COMPARISON OF FIRE PROPERTIES OF AUTOMOTIVE MATERIALS

October 29, 2003

Authors:
Karen C. Battipaglia
A. Leigh Griffith, M.S.
Jason P. Huczek, M.S.
Marc L. Janssens, Ph.D.
Keith R. Willson, Ph.D.

OUTLINE (1 of 3)

- Background
  - CK Pickup Settlement Research
  - NHTSA Project
- Selection of Test Methodology
  - Literature Survey
  - Review of Full-Scale Automotive Fire Tests
  - Fire and Thermal Properties of Materials
  - Candidate Test Methods

OUTLINE (2 of 3)

- Automotive Component Fire Tests
  - Selection of Materials
  - Material Characterization
  - Small-Scale Fire Tests
    - FMVSS 302 Tests
    - Cone Calorimeter Tests
      - Additional Toxic Gas Measurements
    - Smoke and Toxicity Tests
  - Intermediate-Scale Tests (ICAL)
  - Alternative Materials

OUTLINE (3 of 3)

- Data Analysis
  - Introduction
  - Test Methodology
  - Levels of Performance
  - Analysis of Supplemental Smoke Toxicity Measurements and Tests
  - Alternative Materials
- Conclusions & Recommendations
- Acknowledgments
- Questions

BACKGROUND
CK Pickup Truck Settlement Research

- GM agreed to spend $50M on fire research between 1995 and 2000
- Reports can be downloaded from NHTSA web site (http://www.nhtsa.gov, docket #3855)
- Highlights
  - Eight full-scale car burn tests were conducted at FM
  - FM and NIST performed small and intermediate-scale tests on materials and components from 4 models tested at FM
  - SwRI tested primarily interior materials of 4 different models and obtained thermal physical properties and flammability data

BACKGROUND
NHTSA Research Project

- Initiated in July of 2002
- Completed in October 2003
- Objectives
  - Identify or develop a small-scale test method to rate automotive materials consistent with actual fire performance
  - Establish levels of performance for this test method that would significantly alter fire outcome in terms of injury or survivability
- New method pertains to “interior” and “exterior” materials
- Project builds on earlier research performed as a result of CK pickup truck settlement between GM and NHTSA

SELECTION OF TEST METHODOLOGY
Overview

- Literature Survey
  - Fire Statistics, Relevant publications
- Review of Full-Scale Automotive Fire Tests
  - GM reports, Relevant publications
- Fire and Thermal Properties of Materials
  - Taken from NIST and FM publications
- Candidate Test Methods
  - Small Flame Exposure vs. Radiant Exposure

SELECTION OF TEST METHODOLOGY
Literature Survey

- Fire statistics were updated and reviewed
- An extensive literature survey was conducted to determine appropriate test conditions
  - Reviewed fire statistics, full-scale car burn tests, small-scale tests on automotive materials, other modes of transportation
  - Decided to run tests at 20, 35, and 50 kW/m²

SELECTION OF TEST METHODOLOGY
US Automobile Fire Statistics (NFPA)

Period	Fires	Deaths	Injuries	Direct Loss ($M)
1989-1993	321,570	416	2,130	600.0
1990-1994	313,560	406	2,021	606.2
1991-1995	308,760	368	1,830	607.3
1992-1996	298,570	369	1,658	603.8
1993-1997	302,210	343	1,570	645.6
1994-1998	295,170	330	1,430	692.6

SELECTION OF TEST METHODOLOGY
Percentage of Total Fire Statistics (NFPA)

Period	Fires	Deaths	Injuries	Direct Loss
1989-1993	15.9%	8.5%	7.3%	7.0%
1990-1994	15.6%	8.7%	7.0%	7.2%
1991-1995	15.5%	8.1%	6.5%	7.0%
1992-1996	15.1%	7.9%	6.0%	7.0%
1993-1997	15.5%	7.6%	5.9%	7.4%
1994-1998	15.5%	7.5%	5.6%	7.9%

SELECTION OF TEST METHODOLOGY
Summary of Statistics

- Most automobile fire fatalities occur after a collision
- Two distinct scenarios
  - Rear-end collisions resulting in fuel tank rupture and liquid pool fire beneath the vehicle
  - Front-end collisions resulting in a fire originating in the engine compartment
- Material flammability requirements affect primarily the number of fatalities associated with the second scenario
- Federal requirements pertain to “interior” materials and are based on performance in the FMVSS 302 test

SELECTION OF TEST METHODOLOGY Review of Full-Scale Automotive Fire Tests (1 of 2)

- GM Report of Dodge Caravan – Ignition originated in engine compartment
- GM Report of Chevrolet Camaro – Ignition originated in engine compartment
- Summary
  - Between 10 and 15 min. from sustained flaming ignition, flames had spread from engine compartment into passenger compartment

SELECTION OF TEST METHODOLOGY Review of Full-Scale Automotive Fire Tests (2 of 2)

- GM Report of Chevrolet Camaro with and without FR treated HVAC unit – Ignition originated in engine compartment
- Summary
  - Time to flame spread into passenger compartment, effectively unchanged between control and FR vehicle
  - CO concentration peaked at ~ 1000 ppm, measured in passenger compartment at the driver headrest
- Bottom Line
  - In all tests, flame spread into the passenger compartment occurred before conditions became untenable due to temperature and toxicity. In these tests, the heat release recorded at this time was approximately 400 kW. This can be viewed as a critical fire size.

SELECTION OF TEST METHODOLOGY
Fire and Thermal Properties (1 of 3)

Part Description	δ (mm)	ρ_v x10^{-3}(kg/m^3)	c_v (kj/kg-K)	k_v x10^9(kW/m-K)	kρc	α_v (mm^2/s)	T_{ig} (°C)
Battery Cover	5	0.90	2.216	0.20	1.92	0.10	443
Resonator Structure	5	1.06	2.082	0.20	2.70	0.09	374
Resonator Intake Tube	6	1.15	1.745	0.22	2.70	0.11	374
Air Ducts	5	1.04	1.934	0.20	4.25	0.10	443
Brake Fluid Reservoir	20	0.90	2.247	0.20	ND	0.10	ND
Kick Panel Insulation	5	1.95	1.141	0.21	7.78	0.09	374
Headlight Assembly (Clear)	5	1.19	2.061	0.20	4.10	0.08	497
Headlight Assembly (Black)	5	1.19	2.061	0.20	4.10	0.08	497
Fender Sound Reduction Foam	16	0.13	1.624	0.16	74.42	0.76	497
Hood Liner Face	25	0.66	1.319	0.15	16.33	0.17	374
Windshield Wiper Structure	5	1.64	1.140	0.75	1.52	0.40	497

From FM Paper, "A Study of the Flammability of Plastics in Vehicle Components and Parts" (Dodge Caravan)

SELECTION OF TEST METHODOLOGY
Fire and Thermal Properties (2 of 3)

Part Description	T_d (°C)	CHF (kW/m^2) Measured	CHF (kW/m^2) Calculated	TRP Measured	TRP Calculated	FPI	Y_s
Battery Cover	423	15	13	454	342	12	0.071
Resonator Structure	430	10	13	277	241	14	0.072
Resonator Intake Tube	430	10	13	277	241	ND*	0.100
Air Ducts	ND	15	15	333	230	11	0.080
Brake Fluid Reservoir	ND	ND	ND	ND	ND	ND	0.082
Kick Panel Insulation	255	10	7	215	142	18	0.070
Headlight Assembly (Clear)	445	20	23	434	264	9	0.113
Headlight Assembly (Black)	445	20	23	434	264	9	0.113
Fender Sound Reduction Foam	401	20	20	146	62	27	0.098
Hood Liner Face	325	10	6	174	98	23	0.022
Windshield Wiper Structure	414	20	20	483	434	8	0.100

*** ND = Not Defined**

From FM Paper, "A Study of the Flammability of Plastics in Vehicle Components and Parts" (Dodge Caravan)

SELECTION OF TEST METHODOLOGY
Fire and Thermal Properties (3 of 3)

Part Description	ρ_v ?× 10^{-3} (kg/m^3)	T_m (°C)	T_g (°C)	T_d (°C)
Front Wheel Well Liner	0.88	123, 164	ND	282
Air Inlet	0.89	119, 156	24	352
Hood Insulator	0.08	Amorphous	36	336
Radiator Inlet/Outlet Tank	1.18	261	102	430
Engine Cooling Fan	1.44	219	40	430
Power Steering Fluid Reservoir	1.4	261	35	425
Blower Motor Housing	1.22	159	ND	295

From FM Paper, "Thermal Properties of Automotive Polymers, IV - Parts of a Camaro "

SELECTION OF TEST METHODOLOGY
Candidate Test Methods (1 of 3)

- Candidate test methods were explored
  - Small flame exposure tests
    - FMVSS 302, FAR 25.853, ASTM C1166, UL 94, ASTM D2859, ASTM D635, ASTM D568, ASTM D2863, GM 269M…
  - Radiant panel tests
    - ASTM E906, ASTM E662 (with or w/o toxicity), ASTM E1995, ASTM E648, ASTM E162, ASTM D3675, ASTM E1317, ASTM E2058, ASTM E1354…
- Cone calorimeter was selected as the method of choice

SELECTION OF TEST METHODOLOGY
Candidate Test Methods (2 of 3)

	Advantages	Disadvantages
All "Small Flame Exposure" Tests	Inexpensive screening tool that could be used as a method to separate the average material from the subpar material in terms of flammability.	Does not reflect a "real" fire scenario. The heat exposure is too limited and can yield false positives for various materials.
ASTM E 906	Yields a material's heat release rate from a radiant heat exposure. This method is more representative of a real fire scenario.	This method measures heat release rate by way of a thermopile. This method of measurement is obsolete. It would be more relevant if oxygen consumption calorimetry were used.
ASTM E 662	Provides a standard way to measure the optical density of the smoke produced by a burning material. Can be used effectively as a ranking tool.	Data collected in this test are only relevant to this particular test method; they cannot be extrapolated to the material outside the geometry of the test method. In addition, the static state of the test method may influence the burning rate of the material, *i.e.*, the buildup of smoke in the test chamber may affect the rate at which a material burns.
ASTM E 648	Provides a standard way to measure the flame spread of a burning floor covering. Can be used effectively as a ranking tool.	The data collected in this test are only relevant to this particular test method and its geometry. It does not address how a floor covering might burn and spread flame in full scale when it occurs in the same direction as the surrounding air flow.
ASTM E 162	Provides a standard way to measure the flame spread of a burning wall or ceiling covering. Can be used effectively as a ranking tool.	The data collected in this test are only relevant to this particular test method and its geometry. It does not address how a wall or ceiling covering might burn and spread flame in full-scale.

SELECTION OF TEST METHODOLOGY
Candidate Test Methods (3 of 3)

	Advantages	Disadvantages
ASTM D 3675	Provides a standard way to measure the flame spread of a burning seat cushion (flexible cellular material). Can be used effectively as a ranking tool.	The data collected in this test are only relevant to this particular test method and its geometry. It does not address how a seat cushion might burn and spread flame in full-scale.
ASTM E 1317	Provides a standard way to measure the flame spread of a burning wall or ceiling covering. Can be used effectively as a ranking tool.	The data collected in this test are only relevant to this particular test method and its geometry. This method measures heat release rate by way of a thermopile. This method of measurement is obsolete.
ASTM E 2058	Can be operated at a wide range of heat fluxes and oxygen concentrations, which can be varied to simulate various relevant fire scenarios. This test method yields relevant engineering data such as heat release rate, mass loss rate, effective heat of combustion, *etc*., which can be used as input to fire models as part of a fire risk and hazard assessment.	Due to the use of high-temperature heating lamps, the specimens are required to be blackened, which can influence test results. The gas pilot flame used is not ALWAYS the best method for igniting pyrolyzates. This test apparatus can require significant maintenance in the way of calibration of instrumentation and various troubleshooting that is inherent with sophisticated apparatuses. Has not been used for any regulatory purpose as of yet.
ASTM E 1354	Can be operated at a wide range of heat fluxes, which can be varied to simulate various relevant fire scenarios. This test method yields relevant engineering data such as heat release rate, mass loss rate, effective heat of combustion, *etc*., which can be used as input to fire models as part of a fire risk and hazard assessment.	The flow field over the sample surface complicates the analysis of ignition data. This test apparatus can require significant maintenance in the way of calibration of instrumentation and various troubleshooting that is inherent with sophisticated apparatuses.

AUTOMOTIVE COMPONENT FIRE TESTS
Overview

- Selected 18 exterior components from two models previously tested in full-scale at the FM Test Center
  - 1997 Chevrolet Camaro (8)
  - 1996 Dodge Caravan (10)
- Additional set of “improved” materials
- Four types of experiments on materials
  - DSC
  - FMVSS 302 Testing
  - Cone calorimetry at 20, 35, and 50 kW/m²
    - Additional Toxic Gas Measurements
  - Smoke and Toxicity Tests
  - Intermediate-scale calorimetry at 20, 35, and 50 kW/m²

AUTOMOTIVE COMPONENT FIRE TESTS
Material Selection

- Materials were selected on the basis of having been previously tested by FM or NIST as part of the GM Pickup Settlement

Vehicle	Part ID	Part Number
1996 Dodge Caravan	Battery Cover	5235267AB
	Resonator Structure	4861057
	Resonator Intake Tube	53030508
	Air Ducts	4678345
	Break Fluid Reservoir	4683264
	Kick Panel Insulation	4860446
	Headlight Assembly	4857041A
	Fender Sound Reduction Foam	4716345B
	Hood Liner Face	4716832B
	Windshield Wiper Structure	4716051
1997 Chevrolet Camaro	Front Wheel Well Liner	10296526
	Air Inlet	10297291
	Hood Insulator	10278015
	Radiator Inlet/Outlet Tank	52465337
	Engine Cooling Fan	22098787
	Power Steering Fluid Reservoir	26019594
	Windshield with Laminate	10310333
	Blower Motor Housing	52458965

AUTOMOTIVE COMPONENT FIRE TESTS
Material Characterization (1 of 3)

- Objectives
  - Correlate the microscopic properties of the selected component materials, as determined by thermal analysis, with the measured flammability behavior of the selected materials as determined by laboratory- and component-scale comparative methods.
  - Specifically, determine the relationship between the microscopic thermal behavior of the selected polymeric materials and the time to ignition that transpired under radiant heat flux for macroscopic quantities of the same material.
  - In this context, the latent heats of endothermic phase transitions and exothermic heats of reaction of the material measured microscopically provided a bridge to the pre-ignition behavior of material flammability tests.

AUTOMOTIVE COMPONENT FIRE TESTS
Material Characterization (2 of 3)

MDSC Thermal Measurements of Component Materials from the Dodge Caravan

Description	Base Polymer Composition	Endothermic Melt Transition 1 (°C)	Endothermic Heat of Fusion 1 (J/g)	Endothermic Melt Transition 2 (°C)	Endothermic Heat of Fusion 2	Exotherm (°C)	Exothermic Heat of Reaction (J/g)
Battery Cover	Polyethylene	128.25	235.3	NA	NA	NA	NA
Brake Fluid Reservoir	Polypropylene	167.89	137.5	NA	NA	NA	NA
Wiper Structure	SMC/Polyester	77.25	60.98	NA	NA	50.19	11.95
Resonator Intake Tube	Polypropylene/EPDM	161.21	60.61	NA	NA	68.29	2.738
Resonator Structure	Polypropylene	166.64	88.27	NA	NA	NA	NA
Headlight Structure, Black	Polycarbonate	143.37	NA	NA	NA	NA	NA
Headlight Structure, Clear	Polycarbonate	143.26	NA	NA	NA	NA	NA

AUTOMOTIVE COMPONENT FIRE TESTS
Material Characterization (3 of 3)

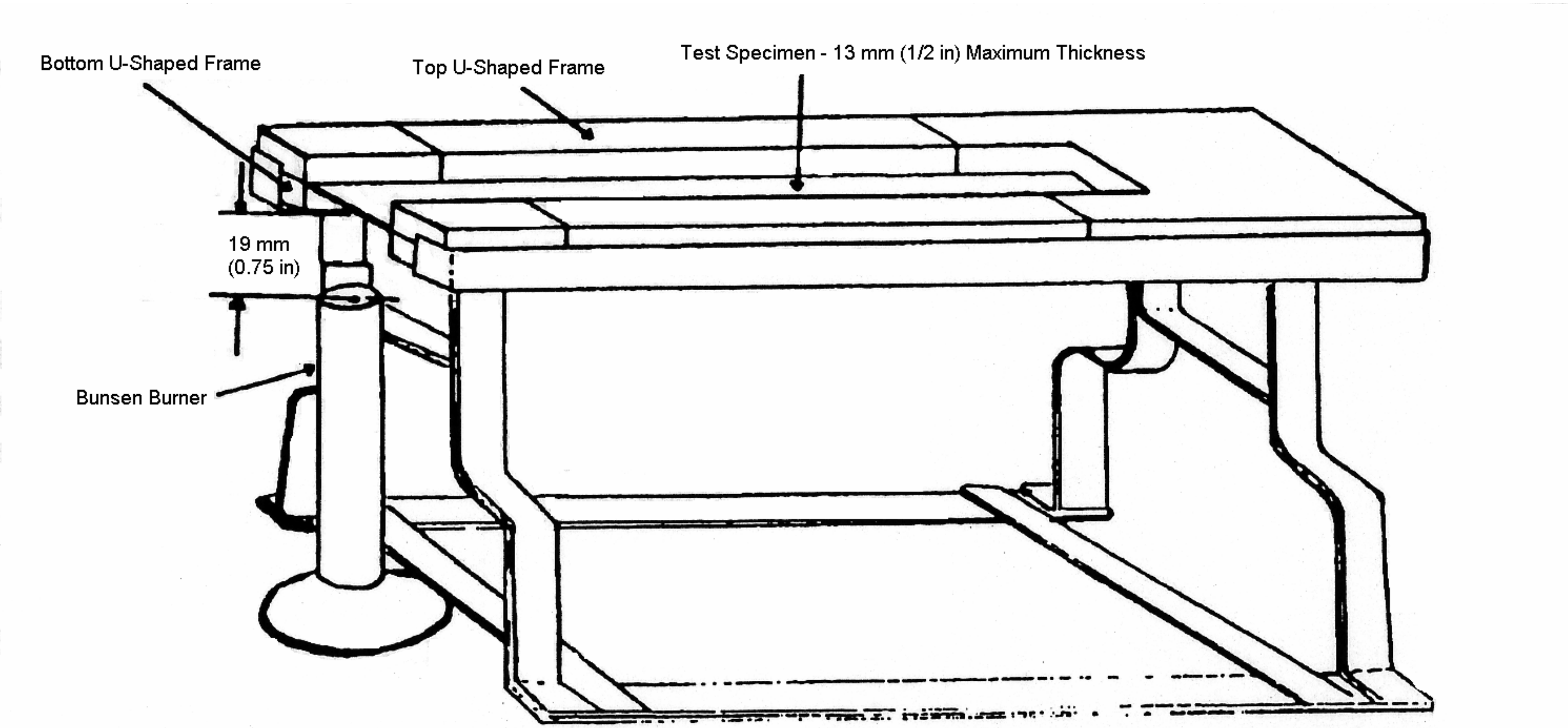
MDSC Thermal Measurements of Component Materials from the Chevrolet Camaro

Description	Base Polymer Composition	Endothermic Melt Transition 1 (°C)	Endothermic Heat of Fusion 1 (J/g)	Endothermic Melt Transition 2 (°C)	Endothermic Heat of Fusion 2	Exotherm (°C)	Exothermic Heat of Reaction (J/g)
Radiator Cooling Fan	Nylon 6	59.79	1.283	221.37	54.08	NA	NA
›wer Steering Reservoir	Nylon 6/6	265.3	55.94	NA	NA	NA	NA
diator Inlet/Outlet Tank	Nylon 6/6	264.82	59.19	NA	NA	NA	NA
Air Inlet	Polyethylene/Polypropylene	113.16	10.58	168.39	64.84	234.34	6.559
ront Wheel Well Liner	Polypropylene	168.46	88.39	NA	NA	240.29	7
lower Motor Housing	Polypropylene	166.74	101	NA	NA	249.09	NA

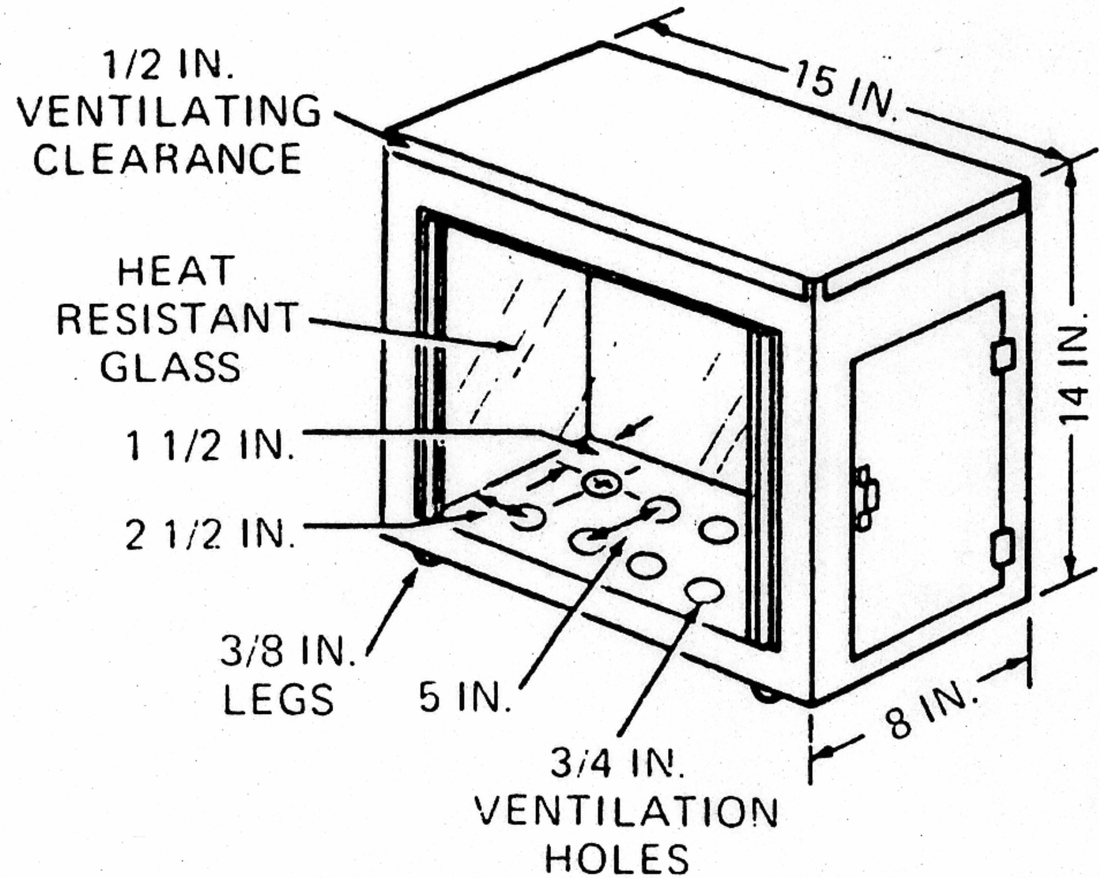
AUTOMOTIVE COMPONENT FIRE TESTS FMVSS 302 Test (1 of 5)

- In effect since 1972
- Materials are tested if any portion of the material is within ½ in. of the passenger compartment air space
- Specimens measure 4 x 14 in. with thickness ≤ ½ in.
- Horizontal specimen is exposed at one end to 1½ in. Bunsen burner flame for 15 s
- Flame travel rate is measured based on the time needed to propagate over 10 in. starting 1 ½ in. from the flame
- Material passes if flame travel rate for five replicates does not exceed 4 in./min

AUTOMOTIVE COMPONENT FIRE TESTS
FMVSS 302 Test (2 of 5)



AUTOMOTIVE COMPONENT FIRE TESTS
FMVSS 302 Test (3 of 5)



AUTOMOTIVE COMPONENT FIRE TESTS
FMVSS 302 Test (4 of 5)

Summary of Test Results - Caravan

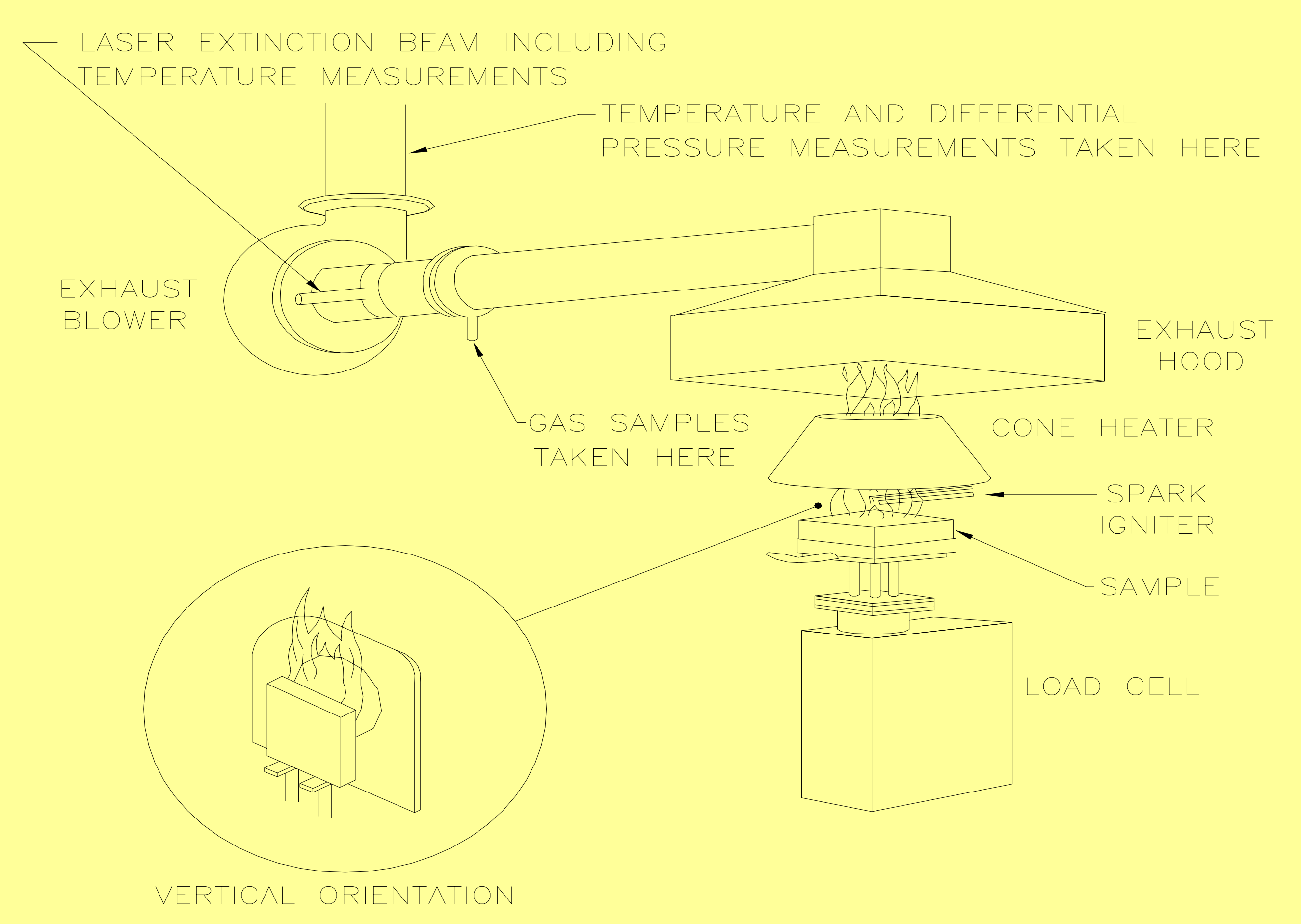
Model	Material	Observations/Comments			Average Burn Rate	Pass/Fail
		Run 1	Run 2	Run 3	(mm/min)	
1996 Dodge Caravan	Battery Cover	Flaming droplets at 36 sec	Flaming droplets at 23 sec	Flaming droplets at 24 sec	68.48	Pass
	Resonator Structure	Melting at 114 sec, Dripping at 120 sec, Burning Floor at 152 sec	Dripping at 108 sec, Burning on Floor at 120 sec	---	50.72	Pass
	Resonator Intake Tube	Flaming droplets at 26 sec	---	---	55.84	Pass
	Air Ducts	Flaming droplets at 46 sec	Flaming droplets at 36 sec	---	36.46	Pass
	Brake Fluid Reservoir	Dripping at 64 sec, Burning on Floor at 244 sec	---	---	19.61	Pass
	Kick Panel Insulation	Could not sustain burning	Ignited and self-extinguished before the first mark	Ignited and self-extinguished before the first mark	0.00	Pass
	Headlight Assembly (Black)	Ignited and self-extinguished before the first mark	Ignited and self-extinguished before the first mark	Ignited and self-extinguished before the first mark	0.00	Pass
	Fender Sound Reduction Foam	Flaming droplets at 6 min, 53 sec	Flaming droplets at 6 min, 8 sec	---	36.23	Pass
	Hood Liner Face	Ignited and went out after removal of pilot flame	Ignited and went out after removal of pilot flame	Ignited and went out after removal of pilot flame	0.00	Pass
	Windshield Wiper Structure	Ignited and went out after removal of pilot flame	Ignited and went out after removal of pilot flame	Ignited and went out after removal of pilot flame	0.00	Pass

AUTOMOTIVE COMPONENT FIRE TESTS
FMVSS 302 Test (5 of 5)

Summary of Test Results - Camaro

Model	Material	Observations/Comments			Average Burn Rate (mm/min)	Pass/Fail
		Run 1	Run 2	Run 3		
1997 Chevrolet Camaro	Front Wheel Well Liner	Dripping at 45 sec, Flaming droplets at 52 sec, Burning on floor at 186 sec	Dripping at 39 sec, Flaming droplets at 50 sec, Burning on floor at 162 sec	---	37.09	Pass
	Air Inlet	Ignited and went out after removal of pilot flame	Flaming droplets at 105 sec, Burning on floor from 105 sec until end of test	Flaming droplets at 105 sec, Burning on floor from 105 sec until end of test	14.80	Pass
	Hood Insulator	Ignited and went out after removal of pilot flame	Ignited and went out after removal of pilot flame	Ignited and went out after removal of pilot flame	0.00	Pass
	Radiator Inlet/Outlet Tank	Ignition, but no dripping, no flaming on floor	Ignited and self-extinguished before the first mark	---	2.25	Pass
	Engine Cooling Fan	Ignited and self-extinguished before the first mark	Ignited and self-extinguished before the first mark	---	0.00	Pass
	Power Steering Fluid Reservoir	Ignited and went out after removal of pilot flame	Ignited and went out after removal of pilot flame	Ignited and went out after removal of pilot flame	0.00	Pass
	Windshield with Laminate	Ignited and self-extinguished before the first mark	Ignited and self-extinguished before the first mark	Ignited and self-extinguished before the first mark	0.00	Pass
	Blower Motor Housing	Flaming droplets at 37 sec	Flaming droplets at 41 sec	---	31.83	Pass

AUTOMOTIVE COMPONENT FIRE TESTS
Cone Calorimeter (1 of 8)



AUTOMOTIVE COMPONENT FIRE TESTS
Cone Calorimeter (2 of 8)

- ASTM E 1354, NFPA 271 and ISO 5660 standards
- 100 x 100 mm specimen size, maximum 50 mm thick
- Irradiance can be set at 0 to 100 kW/m^2
- Pyrolyzates ignited with electric spark
- Specimen placed on load cell (mass loss)
- Heat and smoke release measured in duct
- Can be supplemented with gas analysis
- Data can be used to predict small flame test performance

AUTOMOTIVE COMPONENT FIRE TESTS
Cone Calorimeter (3 of 8)

AUTOMOTIVE COMPONENT FIRE TESTS
Cone Calorimeter (4 of 8)

Summary of Ignition Times - Caravan

Battery Cover		Resonator Structure		Resonator Intake Tube		Air Ducts	
Flux (kW/m^2)	t_{ig} (s)	Flux (kW/m^2)	t_{ig} (s)	Flux (kW/m^2)	t_{ig} (s)	Flux (kW/m^2)	t_{ig} (s)
15	NI	10	NI	10	NI	10	NI
17	NI	11	NI	11	NI	12	NI
19	NI	12	546	12	299	13	186
20	290	15	312	20	115	15	187
20	224	20	163	20	111	20	94
20	387	20	135	35	27	20	86
20	86	35	44	35	26	35	31
35	24	35	43	50	13	35	38
35	23	50	18	50	15	50	15
50	7	50	20			50	17
50	9						

AUTOMOTIVE COMPONENT FIRE TESTS
Cone Calorimeter (5 of 8)

Summary of Ignition Times – Caravan (Cont.)

Brake Fluid Reservoir		Kick Panel Insulation		Headlight Assembly		Fender Sound Red. Foam	
Flux (kW/m^2)	t_{ig} (s)	Flux (kW/m^2)	t_{ig} (s)	Flux (kW/m^2)	t_{ig} (s)	Flux (kW/m^2)	t_{ig} (s)
8	NI	12	NI	20	NI[C]	8	NI
9	NI	14	NI	20	NI	9	NI
10	484	15	NI	20	NI	10	158
12	367	16	378	23	NI[C]	20	3
20	142	20	47	24	513[C]	20	4
20	152	20	56	25	367[C]	35	2
35	62	35	32	35	747	35	2
35	58	35	31	35	395	50	1
35	52	50	24	35	433[C]	50	1
50	32	50	22	35	398[C]		
50	40			36	NI		
				38	217		
				40	104		
				50	71[C]		
				50	31		
				50	33		
				50	60[C]		
				[C] Clear Lens			

AUTOMOTIVE COMPONENT FIRE TESTS
Cone Calorimeter (6 of 8)

Summary of Ignition Times – Caravan (Cont.)

Hood Liner Face		Windshield Wiper Struct.	
Flux (kW/m^2)	t_{ig} (s)	Flux (kW/m^2)	t_{ig} (s)
13	NI	11	NI
14	NI	12	590
15	241	13	565
20	21	15	368
20	NI	20	146
20	16	20	159
35	4	35	79
35	8	35	86
50	4	50	49
50	4	50	41

AUTOMOTIVE COMPONENT FIRE TESTS
Cone Calorimeter (7 of 8)

Summary of Ignition Times - Camaro

Front Wheel Well Liner		Air Inlet		Hood Insulator		Radiator Inlet/Outlet Tank	
Flux (kW/m^2)	t_{ig} (s)	Flux (kW/m^2)	t_{ig} (s)	Flux (kW/m^2)	t_{ig} (s)	Flux (kW/m^2)	t_{ig} (s)
8	NI	10	NI	10	NI	15	NI
9	438	11	452	15	NI	17	NI
10	395	15	238	17	NI	18	NI
12	242	20	129	19	NI	19	560
20	121	20	108	20	9	20	301
20	111	20	108	20	8	20	312
20	88	35	40	20	NI*	35	108
35	37	35	38	20	8	35	89
35	37	50	17	20	12	50	43
50	18	50	16	35	NI*	50	44
50	19			35	2		
				35	2		
				50	NI*		
				50	2		
				50	1		
				* Foil Side			

AUTOMOTIVE COMPONENT FIRE TESTS
Cone Calorimeter (8 of 8)

Summary of Ignition Times – Camaro (Cont.)

Engine Cooling Fan		Power Steering Fluid Reservoir		Windshield with Laminate		Blower Motor Housing	
Flux (kW/m^2)	t_{ig} (s)	Flux (kW/m^2)	t_{ig} (s)	Flux (kW/m^2)	t_{ig} (s)	Flux (kW/m^2)	t_{ig} (s)
15	NI	20	NI	15	NI	8	NI
17	NI	20	NI	16	NI	9	582
18	NI	21	NI	17	425	11	451
19	580	22	517	20	386	13	285
20	347	23	279	20	329	15	207
20	392	25	185	35	113	20	140
35	129	35	152	35	100	20	136
35	152	35	186	50	39	35	50
50	32	50	34	50	86	35	42
50	36	50	31			50	26
		50	37			50	23

AUTOMOTIVE COMPONENT FIRE TESTS
Supplemental Toxicity Tests (1 of 18)

- SwRI Project No. 01.06287 (This additional scope of work was performed under separate contract with funding provided by MVFRI)
- A ThermoNicolet Magna 560 Fourier Transform Infrared (FTIR) spectrometer was used to determine the concentration of several toxic compounds present in the smoke produced by each material tested in the Cone Calorimeter
- The concentration measurements were combined with gas flow rates measured by the Cone Calorimeter to provide a yield in terms of mass of material lost during the burning period.

AUTOMOTIVE COMPONENT FIRE TESTS Supplemental Toxicity Tests (2 of 18)

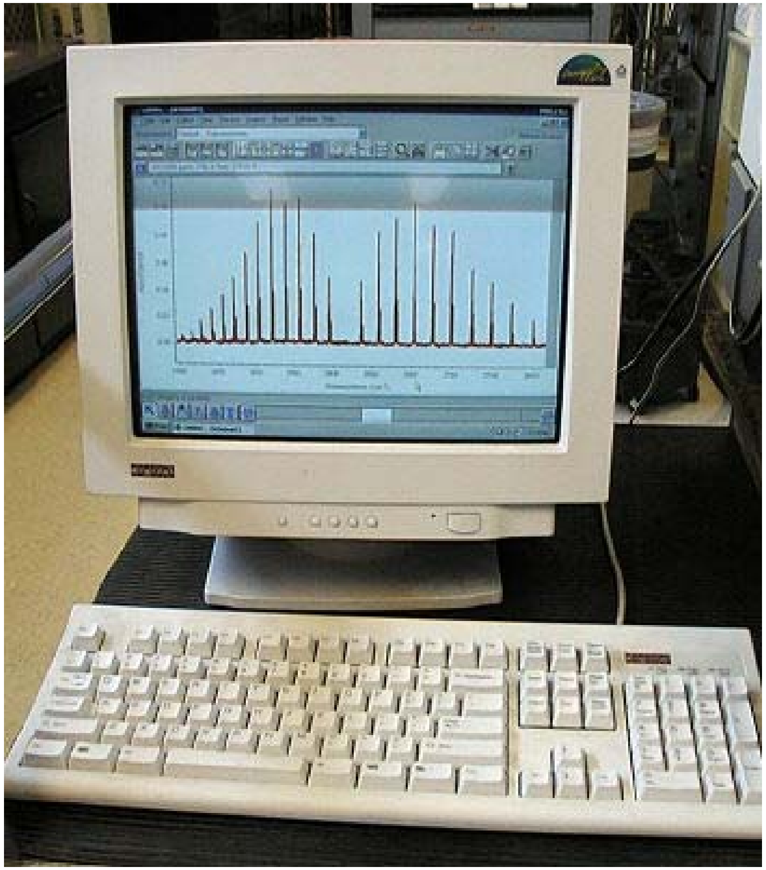
- ASTM E 800 (2001), *Standard Guide for Measurement of Gases Present or Generated During Fires*
  - Analytical methods and sampling considerations for various compounds
- SAFIR report entitled, *Smoke Gas Analysis by Fourier Transform Infrared Spectroscopy – The SAFIR Project*
  - Specific methods and procedures for gas sampling, spectral calibration, and data analysis
  - Nordtest Standard NT FIRE 047, *Combustible Products: Smoke Gas Concentrations, Continuous FTIR Analysis* provided additional guidance in the development of this method

AUTOMOTIVE COMPONENT FIRE TESTS
Supplemental Toxicity Tests (3 of 18)

Maximum Calibration Concentration and Correction Order

Compound	Maximum Concentration (ppm)	Correction Order
CO	7000	5th
CO_2	35,000	5th
HBr	600	3rd
HCl	3000	6th
HCN	140	5th
HF	600	4th
NO_x	350	5th
SO_2	120	5th
Water vapor	23,880	3rd

AUTOMOTIVE COMPONENT FIRE TESTS
Supplemental Toxicity Tests (4 of 18)



AUTOMOTIVE COMPONENT FIRE TESTS
Supplemental Toxicity Tests (5 of 18)

Chevrolet Camaro Test Samples Composition

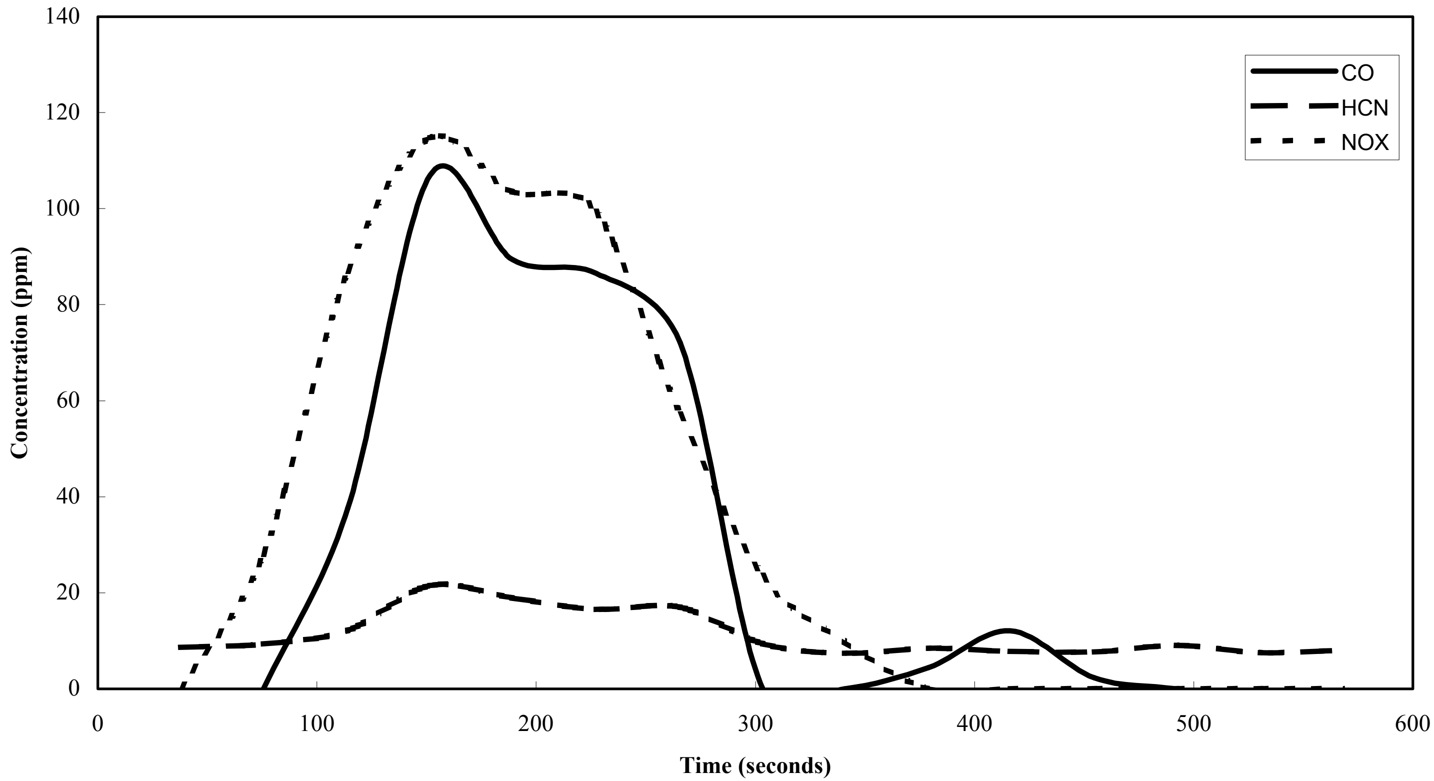
Part No.	Material ID	Composition	Contains
10296526	Front Wheel Well Liner	PP/PE copolymer	$[C_3H_6]_n$ / $[C_2H_4]_n$
10297291	Air Inlet	PP/PE	$[C_3H_6]_n$ / $[C_2H_4]_n$
10278015	Hood Insulator - Foil Side	Nylon 6 and phenolic binder (Novalac)	$[C_6H_{11}ON]_n$ and $C_{63}H_{48}O_{10}$
	Hood Insulator - Fiber side	Phenolic binder (Novalac)	$C_{63}H_{48}O_{10}$
52465337	Radiator Inlet/Outlet Tank	Nylon 6,6	$[C_{12}H_{22}O_2N_2]_n$
22098787	Engine Cooling Fan	Nylon 6	$[C_6H_{11}ON]_n$
26019594	Power Steering Fluid Reservoir	Nylon 6,6	$[C_{12}H_{22}O_2N_2]_n$
10310333	Laminated Windshield		
52458965	Heater Module Blower Motor Housing	Polypropylene	$[C_3H_6]_n$

AUTOMOTIVE COMPONENT FIRE TESTS
Supplemental Toxicity Tests (6 of 18)

Dodge Caravan Test Samples Composition

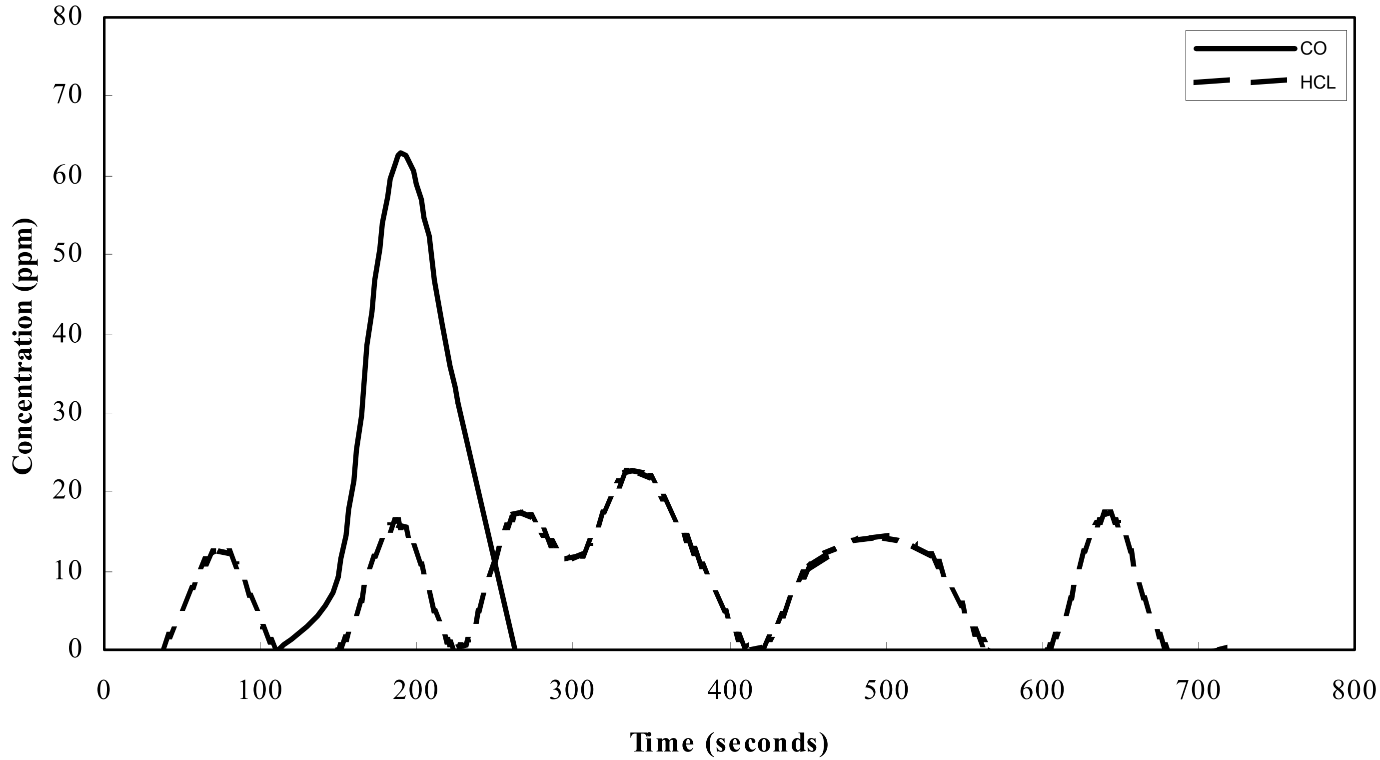
5235267AB	Battery Cover	Polypropylene	$[C_3H_6]_n$
4861057	Resonator Structure	Polypropylene	$[C_3H_6]_n$
53030508	Resonator Intake Tube	Ethylene propylene diene monomer	C_2H_4 and C_3H_6
4678345	Air Ducts	Polyethylene (A) or polypropylene (B)	$[C_2H_4]_n$ or $[C_3H_6]_n$
4683264	Brake Fluid Reservoir	Polypropylene	$[C_3H_6]_n$
4860446	Kick Panel Insulation Backing - Rubber side	Polyvinylchloride	$[C_2H_3Cl]_n$
4857041A	Headlight - Clear Lens	Polycarbonate	$[C_{16}H_{14}O_3]_n$
	Headlight - Black Casing	Polyoxy-methylene	$3[CH_2O]_n$
4716345B	Fender Sound Reduction Foam	Polystyrene	$[C_8H_8]_n$
4716832B	Hoodliner Face	polyethylene terephthalate	$[C_{10}H_8O_4]_n$
4716051	Windshield Wiper Structure	Glass reinforced thermoset polyester resin cross-linked with styrene	$[C_2H_4]_n$ and C_8H_8

AUTOMOTIVE COMPONENT FIRE TESTS
Supplemental Toxicity Tests (7 of 18)



Concentration versus Time Curves for Brake Fluid Reservoir at 50 kW/m^2

AUTOMOTIVE COMPONENT FIRE TESTS
Supplemental Toxicity Tests (8 of 18)



Concentration versus Time Curves for Kick Panel Insulation at 35 kW/m^2

AUTOMOTIVE COMPONENT FIRE TESTS
Supplemental Toxicity Tests (9 of 18)

Maximum CO and CO_2 Concentrations for 1996 Dodge Caravan Parts

Material Description	Composition	Flux (kW/m^2)	CO Max (ppm)			CO_2 at CO Max (ppm)			CO/CO_2 at Max CO		
			Test 1	Test 2	Average	Test 1	Test 2	Average	Test 1	Test 2	Average
Air Ducts (4678345)	PE or PP	20	97	109	103	6798	6667	6732	0.014	0.016	0.015
		35	166	158	162	9727	11054	10390	0.017	0.014	0.016
		50	189	225	207	9787	11801	10794	0.019	0.019	0.019
Battery Cover (5235267AB)	PP	20	39	12	26	4327	90	2209	0.009	NF	0.009
		35	50	35	43	4044	4272	4158	0.012	0.008	0.010
		50	83	55	69	5956	4749	5352	0.014	0.012	0.013
Brake Fluid Reservoir (4683264)	PP	20	95	101	98	6617	6762	6690	0.014	0.015	0.015
		35	259	85	172	13802	5831	9817	0.019	0.015	0.017
		50	205	202	204	10951	10580	10765	0.019	0.019	0.019
Fender Sound Reduction Foam (4716345B)	PS	20	152	39	95	3870	4327	4099	0.039	0.009	0.024
		35	163	176	170	3942	4572	4257	0.041	0.039	0.040
		50	173	153	163	4314	4093	4204	0.040	0.037	0.039
Headlight Lens - Black Casing (4857041A)	Polyoxy-methylene	20	5	5	5	70	77	73	NF	NF	NF
		35	NT	167	167	NT	399	399	NT	NF	NF
		50	253	269	261	5917	5612	5765	0.043	0.048	0.045
Headlight Lens - Clear Lens (4857041A)	PC	20	5	NT	5	63	NT	63	NF	NT	NF
		35	309	NT	309	7533	NT	7533	0.041	NT	0.041
		50	396	NT	396	7988	NT	7988	0.050	NT	0.050

NF = Not Flaming. NT = Not Tested

AUTOMOTIVE COMPONENT FIRE TESTS
Supplemental Toxicity Tests (10 of 18)

Maximum CO and CO_2 Concentrations for 1996 Dodge Caravan Parts (Cont.)

Material Description	Composition	Flux (kW/m^2)	CO Max (ppm)			CO_2 at CO Max (ppm)			CO/CO_2 at Max CO		
			Test 1	Test 2	Average	Test 1	Test 2	Average	Test 1	Test 2	Average
Hoodliner Face (4716832B)	PET	20	322	326	324	265	287	276	NF	NF	NF
		35	361	432	397	352	250	301	NF	NF	NF
		50	227	187	207	385	411	398	NF	NF	NF
Kick Panel Insulation Backing - Rubber side (4860446)	PVC	20	26	38	32	2672	3107	2889	0.010	0.012	0.011
		35	63	72	67	4115	4200	4157	0.015	0.017	0.016
		50	60	46	53	3719	3420	3569	0.016	0.013	0.015
Resonator Intake Tube (53030508)	EPDM Rubber	20	78	57	67	4997	4512	4754	0.016	0.013	0.014
		35	106	116	111	6315	6653	6484	0.017	0.017	0.017
		50	130	112	121	7490	6921	7205	0.017	0.016	0.017
Resonator Structure (4861057)	PP	20	89	95	92	5489	5735	5612	0.016	0.017	0.016
		35	127	120	123	7570	6977	7273	0.017	0.017	0.017
		50	191	160	176	9221	7953	8587	0.021	0.020	0.020
Windshield Wiper Structure (4716051)	PE, PS	20	103	147	125	3307	4306	3806	0.031	0.034	0.033
		35	117	122	119	3664	3829	3747	0.032	0.032	0.032
		50	236	212	224	5995	5718	5856	0.039	0.037	0.038

NF = Not Flaming. NT = Not Tested

AUTOMOTIVE COMPONENT FIRE TESTS
Supplemental Toxicity Tests (11 of 18)

Maximum CO and CO_2 Concentrations for 1997 Chevrolet Camaro Parts

Material Description	Composition	Flux (kW/m^2)	CO Max (ppm)			CO_2 at CO Max (ppm)			CO/CO_2 at Max CO		
			Test 1	Test 2	Average	Test 1	Test 2	Average	Test 1	Test 2	Average
Air Inlet (10297291)	PP, PE	20	24	76	50	3811	6092	4951	0.006	0.012	0.009
		35	145	186	166	10472	11622	11047	0.014	0.016	0.015
		50	234	241	237	13423	13360	13391	0.017	0.018	0.018
Engine Cooling Fan (22098787)	Nylon 6	20	5	5	5	392	53	222	NF	NF	NF
		35	NT	51	51	NT	300	300	NT	NF	NF
		50	112	137	124	378	423	401	NF	NF	NF
Front Wheel Well Liner (10296526)	PP, PE	20	66	69	68	4803	4862	4832	0.014	0.014	0.014
		35	77	52	64	5720	4428	5074	0.013	0.012	0.013
		50	89	366	227	6151	15908	11029	0.014	0.023	0.019
Heater Module Blower Motor Housing (52458965)	PP	20	43	38	40	3954	3422	3688	0.011	0.011	0.011
		35	69	69	69	4760	4444	4602	0.015	0.016	0.015
		50	107	95	101	5447	5153	5300	0.020	0.018	0.019
Hood Insulator - Fiber side (10278015)	Phenolic Binder	20	6	NT	6	17	NT	17	NF	NT	NF
		35	14	NT	14	432	NT	432	NF	NT	NF
		50	40	NT	40	664	NT	664	NF	NT	NF

NF = Not Flaming. NT = Not Tested

AUTOMOTIVE COMPONENT FIRE TESTS
Supplemental Toxicity Tests (12 of 18)

Maximum CO and CO_2 Concentrations for 1997 Chevrolet Camaro Parts (Cont.)

Material Description	Composition	Flux	CO Max (ppm)			CO_2 at CO Max (ppm)			CO/CO_2 at Max CO		
		(kW/m^2)	Test 1	Test 2	Average	Test 1	Test 2	Average	Test 1	Test 2	Average
Hood Insulator - Foil Side (10278015)	Nylon 6 and Phenolic Binder	20	6	NT	6	92	NT	92	NF	NT	NF
		35	5	NT	5	60	NT	60	NF	NT	NF
		50	10	NT	10	148	NT	148	NF	NT	NF
Laminated Windshield (10310333)		20	12	12	12	1724	396	1060	NF	NF	NF
		35	14	11	13	3332	3063	3197	0.004	0.003	0.004
		50	26	14	20	4079	4792	4435	0.006	0.003	0.005
Power Steering Fluid Reservoir (26019594)	Nylon 6,6	20	6	6	6	23	89	56	NF	NF	NF
		35	NT	84	84	NT	4200	4200	NT	0.020	0.020
		50	158	342	250	8554	16547	12550	0.018	0.021	0.020
Radiator Inlet/Outlet Tank (52465337)	Nylon 6,6	20	53	55	54	2696	3759	3227	0.020	0.015	0.017
		35	70	100	85	5764	7031	6397	0.012	0.014	0.013
		50	107	108	108	8236	7545	7891	0.013	0.014	0.014

NF = Not Flaming. NT = Not Tested

AUTOMOTIVE COMPONENT FIRE TESTS
Supplemental Toxicity Tests (13 of 18)

Average CO Yields at 50 kW/m^2

Material Description	Composition	Flux (kW/m^2)	CO Yield (mg/g)		
			Test 1	Test 2	Average
Air Ducts (4678345)	PE or PP	50	22	25	24
Battery Cover (5235267AB)	PP	50	15	11	13
Brake Fluid Reservoir (4683264)	PP	50	25	25	25
Fender Sound Reduction Foam (4716345B)	PS	50	53	50	52
Headlight Lens - Black Casing (4857041A)	Polyoxy-methylene	50	54	53	54
Headlight Lens - Clear Lens (4857041A)	PC	50	50	NT	50
Hoodliner Face (4716832B)	PET	50	148	136	142
Kick Panel Insulation Backing - Rubber side (4860446)	PVC	50	9.5	8.6	9.0
Resonator Intake Tube (53030508)	EPDM Rubber	50	25	16	21
Resonator Structure (4861057)	PP	50	28	28	28
Windshield Wiper Structure (4716051)	PE, PS	50	34	38	36

NT = Not Tested. DNI = Did Not Ignite

AUTOMOTIVE COMPONENT FIRE TESTS
Supplemental Toxicity Tests (14 of 18)

Average CO Yields at 50 kW/m^2 (Cont.)

Material Description	Composition	Flux (kW/m^2)	CO Yield (mg/g)		
			Test 1	Test 2	Average
Air Inlet (10297291)	PP, PE	50	24	18	21
Engine Cooling Fan (22098787)	Nylon 6	50	13	16	15
Front Wheel Well Liner (10296526)	PP, PE	50	14	47	31
Heater Module Blower Motor Housing (52458965)	PP	50	26	24	25
Hood Insulator - Fiber side (10278015)	Phenolic Binder	50	50	NT	50
Hood Insulator - Foil Side (10278015)	Nylon 6 and Phenolic Binder	50	DNI	NT	DNI
Laminated Windshield (10310333)		50	3.5	1.9	2.7
Power Steering Fluid Reservoir (26019594)	Nylon 6,6	50	21	30	26
Radiator Inlet/Outlet Tank (52465337)	Nylon 6,6	50	12	14	13

NT = Not Tested. DNI = Did Not Ignite

AUTOMOTIVE COMPONENT FIRE TESTS
Supplemental Toxicity Tests (15 of 18)

Maximum HCN Concentrations for Nitrogen-Containing Materials

Material Description	Composition	Flux (kW/m^2)	HCN Max (ppm)			CO_2 at HCN Max (ppm)			HCN/CO_2 at HCN Max		
			Test 1	Test 2	Average	Test 1	Test 2	Average	Test 1	Test 2	Average
Engine Cooling Fan (22098787)	Nylon 6	20	10	10	10	14	16	15	NF	NF	NF
		35	NT	15	15	NT	2151	2151	NT	0.0071	0.0071
		50	14	15	15	5254	4312	4783	0.0027	0.0034	0.0031
Hood Insulator - Foil Side (10278015)	Nylon 6 and Phenolic Binder	20	11	NT	11	18	NT	18	NF	NT	NF
		35	11	NT	11	13	NT	13	NF	NT	NF
		50	11	NT	11	26	NT	26	NF	NT	NF
Power Steering Fluid Reservoir (26019594)	Nylon 6,6	20	10	11	11	18	16	17	NF	NF	NF
		35	NT	16	16	NT	3558	3558	NT	0.0045	0.0045
		50	11	13	12	365	16547	8456	0.0304	0.0008	0.0156
Radiator Inlet/Outlet Tank (52465337)	Nylon 6,6	20	14	16	15	2548	3759	3153	0.0055	0.0043	0.0049
		35	19	18	18	6364	7031	6697	0.0030	0.0025	0.0028
		50	22	17	19	8236	7545	7891	0.0026	0.0022	0.0024

NF = Not Flaming. NT = Not Tested

AUTOMOTIVE COMPONENT FIRE TESTS
Supplemental Toxicity Tests (16 of 18)

Maximum NO_x Concentrations for Nitrogen-Containing Materials

Material Description	Composition	Flux (kW/m^2)	NO_x Max (ppm)			CO_2 at NO_x Max (ppm)			NO_x/CO_2 at NO_x Max		
			Test 1	Test 2	Average	Test 1	Test 2	Average	Test 1	Test 2	Average
Engine Cooling Fan (22098787)	Nylon 6	20	19	17	18	308	657	482	NF	NF	NF
		35	NT	26	26	NT	2339	2339	NT	0.0110	0.0110
		50	58	63	60	5254	5422	5338	0.0110	0.0117	0.0113
Hood Insulator - Foil Side (10278015)	Nylon 6 and Phenolic Binder	20	30	NT	30	18	NT	18	NF	NT	NF
		35	11	NT	11	14	NT	14	NF	NT	NF
		50	23	NT	23	29	NT	29	NF	NT	NF
Power Steering Fluid Reservoir (26019594)	Nylon 6,6	20	17	19	18	17	20	19	NF	NF	NF
		35	NT	39	39	NT	4200	4200	NT	0.0094	0.0094
		50	18	32	25	8554	16547	12550	0.0021	0.0019	0.0020
Radiator Inlet/Outlet Tank (52465337)	Nylon 6,6	20	21	37	29	2696	3759	3227	0.0078	0.0099	0.0088
		35	81	95	88	6364	6995	6680	0.0127	0.0136	0.0131
		50	115	114	114	8236	8510	8373	0.0139	0.0133	0.0136

NF = Not Flaming. NT = Not Tested

AUTOMOTIVE COMPONENT FIRE TESTS
Supplemental Toxicity Tests (17 of 18)

Average HCN and NO_x Yields for Nitrogen-Containing Materials at 50 kW/m^2

Material Description	Composition	Flux (kW/m^2)	HCN Yield (mg/g)			NO_x Yield (mg/g)		
			Test 1	Test 2	Average	Test 1	Test 2	Average
Engine Cooling Fan (22098787)	Nylon 6	50	5.0	4.0	4.5	11	12	12
Hood Insulator - Foil Side (10278015)	Nylon 6 and Phenolic Binder	50	DNI	NT	DNI	DNI	NT	DNI
Power Steering Fluid Reservoir (26019594)	Nylon 6,6	50	8.0	4.5	6.3	0.7	2.0	1.4
Radiator Inlet/Outlet Tank (52465337)	Nylon 6,6	50	5.1	4.8	5.0	15	14	15

NT = Not Tested. DNI = Did Not Ignite

AUTOMOTIVE COMPONENT FIRE TESTS
Supplemental Toxicity Tests (18 of 18)

Maximum HCl Concentrations for Chlorine-Containing Materials

Material Description	Composition	Flux (kW/m^2)	HCl Max (ppm)			CO_2 at HCl Max (ppm)			HCl/CO_2 at Max HCl		
			Test 1	Test 2	Average	Test 1	Test 2	Average	Test 1	Test 2	Average
Kick Panel Insulation Backing - Rubber side (4860446)	PVC	20	15	12	13	1702	NF	1702	0.009	NF	0.009
		35	23	20	21	2206	1280	1743	0.010	0.016	0.013
		50	12	12	12	281	1528	905	NF	0.008	0.008

NF = Not Flaming. NT = Not Tested

Average HCl Yields for Chlorine-Containing Materials at 50 kW/m^2

Material Description	Composition	Flux (kW/m^2)	HCl Yield (mg/g)		
			Test 1	Test 2	Average
Kick Panel Insulation Backing - Rubber side (4860446)	PVC	50	4.2	1.1	2.7

AUTOMOTIVE COMPONENT FIRE TESTS
Smoke and Toxicity Tests (1 of 8)

- Based on the Cone Calorimeter results, three materials were selected for testing in both the IMO smoke chamber (Part 2 of Annex 1 to the FTP Code) and the NBS smoke chamber developed by the National Bureau of Standards.
- These materials represented the best, worst, and mid-level performers as evidenced from the CO concentration data collected during the Cone Calorimeter tests. The low-level material was also chosen in order to evaluate hydrogen chloride production relative to data collected from the Cone.
- The additional toxicity tests were conducted as part of the MVFRI project.

AUTOMOTIVE COMPONENT FIRE TESTS
Smoke and Toxicity Tests (2 of 8)

- Part 2 of Annex 1 to the IMO FTP Code
  - Heating element and sample are oriented horizontally
  - Single pilot flame
- Airbus Industrie ABD 0031
  - Heating element and sample are oriented vertically
  - 6-tube pilot burner

AUTOMOTIVE COMPONENT FIRE TESTS
Smoke and Toxicity Tests (3 of 8)

Material Selection for Smoke and Toxicity Testing

Part No.	Auto (see note)	Material ID	Composition	Contains	CO_{MAX} (ppm, from Cone Calorimeter)
4860446	Caravan	Kick Panel Insulation Backing - Rubber side	PVC	$[C_2H_3Cl]_n$	53
4857041A	Caravan	Headlight - Clear Lens	polycarbonate	$[C_{16}H_{14}O_3]_n$	396
4716832B	Caravan	Hoodliner Face	PET	$[C_{10}H_8O_4]_n$	207

AUTOMOTIVE COMPONENT FIRE TESTS
Smoke and Toxicity Tests (4 of 8)

Peak CO and HCl Concentrations (Airbus, Non-Flaming, 25 kW/m^2)

Sample	Peak Concentration (ppm)					
	CO			HCl		
	Test 1	Test 2	Average	Test 1	Test 2	Average
Headlight Lens - Clear Lens (4857041A) Polycarbonate	4	2	3			
Hoodliner Face (4716832B) PET	2563	2095	2329			
Kick Panel Insulation Backing - Rubber side (4860446) PVC	528	731	629	510	631	571

Average CO and HCl Yields (Airbus, Non-Flaming, 25 kW/m^2)

Sample	Average Yield (mg/g)					
	CO			HCl		
	Test 1	Test 2	Average	Test 1	Test 2	Average
Headlight Lens - Clear Lens (4857041A) Polycarbonate	2	1	2			
Hoodliner Face (4716832B) PET	82	61	71			
Kick Panel Insulation Backing - Rubber side (4860446) PVC	10	12	11	22	32	27

AUTOMOTIVE COMPONENT FIRE TESTS
Smoke and Toxicity Tests (5 of 8)

Peak CO and HCl Concentrations (Airbus, Flaming, 25 kW/m^2)

Sample	Peak Concentration (ppm)					
	CO			HCl		
	Test 1	Test 2	Average	Test 1	Test 2	Average
Headlight Lens - Clear Lens (4857041A) Polycarbonate	470	532	501			
Hoodliner Face (4716832B) PET	2096	1765	1931			
Kick Panel Insulation Backing - Rubber side (4860446) PVC	1053	934	994	625	596	611

Average CO and HCl Yields (Airbus, Flaming, 25 kW/m^2)

Sample	Average Yield (mg/g)					
	CO			HCl		
	Test 1	Test 2	Average	Test 1	Test 2	Average
Headlight Lens - Clear Lens (4857041A) Polycarbonate	22	29	26			
Hoodliner Face (4716832B) PET	93	71	82			
Kick Panel Insulation Backing - Rubber side (4860446) PVC	28	31	30	26	28	27

AUTOMOTIVE COMPONENT FIRE TESTS
Smoke and Toxicity Tests (6 of 8)

Peak CO and HCl Concentrations (IMO, Non-Flaming, 25 kW/m^2)

Sample	Peak Concentration (ppm)					
	CO			HCl		
	Test 1	Test 2	Average	Test 1	Test 2	Average
Headlight Lens - Clear Lens (4857041A) Polycarbonate	1	4	2			
Hoodliner Face (4716832B) PET	5860	4400	5130			
Kick Panel Insulation Backing - Rubber side (4860446) PVC	174	3	89	41	30	36

Average CO and HCl Yields (IMO, Non-Flaming, 25 kW/m^2)

Sample	Average Yield (mg/g)					
	CO			HCl		
	Test 1	Test 2	Average	Test 1	Test 2	Average
Headlight Lens - Clear Lens (4857041A) Polycarbonate	1	1	1			
Hoodliner Face (4716832B) PET	228	131	179			
Kick Panel Insulation Backing - Rubber side (4860446) PVC	48	3	25	14	10	12

AUTOMOTIVE COMPONENT FIRE TESTS
Smoke and Toxicity Tests (7 of 8)

Peak CO and HCl Concentrations (IMO, Flaming, 25 kW/m²)

Sample	Peak Concentration (ppm)					
	CO			HCl		
	Test 1	Test 2	Average	Test 1	Test 2	Average
Headlight Lens - Clear Lens (4857041A) Polycarbonate	14	19	17			
Hoodliner Face (4716832B) PET	3470	4020	3745			
Kick Panel Insulation Backing - Rubber side (4860446) PVC	362	9	185	27	11	19

Average CO and HCl Yields (IMO, Flaming, 25 kW/m²)

Sample	Average Yield (mg/g)					
	CO			HCl		
	Test 1	Test 2	Average	Test 1	Test 2	Average
Headlight Lens - Clear Lens (4857041A) Polycarbonate	2	4	3			
Hoodliner Face (4716832B) PET	133	91	112			
Kick Panel Insulation Backing - Rubber side (4860446) PVC	7	2	4	1	4	3

AUTOMOTIVE COMPONENT FIRE TESTS
Smoke and Toxicity Tests (8 of 8)

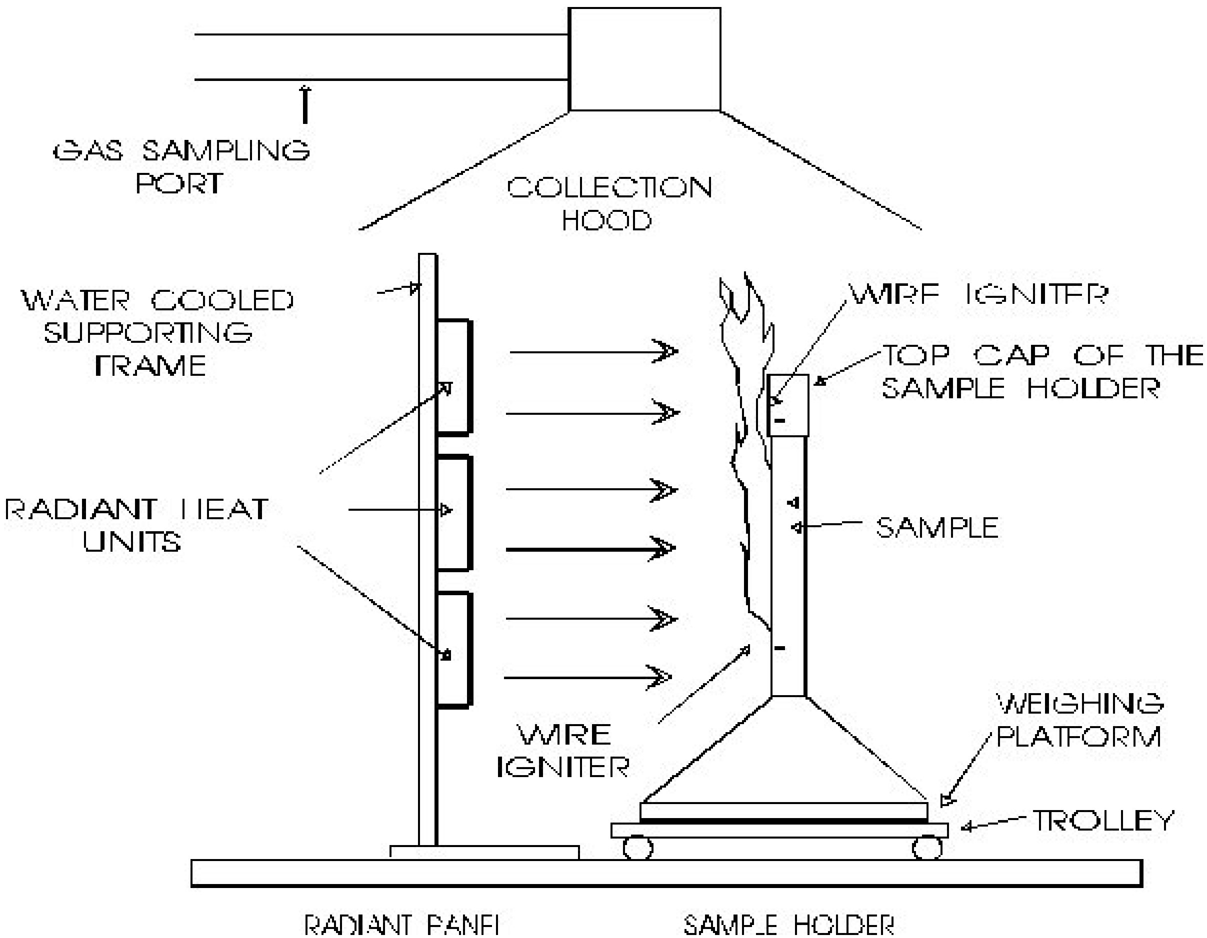
Peak CO and HCl Concentrations (IMO, Non-Flaming, 50 kW/m^2)

Sample	Peak Concentration (ppm)					
	CO			HCl		
	Test 1	Test 2	Average	Test 1	Test 2	Average
Headlight Lens - Clear Lens (4857041A) Polycarbonate	1845	838	1342			
Hoodliner Face (4716832B) PET	4189	2874	3532			
Kick Panel Insulation Backing - Rubber side (4860446) PVC	964	1012	988	1073	1251	1162

Average CO and HCl Yields (IMO, Non-Flaming, 50 kW/m^2)

Sample	Average Yield (mg/g)					
	CO			HCl		
	Test 1	Test 2	Average	Test 1	Test 2	Average
Headlight Lens - Clear Lens (4857041A) Polycarbonate	63	85	74			
Hoodliner Face (4716832B) PET	139	160	150			
Kick Panel Insulation Backing - Rubber side (4860446) PVC	15	34	25	18	80	49

AUTOMOTIVE COMPONENT FIRE TESTS ICAL (1 of 10)



AUTOMOTIVE COMPONENT FIRE TESTS ICAL (2 of 10)

- ASTM E 1623 standard and ISO TR 14696
- Standard specimen is flat and measures 1 x 1 m
- Method can be used to test non-planar surfaces
- Irradiance can be set at 0 to 60 kW/m^2 by changing distance between radiant panel and vertical specimen
- Pyrolyzates ignited with hot wires at top and bottom
- Specimen placed on load cell (mass loss)
- Heat and smoke release measured in ISO 9705 duct

AUTOMOTIVE COMPONENT FIRE TESTS
ICAL (3 of 10)

AUTOMOTIVE COMPONENT FIRE TESTS ICAL (4 of 10)

Battery Cover

Air Ducts

Sound Reduction Foam

Front Wheel Well Liner

Hood Liner Face

Windshield

AUTOMOTIVE COMPONENT FIRE TESTS ICAL (5 of 10)

Test No.	Material Identification	Data File No.	Date Tested	Incident Heat Flux (kW/m^2)	Ignition Time (s)
1	Front Wheel Well Liner	030s3fw1	01/30/03	20	115
2	Battery Cover	031bc1a	01/31/03	20	55
3	Hood Liner Face	0313hl1	01/31/03	20	22
4	Sound Reduction Foam	0313sr1	01/31/03	20	4
5	Air Ducts	0313ad1	01/31/03	20	123
6	Windshield	0313wd1	01/31/03	20	300
7	Hood Liner Face	0343hl2	02/03/03	35	10
8	Sound Reduction Foam	0343sr2	02/03/03	35	7
9	Battery Cover	0343bc2	02/03/03	35	19
10	Air Ducts	0343ad2	02/03/03	35	42
11	Front Wheel Well Liner	0353fw2a	02/04/03	35	40
12	Windshield	0353wd2	02/04/03	35	120
13	Front Wheel Well Liner	0353fw3	02/04/03	50	20
14	Hood Liner Face	0353hl3	02/04/03	50	5
15	Sound Reduction Foam	0353sr3	02/04/03	50	3
16	Battery Cover	0363bc3	02/05/03	50	6
17	Windshield	0363wd3	02/05/03	50	66
18	Air Ducts	0363ad3	02/05/03	50	21

AUTOMOTIVE COMPONENT FIRE TESTS ICAL (6 of 10)

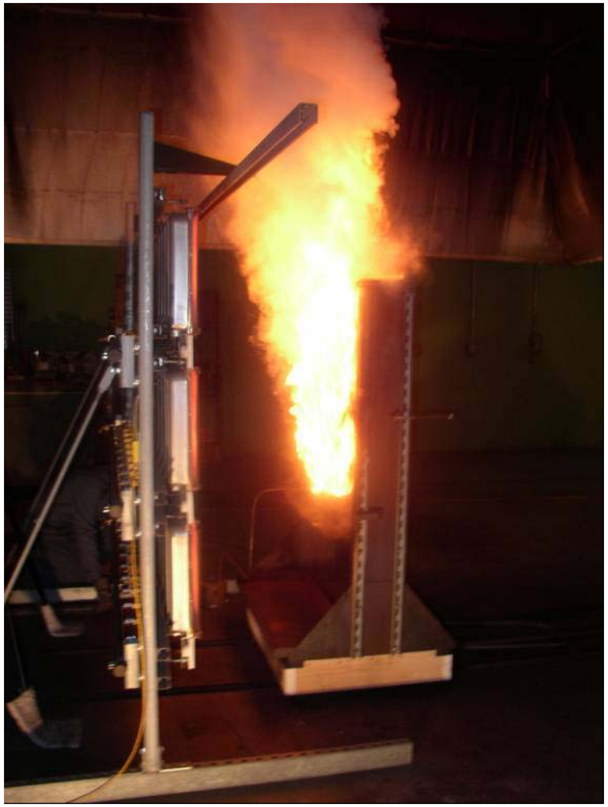
Test No.	Peak Heat Release Rate (HRR) (kW)	Total Heat Released (MJ)	Peak Smoke Production Rate (m^2/s)	Total Smoke Produced (m^2)	Peak CO Generation Rate (g/s)	Total CO Produced (g)	Total Mass Loss (g)
1	161	50	2.3	555	0.65	429	1041
2	200	16	0.9	51	0.49	133	365
3	48	12	1.4	148	1.53	635	867
4	159	19	3.3	199	0.64	131	417
5	447	132	8.4	1949	0.96	923	3027
6	43	32	0.2	108	0.4	539	675
7	84	16	5	133	1.66	590	887
8	159	14	7.7	290	1.05	157	397
9	288	16	2.1	92	0.76	383	401
10	664	125	9.2	1880	0.92	989	2940
11	495	51	6.3	691	1.24	468	1158
12	100	32	0.7	110	0.82	1144	692
13	802	55	9.7	530	1.2	345	1074
14	132	22	7.8	91	1.69	612	877
15	226	16	13.8	399	1.15	170	422
16	603	21	3.4	86	0.86	155	394
17	148	45	1	171	0.8	1150	814
18	709	123	11.1	1748	1.25	2025	2846

AUTOMOTIVE COMPONENT FIRE TESTS ICAL (7 of 10)

Battery Cover

Air Ducts

AUTOMOTIVE COMPONENT FIRE TESTS ICAL (8 of 10)



Sound Reduction Foam

Hood Liner Face

AUTOMOTIVE COMPONENT FIRE TESTS ICAL (9 of 10)

Front Wheel Well Liner

AUTOMOTIVE COMPONENT FIRE TESTS ICAL (10 of 10)

Windshield

AUTOMOTIVE COMPONENT FIRE TESTS
Alternative Materials (1 of 4)

- Objective
  - Explore viable modifications to presently used automotive plastics that endow superior fire performance, and which can serve as suitable, economically viable modifications of standard automotive polymeric components.
- Surface coating technologies that were amenable to under the hood polymeric components were specifically sought-out in this task by employing surface engineering capabilities already established at SwRI.
  - Surface metalization of standard polymeric materials
- Emissivity Hypothesis

AUTOMOTIVE COMPONENT FIRE TESTS
Alternative Materials (2 of 4)

Comparison Between Uncoated and Coated Component Materials from the Dodge Caravan

Dodge Caravan				Uncoated Heat Flux: 50 (kW/m^2)					
Part No.	Description	Base Polymer Composition	Coating	Mass (g)	T_{ig} (s)	Peak HRR (Kw/M^2)	THR (MJ/m^2)	Peak MWHRR (W/g)	MWTHR (kJ/g)
4861057	Resonator Structure	Polypropylene	Aluminum (1.75 μm)	31.3	19	516.5	102.1	143.23	28.31
4861057	Resonator Structure	Polypropylene	Aluminum (3.6 μm)	31.3	19	516.5	102.1	143.23	28.31
4861057	Resonator Structure	Polypropylene	Antimony Oxide (3.2 μm)	31.3	19	516.5	102.1	143.23	28.31
4857041A	Headlight Structure	Polycarbonate	Aluminum (1.75 μm)	38.1	49	356	66.4	81.1	15.13
4857041A	Headlight Structure	Polycarbonate	Aluminum Oxide (3.2 μm)	38.1	49	356	66.4	81.1	15.13

Dodge Caravan				Coated Heat Flux: 50 (kW/m^2)					
Part No.	Description	Base Polymer Composition	Coating	Mass (g)	T_{ig} (s)	Peak HRR (Kw/M^2)	THR (MJ/m^2)	Peak MWHRR (W/g)	MWTHR (kJ/g)
4861057	Resonator Structure	Polypropylene	Aluminum (1.75 μm)	30.4	34	396	102.1	113.07	29.15
4861057	Resonator Structure	Polypropylene	Aluminum (3.6 μm)	35.2	184	479	135.9	118.12	33.51
4861057	Resonator Structure	Polypropylene	Antimony Oxide (3.2 μm)	29.8	74	553	122.4	161.08	35.65
4857041A	Headlight Structure	Polycarbonate	Aluminum (1.75 μm)	26.8	100	319	51.4	103.32	16.65
4857041A	Headlight Structure	Polycarbonate	Aluminum Oxide (3.2 μm)	26.3	73	389	61.9	128.38	20.43

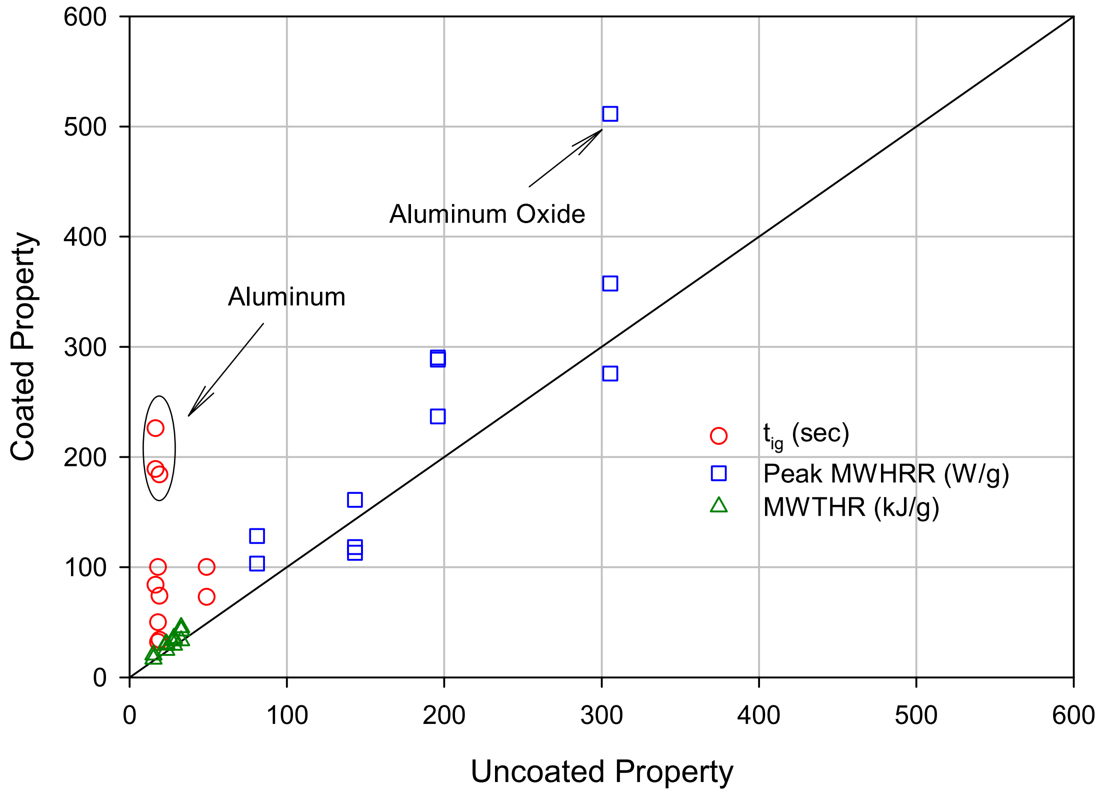
AUTOMOTIVE COMPONENT FIRE TESTS
Alternative Materials (3 of 4)

Comparison Between Uncoated and Coated Component Materials from the Chevrolet Camaro

Chevrolet Camaro				Uncoated Heat Flux: 50 (kW/m^2)					
Part No.	Description	Base Polymer Composition	Coating	Mass (g)	T_{ig} (s)	Peak HRR (Kw/M^2)	THR (MJ/m^2)	Peak MWHRR (W/g)	MWTHR (kJ/g)
10297291	Air Inlet	Polyethylene/Polypropylene	Aluminum (1.75 µm)	21.55	16.5	758.5	81.5	305.51	32.83
10297291	Air Inlet	Polyethylene/Polypropylene	Aluminum (3.6 µm)	21.55	16.5	758.5	81.5	305.51	32.83
10297291	Air Inlet	Polyethylene/Polypropylene	Aluminum Oxide (3.2 µm)	21.55	16.5	758.5	81.5	305.51	32.83
10296526	Front Wheel Well Liner	Polypropylene	Aluminum (1.75 µm)	23.3	18	526	62.6	195.95	23.32
10296526	Front Wheel Well Liner	Polypropylene	Antimony (3.6 µm)	23.3	18	526	62.6	195.95	23.32
10296526	Front Wheel Well Liner	Polypropylene	Antimony Oxide (2.9 µm)	23.3	18	526	62.6	195.95	23.32

Chevrolet Camaro				Coated Heat Flux: 50 (kW/m^2)					
Part No.	Description	Base Polymer Composition	Coating	Mass (g)	T_{ig} (s)	Peak HRR (Kw/M^2)	THR (MJ/m^2)	Peak MWHRR (W/g)	MWTHR (kJ/g)
10297291	Air Inlet	Polyethylene/Polypropylene	Aluminum (1.75 µm)	22.6	189	718	86.7	275.76	33.3
10297291	Air Inlet	Polyethylene/Polypropylene	Aluminum (3.6 µm)	22.8	226	939	110.9	357.48	42.22
10297291	Air Inlet	Polyethylene/Polypropylene	Aluminum Oxide (3.2 µm)	21.2	84	1249	110.6	511.38	45.28
10296526	Front Wheel Well Liner	Polypropylene	Aluminum (1.75 µm)	19.5	100	648	55.3	288.44	24.62
10296526	Front Wheel Well Liner	Polypropylene	Antimony (3.6 µm)	24.7	50	826	83.9	290.27	29.48
10296526	Front Wheel Well Liner	Polypropylene	Antimony Oxide (2.9 µm)	24.3	32s	663	85.9	236.82	30.68

AUTOMOTIVE COMPONENT FIRE TESTS
Alternative Materials (4 of 4)



Correlation Between Coated and Uncoated Test Specimens

DATA ANALYSIS
Overview (1 of 2)

- Introduction
- Test Methodology
- Levels of Performance
  - Comparison Between Small and Intermediate-Scale Heat Release Rate Data
  - FM Fire Hazard Indices
  - Simplified Model to Estimate Fire Growth in an Engine Compartment
  - Relationship Between Cone Calorimeter Data and FMVSS 302 Performance
  - Fire Performance Graph

DATA ANALYSIS
Overview (2 of 2)

- Analysis of Supplemental Smoke Toxicity Measurements and Tests
  - Comparison to Literature Values
  - Comparison of Cone Calorimeter Results with Smoke Box Measurements
  - Application of Limits
  - Use of Yields Measured in the Cone Calorimeter to Determine Toxic Hazard
- Alternative Materials

DATA ANALYSIS
Introduction

- Primary Objectives
  - To identify or develop a test methodology to determine an automotive material fire rating which best correlates to actual fire performance of the material in vehicle burns; and
  - To establish levels of performance using the test methodology that would significantly alter the fire outcome in terms of injury or survivability.
- Secondary Objective
  - To relate the performance of a material when tested according to the proposed methodology to fundamental thermal properties. This information will be useful for material suppliers and automotive components manufacturers in developing formulations that meet the new fire performance levels.

DATA ANALYSIS
Test Methodology (1 of 3)

- Traditional Approach
  - Measures one or several parameters that are believed to be an indication of real fire performance. For example, FMVSS 302, UL 94, etc.
  - Can be useful…but…what if the real ignition source is more severe??
- Modern Approach
  - Hazard assessment
    - Fire scenarios, statistics, probabilities
    - Development of model - simple statistical correlation to a detailed computer simulation
  - Development of Test methodology
    - Provide the properties that are needed for model input. The model can then be used to translate a specific fire performance level to a range of acceptable property values measured in the test

DATA ANALYSIS
Test Methodology (2 of 3)

NHTSA Project

- Statistics
  - Two predominant fire scenarios that lead to fatalities in motor vehicle fires
    - Rear-end collision – underbody pool fire
    - Front-end collision – engine compartment fire
  - Focus on front-end collision scenario
- Full-scale fire tests at FM
  - A fire originating in the engine compartment becomes a threat to trapped occupants in the passenger compartment when the heat release rate reaches approximately 400 kW

DATA ANALYSIS
Test Methodology (3 of 3)

- Development of Model
  - Simple engine fire growth model
  - Model Input
    - Heat release rate properties
    - Ignition properties
- Test Methodology
  - Small-scale calorimeter (Cone Calorimeter or FM Fire Propagation Apparatus)
  - We chose Cone Calorimeter
    - Heat flux and test criteria to be discussed

DATA ANALYSIS
Levels of Performance

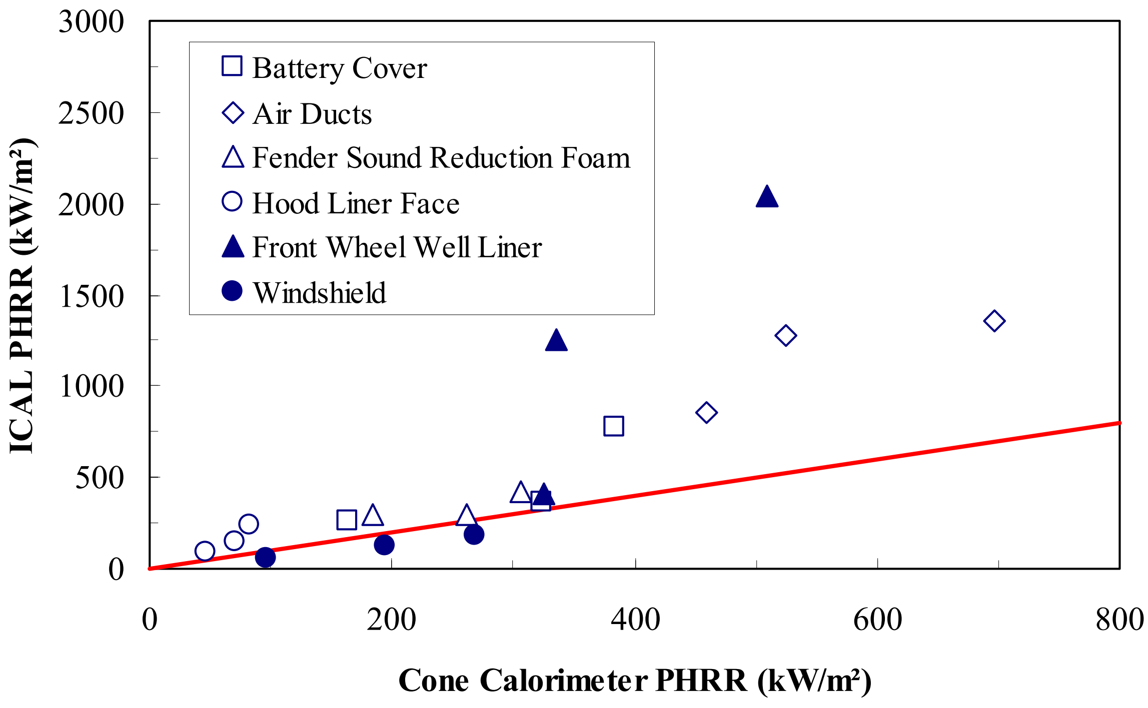
Comparison Between Small and Intermediate-Scale HRR Data (1 of 2)

- Good correlation between Cone and ICAL for wood panel and lumber products
  - Self-supporting
  - Rigid
  - Planar
- Automotive products??
  - Thermoplastic
  - Melt and drip in when exposed to specific thermal conditions

DATA ANALYSIS
Levels of Performance

Comparison Between Small and Intermediate-Scale HRR Data (2 of 2)

- Good correlation for Peak HRR less than 340 kW/m^2
- Larger heat release rates due to melting and dripping
- Pool fire behavior can be ignored – FM reports



DATA ANALYSIS
Levels of Performance

FM Fire Hazard Indices (1 of 5)

- Critical Heat Flux (kW/m^2) - highest heat flux below which ignition does not occur for a very long (theoretically infinite) exposure time
  - Bracketing
  - Extrapolation
    - Intercept with the abscissa of a linear fit through thermally thin ignition points in a graph of the reciprocal of ignition time versus heat flux
    - Polymeric materials with a thickness of a few mm typically behave as a thermally thin solid at heat fluxes below 30 kW/m^2
- Thermal Response Parameter ($kW\text{-}s^{1/2}/m^2$)
  - The reciprocal of the square root of ignition time is plotted versus heat flux
  - The TRP is the reciprocal of the slope of a linear fit through thermally thick data points. Polymeric materials with a thickness of a few mm typically behave as a thermally thick solid at heat fluxes of 30 kW/m^2 or higher

DATA ANALYSIS
Levels of Performance

FM Fire Hazard Indices (2 of 5)

- Fire Propagation Index ($m^{5/3}/kW^{2/3}$-$s^{1/2}$) – The Fire Propagation Index (FPI) is calculated from the following expression:

$$FPI = 1000 \frac{\left(0.042\dot{Q}''\right)^{1/3}}{TRP}$$

Where $\dot{Q}''$ is peak heat release rate in kW/m^2 measured in the Fire Propagation Apparatus at 50 kW/m^2

DATA ANALYSIS
Levels of Performance

FM Fire Hazard Indices (3 of 5)

	Material	CHF (kW/m²) Extrapolation	CHF (kW/m²) Bracket	TRP ($kW\text{-}s^{1/2}/m^2$)	HRR_{peak} (kW/m²) (@ 50 kW/m^2)	FPI ($m^{5/3}/kW^{2/3}\text{-}s^{1/2}$)
1996 Dodge Caravan	Battery Cover	19	19	100	384	25.27
	Resonator Structure	9	11	192	517	14.53
	Resonator Intake Tube	10	11	204	599	14.36
	Air Ducts	8	12	189	697	16.31
	Brake Fluid Reservoir	6	9	427	626	6.96
	Kick Panel Insulation	15	15	492	224	4.29
	Headlight Assembly (Clear)	CHF >20	23	200	312	11.79
	Headlight Assembly (Black)	CHF >20	37	112	401	22.89
	Fender Sound Reduction Foam	10	9	89	307	26.35
	Hood Liner Face	15	14	114	83	13.30
	Windshield Wiper Structure	10	11	381	323	6.26

DATA ANALYSIS
Levels of Performance

FM Fire Hazard Indices (4 of 5)

	Material	CHF (kW/m²) Extrapolation	CHF (kW/m²) Bracket	TRP ($kW\text{-}s^{1/2}/m^2$)	HRR_{peak} (kW/m²) (@ 50 kW/m^2)	FPI ($m^{5/3}/kW^{2/3}\text{-}s^{1/2}$)
1997 Chevrolet Camaro	Front Wheel Well Liner	6	8	220	526	12.75
	Air Inlet	9	10	174	759	18.22
	Hood Insulator	16	19	39	19	23.78
	Radiator Inlet/Outlet Tank	18	18	297	458	9.02
	Engine Cooling Fan	17	18	172	294	13.44
	Power Steering Fluid Reservoir	CHF >20	21	159	655	18.99
	Windshield with Laminate	2	16	238	269	9.43
	Blower Motor Housing	6	8	275	328	8.72

DATA ANALYSIS
Levels of Performance

FM Fire Hazard Indices (5 of 5)

- Tewarson suggests a critical value for the FPI of automotive materials of 10 $m^{5/3}/kW^{2/3}$-$s^{1/2}$ above which flame spread accelerates
  - Based on FM 25-ft corner test
- What does an FPI of 10 $m^{5/3}/kW^{2/3}$-$s^{1/2}$ mean in terms of fire growth in the engine compartment of a motor vehicle?
- What is the corresponding time to reach a heat release rate of 400 kW?

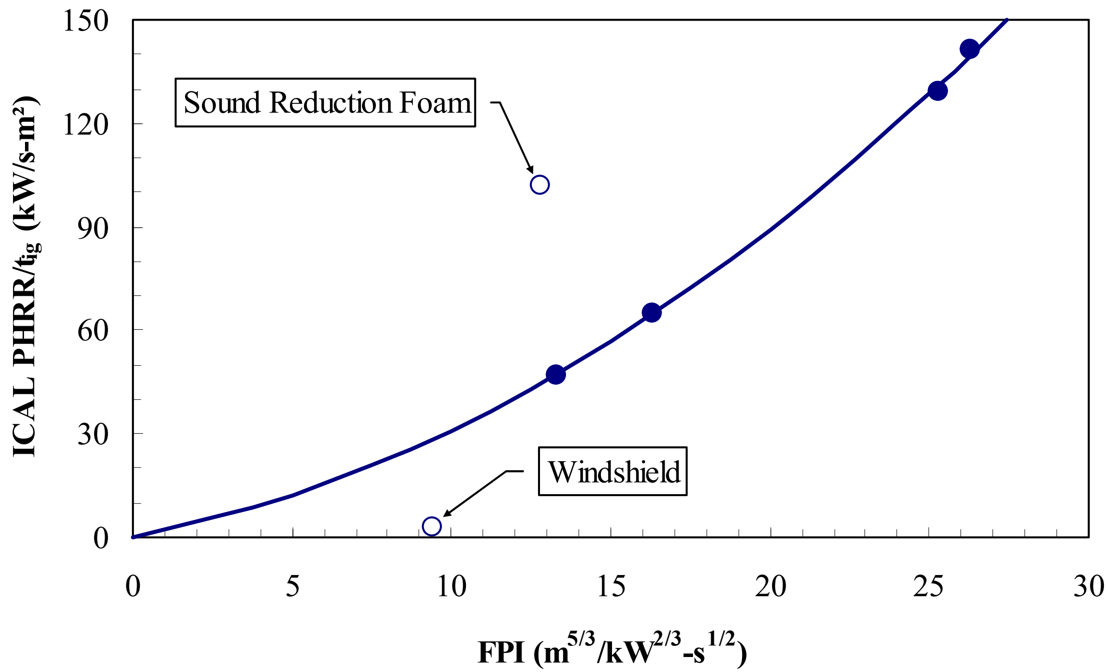
DATA ANALYSIS
Levels of Performance

Simplified Model to Estimate Fire Growth in an Engine Compartment (1 of 16)

- The rate of wind-aided flame spread over the surface of a material increases as the material releases more heat and is easier to ignite
- A higher heat release rate results in a longer flame and a larger area ahead of the flame front that is heated by the flame
- The fire growth rate in a wind-aided flame spread scenario is thus expected to increase with increasing ratios of heat release rate to ignition time for the corresponding thermal exposure conditions

DATA ANALYSIS
Levels of Performance

Simplified Model to Estimate Fire Growth in an Engine Compartment (2 of 16)



Comparison Between Peak Heat Release in the Cone Calorimeter and ICAL

DATA ANALYSIS
Levels of Performance

Simplified Model to Estimate Fire Growth in an Engine Compartment (3 of 16)

- The following assumptions are made to simplify the problem so that an engineering model can be developed:
  - All materials are replaced with the material that has the worst fire performance
  - All materials are redistributed in a continuous horizontal slab with an area equal to that of the hood
- 1st assumption is conservative; 2nd assumption not as conservative

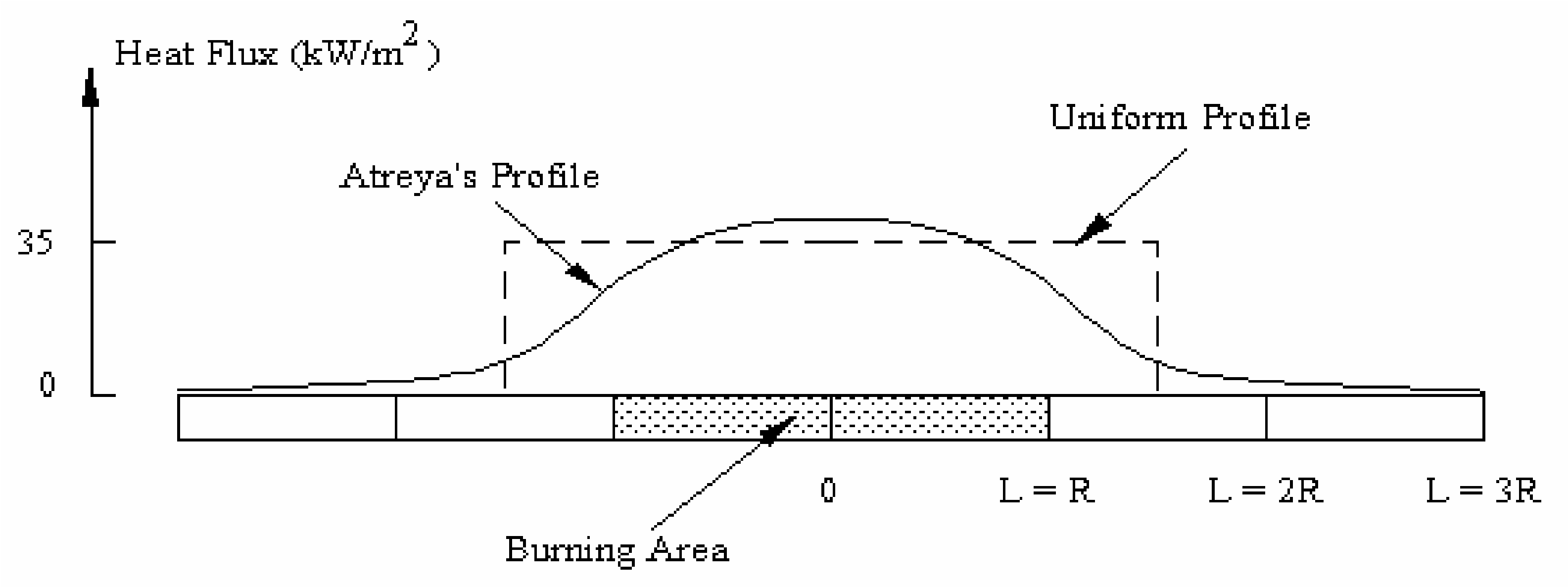
DATA ANALYSIS
Levels of Performance

Simplified Model to Estimate Fire Growth in an Engine Compartment (4 of 16)

- Fire growth estimates in this study are based on a simplified version of Atreya's model to predict flame spread over a horizontal slab of wood
- Atreya used Orloff's approach to calculate the radiant heat flux distribution from the flame to the fuel surface
- The incident radiant heat flux is the highest at the center and drops off by 20-35% at the edge of the burning area
- For the engine fire growth model it is assumed that the radiant heat flux from the flame to the burning surface is uniform.

DATA ANALYSIS
Levels of Performance

Simplified Model to Estimate Fire Growth in an Engine Compartment (5 of 16)



DATA ANALYSIS
Levels of Performance

Simplified Model to Estimate Fire Growth in an Engine Compartment (6 of 16)

- The uniform radiant heat flux is estimated at 35 kW/m^2 based on Atreya's equations applied to a 400 kW fire with a radius of 0.5 m
- The incident heat flux to the fuel surface ahead of the flame front is also assumed to be 35 kW/m^2 between L/R = 1 and L/R = 1.5 and 0 kW/m^2 beyond L/R = 1.5
- The actual radiant heat flux from the flame to the burning fuel surface is slightly higher than 35 kW/m^2, but it is assumed equal to the heat flux to the fuel ahead of the flame front, so that the model only requires heat release rate data at a single heat flux level

DATA ANALYSIS
Levels of Performance

Simplified Model to Estimate Fire Growth in an Engine Compartment (7 of 16)

- The engine fire growth model assumes that initially a circular area with a radius of 0.05 m is exposed to 35 kW/m^2 and ignites after a period equal to the corresponding ignition time measured in the Cone Calorimeter
- The subsequent heat release rate is estimated as the product of the peak heat release rate at 35 kW/m^2 measured in the Cone Calorimeter and the area of the burning surface (0.0079 m^2)
- An average heat release rate at a higher heat flux is probably more consistent, but the peak heat release rate at 35 kW/m^2 is used to minimize the Cone Calorimeter data needed

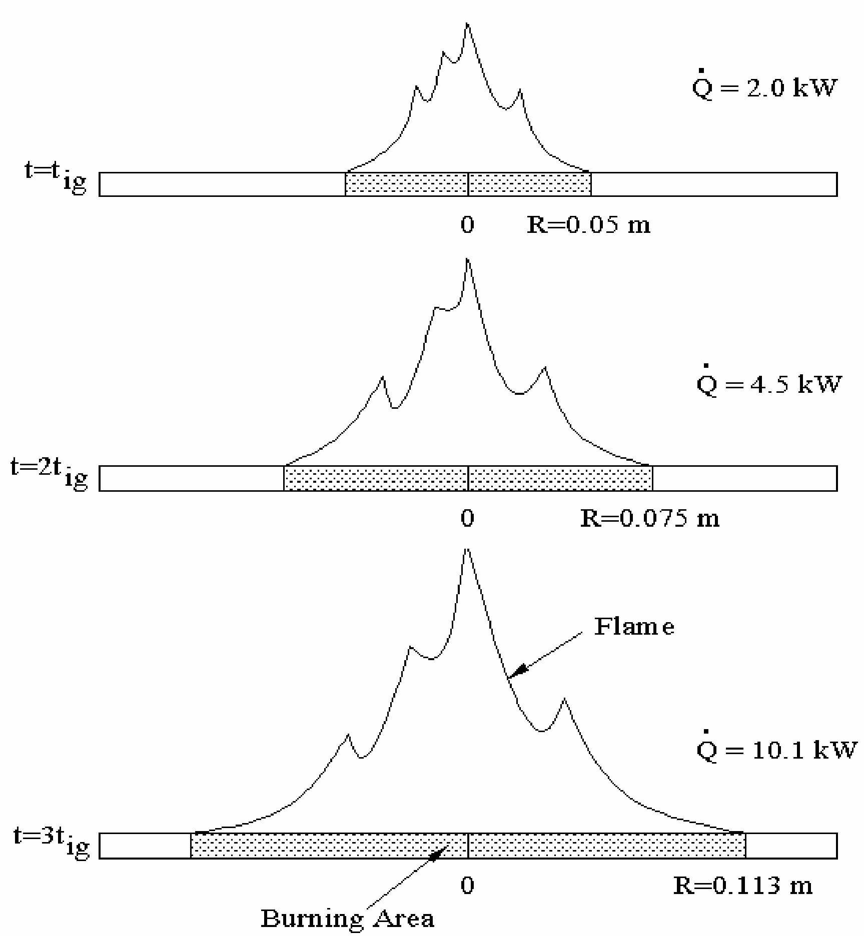
DATA ANALYSIS
Levels of Performance

Simplified Model to Estimate Fire Growth in an Engine Compartment (8 of 16)

- After a period equal to the average Cone Calorimeter ignition time at 35 kW/m^2 an annular region ahead of the flame front ignites
  - The width of this region is half the radius of the initial burning region, so that the radius of the burning area increases by 50%
- After a period equal to three times the Cone Calorimeter ignition time, the radius of the burning area will increase by 50% again
- This process will continue until the heat release rate reaches 400 kW

DATA ANALYSIS
Levels of Performance

Simplified Model to Estimate Fire Growth in an Engine Compartment
(9 of 16)



DATA ANALYSIS
Levels of Performance

Simplified Model to Estimate Fire Growth in an Engine Compartment (10 of 16)

The resulting exponential fire growth model can be represented by the following expression:

$$\dot{Q} = A_0 \dot{Q}'' (1.5)^{\frac{2(t - t_{ig})}{t_{ig}}}$$

where $\dot{Q}$ is the heat release rate of the fire in kW, A_0 is the area initially ignited (assumed to be 0.0079 m^2), $\dot{Q}''$ is the peak heat release rate measured in the Cone Calorimeter at 35 kW/m^2, t is the time in sec, and t_{ig} is the time to ignition measured in the Cone Calorimeter at 35 kW/m^2

DATA ANALYSIS
Levels of Performance

Simplified Model to Estimate Fire Growth in an Engine Compartment (11 of 16)

The time to reach 400 kW when the fire becomes a threat to trapped occupants in the passenger compartment can therefore be calculated from:

$$t = t_{ig}\left[1 + 1.233\,\mathbf{ln}\left(\frac{400}{0.0079\dot{Q}''}\right)\right]$$

DATA ANALYSIS
Levels of Performance

Simplified Model to Estimate Fire Growth in an Engine Compartment (12 of 16)

	Material	t_{ig} (s)	$\dot{Q}''$ (kW/m^2)	$t_{400\ kW}$ (s)	$t_{400\ kW}$ min : sec
Dodge Caravan	Headlight Assembly (Clear)	278	385	1952	32 : 32
	Battery Cover	39	297	287	4 : 47
	Resonator Structure	64	417	443	7 : 23
	Resonator Intake Tube	72	434	497	8 : 17
	Air Ducts	68	560	443	7 : 23
	Brake Fluid Reservoir	270	499	1808	30 : 08
	Kick Panel Insulation	605	205	4720	78 : 40
	Headlight Assembly (Black)	74	158	603	10 : 03
	Fender Sound Reduction Foam	12	251	88	1 : 28
	Hood Liner Face	29	71	269	4 : 29
	Windshield Wiper Structure	252	233	1926	32 : 06

Time to 400 kW Based on Engine Fire Growth Model

DATA ANALYSIS
Levels of Performance

Simplified Model to Estimate Fire Growth in an Engine Compartment (13 of 16)

	Material	t_{ig} (s)	$\dot{Q}''$ (kW/m^2)	$t_{400\ kW}$ (s)	$t_{400\ kW}$ min : sec
Chevy Camaro	**Front Wheel Well Liner**	66	390	465	7 : 45
	Air Inlet	48	686	306	5 : 06
	Hood Insulator	6	21	63	1 : 03
	Radiator Inlet/Outlet Tank	305	344	2187	36 : 27
	Engine Cooling Fan	102	158	831	13 : 51
	Power Steering Fluid Reservoir	129	217	997	16 : 37
	Windshield Laminate	157	187	1242	20 : 42
	Blower Motor Housing	104	268	775	12 : 55

Time to 400 kW Based on Engine Fire Growth Model

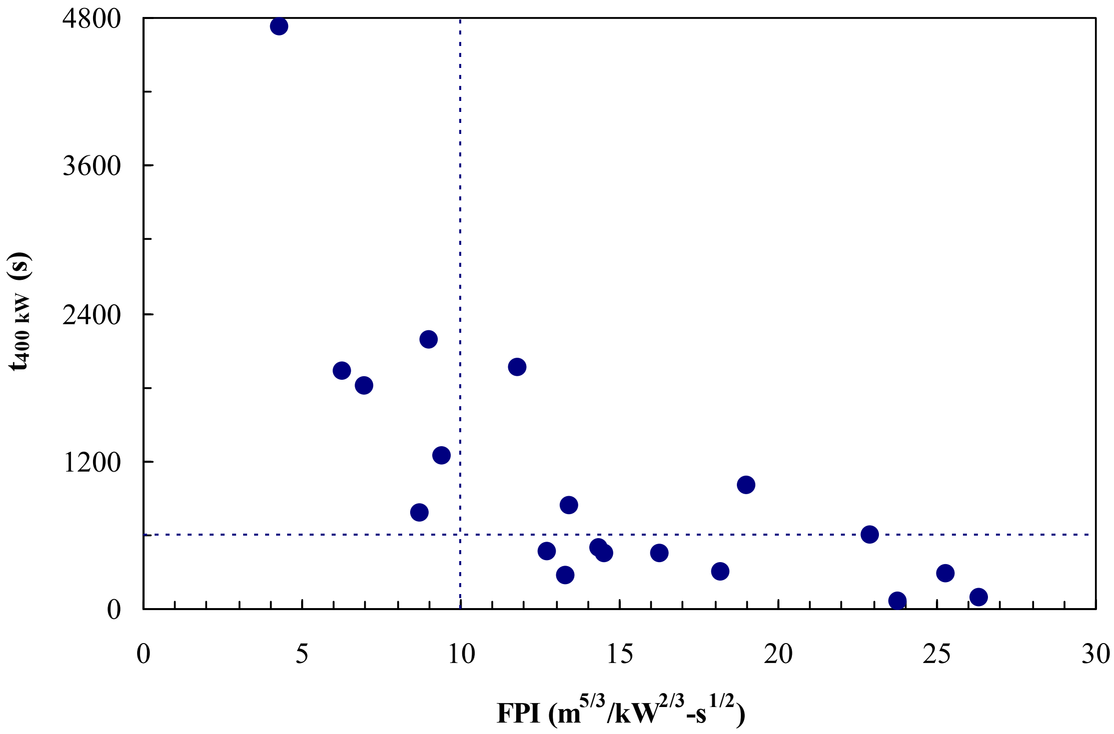
DATA ANALYSIS
Levels of Performance

Simplified Model to Estimate Fire Growth in an Engine Compartment (14 of 16)

- When the peak heat release rate at 35 kW/m2 is plotted versus the FPI, it is observed that any material with an FPI of 10 $m^{5/3}/kW^{2/3}\text{-}s^{1/2}$ or less requires at least 10 minutes to reach the 400 kW threshold
- Note that only Cone Calorimeter data at a single heat flux level are required by the model, while ignition data at multiple heat flux levels are needed to calculate the fire hazard indices used by FM
- The same observation is made when the peak 30-second average heat release rate measured at 50 kW/m^2 is plotted, which further justifies using Cone Calorimeter data at a single heat flux level.

DATA ANALYSIS
Levels of Performance

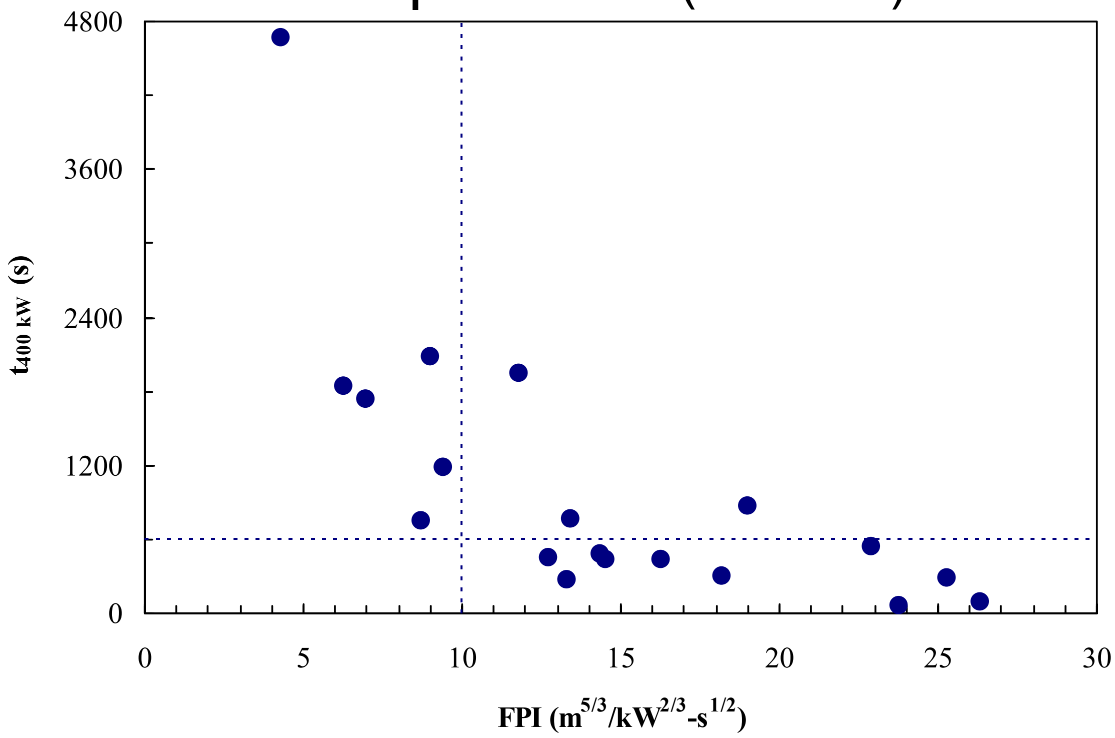
Simplified Model to Estimate Fire Growth in an Engine Compartment (15 of 16)



Time to Reach 400 kW Based on PHRR Measured at 35 kW/m^2 versus FPI

DATA ANALYSIS
Levels of Performance

Simplified Model to Estimate Fire Growth in an Engine Compartment (16 of 16)



Time to Reach 400 kW Based on 30 s PHRR Measured at 50 kW/m² versus FPI

DATA ANALYSIS
Levels of Performance

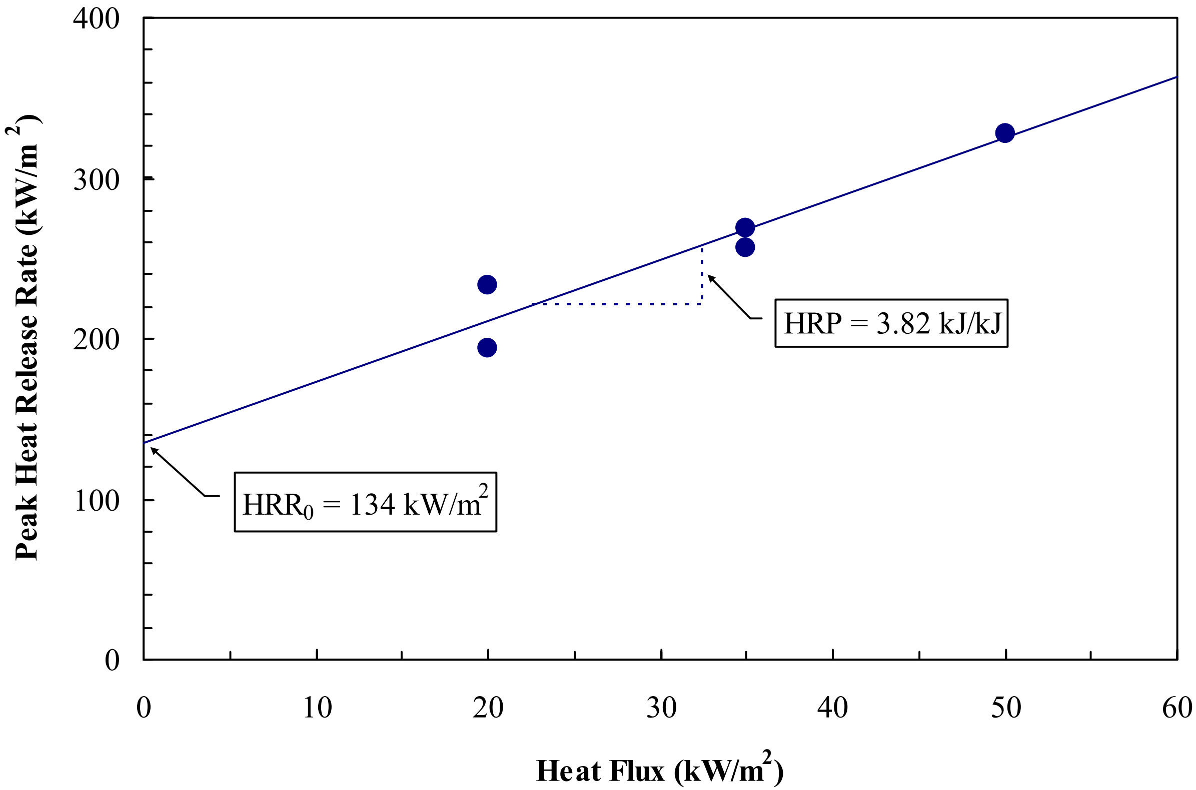
Relationship Between Cone Calorimeter Data and FMVSS 302 Performance (1 of 13)

- Lyon demonstrated that the limiting heat release rate, HRR_0, correlates well with performance in the UL 94 and Limiting Oxygen Index (LOI) tests
- For example, plastics that meet the requirements for a UL 94 V-0 classification appear to have a limiting heat release rate below a critical value, HRR*, of approximately 100 kW/m^2
- Lyon used average heat release rates

DATA ANALYSIS
Levels of Performance

Relationship Between Cone Calorimeter Data and FMVSS 302 Performance (2 of 13)

- Blower Motor Housing
- Determined for Peak Heat Release Rate



DATA ANALYSIS
Levels of Performance

Relationship Between Cone Calorimeter Data and FMVSS 302 Performance (3 of 13)

- We determined the HRR_0 and HRP for the 18 automotive components for 4 different heat release rate parameters
  - Peak HRR
  - Peak 30 sec average HRR
  - 180 sec average HRR
  - Total average HRR
- HRR_0 is not a good indicator of flame propagation in the FMVSS 302 test

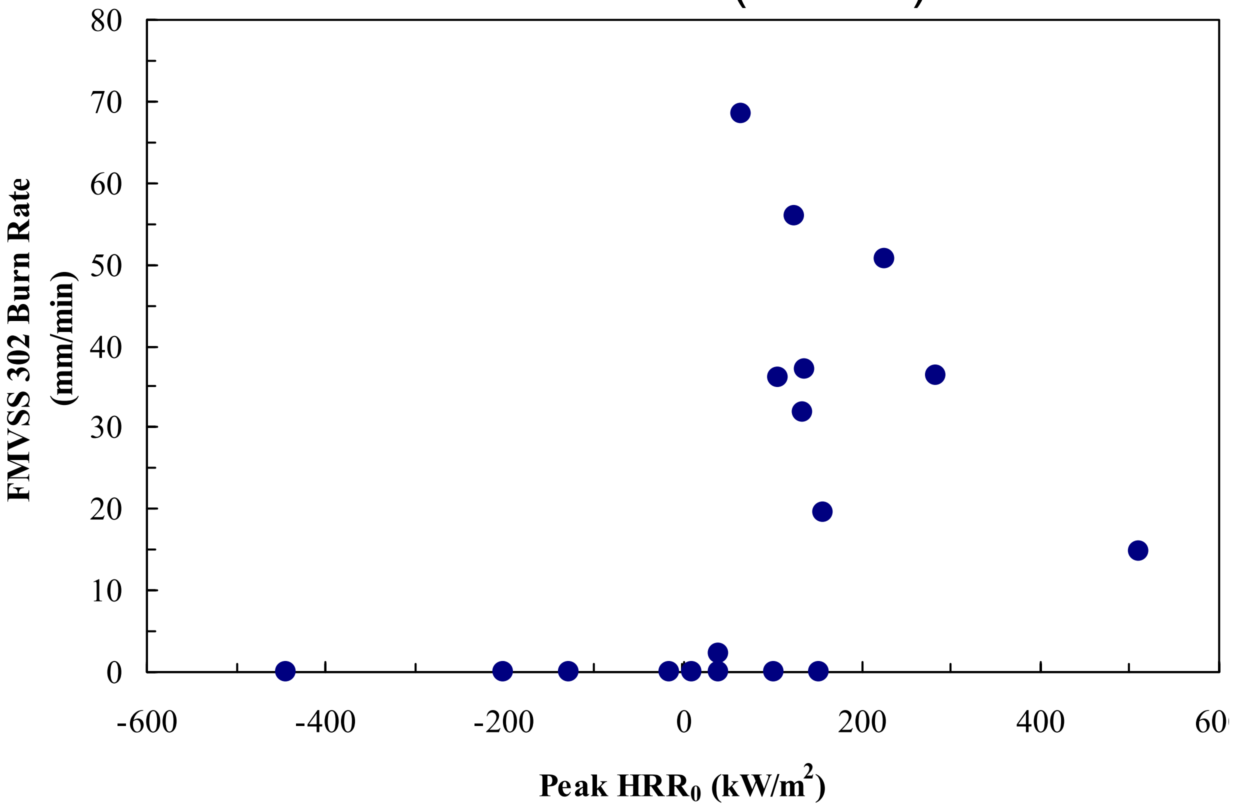
DATA ANALYSIS
Levels of Performance

Relationship Between Cone Calorimeter Data and FMVSS 302 Performance (4 of 13)

Material	Peak		Peak 30 s Average		180 s Average		Test Average	
	HRR_0 (kW/m^2)	HRP (kJ/kJ)	HRR_0 (kW/m^2)	HRP (kJ/kJ)	HRR_0 (kW/m^2)	HRP (kJ/kJ)	HRR_0 (kW/m^2)	HRP (kJ/kJ)
Headlight Assembly (Clear)	346	1.10	244	2.97	117	3.37	133	1.07
Battery Cover	65	6.63	119	4.63	61	1.70	-6	4.22
Resonator Structure	227	5.43	227	5.27	166	4.38	37	5.42
Resonator Intake Tube	125	8.82	134	7.55	101	3.42	-58	5.92
Air Ducts	284	7.90	285	7.32	204	2.87	108	1.72
Brake Fluid Reservoir	158	9.75	158	9.48	85	6.62	12	6.78
Kick Panel Insulation	154	1.48	150	1.42	53	2.25	38	1.42
Headlight Assembly (Black)	-201	10.27	-222	10.53	-377	12.60	-286	9.40
Fender Sound Reduction Foam	107	4.12	79	5.03	71	2.73	23	3.42
Hood Liner Face	41	0.85	45	0.64	2	1.17	29	0.20
Windshield Wiper Structure	103	3.72	139	3.50	121	0.73	49	1.18
Front Wheel Well Liner	136	7.26	175	5.40	107	2.48	37	1.48
Air Inlet	510	5.04	502	4.42	192	4.21	36	4.21
Hood Insulator	11	0.28	3	0.62	1	0.02	6	0.29
Radiator Inlet/Outlet Tank	40	8.68	187	5.30	159	4.13	-18	4.75
Engine Cooling Fan	-128	8.17	-127	8.08	-142	7.72	-67	4.54
Power Steering Fluid Reservoir	-444	18.87	-426	18.27	-289	12.23	-249	9.40
Windshield Laminate	-15	5.75	-5	5.17	28	1.58	7	1.52
Blower Motor Housing	134	3.82	132	3.82	73	4.13	16	4.40

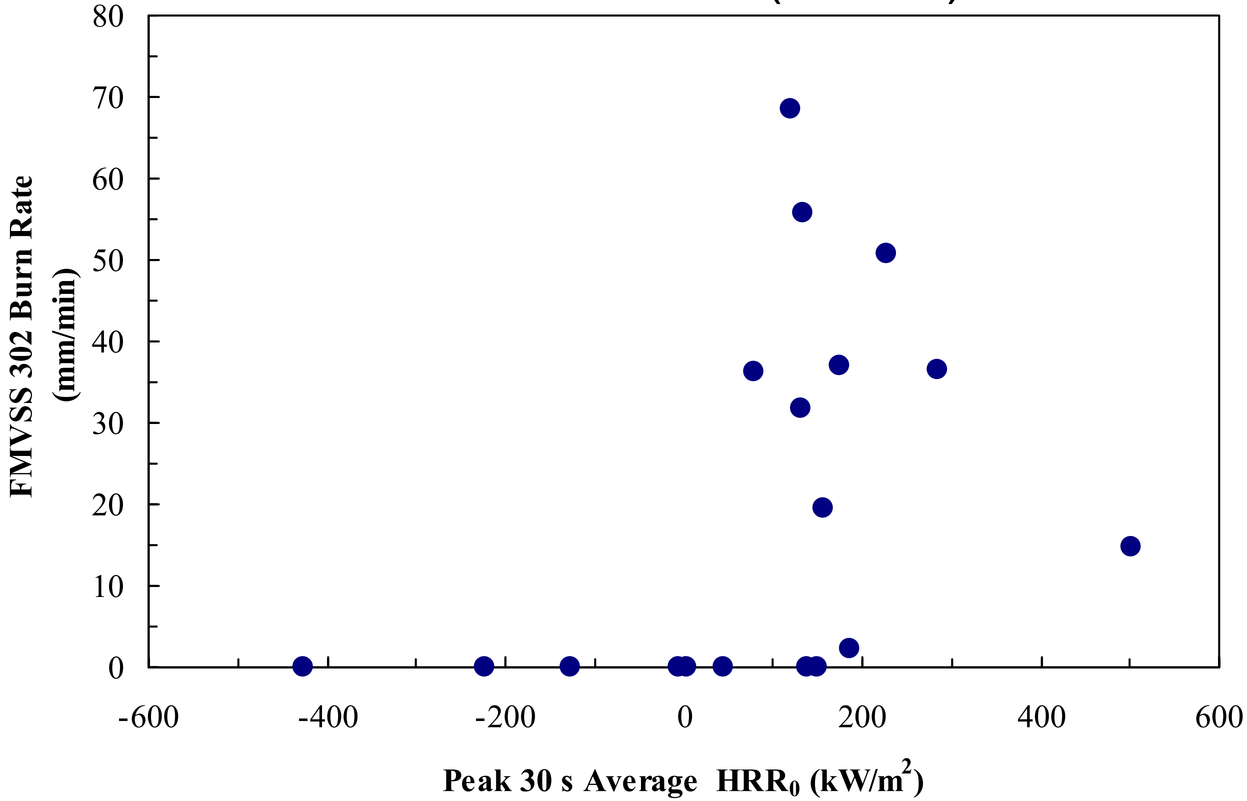
DATA ANALYSIS
Levels of Performance

Relationship Between Cone Calorimeter Data and FMVSS 302 Performance (5 of 13)



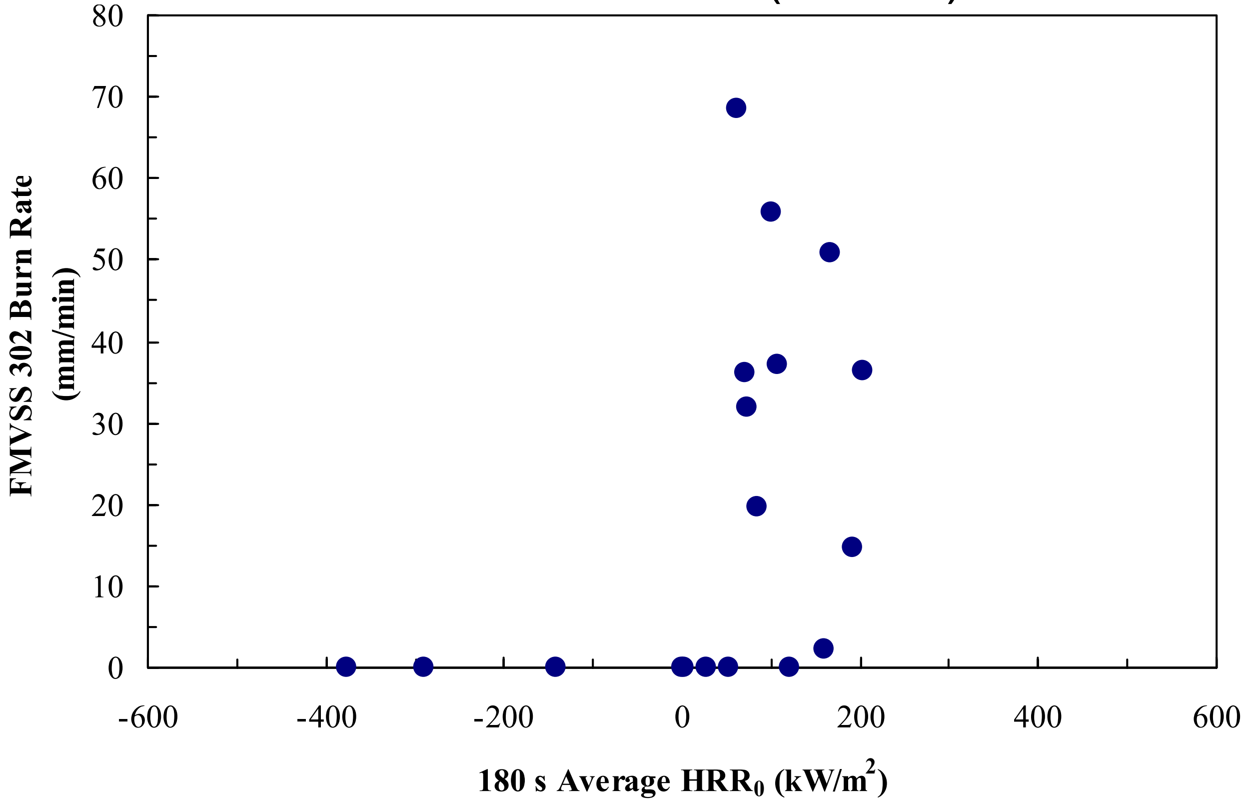
DATA ANALYSIS
Levels of Performance

Relationship Between Cone Calorimeter Data and FMVSS 302 Performance (6 of 13)



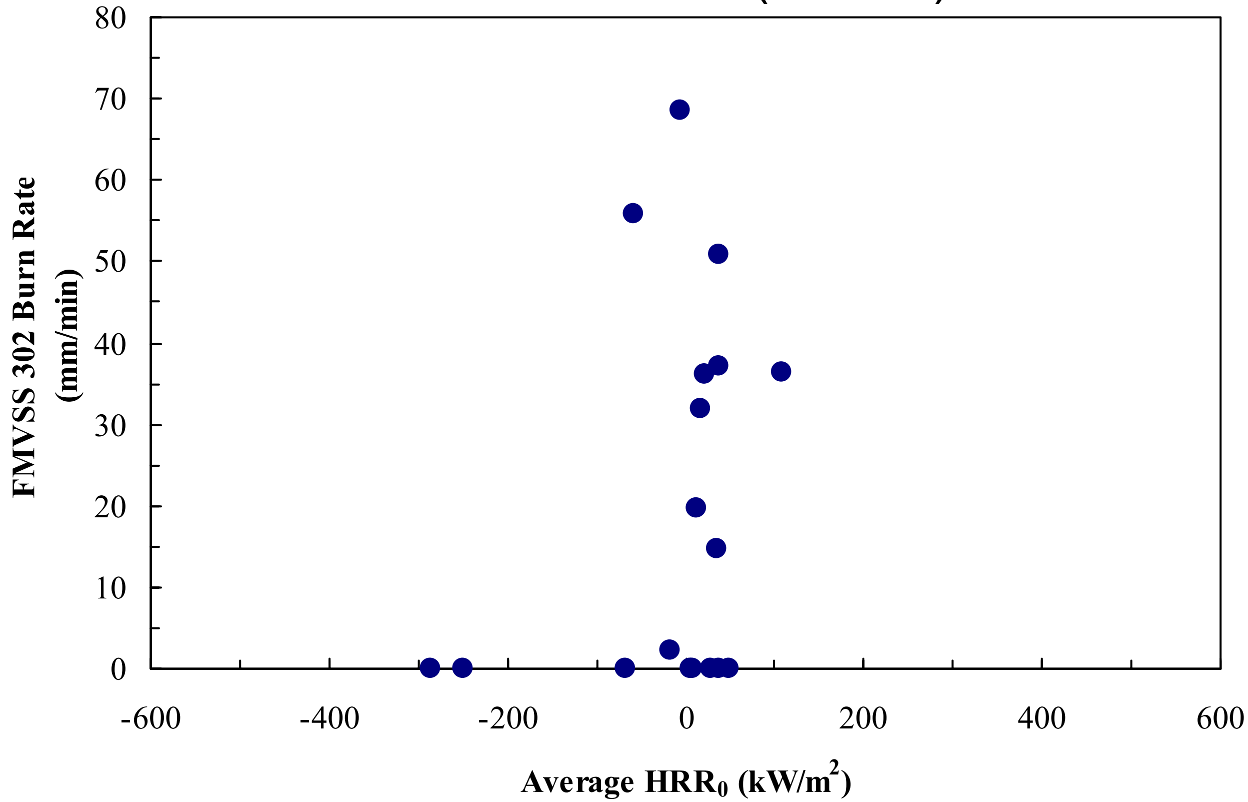
DATA ANALYSIS
Levels of Performance

Relationship Between Cone Calorimeter Data and FMVSS 302 Performance (7 of 13)



DATA ANALYSIS
Levels of Performance

Relationship Between Cone Calorimeter Data and FMVSS 302 Performance (8 of 13)



DATA ANALYSIS
Levels of Performance

Relationship Between Cone Calorimeter Data and FMVSS 302 Performance (9 of 13)

- In a more recent paper, Lyon proposed using the Fire Hazard Parameter (FHP) to rank materials more consistently with UL 94 V performance. The FHP is defined as follows:

$$FHP \equiv \frac{HRR_0}{HRR^*} + HRP$$

- The FHP is actually proportional to the heat release rate at a heat flux level equal to HRR*
- Lyon's improved correlations therefore indicate that heat release rate at a heat flux higher than zero is a better predictor of performance in a small flame propagation test such as UL 94 V and FMVSS 302

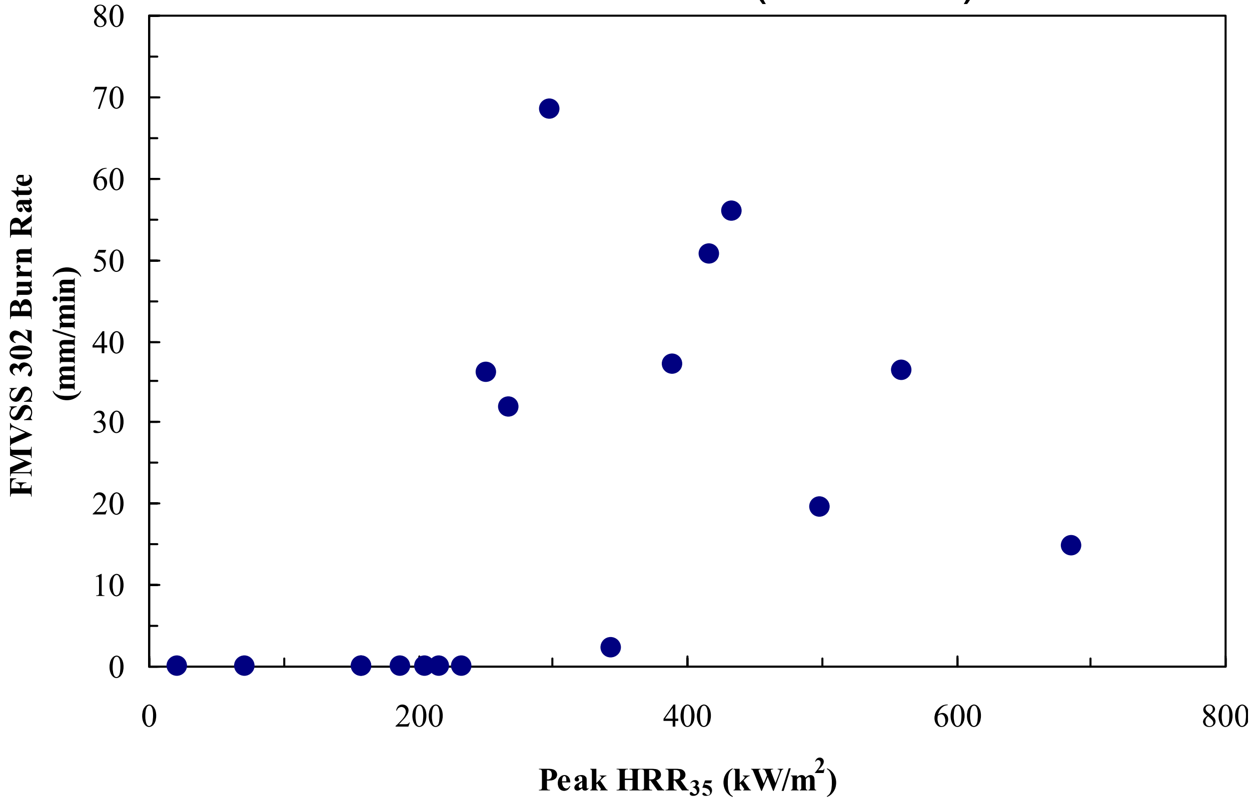
DATA ANALYSIS
Levels of Performance

Relationship Between Cone Calorimeter Data and FMVSS 302 Performance (10 of 13)

- The burn rate in the FMVSS 302 was plotted as a function of the heat release rate at 20, 35, and 50 kW/m^2 calculated from:
  - $HRR_0 + 20 \times HRP$, $HRR_0 + 35 \times HRP$, and $HRR_0 + 50 \times HRP$
- These plots were generated for the four different sets of HRR_0 and HRP values discussed earlier
- The best plot of the 12 that were generated is based on the peak heat release rate at 35 kW/m^2
  - Indicates that a flame will not propagate to the second mark in the FMVSS 302 test if the peak heat release rate in the Cone Calorimeter at 35 W/m^2 does not exceed 250 kW/m^2
  - The figure also shows that there is a poor correlation between peak heat release rates that exceed 250 kW/m^2 and FMVSS 302 burn rates

DATA ANALYSIS
Levels of Performance

Relationship Between Cone Calorimeter Data and FMVSS 302 Performance (11 of 13)



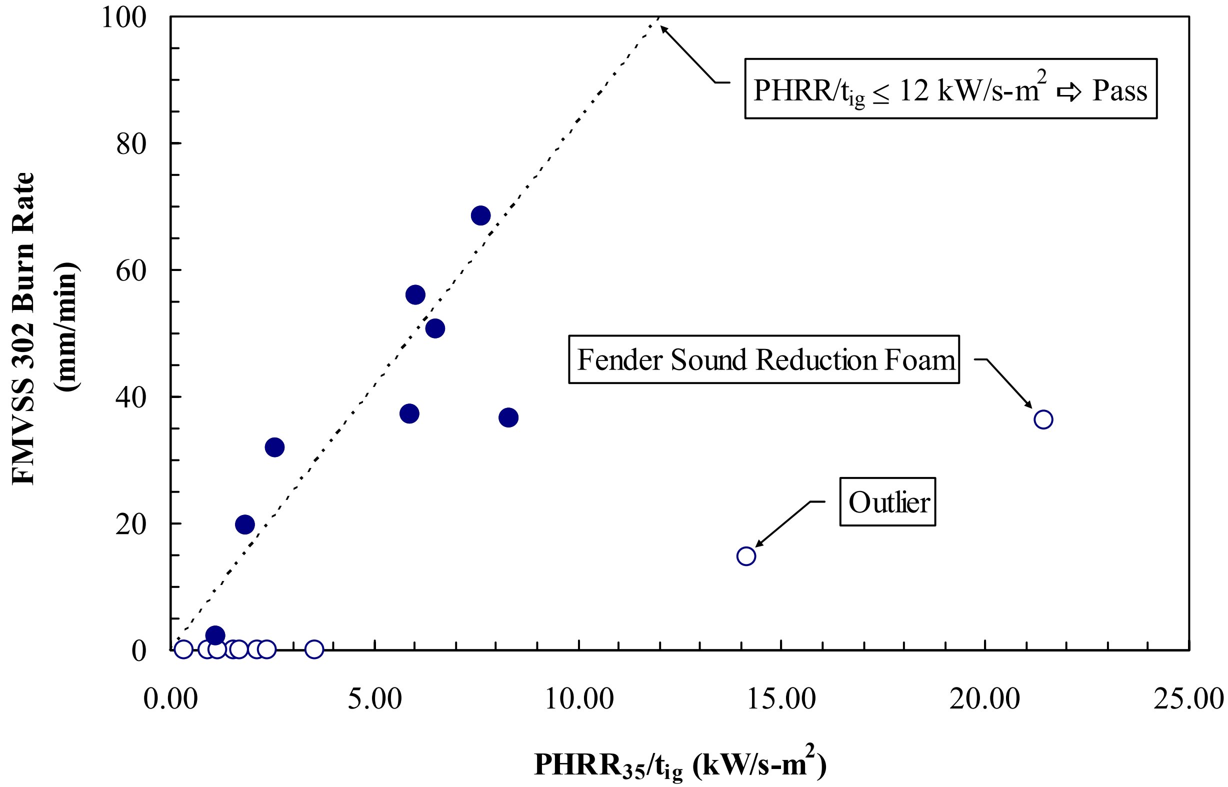
DATA ANALYSIS
Levels of Performance

Relationship Between Cone Calorimeter Data and FMVSS 302 Performance (12 of 13)

- A plot of FMVSS 302 burn rate versus peak heat release rate divided by ignition time at 35 kW/m^2 was generated
  - The use of this ratio is motivated by the fact that the flame length of a laminar diffusion flame is proportional to the heat release rate
  - The assumption is that the distance ahead of the flame front heated by the flame divided by the time to ignite the heated material is expected to correlate well with the burn rate
- Except for a few outliers, the agreement is reasonable. A ratio of 12 or less appears to be a sufficient condition to pass the FMVSS 302 test requirement

DATA ANALYSIS
Levels of Performance

Relationship Between Cone Calorimeter Data and FMVSS 302 Performance (13 of 13)

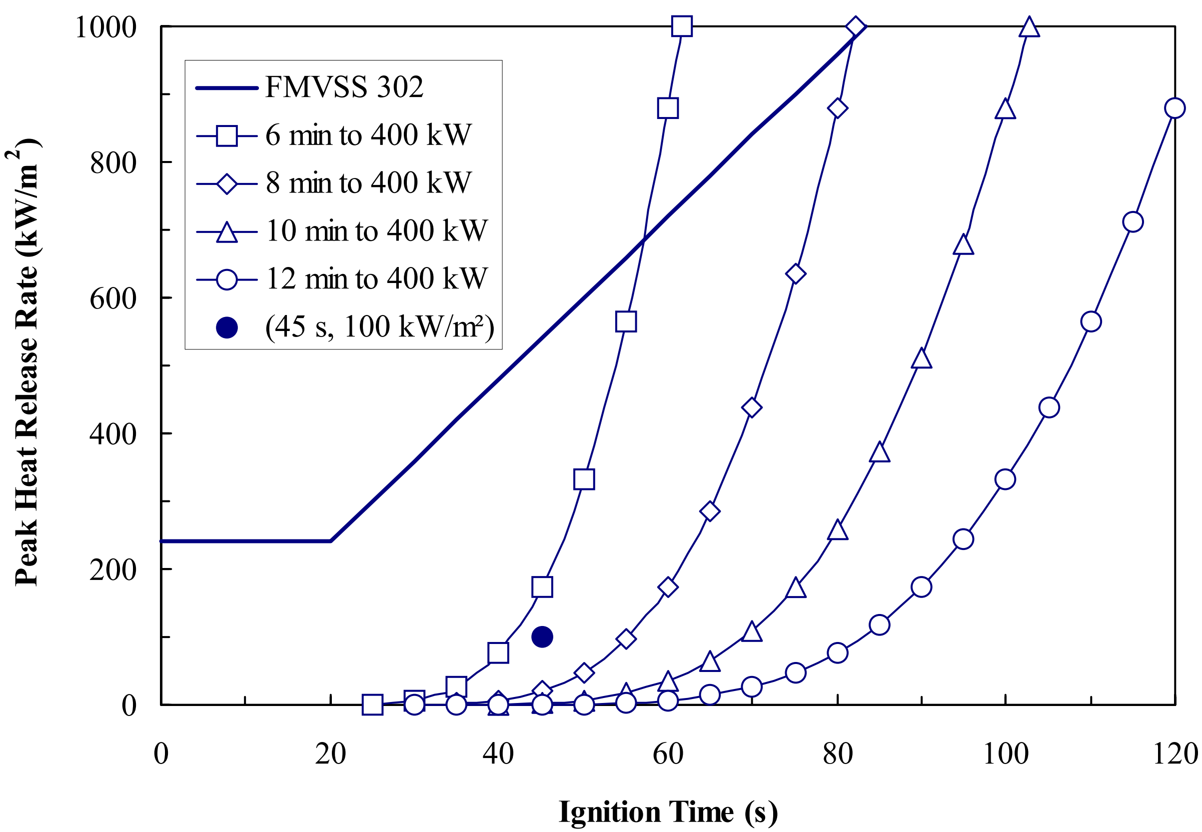


DATA ANALYSIS
Levels of Performance

Fire Performance Graph (1 of 4)

- The results obtained in the previous two sections (engine fire growth model and comparison of Cone data to FMVSS 302 data) can be summarized in graphical form
- A data point that falls below a specific curve indicates that the performance criteria associated with the curve are expected to be met

LEVELS OF PERFORMANCE
Fire Performance Graph (2 of 4)



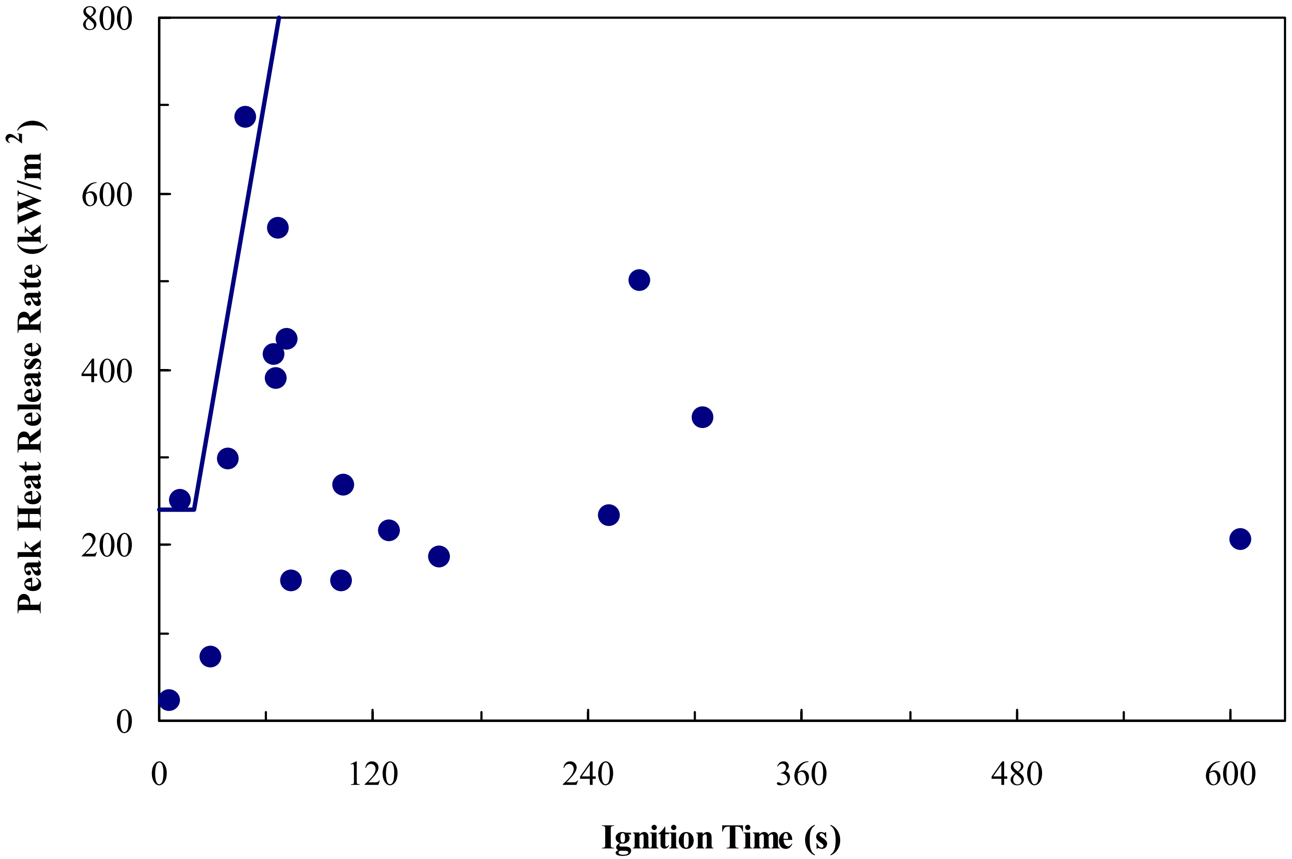
DATA ANALYSIS
Levels of Performance

Fire Performance Graph (3 of 4)

- A FMVSS 302 performance graph with the data points for the 18 materials that were tested was constructed
- Two data points fall slightly above the FMVSS 302 line. These are the points for the fender sound reduction foam and the second outlier in a previous graph relating FMVSS 302 test performance to heat release rate and ignition time
- This indicates that the performance graph provides a sufficient, but not a necessary condition to meet the FMVSS 302 requirements.

DATA ANALYSIS
Levels of Performance

Fire Performance Graph (4 of 4)



DATA ANALYSIS

Analysis of Supplemental Smoke Toxicity Measurements and Tests

Comparison to Literature Values (1 of 3)

- Tewarson has published CO yield data for a variety of polymeric materials generated using the ASTM E 2058 Fire Propagation Apparatus designed by FM
- A comparison between the CO yields measured for the materials used in this study from the MVFRI project and Tewarson's data is shown on the next slide
- The reported values for the PE, PP materials and the nylons are averages of the results obtained from the samples listed in the table.

DATA ANALYSIS

Analysis of Supplemental Smoke Toxicity Measurements and Tests

Comparison to Literature Values (2 of 3)

Material	CO Yields (mg/g)		Number of Samples	Included Samples	
	Tewarson	Measured Values		Vehicle	Sample
PE, PP	24	24±6	7	1996 Dodge Caravan	Air Ducts (4678345), Battery Cover (5235267AB), Brake Fluid Reservoir (4683264), Resonator Structure (4861057
				1997 Chevrolet Camaro	Air Inlet (10297291), Front Wheel Well Liner (10296526), Heater Module Blower Motor Housing (52458965)
PC	54	50	1	1996 Dodge Caravan	Headlight Lens - Clear Lens (4857041A)
Nylons	38	18±7	3	1997 Chevrolet Camaro	Engine Cooling Fan (22098787), Power Steering Fluid Reservoir (26019594), Radiator Inlet/Outlet Tank (52465337)
PS	60	52	1	1996 Dodge Caravan	Fender Sound Reduction Foam (4716345B)
PVC	63	9	1	1996 Dodge Caravan	Kick Panel Insulation Backing - Rubber side (4860446)

DATA ANALYSIS

Analysis of Supplemental Smoke Toxicity Measurements and Tests

Comparison to Literature Values (3 of 3)

- There is reasonable agreement between the results from the MVFRI project and Tewarson's data for the PE/PP, PC, and PS materials
- The poor agreement between the values for the nylon and PVC materials may be an indication of significant differences between the actual materials used in this study and Tewarson's work
- The lower values generally seen in this study may be reflective of the difference in ventilation between the Cone Calorimeter and the Fire Propagation Apparatus

Comparison of Cone Calorimeter Results with Smoke Box Measurements (1 of 4)

- The three materials tested were chosen based upon their performance in the Cone Calorimeter
  - Kick Panel Insulation Backing - Rubber Side (Part # 4860446) was chosen for its low CO_{MAX} value
  - Hood Liner Face (Part # 4716832B) was chosen for its intermediate CO_{MAX} value
  - Headlight – Clear Lens (Part # 4857041A) was chosen for its high CO_{MAX} value
- Peak CO concentration data from the two smoke box tests show a different ranking of the three materials

DATA ANALYSIS

Analysis of Supplemental Smoke Toxicity Measurements and Tests

Comparison of Cone Calorimeter Results with Smoke Box Measurements (2 of 4)

Method	Exposure	Part	Concentration (ppm)	Yield (mg/g)	Concentration(ppm)	Yield (mg/g)
Airbus	25FL	4857041A Headlight - Clear Lens	278	25.8	500.9	
		4716832B Hoodliner Face	927	82.2	1930.6	
		4860446 Kick Panel Insulation Backing - Rubber Side	653	29.5	993.6	
	25NF	4857041A Headlight - Clear Lens	0	0	0	
		4716832B Hoodliner Face	909	71	2329	
		4860446 Kick Panel Insulation Backing - Rubber Side	212	11	630	

DATA ANALYSIS

Analysis of Supplemental Smoke Toxicity Measurements and Tests

Comparison of Cone Calorimeter Results with Smoke Box Measurements (3 of 4)

Method	Exposure	Part	Concentration (ppm)	Yield (mg/g)	Concentration(ppm)	Yield (mg/g)
IMO	25FL	4857041A Headlight - Clear Lens		1	17	8
		4716832B Hoodliner Face		90	3745	171
		4860446 Kick Panel Insulation Backing - Rubber Side		6	185	13
	25NF	4857041A Headlight - Clear Lens		0	2	0
		4716832B Hoodliner Face		148	5130	245
		4860446 Kick Panel Insulation Backing - Rubber Side		23	87	44
	50NF	4857041A Headlight - Clear Lens		103	1342	137
		4716832B Hoodliner Face		215	3532	362
		4860446 Kick Panel Insulation Backing - Rubber Side		32	988	42

DATA ANALYSIS

Analysis of Supplemental Smoke Toxicity Measurements and Tests

Comparison of Cone Calorimeter Results with Smoke Box Measurements (4 of 4)

- At the 25 kW/m^2 exposures, the Headlight material produces the lowest CO concentrations and yields, rather than the highest
- The Headlight material shows an increase in CO levels relative to the other two materials in the 50 kW/m^2 IMO test

DATA ANALYSIS

Analysis of Supplemental Smoke Toxicity Measurements and Tests

Application of Limits (1 of 6)

- Airbus, Bombardier, and the IMO all require that materials meet certain limits on the concentration of gases measured during a standard smoke box measurement

	Airbus	Bombardier	IMO
CO_2	None	90000	None
CO	1000	3500	1450
HF	100	100	600
HCl	150	500	600
HBr	None	100	600
NO_x	100	100	350
HCN	150	100	140
SO_2	100	100	120

DATA ANALYSIS

Analysis of Supplemental Smoke Toxicity Measurements and Tests

Application of Limits (2 of 6)

- Airbus ABD 0031 requires that the average concentration of each gas as measured according to AITM 3.0005 shall not exceed the listed limits
- Bombardier's SMP 800-C also places limits on the average concentrations observed, but specifies wet chemistry
- Part 2 of Annex 1 to the IMO FTP Code places limits on the peak concentration observed during the test

DATA ANALYSIS

Analysis of Supplemental Smoke Toxicity Measurements and Tests

Application of Limits (3 of 6)

	Sample	Average Concentration (ppm)			
		CO	CO_2	HCl	NO_x
25FL	Headlight Lens - Clear Lens (4857041A) Polycarbonate	278	7635	0	0
	Hoodliner Face (4716832B) PET	927	4039	0	0
	Kick Panel Insulation Backing - Rubber side (4860446) PVC	653	7273	461	0
25NF	Headlight Lens - Clear Lens (4857041A) Polycarbonate	3	82	0	0
	Hoodliner Face (4716832B) PET	908	1579	0	0
	Kick Panel Insulation Backing - Rubber side (4860446) PVC	212	2061	399	0
Limits		1000	none	150	100
Result	Headlight Lens - Clear Lens (4857041A) Polycarbonate	Pass	NA	Pass	Pass
	Hoodliner Face (4716832B) PET	Pass	NA	Pass	Pass
	Kick Panel Insulation Backing - Rubber side (4860446) PVC	Pass	NA	FAIL	Pass

Performance Compared to Airbus +Acceptance Criteria

DATA ANALYSIS

Analysis of Supplemental Smoke Toxicity Measurements and Tests

Application of Limits (4 of 6)

	Sample	Average Concentration (ppm)			
		CO	CO_2	HCl	NO_x
25FL	**Headlight Lens - Clear Lens (4857041A) Polycarbonate**	278	7635	0	0
	Hoodliner Face (4716832B) PET	927	4039	0	0
	Kick Panel Insulation Backing - Rubber side (4860446) PVC	653	7273	461	0
25NF	**Headlight Lens - Clear Lens (4857041A) Polycarbonate**	3	82	0	0
	Hoodliner Face (4716832B) PET	908	1579	0	0
	Kick Panel Insulation Backing - Rubber side (4860446) PVC	212	2061	399	0
Limits		3500	90000	500	100
Result	**Headlight Lens - Clear Lens (4857041A) Polycarbonate**	Pass	Pass	Pass	Pass
	Hoodliner Face (4716832B) PET	Pass	Pass	Pass	Pass
	Kick Panel Insulation Backing - Rubber side (4860446) PVC	Pass	Pass	Pass	Pass

Performance Compared to Bombardier Acceptance Criteria

DATA ANALYSIS

Analysis of Supplemental Smoke Toxicity Measurements and Tests

Application of Limits (5 of 6)

	Sample	Average Concentration (ppm)			
		CO	CO_2	HCl	NO_x
25FL	Headlight Lens - Clear Lens (4857041A) Polycarbonate	17	5991	0	0
	Hoodliner Face (4716832B) PET	3745	15873	0	0
	Kick Panel Insulation Backing - Rubber side (4860446) PVC	185	2406	19	0
25NF	Headlight Lens - Clear Lens (4857041A) Polycarbonate	2	221	0	0
	Hoodliner Face (4716832B) PET	5130	5631	0	0
	Kick Panel Insulation Backing - Rubber side (4860446) PVC	89	793	36	0
50NF	Headlight Lens - Clear Lens (4857041A) Polycarbonate	1342	NT	0	0
	Hoodliner Face (4716832B) PET	3532	5170	0	0
	Kick Panel Insulation Backing - Rubber side (4860446) PVC	988	18329	1162	77
Limits		1450	none	600	350
Result	Headlight Lens - Clear Lens (4857041A) Polycarbonate	Pass	NA	Pass	Pass
	Hoodliner Face (4716832B) PET	FAIL	NA	Pass	Pass
	Kick Panel Insulation Backing - Rubber side (4860446) PVC	Pass	NA	FAIL	Pass

Performance Compared to IMO Acceptance Criteria

DATA ANALYSIS

Analysis of Supplemental Smoke Toxicity Measurements and Tests

Application of Limits (6 of 6)

- Kick Panel Insulation Backing - Rubber Side (Part # 4860446) failed to meet the criteria set by Airbus, due to excessive HCl formation in both flaming and non-flaming modes
- It also failed to meet the IMO criteria due to excessive HCl production during the 50 kW/m^2 exposure
- The Hoodliner Face (Part # 4716832B) failed to meet the criteria set by the IMO due to excessive CO production at both exposures and flaming modes
- All materials met the Bombardier specifications

DATA ANALYSIS

Analysis of Supplemental Smoke Toxicity Measurements and Tests

Use of Yields Measured in the Cone Calorimeter to Determine Toxic Hazard (1 of 3)

- The yields measured in the Cone Calorimeter, in theory, can be used to determine the toxic hazard to occupants in the passenger compartment from the products of combustion generated in an engine fire
- This calculation is very complex
  - Determine the burning rate of each part in the engine compartment as a function of time
  - The product of burning rate and yield of a particular toxic gas is equal to the generation rate of that gas
  - Based on the yields and mass loss rates, it is possible to determine the generation rate of different toxic gases as a function of time for each component

DATA ANALYSIS

Analysis of Supplemental Smoke Toxicity Measurements and Tests

Use of Yields Measured in the Cone Calorimeter to Determine Toxic Hazard (2 of 3)

- This calculation is very complex (cont.)
  - Next, it is necessary to determine how the generated toxic gases are diluted by entrained air and how the resulting gas mixture migrates into the passenger compartment
  - This leads to concentration versus time curves of the gas mixture to which occupants of the passenger compartment are exposed
  - A Fractional Effective Dose can be calculated to determine the time to incapacitation and lethality

DATA ANALYSIS

Analysis of Supplemental Smoke Toxicity Measurements and Tests

Use of Yields Measured in the Cone Calorimeter to Determine Toxic Hazard (3 of 3)

- There are obviously many sources of uncertainty in these calculations, but modeling smoke transport from the fire to the passenger compartment appears to be, by far, the most difficult part of the problem
- In addition, because the full-scale vehicle burn tests at FM demonstrated that toxicity appears to be a secondary issue, the effort to perform toxic hazard calculations can hardly be justified

DATA ANALYSIS

Alternative Materials (1 of 3)

- The use of metallic coatings to improve the fire performance of automotive materials has been explored
- It takes more time to ignite the coated specimens, but in some cases the peak heat release rate is higher than for the uncoated specimens
- Unfortunately, Cone Calorimeter data for the coated specimens are not available at 35 kW/m^2 and the net effect on the fire growth rate, according our engine fire growth model, cannot be determined.

DATA ANALYSIS

Alternative Materials (2 of 3)

- Instead, the times to reach 400 kW based on the ignition time and peak heat release rate at 50 kW/m^2 are provided
- The calculations show that all coatings result in a significantly lower fire growth rate
- It can be concluded, therefore, that application of a metallic coating presents a viable approach to improve the fire performance of automotive materials and bring their hazard below a specified level

DATA ANALYSIS

Alternative Materials (3 of 3)

Effect of Coatings on the Fire Hazard of Automotive Materials

Vehicle	Component	Coating	Uncoated			Coated		
			t_{ig} (s)	PHRR (kW/m^2)	$t_{400\ kW}$ (s)	t_{ig} (s)	PHRR (kW/m^2)	$t_{400\ kW}$ (s)
Caravan	Resonator Structure	1.75 μm Aluminum	19	517	126	34	396	237
Caravan	Resonator Structure	3.6 μm Aluminum	19	517	126	184	479	1242
Caravan	Resonator Structure	3.2 μm Antinmony Oxide	19	517	126	74	553	486
Caravan	Headlight	1.75 mm Aluminum	49	356	349	100	319	725
Caravan	Headlight	3.2 μm Antinmony Oxide	49	356	349	73	389	511
Camaro	Front Wheel Well Liner	1.75 μm Aluminum	18	526	119	100	648	637
Camaro	Front Wheel Well Liner	3.6 μm Antimony	18	526	119	50	826	304
Camaro	Front Wheel Well Liner	2.9 μm Antinmony Oxide	18	526	119	32	663	203
Camaro	Air Inlet	1.75 μm Aluminum	17	759	102	189	718	1181
Camaro	Air Inlet	3.6 μm Aluminum	17	759	102	226	939	1337
Camaro	Air Inlet	3.2 μm Aluminum Oxide	17	759	102	84	1249	467

CONCLUSIONS & RECOMMENDATIONS (1 of 9)

- The objectives of the NHTSA project are:
  - To develop a small-scale test methodology to rate automotive materials consistent with actual fire performance in vehicle burns and
  - To establish levels of performance for this test methodology that would significantly alter the fire outcome in terms of injury or survivability
- It has been demonstrated that the FMVSS 302 test, which is currently required for interior materials, is relatively mild and corresponds to a low level of performance in actual vehicle fires
- Moreover, it is a pass/fail type test and it may not be possible to change the acceptance criteria such that actual fire performance is sufficiently improved to result in the desired reduction of motor vehicle fire injuries and fatalities

CONCLUSIONS & RECOMMENDATIONS (2 of 9)

- It is also shown in Section 5.3 that the Cone Calorimeter provides quantitative data that can be used to determine the heat release rate of a growing engine fire as a function of time
- Full-scale vehicle burn tests have shown that post-crash engine fires become a threat to occupants trapped in the passenger compartment when the heat release rate reaches approximately 400 kW

CONCLUSIONS & RECOMMENDATIONS (3 of 9)

- Consequently, the time to this critical condition for a specific material can be determined on the basis of the following equation

$$t_{cr} = t_{ig}\left[1 + 1.233\,\mathbf{ln}\left(\frac{400}{0.0079\dot{Q}''}\right)\right]$$

where t_{cr} is the time to a critical condition (heat release rate of 400 kW) in sec, t_{ig} is the time to ignition measured in the Cone Calorimeter at 35 kW/m^2, and is the peak heat release rate measured in the Cone Calorimeter at 35 kW/m^2

CONCLUSIONS & RECOMMENDATIONS (4 of 9)

- Based on NHTSA's goal for a reduction of the number of fatalities and injuries in motor vehicle fires, it is recommended that statistics of post-crash fires originating in the engine compartment be analyzed to determine the corresponding shortest time for fire spread into the passenger compartment, t_{min}
- If materials are used so that the actual time is equal to or greater than t_{min}, the expected number of fatalities will be equal to or less than the desired number
- In summary, it is suggested that candidate materials for components in the engine compartment be tested in the Cone Calorimeter at 35 kW/m^2, and that acceptance be based on the requirement that $t_{cr} \geq t_{min}$

CONCLUSIONS & RECOMMENDATIONS (5 of 9)

- To validate this concept, a number of comparative full-scale fires tests could be conducted
- It was demonstrated in this study that the use of metallic coatings is a viable option to improve fire performance and delay fire growth in the engine compartment of a motor vehicle
- Therefore, it is suggested that at least two experiments be conducted
- Both experiments involve the same make and vehicle model. The vehicle is first tested without any modifications. Surfaces of plastic components in the engine compartment are treated with a metallic coating prior to the second test
- The fire initiates in the engine compartment and temperatures, heat fluxes and toxic gas species are measured to determine the time to untenable conditions for occupants in the passenger compartment

CONCLUSIONS & RECOMMENDATIONS (6 of 9)

- The NHTSA project only addresses materials of plastic components in the engine compartment.
- Motor vehicle fires that originated in the passenger compartment would have to be analyzed to determine whether the same Cone Calorimeter criteria are adequate, or whether they can or should be changed to meet specific survivability objectives for this fire scenario
- A similar analysis would also have to be performed to address fires that involve a rear-end collision and subsequent underbody pool fire
  - For this scenario it may not be possible to meet survivability objectives through material performance specifications, and other fire protection strategies may have to be explored (fire-resistant boundaries, fire suppression systems, etc.)

CONCLUSIONS & RECOMMENDATIONS (7 of 9)

- The MVFRI project involved additional measurements of toxic gases in the duct for most of the Cone Calorimeter tests
- Concentrations of CO, CO_2, HCl, HCN, and NO_x were measured continuously during each test with an FTIR spectrometer
- The concentration measurements were used to calculate yields, *i.e.*, the total mass of each toxic gas generated during flaming combustion divided by the mass loss of the fuel over the same period
- CO yields obtained in this study are comparable in magnitude, but consistently lower than values reported in the literature for the same generic classes of materials
  - This can be explained by the fact that the literature values were obtained in the Fire Propagation Apparatus (ASTM E 2058) under reduced ventilation conditions compared to the Cone Calorimeter.

CONCLUSIONS & RECOMMENDATIONS (8 of 9)

- Three materials were selected from the set of 18 for an evaluation in two commonly used toxicity test procedures
  - The Airbus ABD 0031 procedure is based on the NBS smoke chamber (ASTM E 662) and involves supplemental gas analysis
  - The IMO smoke and toxicity test procedure is detailed in Part 2 of Annex 1 to the FTP code and is based on a modified version of the NBS smoke chamber as described in ISO standard 5659 Part 2
  - Both procedures specify acceptance criteria that include limiting concentrations of CO, HCl, HCN, NO_x, and a few additional gases
- The three materials that were selected had the lowest, median, and highest peak CO concentrations in the Cone Calorimeter tests for all of the materials that were tested

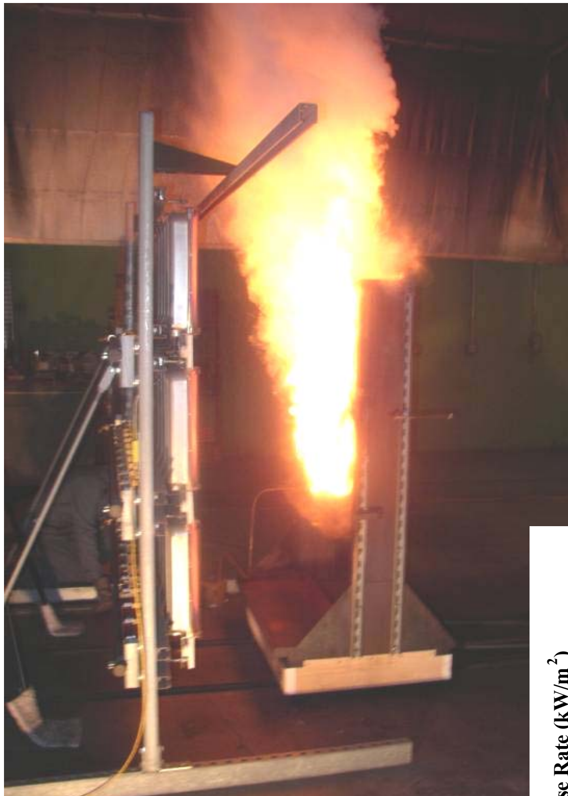
CONCLUSIONS & RECOMMENDATIONS (9 of 9)

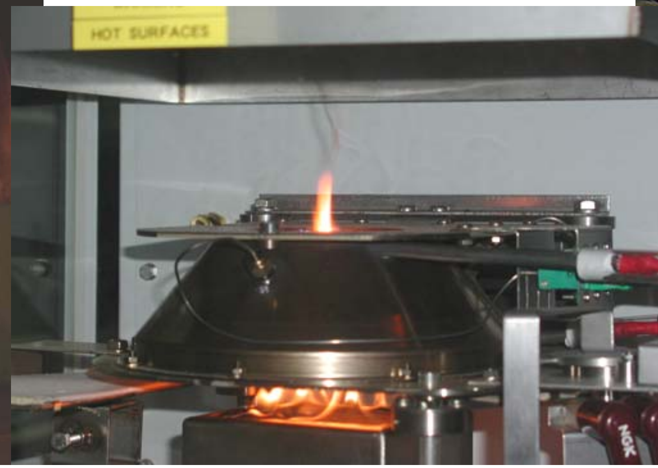
- The material with low peak CO concentration in the Cone Calorimeter was a PVC and exceeded the limits for HCl in the IMO and Airbus tests
- The material with median CO in the Cone Calorimeter failed the IMO test, and the material with high CO in the Cone Calorimeter marginally met the IMO and Airbus requirements
- It can be concluded from these tests that the CO concentrations in the Cone Calorimeter are not consistent with those in box-type toxicity tests
  - This can be explained by the fact that plenty of excess air is continuously supplied in the Cone Calorimeter, while the atmosphere in the IMO and Airbus smoke chambers typically becomes vitiated during a test

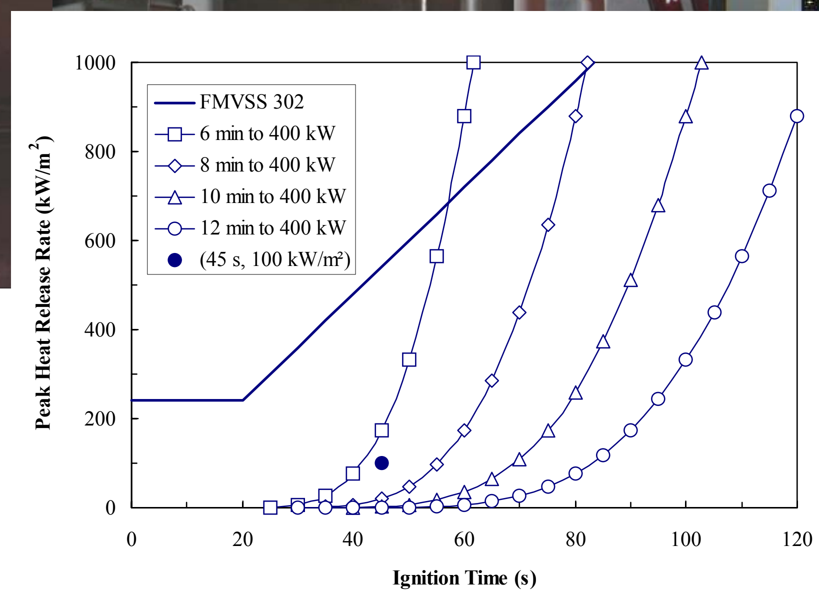
ACKNOWLEDGEMENTS

- The authors greatly appreciate the financial support for this project from Mr. Carl Ragland at the National Highway Traffic Safety Administration (NHTSA) of the US Department of Transportation (DOT) in Washington, DC
- The authors also would like to thank Dr. Joe Urbas at the Pacific Fire Laboratory in Kelso, WA for conducting the ICAL experiments
- Also, the authors would like to thank Drs. Ken Digges and Rhoads Stephenson at the Motor Vehicle Fire Safety Institute (MVFRI) in Charlottesville, VA for additional funding of the toxicity study

QUESTIONS?




HOT SURFACES


Peak Heat Release Rate (kW/m^2)
Ignition Time (s)
FMVSS 302
6 min to 400 kW
8 min to 400 kW
10 min to 400 kW
12 min to 400 kW
(45 s, 100 kW/m²)
0
200
400
600
800
1000
0
20
40
60
80
100
120