self-explanatory.

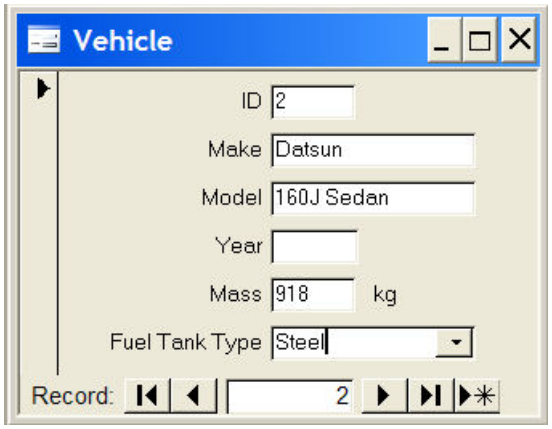

Figure 1. Vehicle Table Form with Data from Series 1, Test 1.

3.2 Laboratory Table

The second table includes some important information concerning the laboratory where the test was performed. Figure 2 shows the corresponding form after entering the data from Series 1, Test 1. The ID field contains the primary key automatically assigned by Access. The remaining fields are self-explanatory.

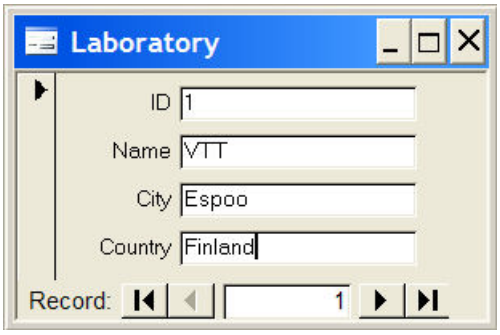

Figure 2. Laboratory Table Form with Data from Series 1, Test 1.

3.3 Publication Table

Figure 3 shows important information concerning the publication that can be consulted to obtain more information about the test. The ID field contains the primary key automatically assigned by Access. The remaining fields are self-explanatory.

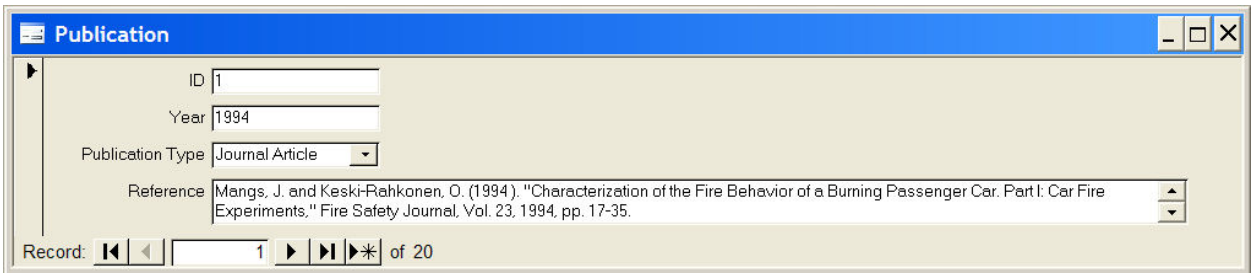

Figure 3. Publication Table Form with Data from Series 1, Test 1.

3.4 Test Table

Figure 4 shows the form for the main table. It provides information concerning the test setup and conditions and the primary results. There are links to the other three tables and to the vector data (heat release rate vs. time, etc.) in separate MS Excel workbooks. The ID field contains the primary key automatically assigned by Access. The remaining fields are described in Table 1.

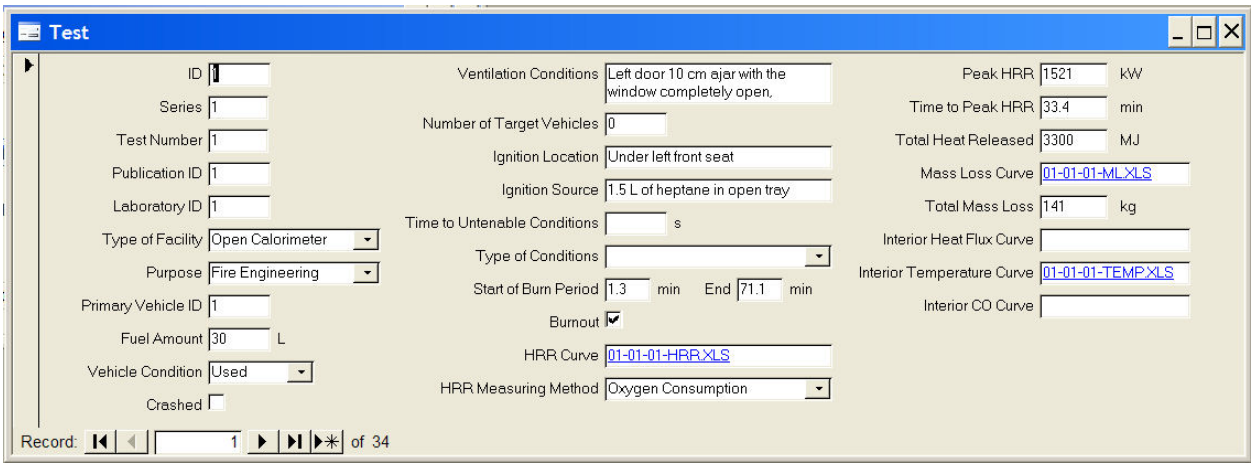

Figure 4. Test Table Form with Data from Series 1, Test 1.

The start of the burn period is defined as the time when the heat release rate reaches 10% of the peak, because there is a large variation among tests of the fire growth delay from the start of the test, i.e., time of application of the ignition source, to the time when the heat release rate starts to rise beyond that from the ignition source. The end of the burn period is defined as the time when the heat release rate drops back to 10% of the peak. This definition eliminates inconsistencies due to the criteria for termination of a test used in different laboratories.

Table 1. Test Table Fields.

Field	Description
Series	Sequential test series number
Test Number	Number of the test within the series
Publication ID	Link to the Publication Table
Laboratory ID	Link to the Laboratory Table
Type of Facility	Type of facility to measure heat release rate (HRR) (Corner Calorimeter, Open Calorimeter, Parking Garage, Rail Shuttle Car, Room Calorimeter, Tunnel or Other)
Purpose	Purpose for performing the test (Arson Investigation, Fire Engineering, Fire Hazard Assessment or Other)
Primary Vehicle ID	Link to the Vehicle Table
Fuel Amount	Amount of fuel in the tank in liters
Vehicle Condition	Condition of the vehicle (New, Used or Unknown)
Crashed	Has the vehicle been involved in a crash prior to the test?
Ventilation Conditions	How is air supplied to the passenger compartment?
Number of Target Vehicles	Number of vehicles adjacent to the test vehicle
Ignition Location	Location of ignition source
Ignition Source	Ignition source used to start the fire
Time to Untenable Conditions	Time to untenable conditions in seconds
Type of Conditions	Type of untenability conditions (Flame Penetration, Heat Flux, Temperature, Toxicity or Other)
Start of Burn Period	Defined as the time in min when the HRR first reaches 10% of its peak
End of Burn Period	Defined as the time in min to decline of the HRR to 10% of its peak
Burnout	Was the vehicle allowed to burn out before the test was terminated?
HRR Curve	Link to Excel workbook that contains HRR data
HRR Measuring Method	Measurement technique used to determine HRR (Mass Loss, Oxygen Consumption, Temperature Rise, Other)
Peak HRR	Maximum HRR measured during the test in kW
Time to Peak HRR	Time to peak HRR in min
Total Heat Released	Total heat released during the test in MJ
Mass Loss Curve	Link to Excel workbook that contains mass loss data
Total Mass Loss	Total mass loss in kg
Interior Heat Flux Curve	Link to Excel workbook that contains interior heat flux data
Interior Temperature Curve	Link to Excel workbook that contains interior temperature data
Interior CO Curve	Link to Excel workbook that contains interior CO concentration data

3.5 Curves

The test table has links to Excel workbooks that contain the vector data available. These Excel workbooks were generated by digitizing the relevant graphs in the reference publication. A freeware program called Plot Digitizer (available at publication from SourceForge at http://plotdigitizer.sourceforge.net/) was used for this purpose. Five types of data were considered:

- heat release rate vs. time;
- mass loss vs. time;
- gas temperature inside the passenger compartment vs. time;
- incident heat flux inside the passenger compartment vs. time; and
- CO concentration inside the passenger compartments vs. time.

4.0 USING THE DATABASE

A complete report was generated of the information in the database, including the charts in the linked Excel files. This report can be found in Appendix A. It is obvious from the report that a significant number of fields are blank. The laboratories were contacted to obtain the missing information, without much success. The laboratories were also asked whether they could share any photographic or video documentation of the tests. VTT responded that video tapes could be provided. Unfortunately, the funds to cover the costs of the duplication and conversion were not available. BRI supplied a set of photographs without cross-references to the tests in Series Ten. The photographs are duplicated in Appendix B.

Despite the sparse nature of the database, it is still a useful tool for the fire protection engineering community. The two examples in the following sub-sections illustrate the use of the database.

4.1 Heat of Combustion

The heat release rates measured in the Series Five and Series Ten tests were obtained by multiplying the measured mass loss rate with an average value of the heat of combustion. TNO and BRI used 25 MJ/kg and 32 MJ/kg, respectively. Given the years when these two test series were conducted, this seems to indicate that the heat of combustion has risen over the years. Perhaps there are more tests with mass loss measurements that could be added to the database if a representative value for the heat of combustion would be known. Figure 5 shows a query of the database to find all tests that meet the following criteria:

1. Heat release rate measurements were based on oxygen consumption calorimetry.
2. Mass loss was measured.
3. The test was not terminated before burnout.

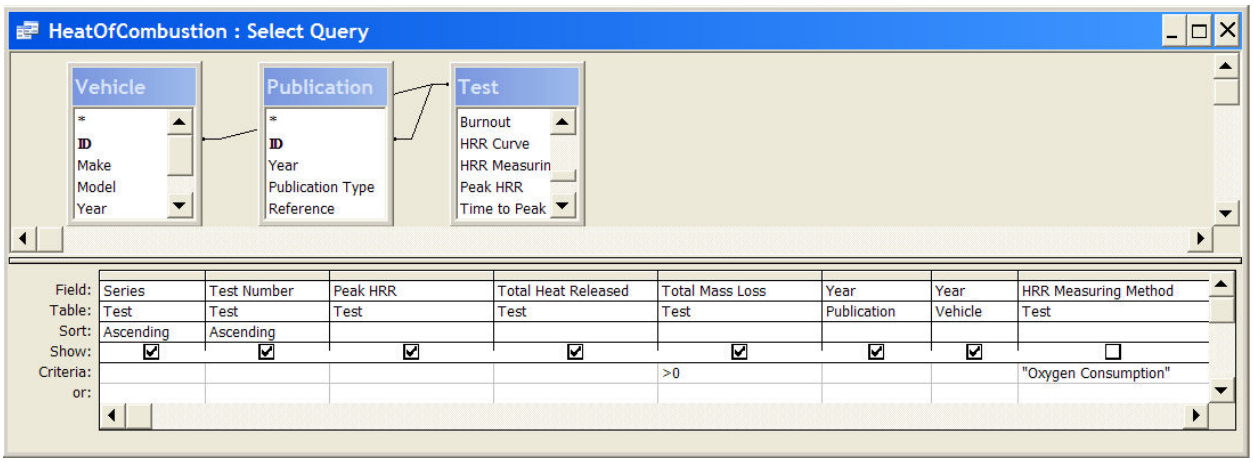

Figure 5. Heat of Combustion Database Query.

Table 2 summarizes the results of the query. Figure 6 shows the heat of combustion as a function of the year of publication for the tests that meet the criteria of the query (circles). It would have been better to plot the heat release rate as a function of the year of the vehicle. Unfortunately, the year of the vehicle is not known in most cases as is apparent from Table 2.

The trend line in Figure 6 has a slope of 0.96 and a constant of -1892.6. The line is rather qualitative in nature since, for example, variations in the amount of fuel in the tank between the tests are not accounted for. It seems to indicate that the heat of combustion has indeed increased over time, and the figure could be used to estimate a reasonable value for the heat of combustion based on the year of publication of the mass loss data. Note that the values used by TNO and BRI are reasonably consistent with the trend line (square symbols in Figure 6).

4.2 Duration of Burn Period

In some cases, for example, a motor vehicle fire in a congested tunnel pile-up, the fire department might not be able to approach the vehicle and put the fire out. To determine the appropriate level of fire protection for the structure, it is of interest to know how long motor vehicle fires last. The Test Table in the database does not have a field for the duration of the burning period, but there are fields for the start and the end of the burn period. The duration can be calculated as the difference between the two. Figure 7 shows the query to select all tests that have start and end times and were allowed to burn out. Table 3 gives the results of the query and Figure 8 shows the corresponding frequency distribution. The mean is approximately 48 min with a standard deviation of approximately 23 min.

Table 2. Results of the Heat of Combustion Query.

Series	Test Number	Peak HRR (kW)	THR (MJ)	TML (kg)	Heat of Combustion (MJ/kg)	Publication Year	Vehicle Year
1	1	1521	3300	141	23.4	1994	
1	2	1859	3000	143	21.0	1994	
1	3	1972	3900	176	22.2	1994	
4	3	3439	2100	138	15.2	1997	
4	7	8188	6670	275	24.3	1997	
4	8	4063	4090	184	22.2	1997	
6	1	3630	3100	100	31.0	2000	
6	2	1710	3200	108	29.6	2000	
6	3	4470	8000	270	29.6	2000	
9	1	9854	6806	262	26.0	2002	1994
9	2	8283	7000	255	27.5	2002	1994

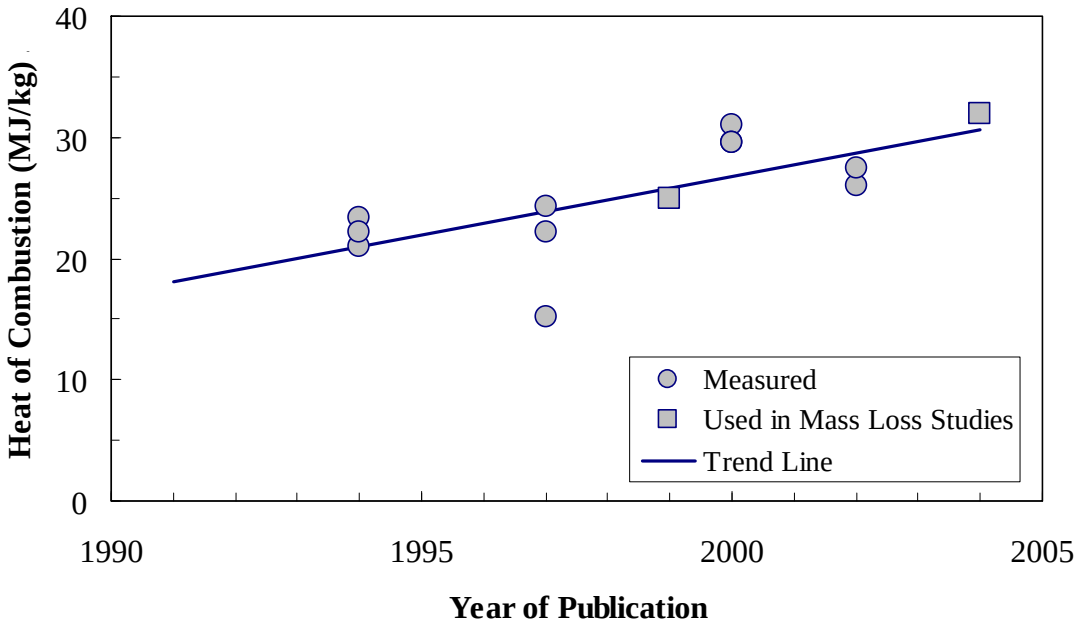

Figure 6. Heat of Combustion vs. Publication Year.

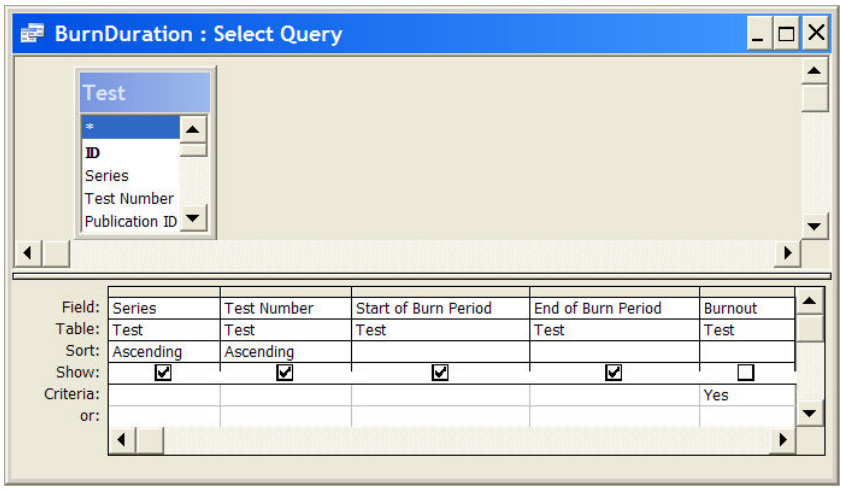

Figure 7. Burn Duration Database Query.

Table 3. Results of the Burn Duration Query.

Series	Test Number	Start (min)	End (min)	Duration (min)
1	1	1.3	71.1	69.8
1	2	3.9	52.5	48.6
1	3	2.9	91.6	88.7
2	1	6.2	56.3	50.1
3	2	5.7	44.3	38.6
4	3	1.7	22.6	20.9
4	7	3.5	54.6	51.1
4	8	12.3	55.1	42.8
5	1	8.6	26.2	17.6
5	11	10.5	43.3	32.8
5	12	4.5	32.2	27.7
6	1	4.3	28.9	24.6
6	2	10.3	67.2	56.9
6	3	3.9	51.3	47.4
9	1	6.3	45.1	38.8
9	2	4.9	49.6	44.7
10	2	3.4	51.8	48.4
10	3	8.8	89.4	80.6
10	4	8.1	55.0	46.9
10	5	12.2	59.7	47.5
11	1	17.7	131.6	113.9
12	1	10.6	35.8	25.2
			N	22
			Mean	48.3
			SD	23.1

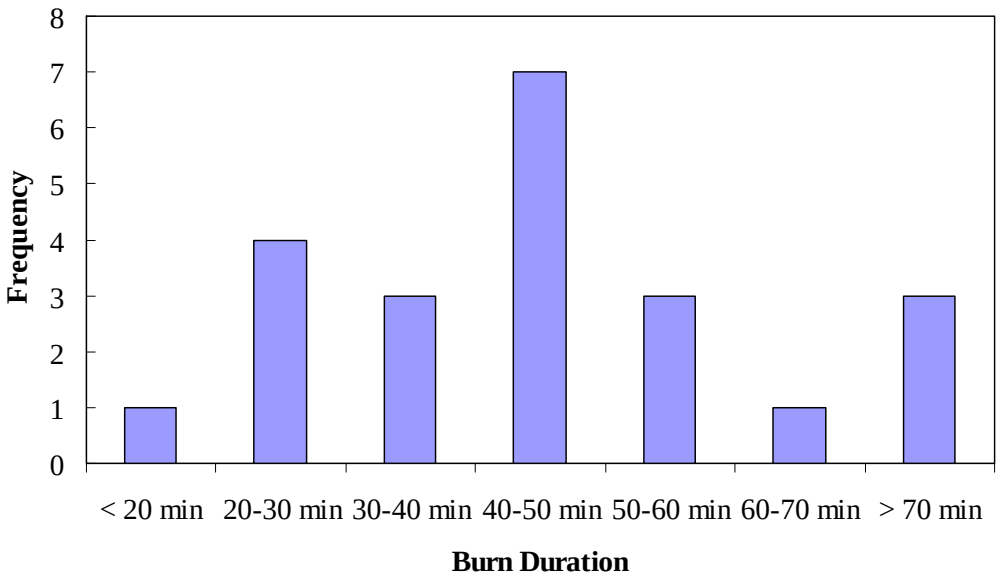

Figure 8. Burn Duration Frequency Distribution.

5.0 CONCLUSIONS AND RECOMMENDATIONS

This report describes the development of a database of full-scale motor vehicle fire test results. The data were obtained from a careful review of 20 publications. The data may be useful in fire engineering, e.g., fire design of parking garages and similar structures, fire hazard assessment of automotive materials in post-collision fires, etc. Unfortunately many of the fields in the database are blank. This is because the data reported in the publications describing the tests are incomplete. It is recommended to make the database accessible for free over the Internet and to have the laboratories that conducted the tests fill in the blanks. In addition, this will encourage laboratories to expand the database with recent test results. Finally, fire engineers using the data will be able to submit comments and suggestions for improvement of the database. Users who do not have MS Office 2003 or higher can use OpenOffice (freeware available at publication from http://www.openoffice.org) to manage the database, create queries and reports and read the Excel files.

6.0 ACKNOWLEDGEMENTS

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7.0 REFERENCES

1. Mangs, J., and Keski-Rahkonen, O. (1994). “Characterization of the Fire Behavior of a Burning Passenger Car. Part I: Car Fire Experiments,” *Fire Safety Journal*, Vol. 23, 1994, pp. 17-35.

2. Steinert, C. (1994). “Smoke and Heat Production in Tunnel Fires,” in International Conference on Fires in Tunnels, Swedish National Testing and Research Institute, Borås, Sweden, pp.123-137.

3. Shipp, M., and Spearpoint, M. (1995). “Measurements of the Severity of Fires Involving Private Motor Vehicles.” *Fire and Materials*, Vol. 19, pp. 143-151.

4. Joyeux, D. (1997). “Natural Fires in Closed Car Parks – Car Fire Tests.” CTICM Report No. INC 96/294d DJ/NB, CTICM, Metz, France.

5. Van Oerle, N., Lemaire, A., and van de Leur, P. (1999). “Effectiveness of Forced Ventilation in Closed Car Parks (in Dutch).” TNO Report No. 1999-CVB-RR1442, TNO, Delft, the Netherlands.

6. Steinert, C. (2000). "Experimental Investigation of Burning and Fire Jumping Behavior of Automobiles (in German)." *VFDB*, Vol. 49, pp. 163-172.

7. Stroup, D., DeLauter, L., Lee, L., and Roadermel, G. (2001). "Passenger Minivan Fire Tests," FR 4011, National Institute of Standards and Technology, Gaithersburg, MD.

8. Santrock, J. (2001). "Evaluation of Motor Vehicle Fire Initiation and Propagation, Part 3: Propagation in an Engine Compartment Fire in a 1996 Passenger Van," NHTSA 1998 3588-119, General Motors Corporation, Warren, MI.

9. Santrock, J. (2002). "Evaluation of Motor Vehicle Fire Initiation and Propagation, Part 4: Propagation of an Underbody Gasoline Pool Fire in a 1996 Passenger Van," NHTSA 1998 3588-143, General Motors Corporation, Warren, MI.

10. Santrock, J. (2002). "Evaluation of Motor Vehicle Fire Initiation and Propagation, Part 6: Propagation of an Underbody Gasoline Pool Fire in a 1997 Rear Wheel Drive Passenger Car," NHTSA 1998-3588-158, General Motors Corporation, Warren, MI.

11. Santrock, J. (2002). "Evaluation of Motor Vehicle Fire Initiation and Propagation, Part 7: Propagation of an Engine Compartment Fire in a 1997 Rear Wheel Drive Passenger Car," NHTSA 1998-3588-178, General Motors Corporation, Warren, MI.

12. Santrock, J. (2002). "Evaluation of Motor Vehicle Fire Initiation and Propagation, Part 9: Propagation of a Rear-Underbody Gasoline Pool Fire in a 1998 Sport Utility Vehicle," NHTSA 1998-3588-188, General Motors Corporation, Warren, MI.

13. Santrock, J. (2002). "Evaluation of Motor Vehicle Fire Initiation and Propagation, Part 10: Propagation of a Mid-Underbody Gasoline Pool Fire in a 1998 Sport Utility Vehicle," NHTSA 1998-3588-189, General Motors Corporation, Warren, MI.

14. Santrock, J. (2002). "Demonstration of Enhanced Fire Safety Technology-Fire Retardant Materials-Part 1: Full Scale Vehicle Fire Tests of a Control Vehicle and a Test Vehicle Containing an HVAC Module Made from Polymers Containing Flame Retardant Chemicals," NHTSA 1998-3588-190, General Motors Corporation, Warren, MI.

15. Santrock, J. (2003). "Evaluation of Motor Vehicle Fire Initiation and Propagation, Part 12: Propagation of an Underbody Gasoline Pool Fire in a 1998 Front-Wheel Drive Passenger Vehicle," NHTSA 1998-3588-201, General Motors Corporation, Warren, MI.

16. Santrock, J. (2003). "Evaluation of Motor Vehicle Fire Initiation and Propagation, Part 13: Propagation of an Engine Compartment Fire in a 1998 Front-Wheel Drive Passenger Vehicle," NHTSA 1998-3588-203, General Motors Corporation, Warren, MI.

17. Joyeux, D., Kruppa, J., Cajot, L., Schleich, J., Van de Leur, P., and Twilt, L. (2002). "Demonstration of Real Fire Tests in Car Parks and High Buildings," Final Report, Contract No. 7215 PP 025, CTICM, Metz, France.

18. Shintani, Y., Kakae, N., Harada, K., Masuda, H., and Takahashi, W. (2004). “Experimental Investigation of Burning Behavior of Automobiles,” 6th Asia-Oceania Symposium on Fire Science and Technology, pp. 618-629.

19. Anonymous (2004). “CTICM Fire Tests on Cars,” CITCM, Metz, France.

20. Lönnermark, A., and Blomqvist, P. (2006). “Emissions from an Automobile Fire,” *Chemosphere*, Vol. 62, pp. 1043-1056.

21. Haack, A. (1994). “Introduction to the Eureka-EU 499 Firetun Project,” in International Conference on Fires in Tunnels, Swedish National Testing and Research Institute, Borås, Sweden, pp. 3-19.

22. Richter, E., and Vauquelin, O. (1994). “Description of Measuring Techniques Used in the EUREKA Project,” in International Conference on Fires in Tunnels, Swedish National Testing and Research Institute, Borås, Sweden, pp. 20-35.

23. French, S. (1994). “EUREKA 499 HGV Fire Test (November 1992),” in International Conference on Fires in Tunnels, Swedish National Testing and Research Institute, Borås, Sweden, pp. 63-85.

24. Grant, G., and Drysdale, D. (1997). “Estimating Heat Release Rates from Large-Scale Tunnel Fires,” in Fifth International Symposium on Fire Safety Science, Melbourne, Australia, pp. 1213-1224.

25. Ingason, H. (1994). “Heat Release Rate Measurements in Tunnel Fires,” in International Conference on Fires in Tunnels, Swedish National Testing and Research Institute, Borås, Sweden, pp. 86-103.

26. Sørlie, R., and Mathisen, H. (1994). ”Measurements and Calculations of the Heat Release Rate in Tunnel Fires: Fire Test ‘Heavy Goods Vehicle’,” in International Conference on Fires in Tunnels, Swedish National Testing and Research Institute, Borås, Sweden, pp. 104-122.

27. Jensen, J., and Santrock, J. (1998). “Evaluation of Motor Vehicle Fire Initiation and Propagation, Vehicle Crash and Fire Propagation Test Program,” in 16th International Technical Conference on the Enhanced Safety of Vehicles, Windsor, ON, pp. 813-827.

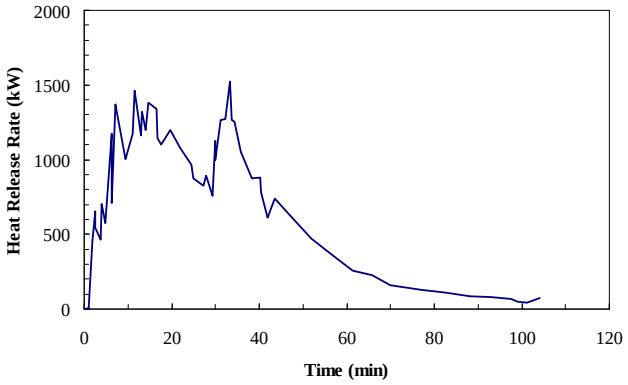
APPENDIX A

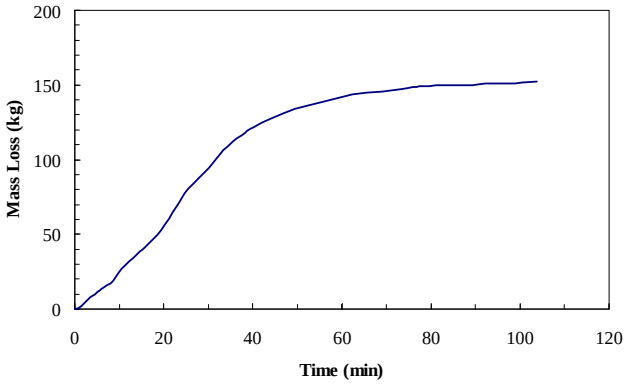
COMPLETE REPORT OF INFORMATION IN THE DATABASE

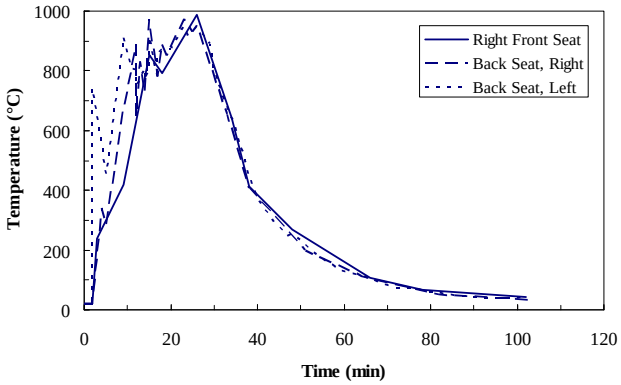
(Consisting of 68 Pages)

Test Series	1	**Test Number**	1
Lab Name	VTT		
City	Espoo	**Country**	Finland
Type of Facility	Open Calorimeter		
Purpose of Test	Fire Engineering		
Vehicle Make	Ford		
Vehicle Model	Taunus		
Vehicle Year			
Vehicle Mass (kg)	990		
Fuel Tank Type	Steel		
Fuel Amount (L)	30		
Vehicle Condition	Used		
Post-Collision			
Ventilation Conditions	Left door 10 cm ajar with the window completely open, right door closed with window rolled down 5 cm		
Number of Target Vehicles	0		
Ignition Location	Under left front seat		
Ignition Source	1.5 L of heptane in open tray		
Untenable Conditions (s)			
Type of Conditions			
Start of Burn Period (min)	1.3		
End of Burn Period (min)	71.1		
Burnout	✓		
HRR Curve	01-01-01-HRR.XLS		
HRR Measuring Method	Oxygen Consumption		
Peak HRR (kW)	1521		
Time to Peak HRR (min)	33.4		
Total Heat Released (MJ)	3300		
Mass Loss Curve	01-01-01-ML.XLS		
Total Mass Loss (kg)	141		
Interior Heat Flux Curve			
Interior Temperature Curve	01-01-01-TEMP.XLS		
Interior CO Curve			

Reference Mangs, J. and Keski-Rahkonen, O. (1994). "Characterization of the Fire Behavior of a Burning Passenger Car. Part I: Car Fire Experiments," Fire Safety Journal, Vol. 23, 1994, pp. 17-35.

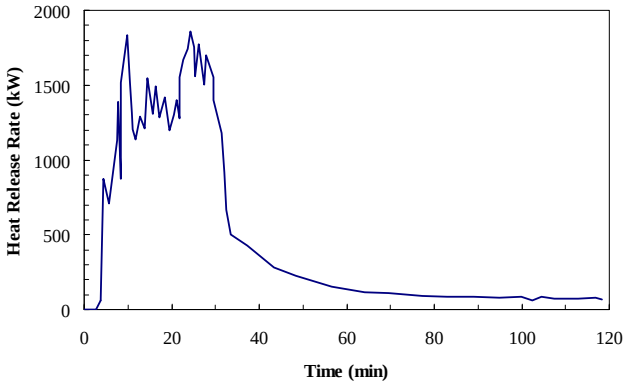

Heat Release Rate (kW)
2000
1500
1000
500
0
0
20
40
60
80
100
120
Time (min)

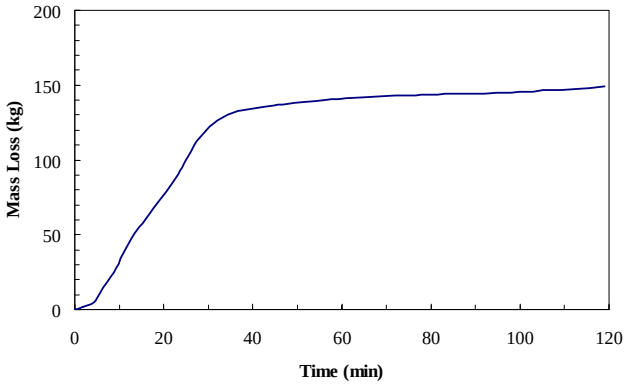

Mass Loss (kg)
200
150
100
50
0
0
20
40
60
80
100
120
Time (min)

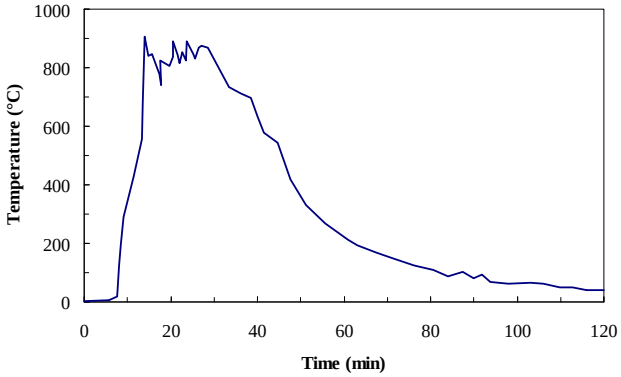

Temperature (°C)
1000
800
600
400
200
0
0
20
40
60
80
100
120
Time (min)
Right Front Seat
Back Seat, Right
Back Seat, Left

Test Series	1 **Test Number** 2
Lab Name	VTT
City	Espoo **Country** Finland
Type of Facility	Open Calorimeter
Purpose of Test	Fire Engineering
Vehicle Make	Datsun
Vehicle Model	160J Sedan
Vehicle Year	
Vehicle Mass (kg)	918
Fuel Tank Type	Steel
Fuel Amount (L)	30
Vehicle Condition	Used
Post-Collision	
Ventilation Conditions	All doors closed, left front window completely open, other windows rolled down 5 cm
Number of Target Vehicles	0
Ignition Location	Under the engine
Ignition Source	3 L of heptane in open tray
Untenable Conditions (s)	
Type of Conditions	
Start of Burn Period (min)	3.9
End of Burn Period (min)	52.5
Burnout	✓
HRR Curve	01-02-01-HRR.xls
HRR Measuring Method	Oxygen Consumption
Peak HRR (kW)	1859
Time to Peak HRR (min)	24.3
Total Heat Released (MJ)	3000
Mass Loss Curve	01-02-01-ML.xls
Total Mass Loss (kg)	143
Interior Heat Flux Curve	
Interior Temperature Curve	01-02-01-TEMP.xls
Interior CO Curve	

Reference Mangs, J. and Keski-Rahkonen, O. (1994). "Characterization of the Fire Behavior of a Burning Passenger Car. Part I: Car Fire Experiments," Fire Safety Journal, Vol. 23, 1994, pp. 17-35.

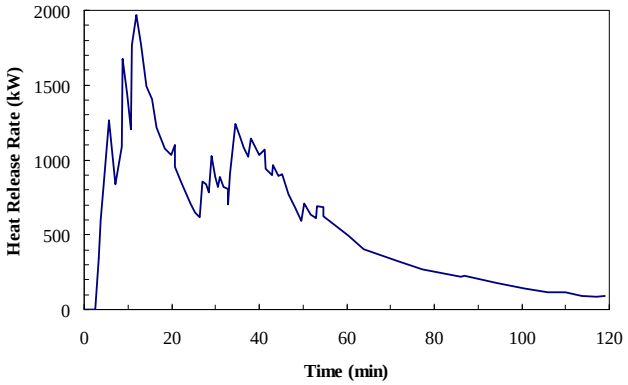

Heat Release Rate (kW)
2000
1500
1000
500
0
0
20
40
60
80
100
120
Time (min)

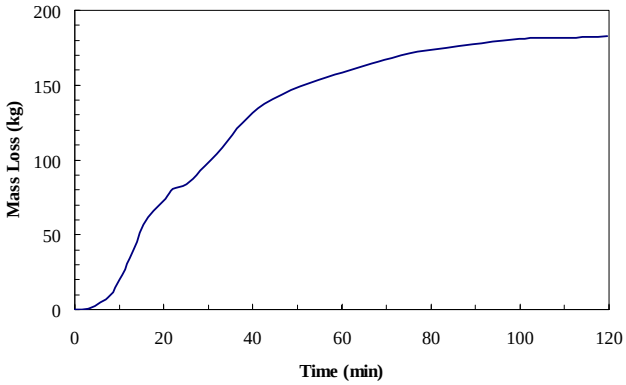

Mass Loss (kg)
200
150
100
50
0
0
20
40
60
80
100
120
Time (min)

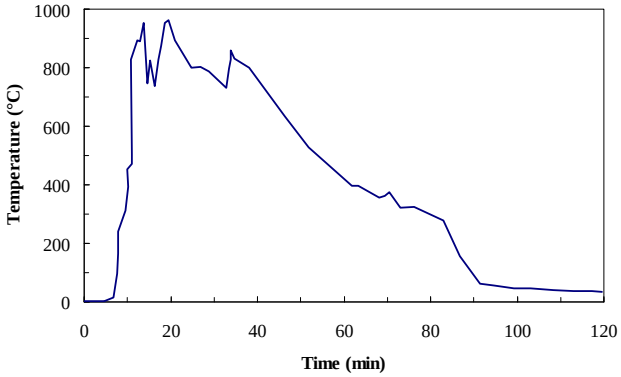

Temperature (°C)
1000
800
600
400
200
0
0
20
40
60
80
100
120
Time (min)

Test Series	1 **Test Number** 3
Lab Name	VTT
City	Espoo **Country** Finland
Type of Facility	Open Calorimeter
Purpose of Test	Fire Engineering
Vehicle Make	Datsun
Vehicle Model	180B Sedan
Vehicle Year	
Vehicle Mass (kg)	1102
Fuel Tank Type	Steel
Fuel Amount (L)	30
Vehicle Condition	Used
Post-Collision	
Ventilation Conditions	All doors closed, left front window completely open, other windows rolled down 5 cm
Number of Target Vehicles	0
Ignition Location	Under the engine
Ignition Source	3 L of heptane in open tray
Untenable Conditions (s)	
Type of Conditions	
Start of Burn Period (min)	2.9
End of Burn Period (min)	91.6
Burnout	✓
HRR Curve	01-03-01-HRR.xls
HRR Measuring Method	Oxygen Consumption
Peak HRR (kW)	1972
Time to Peak HRR (min)	12
Total Heat Released (MJ)	3900
Mass Loss Curve	01-03-01-ML.xls
Total Mass Loss (kg)	176
Interior Heat Flux Curve	
Interior Temperature Curve	01-03-01-TEMP.xls
Interior CO Curve	

Reference Mangs, J. and Keski-Rahkonen, O. (1994). "Characterization of the Fire Behavior of a Burning Passenger Car. Part I: Car Fire Experiments," Fire Safety Journal, Vol. 23, 1994, pp. 17-35.

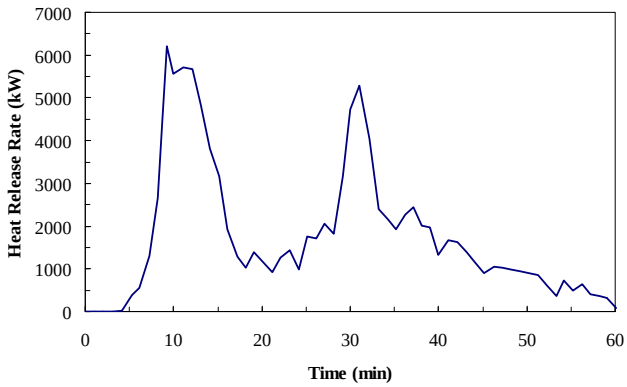

Heat Release Rate (kW)
2000
1500
1000
500
0
0
20
40
60
80
100
120
Time (min)


Mass Loss (kg)
200
150
100
50
0
0
20
40
60
80
100
120
Time (min)


Temperature (°C)
1000
800
600
400
200
0
0
20
40
60
80
100
120
Time (min)

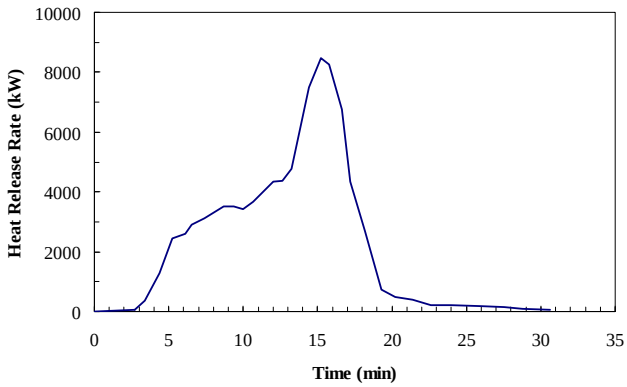
Test Series	2 **Test Number** 1
Lab Name	TU Braunschweig
City	Braunschweig **Country** Germany
Type of Facility	Tunnel
Purpose of Test	Fire Engineering
Vehicle Make	Unknown
Vehicle Model	Unknown
Vehicle Year	
Vehicle Mass (kg)	
Fuel Tank Type	Unknown
Fuel Amount (L)	
Vehicle Condition	Unknown
Post-Collision	
Ventilation Conditions	
Number of Target Vehicles	0
Ignition Location	
Ignition Source	
Untenable Conditions (s)	
Type of Conditions	
Start of Burn Period (min)	6.2
End of Burn Period (min)	56.3
Burnout	✓
HRR Curve	02-01-02-HRR.xls
HRR Measuring Method	Oxygen Consumption
Peak HRR (kW)	6206
Time to Peak HRR (min)	9.2
Total Heat Released (MJ)	7000
Mass Loss Curve	
Total Mass Loss (kg)	
Interior Heat Flux Curve	
Interior Temperature Curve	
Interior CO Curve	

Reference Steinert, C. (1994). "Smoke and Heat Production in Tunnel Fires," in International Conference on Fires in Tunnels, Swedish National Testing and Research Institute, Borås, Sweden, pp.123-137.


Heat Release Rate (kW)
7000
6000
5000
4000
3000
2000
1000
0
0
10
20
30
40
50
60
Time (min)

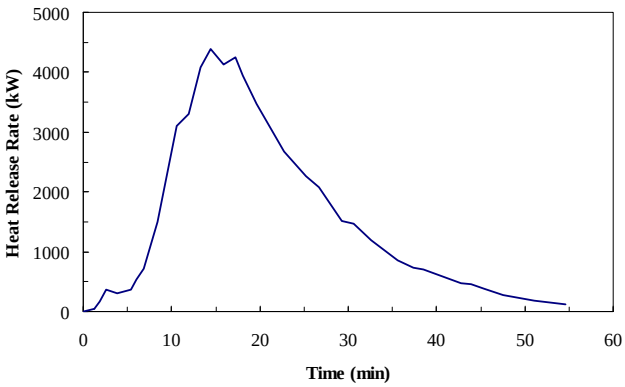
Test Series	3 **Test Number** 1
Lab Name	FRS BRE
City	Watford **Country** UK
Type of Facility	Rail Shuttle Car
Purpose of Test	Fire Engineering
Vehicle Make	Austin
Vehicle Model	Meastro
Vehicle Year	1982
Vehicle Mass (kg)	
Fuel Tank Type	Steel
Fuel Amount (L)	40
Vehicle Condition	Used
Post-Collision	
Ventilation Conditions	Driver and front passenger side windows completely open
Number of Target Vehicles	0
Ignition Location	On front seat
Ignition Source	No. 7 wood crib (peak HRR of about 10 kW)
Untenable Conditions (s)	
Type of Conditions	
Start of Burn Period (min)	3.9
End of Burn Period (min)	19.2
Burnout	
HRR Curve	03-01-03-HRR.xls
HRR Measuring Method	Oxygen Consumption
Peak HRR (kW)	8482
Time to Peak HRR (min)	15.2
Total Heat Released (MJ)	4008
Mass Loss Curve	
Total Mass Loss (kg)	
Interior Heat Flux Curve	
Interior Temperature Curve	
Interior CO Curve	

Reference Shipp, M. and Spearpoint, M. (1995). "Measurements of the Severity of Fires Involving Private Motor Vehicles," Fire and Materials, Vol. 19, pp. 143-151.


Heat Release Rate (kW)
10000
8000
6000
4000
2000
0
0
5
10
15
20
25
30
35
Time (min)

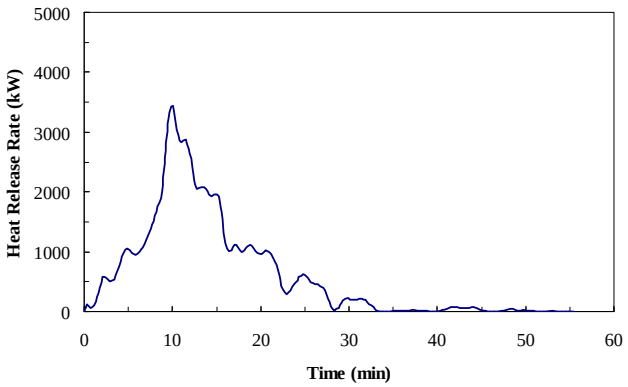
Test Series	3 **Test Number** 2
Lab Name	FRS BRE
City	Watford **Country** UK
Type of Facility	Rail Shuttle Car
Purpose of Test	Fire Engineering
Vehicle Make	Citroen
Vehicle Model	BX 14 RE
Vehicle Year	1986
Vehicle Mass (kg)	
Fuel Tank Type	Plastic
Fuel Amount (L)	44
Vehicle Condition	Used
Post-Collision	
Ventilation Conditions	Driver and front passenger side windows completely open
Number of Target Vehicles	0
Ignition Location	Engine compartment under hood
Ignition Source	400 mL gasoline in foil tray (100 mL spilled)
Untenable Conditions (s)	
Type of Conditions	
Start of Burn Period (min)	5.7
End of Burn Period (min)	44.3
Burnout	✓
HRR Curve	03-02-03-HRR.xls
HRR Measuring Method	Oxygen Consumption
Peak HRR (kW)	4390
Time to Peak HRR (min)	14.4
Total Heat Released (MJ)	4957
Mass Loss Curve	
Total Mass Loss (kg)	
Interior Heat Flux Curve	
Interior Temperature Curve	
Interior CO Curve	

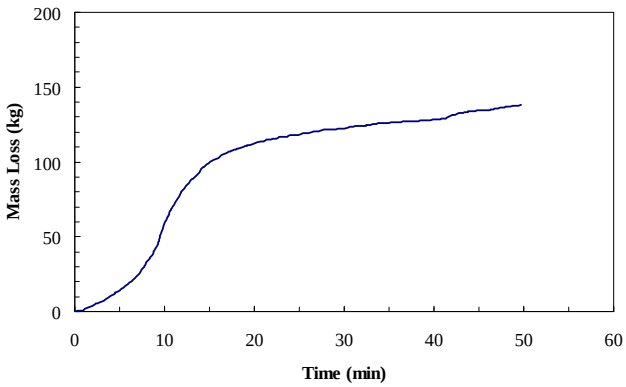
Reference Shipp, M. and Spearpoint, M. (1995). "Measurements of the Severity of Fires Involving Private Motor Vehicles," Fire and Materials, Vol. 19, pp. 143-151.


Heat Release Rate (kW)
5000
4000
3000
2000
1000
0
0
10
20
30
40
50
60
Time (min)

Test Series	4	**Test Number**	3
Lab Name	CTICM		
City	Metz	**Country**	France
Type of Facility	Corner Calorimeter		
Purpose of Test	Fire Engineering		
Vehicle Make	Renault		
Vehicle Model	5		
Vehicle Year			
Vehicle Mass (kg)	757		
Fuel Tank Type	Unknown		
Fuel Amount (L)			
Vehicle Condition	Used		
Post-Collision Ventilation Conditions			
Number of Target Vehicles	0		
Ignition Location	Under left front seat		
Ignition Source	1.5 L gasoline in open tray		
Untenable Conditions (s)			
Type of Conditions			
Start of Burn Period (min)	1.7		
End of Burn Period (min)	22.6		
Burnout	✓		
HRR Curve	04-03-04-HRR.xls		
HRR Measuring Method	Oxygen Consumption		
Peak HRR (kW)	3439		
Time to Peak HRR (min)	10		
Total Heat Released (MJ)	2100		
Mass Loss Curve	04-03-04-ML.XLS		
Total Mass Loss (kg)	138		
Interior Heat Flux Curve			
Interior Temperature Curve			
Interior CO Curve			

Reference Joyeux, D. (1997). "Natural Fires in Closed Car Parks: Car Fire Tests," CTICM Report No. INC 96/294d DJ/NB, CTICM, Metz, France.


Heat Release Rate (kW)
5000
4000
3000
2000
1000
0
0
10
20
30
40
50
60
Time (min)

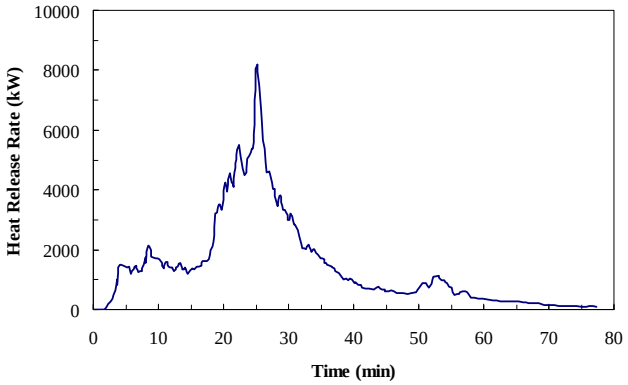

Mass Loss (kg)
200
150
100
50
0
0
10
20
30
40
50
60
Time (min)

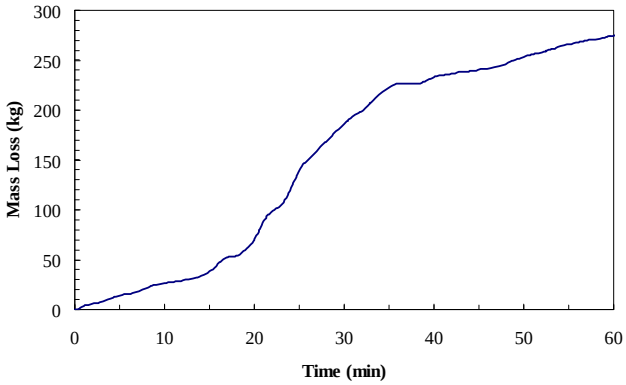
Test Series	4	**Test Number**	7

Lab Name	CTICM		
City	Metz	**Country**	France

Type of Facility	Open Calorimeter
Purpose of Test	Fire Engineering
Vehicle Make	Unknown
Vehicle Model	Unknown
Vehicle Year	
Vehicle Mass (kg)	1303
Fuel Tank Type	Unknown
Fuel Amount (L)	
Vehicle Condition	Used
Post-Collision	
Ventilation Conditions	
Number of Target Vehicles	0
Ignition Location	Under left front seat
Ignition Source	1.5 L gasoline in open tray
Untenable Conditions (s)	
Type of Conditions	
Start of Burn Period (min)	3.5
End of Burn Period (min)	54.6
Burnout	✓
HRR Curve	04-07-04-HRR.xls
HRR Measuring Method	Oxygen Consumption
Peak HRR (kW)	8188
Time to Peak HRR (min)	25.2
Total Heat Released (MJ)	6670
Mass Loss Curve	04-07-04-ML.xls
Total Mass Loss (kg)	275
Interior Heat Flux Curve	
Interior Temperature Curve	
Interior CO Curve	

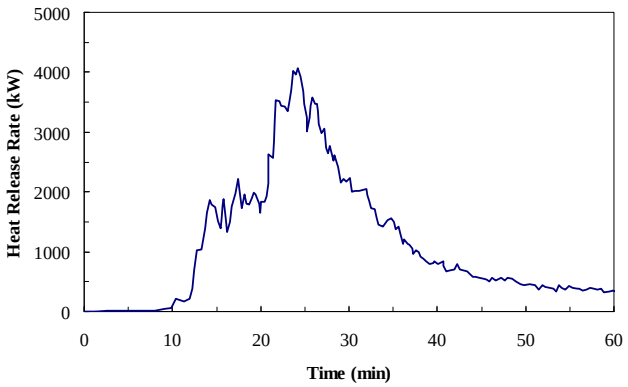
Reference Joyeux, D. (1997). "Natural Fires in Closed Car Parks: Car Fire Tests," CTICM Report No. INC 96/294d DJ/NB, CTICM, Metz, France.

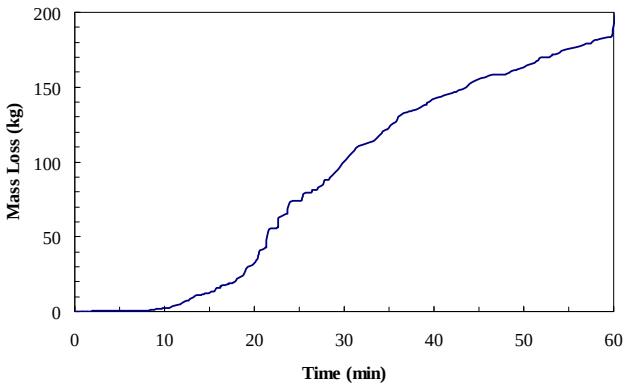

Heat Release Rate (kW)
10000
8000
6000
4000
2000
0
0
10
20
30
40
50
60
70
80
Time (min)


Mass Loss (kg)
300
250
200
150
100
50
0
0
10
20
30
40
50
60
Time (min)

Test Series	4 **Test Number** 8
Lab Name	CTICM
City	Metz **Country** France
Type of Facility	Open Calorimeter
Purpose of Test	Fire Engineering
Vehicle Make	Unknown
Vehicle Model	Unknown
Vehicle Year	
Vehicle Mass (kg)	830
Fuel Tank Type	Unknown
Fuel Amount (L)	
Vehicle Condition	Used
Post-Collision	
Ventilation Conditions	
Number of Target Vehicles	0
Ignition Location	Under gear box
Ignition Source	1 L gasoline in open tray
Untenable Conditions (s)	
Type of Conditions	
Start of Burn Period (min)	12.3
End of Burn Period (min)	55.1
Burnout	✓
HRR Curve	04-08-04-HRR.xls
HRR Measuring Method	Oxygen Consumption
Peak HRR (kW)	4063
Time to Peak HRR (min)	24.1
Total Heat Released (MJ)	4090
Mass Loss Curve	04-08-04-ML.xls
Total Mass Loss (kg)	184
Interior Heat Flux Curve	
Interior Temperature Curve	
Interior CO Curve	

Reference Joyeux, D. (1997). "Natural Fires in Closed Car Parks: Car Fire Tests," CTICM Report No. INC 96/294d DJ/NB, CTICM, Metz, France.


Heat Release Rate (kW)
5000
4000
3000
2000
1000
0
0
10
20
30
40
50
60
Time (min)

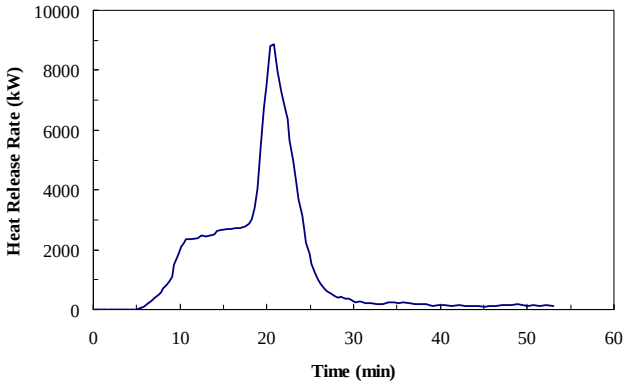

Mass Loss (kg)
200
150
100
50
0
0
10
20
30
40
50
60
Time (min)

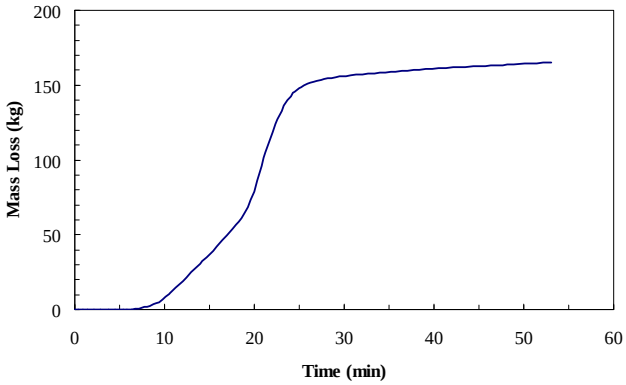
Test Series	5	**Test Number**	1

Lab Name	TNO		
City	Delft	**Country**	Netherlands

Type of Facility	Parking Garage
Purpose of Test	Fire Engineering
Vehicle Make	Peugeot
Vehicle Model	309
Vehicle Year	
Vehicle Mass (kg)	
Fuel Tank Type	Unknown
Fuel Amount (L)	
Vehicle Condition	Used
Post-Collision	
Ventilation Conditions	
Number of Target Vehicles	
Ignition Location	
Ignition Source	
Untenable Conditions (s)	
Type of Conditions	
Start of Burn Period (min)	8.6
End of Burn Period (min)	26.2
Burnout	✓
HRR Curve	05-01-05-HRR.xls
HRR Measuring Method	Mass Loss
Peak HRR (kW)	8872
Time to Peak HRR (min)	20.8
Total Heat Released (MJ)	4134
Mass Loss Curve	05-01-05-ML.xls
Total Mass Loss (kg)	165
Interior Heat Flux Curve	
Interior Temperature Curve	
Interior CO Curve	

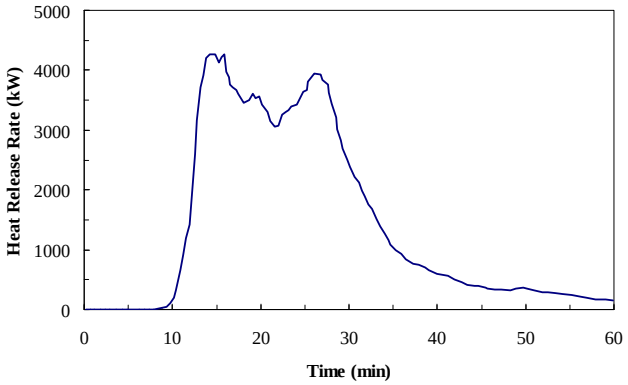
Reference Van Oerle, N., Lemaire, A. and van de Leur, P. (1999). "Effectiveness of Forced Ventilation in Closed Car Parks (in Dutch)," TNO Report No. 1999-CVB-RR1442, TNO, Delft, the Netherlands.

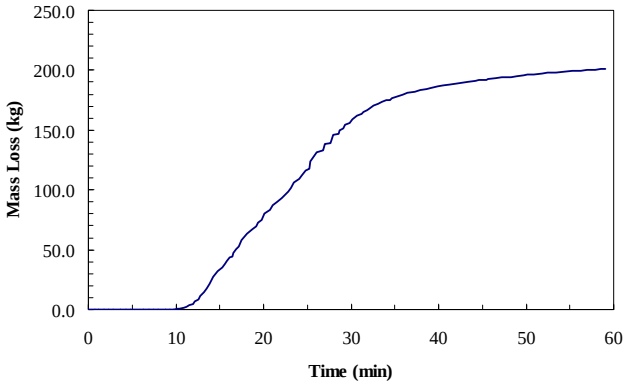

Heat Release Rate (kW)
10000
8000
6000
4000
2000
0
0
10
20
30
40
50
60
Time (min)


Mass Loss (kg)
200
150
100
50
0
0
10
20
30
40
50
60
Time (min)

Test Series	5	**Test Number**	11
Lab Name	TNO		
City	Delft	**Country**	Netherlands
Type of Facility	Parking Garage		
Purpose of Test	Fire Engineering		
Vehicle Make	Renault		
Vehicle Model	Espace		
Vehicle Year			
Vehicle Mass (kg)			
Fuel Tank Type	Unknown		
Fuel Amount (L)			
Vehicle Condition	Used		
Post-Collision			
Ventilation Conditions			
Number of Target Vehicles			
Ignition Location			
Ignition Source			
Untenable Conditions (s)			
Type of Conditions			
Start of Burn Period (min)	10.5		
End of Burn Period (min)	43.3		
Burnout	✓		
HRR Curve	05-11-05-HRR.xls		
HRR Measuring Method	Mass Loss		
Peak HRR (kW)	4270		
Time to Peak HRR (min)	15.8		
Total Heat Released (MJ)	5028		
Mass Loss Curve	05-11-05-ML.xls		
Total Mass Loss (kg)	201		
Interior Heat Flux Curve			
Interior Temperature Curve			
Interior CO Curve			

Reference Van Oerle, N., Lemaire, A. and van de Leur, P. (1999). "Effectiveness of Forced Ventilation in Closed Car Parks (in Dutch)," TNO Report No. 1999-CVB-RR1442, TNO, Delft, the Netherlands.


Heat Release Rate (kW)
5000
4000
3000
2000
1000
0
0
10
20
30
40
50
60
Time (min)

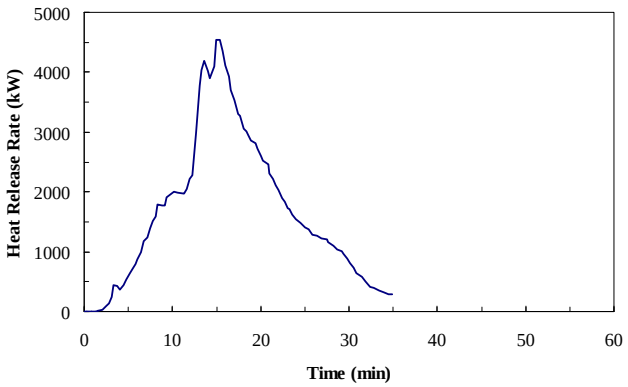

Mass Loss (kg)
250.0
200.0
150.0
100.0
50.0
0.0
0
10
20
30
40
50
60
Time (min)

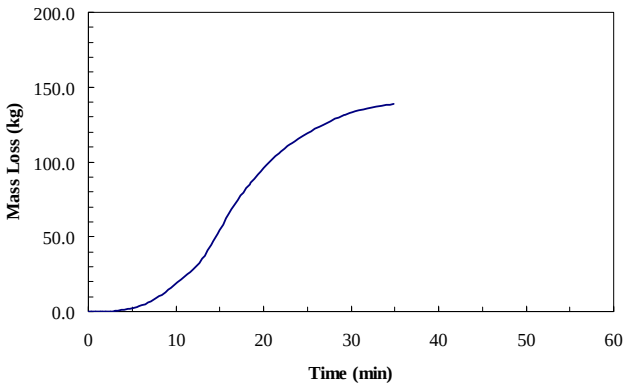
Test Series	5	**Test Number**	12

Lab Name	TNO		
City	Delft	**Country**	Netherlands

Type of Facility	Parking Garage
Purpose of Test	Fire Engineering
Vehicle Make	Opel
Vehicle Model	Kadett
Vehicle Year	
Vehicle Mass (kg)	
Fuel Tank Type	Unknown
Fuel Amount (L)	
Vehicle Condition	Used
Post-Collision	
Ventilation Conditions	
Number of Target Vehicles	
Ignition Location	
Ignition Source	
Untenable Conditions (s)	
Type of Conditions	
Start of Burn Period (min)	4.5
End of Burn Period (min)	32.2
Burnout	✓
HRR Curve	05-12-05-HRR.xls
HRR Measuring Method	Mass Loss
Peak HRR (kW)	4549
Time to Peak HRR (min)	15.4
Total Heat Released (MJ)	3466
Mass Loss Curve	05-12-05-ML.xls
Total Mass Loss (kg)	139
Interior Heat Flux Curve	
Interior Temperature Curve	
Interior CO Curve	

Reference Van Oerle, N., Lemaire, A. and van de Leur, P. (1999). "Effectiveness of Forced Ventilation in Closed Car Parks (in Dutch)," TNO Report No. 1999-CVB-RR1442, TNO, Delft, the Netherlands.


Heat Release Rate (kW)
5000
4000
3000
2000
1000
0
0
10
20
30
40
50
60
Time (min)

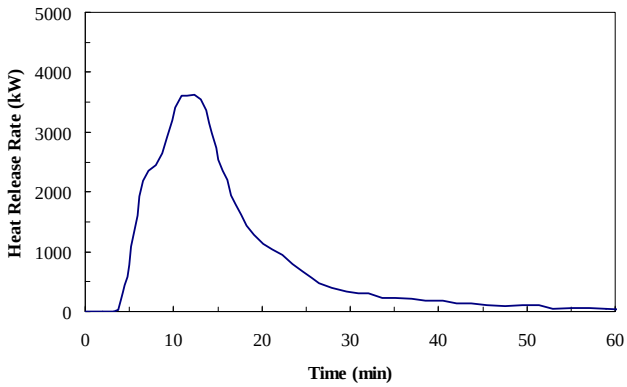

Mass Loss (kg)
200.0
150.0
100.0
50.0
0.0
0
10
20
30
40
50
60
Time (min)

Test Series	6	**Test Number**	1

Lab Name	MPA		
City	Leipzig	**Country**	Germany

Type of Facility	Room Calorimeter
Purpose of Test	Fire Engineering
Vehicle Make	Trabant
Vehicle Model	Limousine
Vehicle Year	
Vehicle Mass (kg)	695
Fuel Tank Type	Unknown
Fuel Amount (L)	15
Vehicle Condition	Used
Post-Collision	
Ventilation Conditions	Slight gap at top of windows
Number of Target Vehicles	0
Ignition Location	Front seat
Ignition Source	250 mL isopropanol
Untenable Conditions (s)	
Type of Conditions	
Start of Burn Period (min)	4.3
End of Burn Period (min)	28.9
Burnout	✓
HRR Curve	06-01-06-HRR.xls
HRR Measuring Method	Oxygen Consumption
Peak HRR (kW)	3630
Time to Peak HRR (min)	12.4
Total Heat Released (MJ)	3100
Mass Loss Curve	
Total Mass Loss (kg)	100
Interior Heat Flux Curve	
Interior Temperature Curve	
Interior CO Curve	

Reference Steinert, C. (2000). "Experimental Investigation of Burning and Fire Jumping Behavior of Automobiles (in German)," VFDB, Vol. 49, pp. 163-172.


5000
4000
3000
2000
1000
0
Heat Release Rate (kW)
0
10
20
30
40
50
60
Time (min)

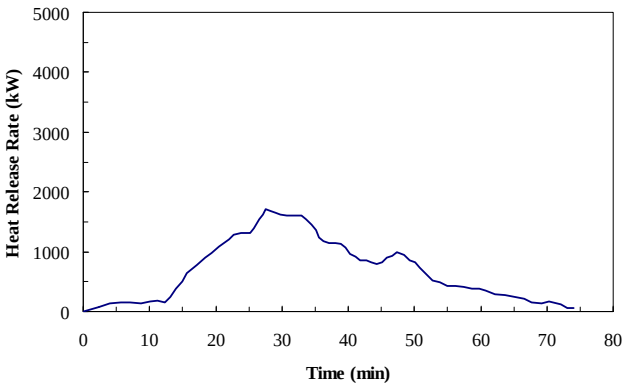
Test Series	6	**Test Number**	2

Lab Name	MPA		
City	Leipzig	**Country**	Germany

Type of Facility	Room Calorimeter
Purpose of Test	Fire Engineering
Vehicle Make	Rover-Austin
Vehicle Model	Metro LS
Vehicle Year	
Vehicle Mass (kg)	893
Fuel Tank Type	Unknown
Fuel Amount (L)	15
Vehicle Condition	Used
Post-Collision	
Ventilation Conditions	Slight gap at top of windows

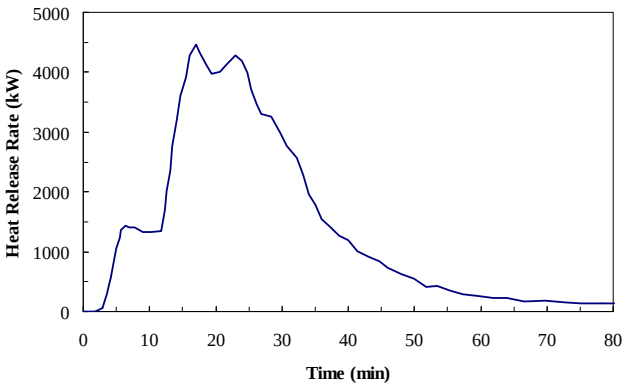
Number of Target Vehicles	0
Ignition Location	Front seat
Ignition Source	250 mL isopropanol
Untenable Conditions (s)	
Type of Conditions	
Start of Burn Period (min)	10.3
End of Burn Period (min)	67.2
Burnout	✓
HRR Curve	06-02-06-HRR.xls
HRR Measuring Method	Oxygen Consumption
Peak HRR (kW)	1710
Time to Peak HRR (min)	27.6
Total Heat Released (MJ)	3200
Mass Loss Curve	
Total Mass Loss (kg)	108
Interior Heat Flux Curve	
Interior Temperature Curve	
Interior CO Curve	

Reference Steinert, C. (2000). "Experimental Investigation of Burning and Fire Jumping Behavior of Automobiles (in German)," VFDB, Vol. 49, pp. 163-172.


Heat Release Rate (kW)
5000
4000
3000
2000
1000
0
0
10
20
30
40
50
60
70
80
Time (min)

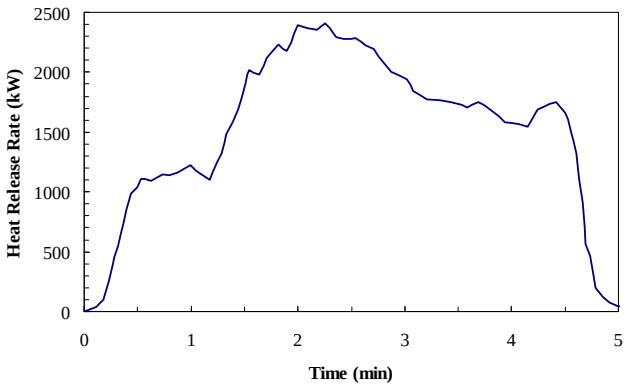
Test Series	6	**Test Number**	3
Lab Name	MPA		
City	Leipzig	**Country**	Germany
Type of Facility	Room Calorimeter		
Purpose of Test	Fire Engineering		
Vehicle Make	Citroen		
Vehicle Model	BX 16 RE		
Vehicle Year			
Vehicle Mass (kg)	1067		
Fuel Tank Type	Unknown		
Fuel Amount (L)	15		
Vehicle Condition	Used		
Post-Collision			
Ventilation Conditions	Slight gap at top of windows		
Number of Target Vehicles	0		
Ignition Location	Front seat		
Ignition Source	250 mL isopropanol		
Untenable Conditions (s)			
Type of Conditions			
Start of Burn Period (min)	3.9		
End of Burn Period (min)	51.3		
Burnout	✓		
HRR Curve	06-03-06-HRR.xls		
HRR Measuring Method	Oxygen Consumption		
Peak HRR (kW)	4470		
Time to Peak HRR (min)	17		
Total Heat Released (MJ)	8000		
Mass Loss Curve			
Total Mass Loss (kg)	270		
Interior Heat Flux Curve			
Interior Temperature Curve			
Interior CO Curve			

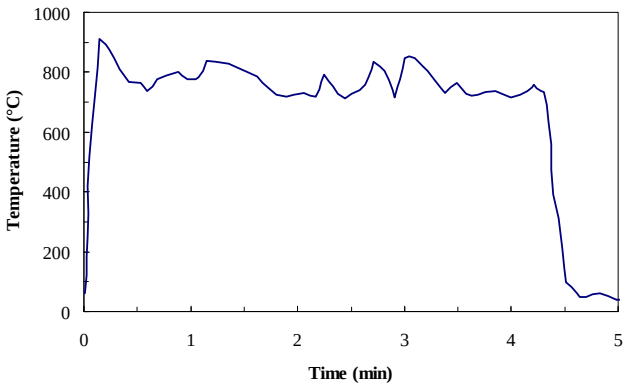
Reference Steinert, C. (2000). "Experimental Investigation of Burning and Fire Jumping Behavior of Automobiles (in German)," VFDB, Vol. 49, pp. 163-172.


Heat Release Rate (kW)
5000
4000
3000
2000
1000
0
0
10
20
30
40
50
60
70
80
Time (min)

Test Series	7 **Test Number** 2
Lab Name	NIST BFRL
City	Gaithersburg, MD **Country** USA
Type of Facility	Open Calorimeter
Purpose of Test	Arson Investigation
Vehicle Make	Unknown
Vehicle Model	Unknown (Minivan)
Vehicle Year	1995
Vehicle Mass (kg)	
Fuel Tank Type	Unknown
Fuel Amount (L)	
Vehicle Condition	Used
Post-Collision	
Ventilation Conditions	Driver and passenger window open
Number of Target Vehicles	0
Ignition Location	Poured on driver's seat
Ignition Source	2 L of gasoline
Untenable Conditions (s)	
Type of Conditions	
Start of Burn Period (min)	0.2
End of Burn Period (min)	4.8
Burnout	
HRR Curve	07-02-07-HRR.xls
HRR Measuring Method	Oxygen Consumption
Peak HRR (kW)	2405
Time to Peak HRR (min)	2.3
Total Heat Released (MJ)	459
Mass Loss Curve	
Total Mass Loss (kg)	
Interior Heat Flux Curve	
Interior Temperature Curve	07-02-07-TEMP.XLS
Interior CO Curve	

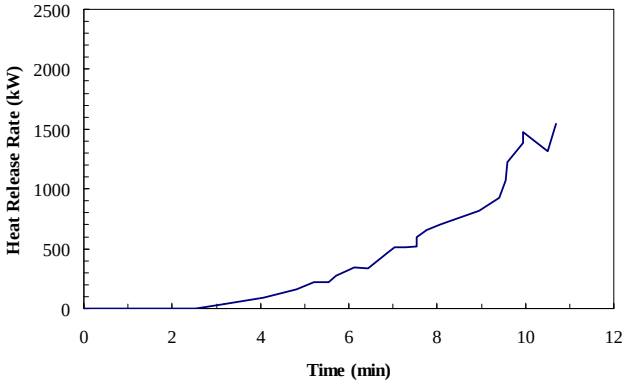
Reference Stroup, D., DeLauter, L., Lee, L. and Roadermel, G. (2001). "Passenger Minivan Fire Tests," FR 4011, National Institute of Standards and Technology, Gaithersburg, MD.

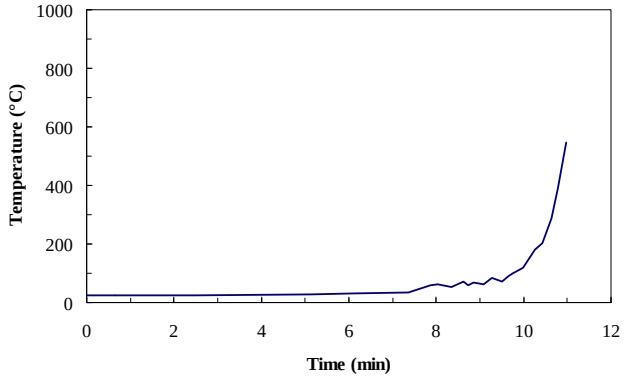

Heat Release Rate (kW)
2500
2000
1500
1000
500
0
0
1
2
3
4
5
Time (min)

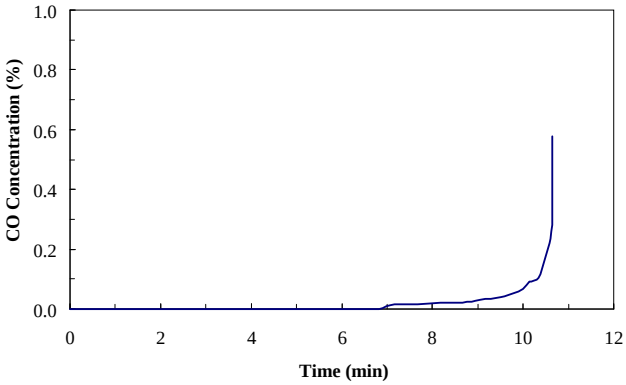

Temperature (°C)
1000
800
600
400
200
0
0
1
2
3
4
5
Time (min)

Test Series	8 **Test Number** 1
Lab Name	FM Research Center
City	West Gloucester, RI **Country** USA
Type of Facility	Open Calorimeter
Purpose of Test	Fire Hazard Assessment
Vehicle Make	Dodge
Vehicle Model	Caravan Sport
Vehicle Year	1996
Vehicle Mass (kg)	1981
Fuel Tank Type	Unknown
Fuel Amount (L)	
Vehicle Condition	Used
Post-Collision	
Ventilation Conditions	Driver and passenger window slightly open
Number of Target Vehicles	0
Ignition Location	Around battery and power distributor housing
Ignition Source	Electrical wire igniter
Untenable Conditions (s)	160
Type of Conditions	Flame Penetration
Start of Burn Period (min)	
End of Burn Period (min)	
Burnout	
HRR Curve	08-01-08-HRR.xls
HRR Measuring Method	Oxygen Consumption
Peak HRR (kW)	1545
Time to Peak HRR (min)	10.7
Total Heat Released (MJ)	254
Mass Loss Curve	
Total Mass Loss (kg)	
Interior Heat Flux Curve	
Interior Temperature Curve	08-01-08-TEMP.xls
Interior CO Curve	08-01-08-XCO.xls

Reference Santrock, J. (2001). "Evaluation of Motor Vehicle Fire Initiation and Propagation, Part 3: Propagation in an Engine Compartment Fire in a 1996 Passenger Van," NHTSA 1998 3588-119, General Motors Corporation, Warren, MI.

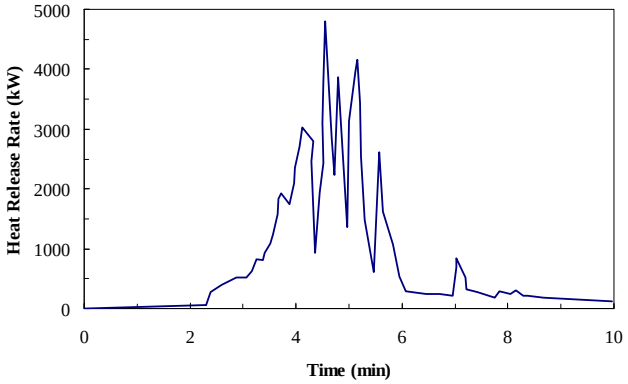

Heat Release Rate (kW)
2500
2000
1500
1000
500
0
0
2
4
6
8
10
12
Time (min)

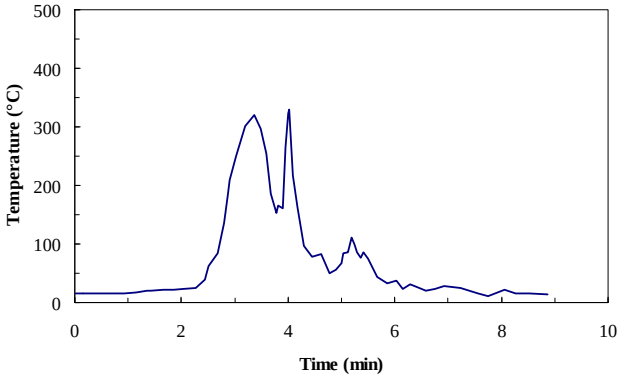

Temperature (°C)
1000
800
600
400
200
0
0
2
4
6
8
10
12
Time (min)

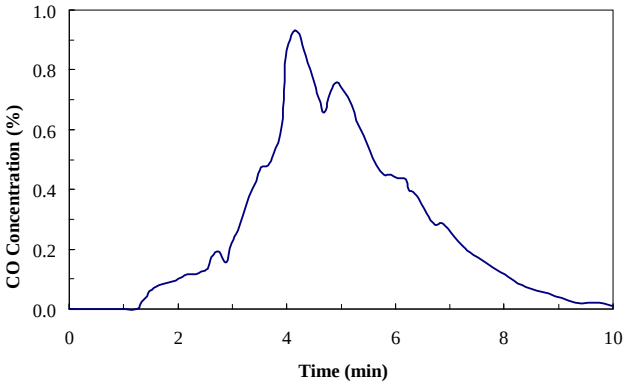

CO Concentration (%)
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
10
12
Time (min)

Test Series	8 **Test Number** 2
Lab Name	FM Research Center
City	West Gloucester, RI **Country** USA
Type of Facility	Open Calorimeter
Purpose of Test	Fire Hazard Assessment
Vehicle Make	Plymouth
Vehicle Model	Voyager
Vehicle Year	1996
Vehicle Mass (kg)	1946
Fuel Tank Type	Unknown
Fuel Amount (L)	38
Vehicle Condition	Used
Post-Collision Ventilation Conditions	Rear hatch window broken, left rear vent window open, left rear quarter panel cracked from crash
Number of Target Vehicles	0
Ignition Location	Under vehicle
Ignition Source	Pool from 243 ML/min fuel tank leak ignited at 30s
Untenable Conditions (s)	165
Type of Conditions	Flame Penetration
Start of Burn Period (min)	
End of Burn Period (min)	
Burnout	
HRR Curve	08-02-09-HRR.xls
HRR Measuring Method	Oxygen Consumption
Peak HRR (kW)	4797
Time to Peak HRR (min)	4.6
Total Heat Released (MJ)	421
Mass Loss Curve	
Total Mass Loss (kg)	
Interior Heat Flux Curve	
Interior Temperature Curve	08-02-09-TEMP.xls
Interior CO Curve	08-02-09-XCO.xls

Reference Santrock, J. (2002). "Evaluation of Motor Vehicle Fire Initiation and Propagation, Part 4: Propagation of an Underbody Gasoline Pool Fire in a 1996 Passenger Van," NHTSA 1998 3588-143, General Motors Corporation, Warren, MI.

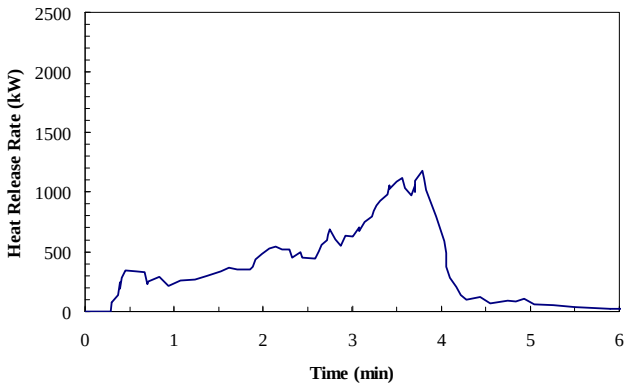

Heat Release Rate (kW)
5000
4000
3000
2000
1000
0
0
2
4
6
8
10
Time (min)

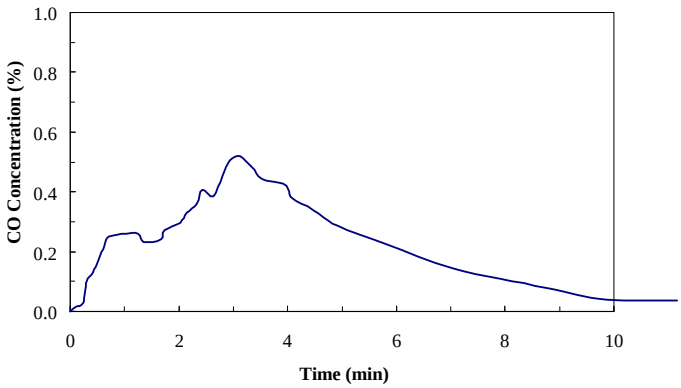

Temperature (°C)
500
400
300
200
100
0
0
2
4
6
8
10
Time (min)


CO Concentration (%)
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
10
Time (min)

Test Series	8 **Test Number** 3
Lab Name	FM Research Center
City	West Gloucester, RI **Country** USA
Type of Facility	Open Calorimeter
Purpose of Test	Fire Hazard Assessment
Vehicle Make	Chevrolet
Vehicle Model	Camaro
Vehicle Year	1997
Vehicle Mass (kg)	1811
Fuel Tank Type	Unknown
Fuel Amount (L)	
Vehicle Condition	Used
Post-Collision	
Ventilation Conditions	Left side door window and rear compartment lift window were shattered, gap between the bottom of the left door and frame
Number of Target Vehicles	0
Ignition Location	Under vehicle
Ignition Source	Pool from 515 ML/min fuel tank leak ignited at 30s
Untenable Conditions (s)	165
Type of Conditions	Flame Penetration
Start of Burn Period (min)	
End of Burn Period (min)	
Burnout	
HRR Curve	08-03-10-HRR.xls
HRR Measuring Method	Oxygen Consumption
Peak HRR (kW)	1181
Time to Peak HRR (min)	3.8
Total Heat Released (MJ)	130
Mass Loss Curve	
Total Mass Loss (kg)	
Interior Heat Flux Curve	
Interior Temperature Curve	
Interior CO Curve	08-03-10-XCO.xls

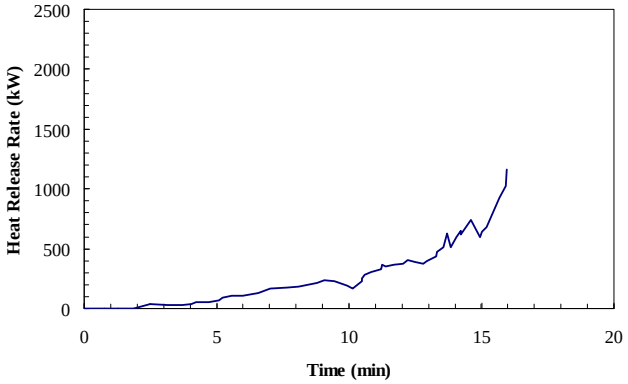
Reference Santrock, J. (2002). "Evaluation of Motor Vehicle Fire Initiation and Propagation, Part 6: Propagation of an Underbody Gasoline Pool Fire in a 1997 Rear Wheel Drive Passenger Car," NHTSA 1998-3588-158, General Motors Corporation, Warren, MI.

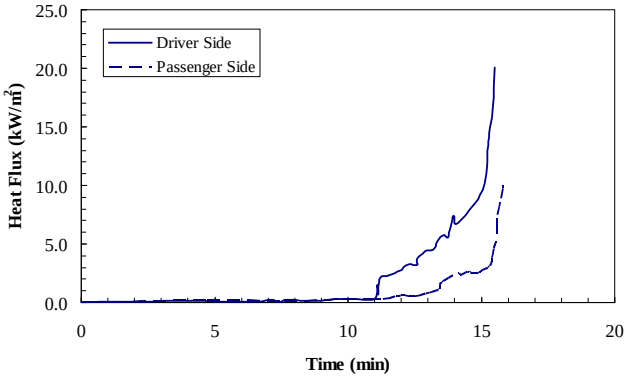

Heat Release Rate (kW)
2500
2000
1500
1000
500
0
0
1
2
3
4
5
6
Time (min)

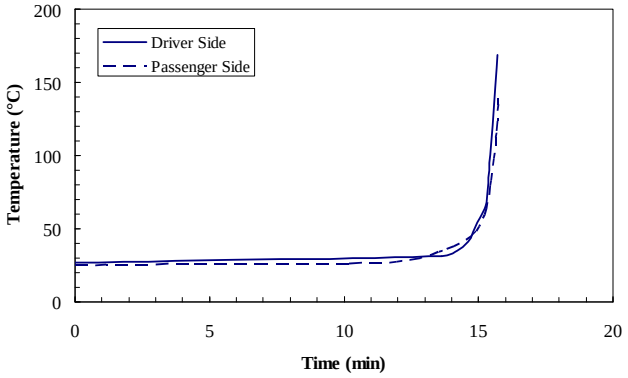

CO Concentration (%)
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
10
Time (min)

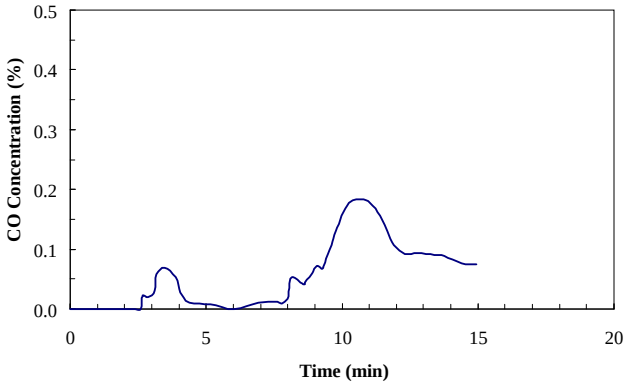
Test Series	8 **Test Number** 4
Lab Name	FM Research Center
City	West Gloucester, RI **Country** USA
Type of Facility	Open Calorimeter
Purpose of Test	Fire Hazard Assessment
Vehicle Make	Chevrolet
Vehicle Model	Camaro
Vehicle Year	1997
Vehicle Mass (kg)	1849
Fuel Tank Type	Unknown
Fuel Amount (L)	
Vehicle Condition	Used
Post-Collision Ventilation Conditions	Windshield and right door window were broken and a section of the weld seam between the floor pan and inner rocker panel was separated
Number of Target Vehicles	0
Ignition Location	Engine compartment
Ignition Source	Propane torch flame impinging on HVAC module
Untenable Conditions (s)	630
Type of Conditions	Flame Penetration
Start of Burn Period (min)	
End of Burn Period (min)	
Burnout	
HRR Curve	08-04-11-HRR.xls
HRR Measuring Method	Oxygen Consumption
Peak HRR (kW)	1161
Time to Peak HRR (min)	16
Total Heat Released (MJ)	233
Mass Loss Curve	
Total Mass Loss (kg)	
Interior Heat Flux Curve	08-04-11-FLUX.xls
Interior Temperature Curve	08-04-11-TEMP.xls
Interior CO Curve	08-04-11-XCO.xls

Reference Santrock, J. (2002). "Evaluation of Motor Vehicle Fire Initiation and Propagation, Part 7: Propagation of an Engine Compartment Fire in a 1997 Rear Wheel Drive Passenger Car," NHTSA 1998-3588-178, General Motors Corporation, Warren, MI.


Heat Release Rate (kW)
2500
2000
1500
1000
500
0
0
5
10
15
20
Time (min)

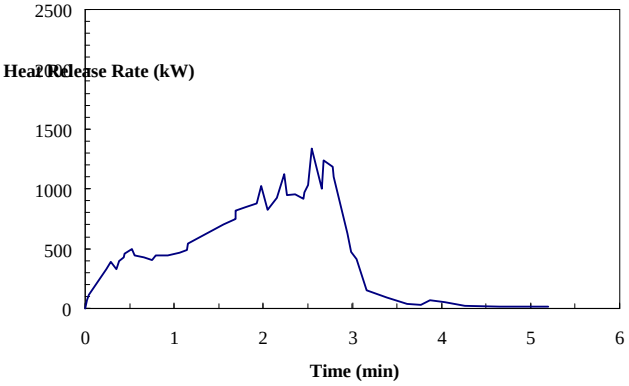

Heat Flux (kW/m²)
25.0
20.0
15.0
10.0
5.0
0.0
Driver Side
Passenger Side
0
5
10
15
20
Time (min)

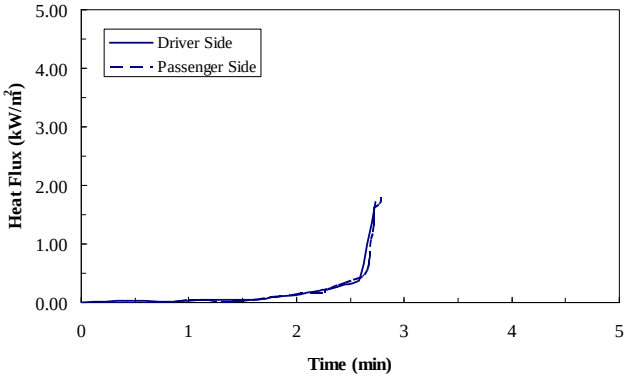

Temperature (°C)
200
150
100
50
0
Driver Side
Passenger Side
0
5
10
15
20
Time (min)

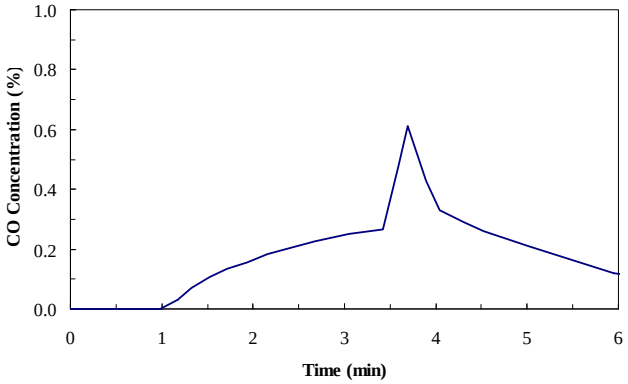

CO Concentration (%)
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
Time (min)

Test Series	8 **Test Number** 5
Lab Name	FM Research Center
City	West Gloucester, RI **Country** USA
Type of Facility	Open Calorimeter
Purpose of Test	Fire Hazard Assessment
Vehicle Make	Ford
Vehicle Model	Explorer
Vehicle Year	1998
Vehicle Mass (kg)	2249
Fuel Tank Type	Unknown
Fuel Amount (L)	
Vehicle Condition	Used
Post-Collision	
Ventilation Conditions	Window openings on the left and right quarter panels; additional opening on the rear lift gate, left rear door, door frames and seams along the rear compartment floor panels
Number of Target Vehicles	0
Ignition Location	Under vehicle
Ignition Source	Pool from 750 ML/min fuel tank leak ignited at 30s
Untenable Conditions (s)	125
Type of Conditions	Flame Penetration
Start of Burn Period (min)	
End of Burn Period (min)	
Burnout	
HRR Curve	08-05-12-HRR.xls
HRR Measuring Method	Oxygen Consumption
Peak HRR (kW)	1337
Time to Peak HRR (min)	2.5
Total Heat Released (MJ)	131
Mass Loss Curve	
Total Mass Loss (kg)	
Interior Heat Flux Curve	08-05-12-FLUX.xls
Interior Temperature Curve	
Interior CO Curve	08-05-12-XCO.xls

Reference Santrock, J. (2002). "Evaluation of Motor Vehicle Fire Initiation and Propagation, Part 9: Propagation of a Rear-Underbody Gasoline Pool Fire in a 1998 Sport Utility Vehicle," NHTSA 1998-3588-188, General Motors Corporation, Warren, MI.

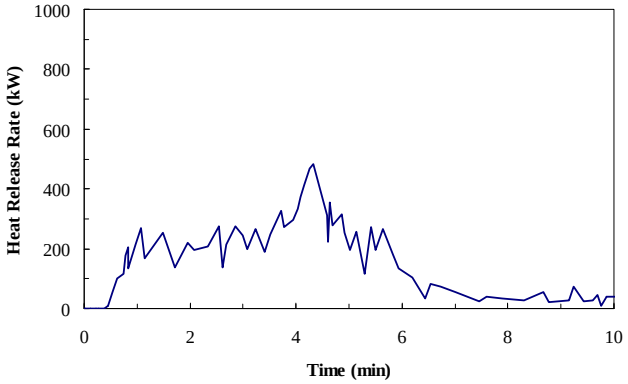

Heat Release Rate (kW)
2500
2000
1500
1000
500
0
0
1
2
3
4
5
6
Time (min)

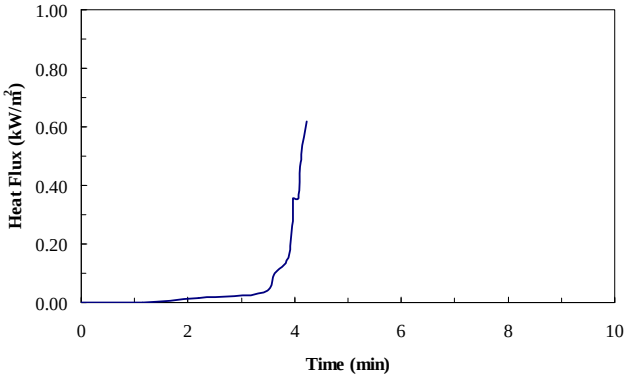

Heat Flux (kW/m²)
5.00
4.00
3.00
2.00
1.00
0.00
Driver Side
Passenger Side
0
1
2
3
4
5
Time (min)

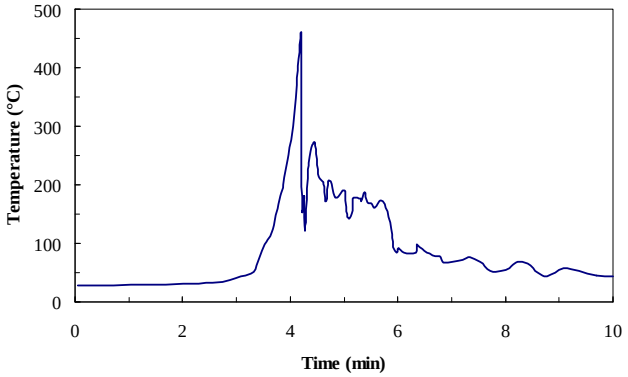

CO Concentration (%)
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
5
6
Time (min)

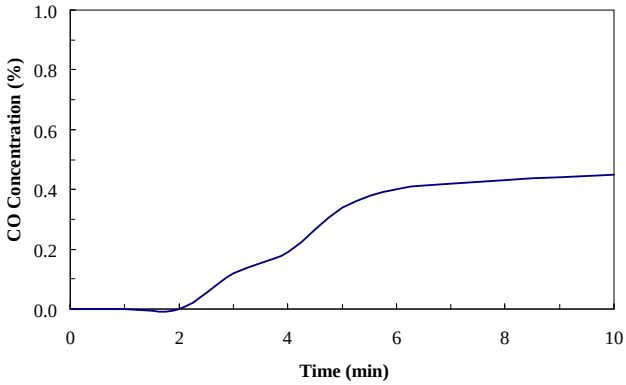
Test Series	8 **Test Number** 6
Lab Name	FM Research Center
City	West Gloucester, RI **Country** USA
Type of Facility	Open Calorimeter
Purpose of Test	Fire Hazard Assessment
Vehicle Make	Ford
Vehicle Model	Explorer
Vehicle Year	1998
Vehicle Mass (kg)	2232
Fuel Tank Type	Unknown
Fuel Amount (L)	
Vehicle Condition	Used
Post-Collision	
Ventilation Conditions	Pass through openings under left front seat; shift lever; drain holes, left door and door sills
Number of Target Vehicles	0
Ignition Location	Under vehicle (mid-body)
Ignition Source	Pool from 350 ML/min fuel tank leak ignited at 30s
Untenable Conditions (s)	10
Type of Conditions	Flame Penetration
Start of Burn Period (min)	
End of Burn Period (min)	
Burnout	
HRR Curve	08-06-13-HRR.xls
HRR Measuring Method	Oxygen Consumption
Peak HRR (kW)	484
Time to Peak HRR (min)	4.3
Total Heat Released (MJ)	90
Mass Loss Curve	
Total Mass Loss (kg)	
Interior Heat Flux Curve	08-06-13-FLUX.xls
Interior Temperature Curve	08-06-13-TEMP.xls
Interior CO Curve	08-06-13-XCO.xls

Reference Santrock, J. (2002). "Evaluation of Motor Vehicle Fire Initiation and Propagation, Part 10: Propagation of a Mid-Underbody Gasoline Pool Fire in a 1998 Sport Utility Vehicle," NHTSA 1998-3588-189, General Motors Corporation, Warren, MI.


Heat Release Rate (kW)
1000
800
600
400
200
0
0
2
4
6
8
10
Time (min)

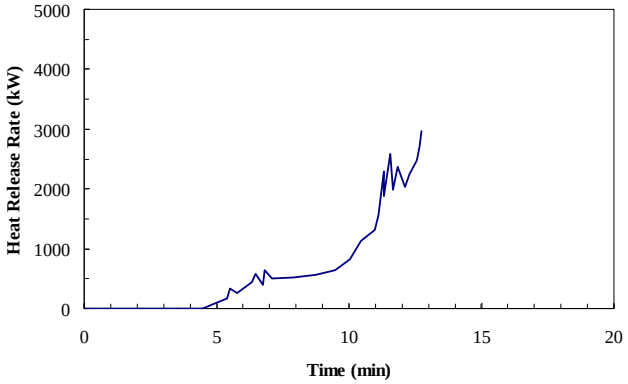

Heat Flux (kW/m²)
1.00
0.80
0.60
0.40
0.20
0.00
0
2
4
6
8
10
Time (min)

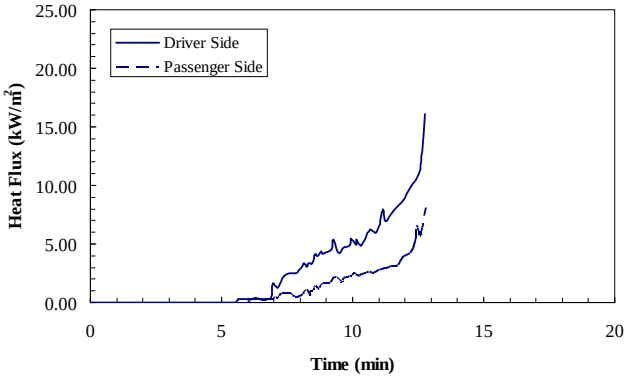

Temperature (°C)
500
400
300
200
100
0
0
2
4
6
8
10
Time (min)

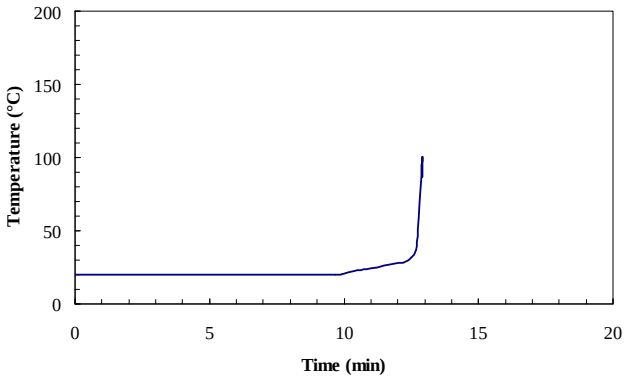

CO Concentration (%)
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
10
Time (min)

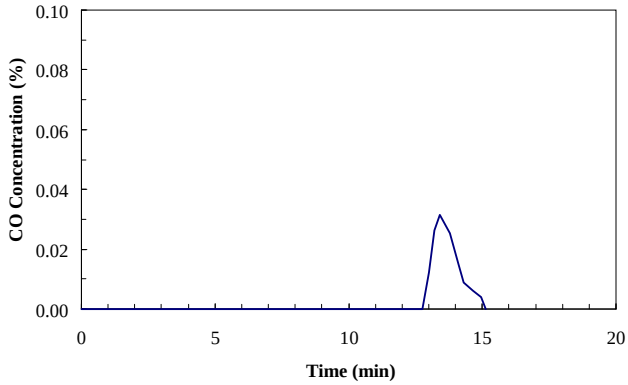
Test Series	8 **Test Number** 7
Lab Name	FM Research Center
City	West Gloucester, RI **Country** USA
Type of Facility	Open Calorimeter
Purpose of Test	Fire Hazard Assessment
Vehicle Make	Chevrolet
Vehicle Model	Camaro (Modified - FR HVAC)
Vehicle Year	1999
Vehicle Mass (kg)	1848
Fuel Tank Type	Unknown
Fuel Amount (L)	
Vehicle Condition	Used
Post-Collision	
Ventilation Conditions	Doors closed with windows raised to full closed position, right window glass (passenger door) of the vehicle broken
Number of Target Vehicles	0
Ignition Location	In air cleaner housing in engine compartment
Ignition Source	Nichrome wires wrapped around PP sheet (1.2 kW)
Untenable Conditions (s)	767
Type of Conditions	Flame Penetration
Start of Burn Period (min)	
End of Burn Period (min)	
Burnout	
HRR Curve	08-07-14-HRR.xls
HRR Measuring Method	Oxygen Consumption
Peak HRR (kW)	2973
Time to Peak HRR (min)	12.7
Total Heat Released (MJ)	445
Mass Loss Curve	
Total Mass Loss (kg)	
Interior Heat Flux Curve	08-07-14-FLUX.xls
Interior Temperature Curve	08-07-14-TEMP.xls
Interior CO Curve	08-07-14-XCO.xls

Reference Santrock, J. (2002). "Demonstration of Enhanced Fire Safety Technology-Fire Retardant Materials-Part 1: Full Scale Vehicle Fire Tests of a Control Vehicle and a Test Vehicle Containing FR Chemicals," NHTSA 1998-3588-190, GM Corporation, Warren,


Heat Release Rate (kW)
5000
4000
3000
2000
1000
0
0
5
10
15
20
Time (min)

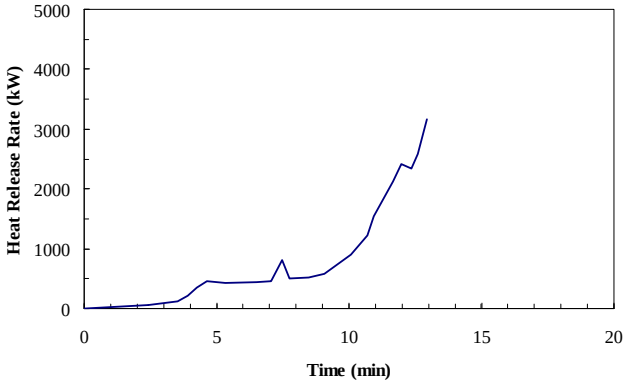

Heat Flux (kW/m²)
25.00
20.00
15.00
10.00
5.00
0.00
Driver Side
Passenger Side
0
5
10
15
20
Time (min)

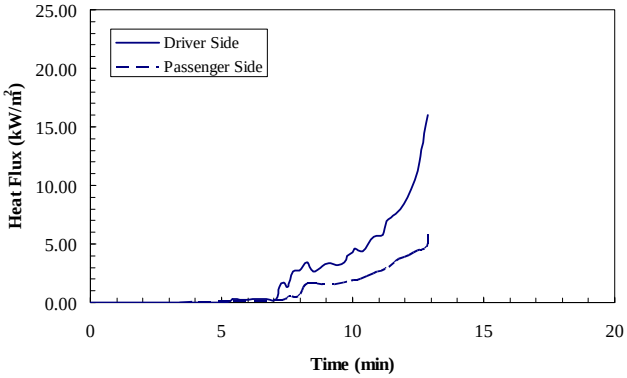

Temperature (°C)
200
150
100
50
0
0
5
10
15
20
Time (min)

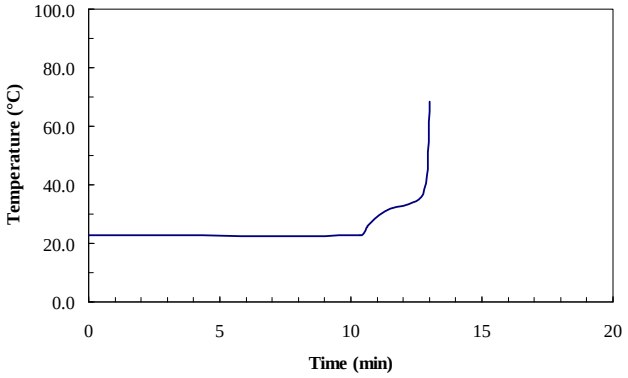

CO Concentration (%)
0.10
0.08
0.06
0.04
0.02
0.00
0
5
10
15
20
Time (min)

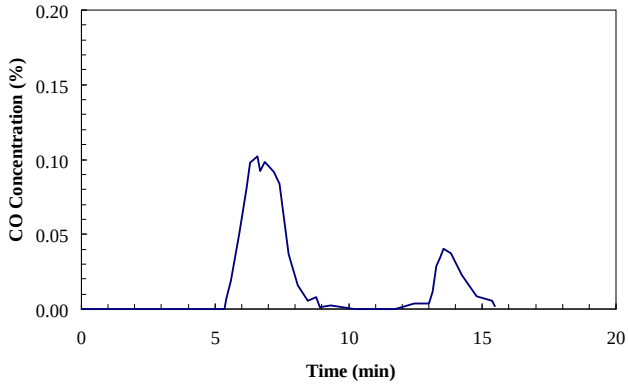
Test Series	8 **Test Number** 8
Lab Name	FM Research Center
City	West Gloucester, RI **Country** USA
Type of Facility	Open Calorimeter
Purpose of Test	Fire Hazard Assessment
Vehicle Make	Chevrolet
Vehicle Model	Camaro
Vehicle Year	1999
Vehicle Mass (kg)	1848
Fuel Tank Type	Unknown
Fuel Amount (L)	
Vehicle Condition	Used
Post-Collision	
Ventilation Conditions	Doors closed with windows raised to full closed position, right window glass (passenger door) of the vehicle broken
Number of Target Vehicles	0
Ignition Location	In air cleaner housing in engine compartment
Ignition Source	Nichrome wires wrapped around PP sheet (1.2 kW)
Untenable Conditions (s)	770
Type of Conditions	Flame Penetration
Start of Burn Period (min)	
End of Burn Period (min)	
Burnout	
HRR Curve	08-08-14-HRR.xls
HRR Measuring Method	Oxygen Consumption
Peak HRR (kW)	3173
Time to Peak HRR (min)	12.9
Total Heat Released (MJ)	540
Mass Loss Curve	
Total Mass Loss (kg)	
Interior Heat Flux Curve	08-08-14-FLUX.xls
Interior Temperature Curve	08-08-14-TEMP.xls
Interior CO Curve	08-08-14-XCO.xls

Reference Santrock, J. (2002). "Demonstration of Enhanced Fire Safety Technology-Fire Retardant Materials-Part 1: Full Scale Vehicle Fire Tests of a Control Vehicle and a Test Vehicle Containing FR Chemicals," NHTSA 1998-3588-190, GM Corporation, Warren,


Heat Release Rate (kW)
5000
4000
3000
2000
1000
0
0
5
10
15
20
Time (min)

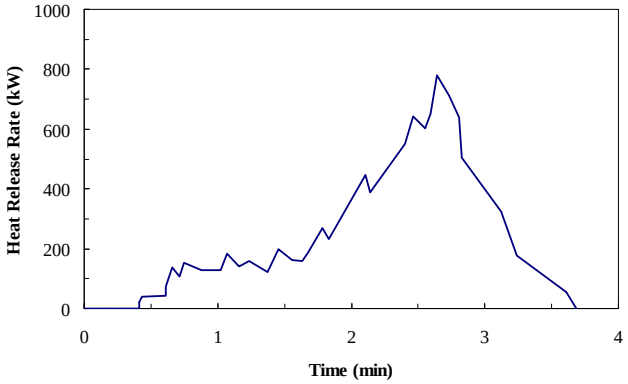

Heat Flux (kW/m²)
25.00
20.00
15.00
10.00
5.00
0.00
Driver Side
Passenger Side
0
5
10
15
20
Time (min)

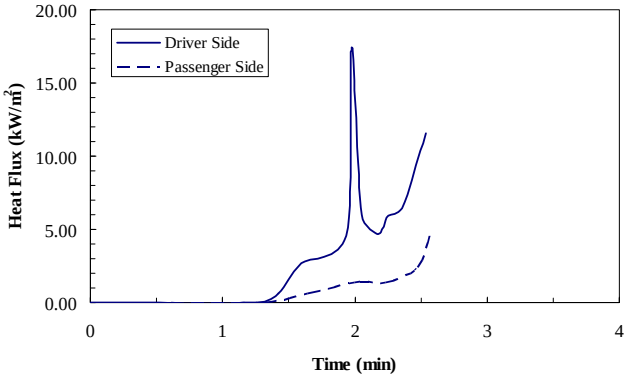

Temperature (°C)
100.0
80.0
60.0
40.0
20.0
0.0
0
5
10
15
20
Time (min)

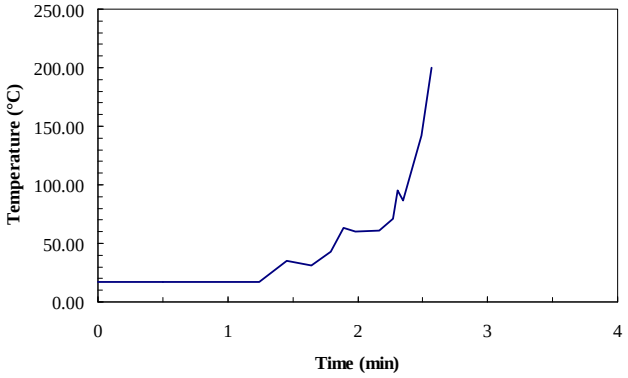

CO Concentration (%)
0.20
0.15
0.10
0.05
0.00
0
5
10
15
20
Time (min)

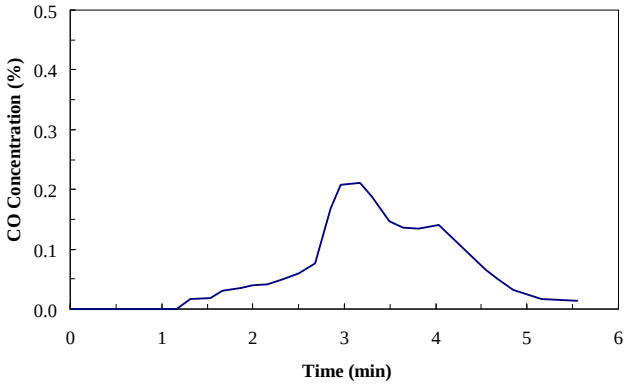
Test Series	8 **Test Number** 9
Lab Name	FM Research Center
City	West Gloucester, RI **Country** USA
Type of Facility	Open Calorimeter
Purpose of Test	Fire Hazard Assessment
Vehicle Make	Honda
Vehicle Model	Accord
Vehicle Year	1998
Vehicle Mass (kg)	1649
Fuel Tank Type	Unknown
Fuel Amount (L)	
Vehicle Condition	Used
Post-Collision	
Ventilation Conditions	All doors closed and front door windows raised, left and right rear door glass broken
Number of Target Vehicles	0
Ignition Location	Under vehicle
Ignition Source	Pool from 400 ML/min fuel tank leak ignited at 35s
Untenable Conditions (s)	83
Type of Conditions	Flame Penetration
Start of Burn Period (min)	
End of Burn Period (min)	
Burnout	
HRR Curve	08-09-15-HRR.xls
HRR Measuring Method	Oxygen Consumption
Peak HRR (kW)	780
Time to Peak HRR (min)	2.6
Total Heat Released (MJ)	1816
Mass Loss Curve	
Total Mass Loss (kg)	
Interior Heat Flux Curve	08-09-15-FLUX.xls
Interior Temperature Curve	08-09-15-TEMP.xls
Interior CO Curve	08-09-15-XCO.xls

Reference Santrock, J. (2003). "Evaluation of Motor Vehicle Fire Initiation and Propagation, Part 12: Propagation of an Underbody Gasoline Pool Fire in a 1998 Front-Wheel Drive Passenger Vehicle," NHTSA 1998-3588-201, General Motors Corporation, Warren, MI.


Heat Release Rate (kW)
1000
800
600
400
200
0
0
1
2
3
4
Time (min)

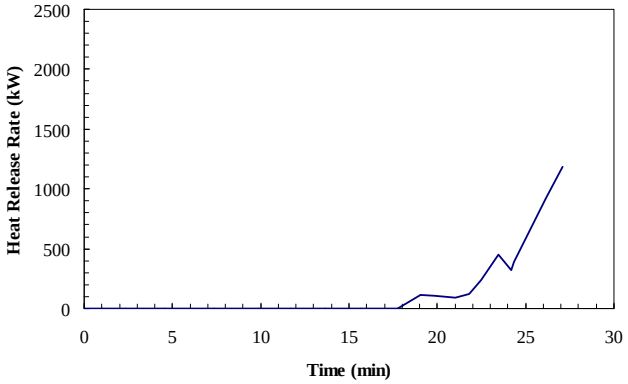

Heat Flux (kW/m²)
20.00
15.00
10.00
5.00
0.00
Driver Side
Passenger Side
0
1
2
3
4
Time (min)

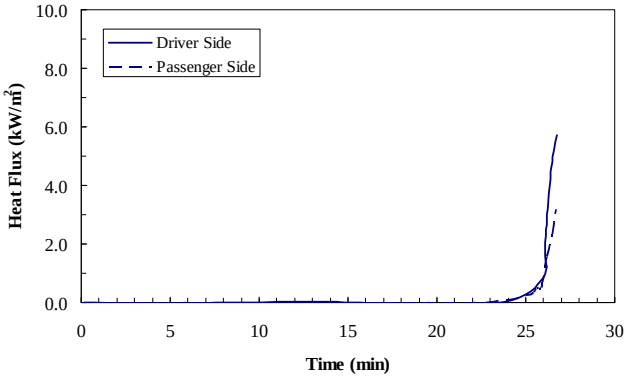

Temperature (°C)
250.00
200.00
150.00
100.00
50.00
0.00
0
1
2
3
4
Time (min)

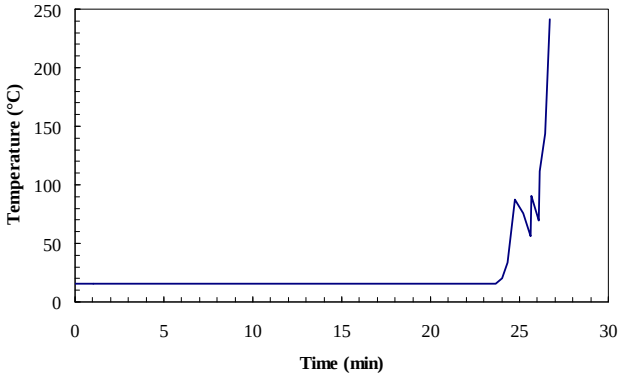

CO Concentration (%)
0.5
0.4
0.3
0.2
0.1
0.0
0
1
2
3
4
5
6
Time (min)

Test Series	8 **Test Number** 10
Lab Name	FM Research Center
City	West Gloucester, RI **Country** USA
Type of Facility	Open Calorimeter
Purpose of Test	Fire Hazard Assessment
Vehicle Make	Honda
Vehicle Model	Accord
Vehicle Year	1998
Vehicle Mass (kg)	1738
Fuel Tank Type	Unknown
Fuel Amount (L)	
Vehicle Condition	Used
Post-Collision	
Ventilation Conditions	Windshield and right front door glass broken
Number of Target Vehicles	0
Ignition Location	Windshield washer fluid reservoir
Ignition Source	Methanol vapor
Untenable Conditions (s)	1560
Type of Conditions	Flame Penetration
Start of Burn Period (min)	
End of Burn Period (min)	
Burnout	
HRR Curve	08-10-16-HRR.xls
HRR Measuring Method	Oxygen Consumption
Peak HRR (kW)	1189
Time to Peak HRR (min)	27.1
Total Heat Released (MJ)	199
Mass Loss Curve	
Total Mass Loss (kg)	
Interior Heat Flux Curve	08-10-16-FLUX.xls
Interior Temperature Curve	08-10-16-TEMP.xls
Interior CO Curve	

Reference Santrock, J. (2003). "Evaluation of Motor Vehicle Fire Initiation and Propagation, Part 13: Propagation of an Engine Compartment Fire in a 1998 Front-Wheel Drive Passenger Vehicle," NHTSA 1998-3588-203, General Motors Corporation, Warren, MI.

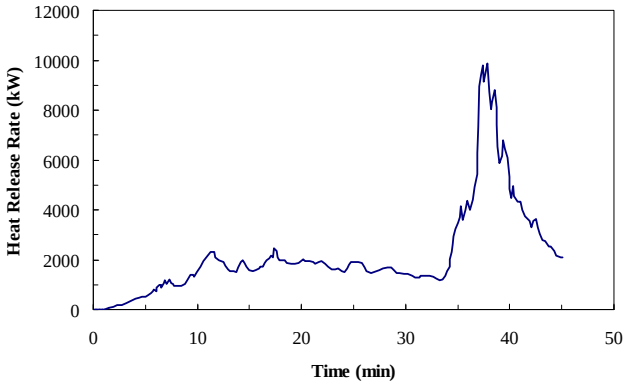

Heat Release Rate (kW)
2500
2000
1500
1000
500
0
0
5
10
15
20
25
30
Time (min)

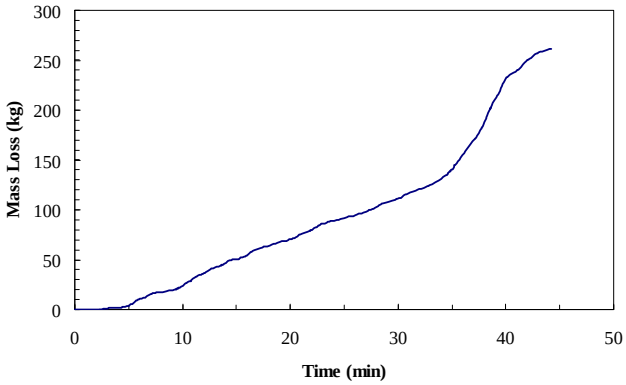

Heat Flux (kW/m²)
10.0
8.0
6.0
4.0
2.0
0.0
Driver Side
Passenger Side
0
5
10
15
20
25
30
Time (min)


Temperature (°C)
250
200
150
100
50
0
0
5
10
15
20
25
30
Time (min)

Test Series	9 **Test Number** 1
Lab Name	CTICM
City	Metz **Country** France
Type of Facility	Corner Calorimeter
Purpose of Test	Fire Engineering
Vehicle Make	Peugeot
Vehicle Model	406 Break
Vehicle Year	1994
Vehicle Mass (kg)	1454
Fuel Tank Type	Unknown
Fuel Amount (L)	40
Vehicle Condition	New
Post-Collision	
Ventilation Conditions	
Number of Target Vehicles	0
Ignition Location	Under gear box
Ignition Source	1.5 L gasoline in open tray
Untenable Conditions (s)	
Type of Conditions	
Start of Burn Period (min)	6.3
End of Burn Period (min)	45.1
Burnout	✓
HRR Curve	09-01-17-HRR.xls
HRR Measuring Method	Oxygen Consumption
Peak HRR (kW)	9854
Time to Peak HRR (min)	37.8
Total Heat Released (MJ)	6806
Mass Loss Curve	09-01-17-ML.xls
Total Mass Loss (kg)	262
Interior Heat Flux Curve	
Interior Temperature Curve	
Interior CO Curve	

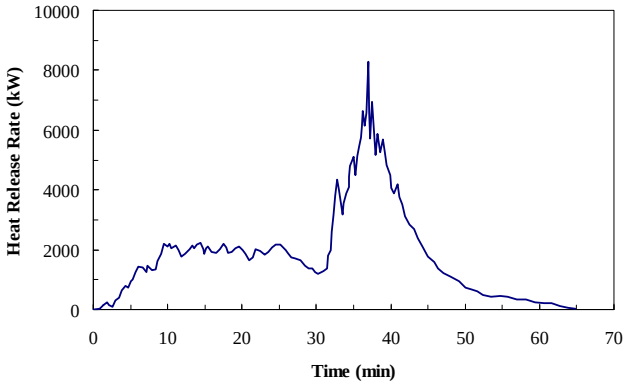
Reference Joyeux, D., Kruppa, J., Cajot, L., Schleich, J., Van de Leur, P., and Twilt, L. (2002). "Demonstration of Real Fire Tests in Car Parks and High Buildings," Final Report, Contract No. 7215 PP 025, CTICM, Metz, France.

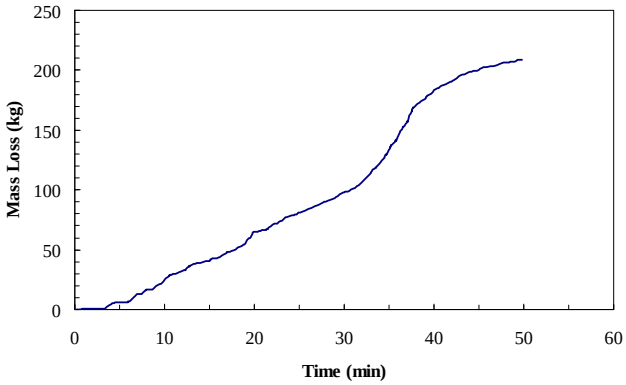

Heat Release Rate (kW)
12000
10000
8000
6000
4000
2000
0
0
10
20
30
40
50
Time (min)


Mass Loss (kg)
300
250
200
150
100
50
0
0
10
20
30
40
50
Time (min)

Test Series	9 **Test Number** 2
Lab Name	CTICM
City	Metz **Country** France
Type of Facility	Corner Calorimeter
Purpose of Test	Fire Engineering
Vehicle Make	Peugeot
Vehicle Model	406 Berline
Vehicle Year	1994
Vehicle Mass (kg)	1382
Fuel Tank Type	Unknown
Fuel Amount (L)	41
Vehicle Condition	New
Post-Collision	
Ventilation Conditions	
Number of Target Vehicles	0
Ignition Location	Under gear box
Ignition Source	1.5 L gasoline in open tray
Untenable Conditions (s)	
Type of Conditions	
Start of Burn Period (min)	4.9
End of Burn Period (min)	49.6
Burnout	✓
HRR Curve	09-02-17-HRR.xls
HRR Measuring Method	Oxygen Consumption
Peak HRR (kW)	8283
Time to Peak HRR (min)	36.9
Total Heat Released (MJ)	7000
Mass Loss Curve	09-02-17-ML.xls
Total Mass Loss (kg)	255
Interior Heat Flux Curve	
Interior Temperature Curve	
Interior CO Curve	

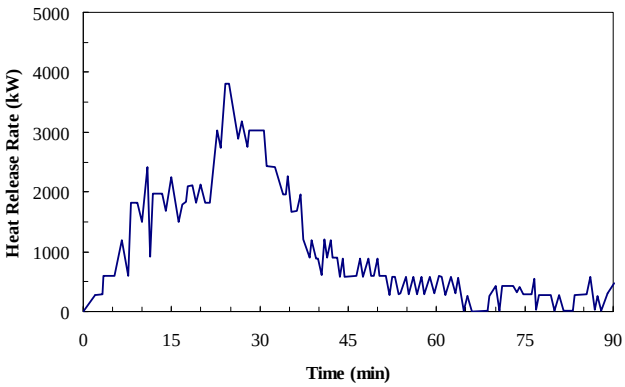
Reference Joyeux, D., Kruppa, J., Cajot, L., Schleich, J., Van de Leur, P., and Twilt, L. (2002). "Demonstration of Real Fire Tests in Car Parks and High Buildings," Final Report, Contract No. 7215 PP 025, CTICM, Metz, France.


Heat Release Rate (kW)
10000
8000
6000
4000
2000
0
0
10
20
30
40
50
60
70
Time (min)


Mass Loss (kg)
250
200
150
100
50
0
0
10
20
30
40
50
60
Time (min)

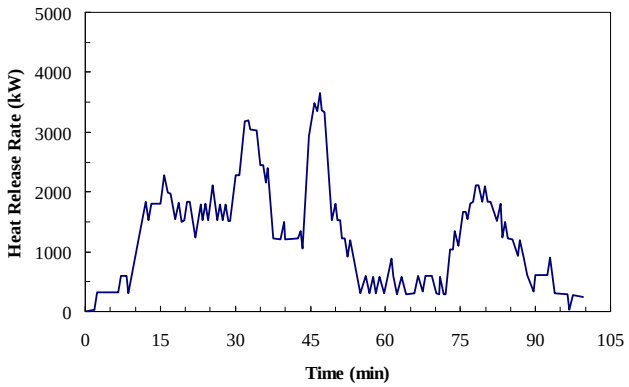
Test Series	10 **Test Number** 2
Lab Name	BRI
City	Tsukuba **Country** Japan
Type of Facility	Open Calorimeter
Purpose of Test	Fire Engineering
Vehicle Make	Unknown
Vehicle Model	Unknown
Vehicle Year	
Vehicle Mass (kg)	1182
Fuel Tank Type	Unknown
Fuel Amount (L)	
Vehicle Condition	Used
Post-Collision	
Ventilation Conditions	Driver and passenger windows rolled down 10 cm
Number of Target Vehicles	0
Ignition Location	Driver's seat
Ignition Source	Cloth soaked with methanol
Untenable Conditions (s)	
Type of Conditions	
Start of Burn Period (min)	3.4
End of Burn Period (min)	51.8
Burnout	✓
HRR Curve	10-02-18-HRR.xls
HRR Measuring Method	Mass Loss
Peak HRR (kW)	3801
Time to Peak HRR (min)	24.1
Total Heat Released (MJ)	5280
Mass Loss Curve	
Total Mass Loss (kg)	165
Interior Heat Flux Curve	
Interior Temperature Curve	
Interior CO Curve	

Reference Shintani, Y., Kakae, N., Harada, K., Masuda, H., Takahashi, W. (2004)."Experimental Investigation of Burning Behavior of Automobiles," 6th Asia-Oceania Symposium on Fire Science and Technology, pp. 618-629.


Heat Release Rate (kW)
5000
4000
3000
2000
1000
0
0
15
30
45
60
75
90
Time (min)

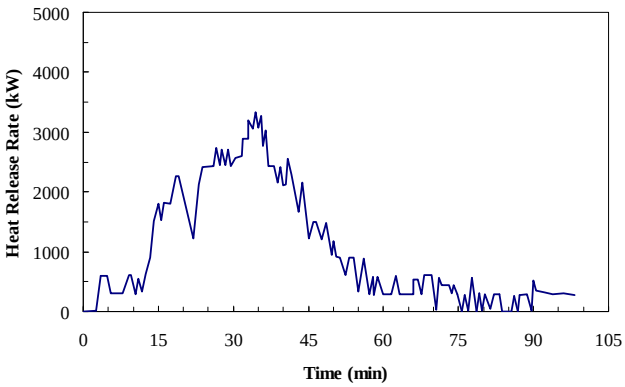
Test Series	10 **Test Number** 3
Lab Name	BRI
City	Tsukuba **Country** Japan
Type of Facility	Open Calorimeter
Purpose of Test	Fire Engineering
Vehicle Make	Unknown
Vehicle Model	Unknown
Vehicle Year	
Vehicle Mass (kg)	1470
Fuel Tank Type	Unknown
Fuel Amount (L)	
Vehicle Condition	Used
Post-Collision	
Ventilation Conditions	Driver and passenger windows rolled down 10 cm
Number of Target Vehicles	0
Ignition Location	Driver's seat
Ignition Source	Cloth soaked with methanol
Untenable Conditions (s)	
Type of Conditions	
Start of Burn Period (min)	8.8
End of Burn Period (min)	89.4
Burnout	✓
HRR Curve	10-03-18-HRR.xls
HRR Measuring Method	Mass Loss
Peak HRR (kW)	3650
Time to Peak HRR (min)	46.9
Total Heat Released (MJ)	5280
Mass Loss Curve	
Total Mass Loss (kg)	186
Interior Heat Flux Curve	
Interior Temperature Curve	
Interior CO Curve	

Reference Shintani, Y., Kakae, N., Harada, K., Masuda, H., Takahashi, W. (2004)."Experimental Investigation of Burning Behavior of Automobiles," 6th Asia-Oceania Symposium on Fire Science and Technology, pp. 618-629.


Heat Release Rate (kW)
5000
4000
3000
2000
1000
0
0
15
30
45
60
75
90
105
Time (min)

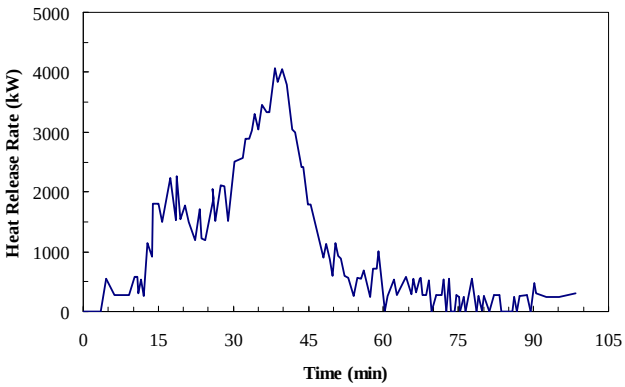
Test Series	10 **Test Number** 4
Lab Name	BRI
City	Tsukuba **Country** Japan
Type of Facility	Open Calorimeter
Purpose of Test	Fire Engineering
Vehicle Make	Unknown
Vehicle Model	Unknown
Vehicle Year	
Vehicle Mass (kg)	1920
Fuel Tank Type	Unknown
Fuel Amount (L)	
Vehicle Condition	Used
Post-Collision	
Ventilation Conditions	Driver and passenger windows rolled down 10 cm
Number of Target Vehicles	0
Ignition Location	Driver's seat
Ignition Source	Cloth soaked with methanol
Untenable Conditions (s)	
Type of Conditions	
Start of Burn Period (min)	8.1
End of Burn Period (min)	55
Burnout	✓
HRR Curve	10-04-18-HRR.xls
HRR Measuring Method	Mass Loss
Peak HRR (kW)	3332
Time to Peak HRR (min)	34.4
Total Heat Released (MJ)	7648
Mass Loss Curve	
Total Mass Loss (kg)	239
Interior Heat Flux Curve	
Interior Temperature Curve	
Interior CO Curve	

Reference Shintani, Y., Kakae, N., Harada, K., Masuda, H., Takahashi, W. (2004)."Experimental Investigation of Burning Behavior of Automobiles," 6th Asia-Oceania Symposium on Fire Science and Technology, pp. 618-629.


Heat Release Rate (kW)
5000
4000
3000
2000
1000
0
0
15
30
45
60
75
90
105
Time (min)

Test Series	10 **Test Number** 5
Lab Name	BRI
City	Tsukuba **Country** Japan
Type of Facility	Open Calorimeter
Purpose of Test	Fire Engineering
Vehicle Make	Unknown
Vehicle Model	Unknown
Vehicle Year	
Vehicle Mass (kg)	1380
Fuel Tank Type	Unknown
Fuel Amount (L)	
Vehicle Condition	Used
Post-Collision	
Ventilation Conditions	Driver and passenger windows rolled down 10 cm
Number of Target Vehicles	0
Ignition Location	Driver's seat
Ignition Source	Cloth soaked with methanol
Untenable Conditions (s)	
Type of Conditions	
Start of Burn Period (min)	12.2
End of Burn Period (min)	59.7
Burnout	✓
HRR Curve	10-05-18-HRR.xls
HRR Measuring Method	Mass Loss
Peak HRR (kW)	4073
Time to Peak HRR (min)	38.3
Total Heat Released (MJ)	6144
Mass Loss Curve	
Total Mass Loss (kg)	192
Interior Heat Flux Curve	
Interior Temperature Curve	
Interior CO Curve	

Reference Shintani, Y., Kakae, N., Harada, K., Masuda, H., Takahashi, W. (2004)."Experimental Investigation of Burning Behavior of Automobiles," 6th Asia-Oceania Symposium on Fire Science and Technology, pp. 618-629.


Heat Release Rate (kW)
5000
4000
3000
2000
1000
0
0
15
30
45
60
75
90
105
Time (min)

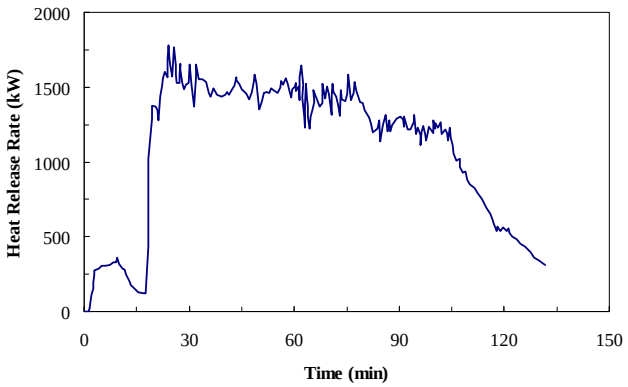
Test Series	11	**Test Number**	1

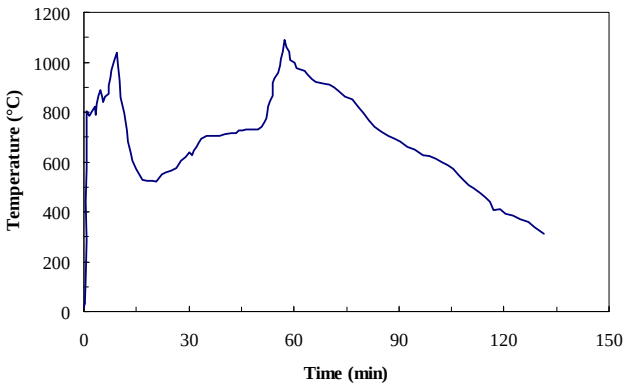
Lab Name	CTICM		
City	Metz	**Country**	France

Type of Facility	Room Calorimeter
Purpose of Test	Fire Engineering
Vehicle Make	Citroen
Vehicle Model	BX
Vehicle Year	1989
Vehicle Mass (kg)	874
Fuel Tank Type	Unknown
Fuel Amount (L)	40
Vehicle Condition	Used
Post-Collision	
Ventilation Conditions	Passenger front window open, all other windows closed

Number of Target Vehicles	1
Ignition Location	Under driver's seat
Ignition Source	1.5 L gasoline in open tray
Untenable Conditions (s)	
Type of Conditions	
Start of Burn Period (min)	17.7
End of Burn Period (min)	131.6
Burnout	✓
HRR Curve	11-01-19-HRR.xls
HRR Measuring Method	Oxygen Consumption
Peak HRR (kW)	1780
Time to Peak HRR (min)	24
Total Heat Released (MJ)	8500
Mass Loss Curve	
Total Mass Loss (kg)	
Interior Heat Flux Curve	
Interior Temperature Curve	11-01-19-TEMP.xls
Interior CO Curve	

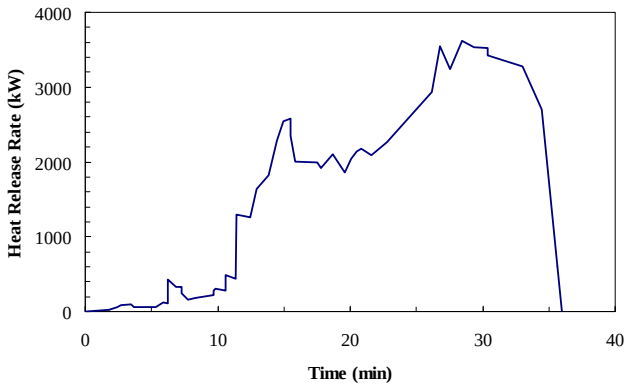
Reference Anonymous (2004)."CTICM Fire Tests on Cars," CITCM, Metz, France.


Heat Release Rate (kW)
2000
1500
1000
500
0
0
30
60
90
120
150
Time (min)


Temperature (°C)
1200
1000
800
600
400
200
0
0
30
60
90
120
150
Time (min)

Test Series	12	**Test Number**	1
Lab Name	SP		
City	Borås	**Country**	Sweden
Type of Facility	Open Calorimeter		
Purpose of Test	Fire Engineering		
Vehicle Make	Unknown		
Vehicle Model	Unknown		
Vehicle Year	1998		
Vehicle Mass (kg)			
Fuel Tank Type	Unknown		
Fuel Amount (L)	0		
Vehicle Condition	Used		
Post-Collision			
Ventilation Conditions			
Number of Target Vehicles	0		
Ignition Location	On driver's seat and right rear passenger seat		
Ignition Source	0.21 L of mineral spirits		
Untenable Conditions (s)			
Type of Conditions			
Start of Burn Period (min)	10.6		
End of Burn Period (min)	35.8		
Burnout	✓		
HRR Curve	12-01-20-HRR.xls		
HRR Measuring Method	Oxygen Consumption		
Peak HRR (kW)	3618		
Time to Peak HRR (min)	28.4		
Total Heat Released (MJ)	3800		
Mass Loss Curve			
Total Mass Loss (kg)			
Interior Heat Flux Curve			
Interior Temperature Curve			
Interior CO Curve			

Reference Lönnermark, A. and Blomqvist, P. (2006)."Emissions from an Automobile Fire," Chemosphere, Vol. 62, pp. 1043-1056.


Heat Release Rate (kW)
4000
3000
2000
1000
0
0
10
20
30
40
Time (min)

APPENDIX B

PHOTOGRAPHS FROM TESTS PERFORMED AT THE BUILDING RESEARCH INSTITUTE OF JAPAN (BRI)

(Consisting of 9 Pages)

Compact Sedan

550 cc

Ignition

5 min

5 min

10 min

10 min

50 min

End

Mid-Size Sedan

2000 cc

Ignition

20 min

20 min

30 min

30 min

80 min

End

Mid-Size Sedan

2000 cc

Ignition

20 min

20 min

30 min

30 min

80 min


End

Large Sedan

3000 cc

Ignition

30 min

30 min

40 min

40 min

80 min

End

Large Sedan

3000 cc

Ignition

20 min

20 min

40 min


40 min

60 min

End

Luxury Sedan

5800 cc

Ignition

70 min

70 min

90 min

90 min

140 min

End

Sport Utility Vehicle

3000 cc

Ignition

20 min

20 min

40 min

40 min

70 min

End

Sport Utility Vehicle

3000 cc

Ignition

20 min

20 min

50 min

50 min

80 min

End

Minivan

3000 cc

Ignition

10 min

10 min

20 min

20 min

50 min

End