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July 31, 1997

The Honorable Philip R. Recht
Deputy Administrator
NATIONAL HIGHWAY TRAFFIC
SAFETY ADMINISTRATION
400 Seventh Street, S.W., Room 520
Washington, DC 20590

Dear Mr. Recht:

Re: **Settlement Agreement**
Section B. Fire Safety Research

Enclosed is a technical report entitled "Evaluation of Motor Vehicle Fire Initiation and Propagation, Part 1: Vehicle Crash and Fire Propagation Test Program."

This relates to Project B.3 Fire Initiation and Propagation Tests.

Sincerely,

James A. Durkin
Attorney

JAD:dld
Enclosure

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Evaluation of Motor Vehicle Fire Initiation and Propagation
Part 1: Vehicle Crash and Fire Propagation Test Program

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Introduction

On March 7, 1995, General Motors and the US Department of Transportation entered into an agreement (hereafter referred to as the Agreement) to settle a dispute regarding the safety of 1970-1991 full-sized GM pickup trucks equipped with fuel tanks mounted outboard of the frame rails. Part of this Agreement involves the establishment of a 5 year, $10 million motor vehicle fire safety research program. The overall objectives of this research program are to better understand how vehicle fires start and spread and to determine what can be done to prevent, contain and extinguish such fires. To this end, GM and the National Highway Traffic Safety Administration (NHTSA) have jointly developed 14 separate vehicle fire safety research projects. One of these projects, entitled "B.3 Fire Initiation and Propagation Tests", is the subject of this technical report.

This report outlines the overall strategies for this research project including research objectives, testing matrix, test conditions, and vehicle selection criteria. This report does not present results of any tests; these will be documented in subsequent technical reports. The following statement describing Project B.3 was developed by GM and the National Highway Traffic Safety Administration:

> "Vehicle crash tests, including for example frontal and rear impacts, will be conducted. The crash test results, particularly the fluid plumes that result from component failures during the collision events, will be analyzed for fire initiation potential. These data will be used to develop a standard initiation protocol. Crash tested vehicles will be burned, using this standard initiation protocol; and fire propagation characteristics, such as component temperatures, flame spread and combustion off-gases will be studied, particularly in their effects in the passenger compartment."

The project statement of work delineated three major objectives:

1. Design and conduct vehicle crash tests to identify fire initiation potential. Specific objectives include:
    - Determine potential heat sources such as electrical shorts or hot surfaces during or after the impact;
    - Identify potential fuel sources including: gasoline leaks, other fluid leaks, presence of hydrocarbon vapors resulting from fluid leaks, and solid fuel sources;
    - Measure standard vehicle crashworthiness and occupant injury parameters.

    As necessary, the crash test protocol developed for this work will utilize specialized instrumentation and test conditions not normally used for vehicle certification or engineering development.

2. Develop standard initiation protocols for the vehicle fire propagation tests. The objective of this task is to develop controlled, reproducible, and realistic procedures for igniting fires for use in the vehicle fire tests. Ignition protocols will be developed to simulate both engine compartment fires and gasoline-pool fires.

3. Design and conduct vehicle fire propagation tests using the vehicles crash-tested in Task 1 and the initiation protocols developed in Task 2. The objectives of the fire propagation tests include:
    - Determine the major paths and time-lines for fire propagation, especially entry of fire into the passenger compartment;

- Identify what components burn and measure the thermal environments around these components during the fire;
- Measure air temperature, heat fluxes, and toxic gas concentrations in the passenger compartment.

Two research laboratories with expertise in fire science are participating in this research program. The Building and Fire Research Laboratory of the National Institute of Standards and Technology (NIST) is participating through a cooperative research and development agreement (CRADA). Factory Mutual Research Corporation (FMRC) is involved in this research program through a research contract. Technical personnel from GM and from the NHTSA selected the vehicles and developed the crash test conditions to be used in this program. Technical personnel from GM, NHTSA, NIST, and FMRC worked jointly to develop the protocols for fire initiation and for the fire propagation tests.

1. Design and Conduct Vehicle Crash Tests

Research Objectives

The objective of these crash tests is to develop a better understanding of events that occur during a vehicle collision which could result in a post-collision fire. Fire requires three components: a source of heat, a source of fuel, and oxygen. Here, fuel refers to any flammable or combustible material that can ignite when exposed to heat. Combustion is a self-sustaining gas-phase chemical reaction in which the heat released by oxidation of the fuel is sufficient to maintain the oxidation process. Ignition of the fuel can occur by one of two mechanisms [1,2]. Piloted ignition occurs when a flame or spark ignites a fuel/air mixture, where the concentration of the fuel in air is within the lower- and upper-limits of flammability. Ignition can occur in the absence of a pilot source if the temperature of the igniting object is greater than the autoignition temperature of one of its constituent materials.

Potential fuels for a post-collision fire could be any of the flammable or combustible liquids, or combustible solids in the vehicle. Most automotive fluids are flammable or combustible, or contain combustible constituents. Gasoline, motor oil, and power steering fluid are mixtures of hydrocarbons. Brake fluids conforming to DOT3 or DOT4 specifications [3] are composed of end-capped poly(glycol ethers). Although engine coolant and washer fluid are water-based, both fluids contain combustible components: ethylene or propylene glycol and methanol, respectively. Damage caused by the vehicle crush may produce leaks in some of the fluid systems, releasing these fuels into or around the vehicle. The plastics and elastomers used in vehicles also are combustible. The amount of thermal energy required to increase the temperature of a combustible solid to above its flash-point or fire-point is generally greater than that required for any of the automotive fluids. One exception can be foamed solid materials which, because of their lower density, are often more easily ignited than liquids.

A number of ignition sources could be present during a crash, some of which are not present in an undeformed vehicle. Hot surfaces such as those of the exhaust system, which includes the exhaust manifold, exhaust pipes, and catalytic converter, can act as an ignition source by transferring thermal energy (heat) to a contacting combustible material raising its temperature above the autoignition temperature for that material. Short circuits in the electrical system caused by the vehicle crush can ignite combustible materials by the same mechanism. Electrical arcing, metal-to-metal and metal-to-ground (road surface) friction-sparks can be piloted ignition sources for a flammable vapor only if the concentration of the vapor is within its limits of flammability when and where the arc or spark occurs.

It is the goal of these tests to characterize both fuel sources and ignition sources in the vehicle crash tests described below.

Test Vehicles

In order to represent the current United States vehicle fleet, several different vehicle types produced by different manufacturers will be used for these crash tests. The purpose of the crash testing is not to compare the performance of different vehicle models or vehicle types but rather to increase the understanding of post-collision fires and how they start. As it will not be feasible to test all vehicle types currently available in the market, the following four vehicle types were selected: 1) passenger van, 2) rear wheel drive mid-sized passenger car, 3) sport utility vehicle, and 4) front wheel drive mid-sized passenger car. Both a front- and a rear-wheel drive passenger car will be tested because these vehicle types have significantly different power-train configurations. As shown in Table 1, the market segments represented by midsize cars, vans, and sport utility vehicles, cumulatively account for greater than 50% of 1995 United States passenger vehicle sales [4].

Table 1
Year-To-Date Sales of Passenger Cars and Light Trucks in the United States for 1995 By Market Segment [4]
(As Of October 15, 1995)

MARKET SEGMENT	MARKET SHARE
small car	15.7
mid-size car	28.8
large car	6.5
luxury car	8.0
sport-utility vehicle	11.6
van	11.6
pickup truck	18.3

Since the results of these tests will be available to the public, and will be accessible by the entire automobile industry, the specific models selected for these tests are from different manufacturers. Also, selection of vehicles from a variety of manufacturers will result in a better representation of the overall vehicle fleet than would the selection of several vehicles from a single manufacturer. Market share by manufacturer for the 1995 U.S. market of cars and trucks is shown in Table 2 [5].

Table 2
Market Share of
1995 Model Year United States Vehicle Sales [5]

Manufacturer	Market Share		
	Cars	Trucks	Total Vehicle
Chrysler	9.2	22.1	14.5
Ford	21.4	32.2	25.8
General Motors	33.5	31.8	32.8
Total Asian-Based	31.0	13.7	23.9
Total European-Based	5.0	0.3	3.1

Vehicle selection was based on three criteria: 1) each of the four vehicle types will be represented, 2) the three U.S.-based manufacturers and at least one Asian manufacturer will be represented, and 3) only vehicles with significant sales volume were considered. The vehicles are not necessarily segment leaders, but strong sales performers in their respective markets. The following models were selected for these tests:

- 1996 Dodge Caravan Sport
  (w/ 3.3 l V6, 4 speed automatic, driver-side sliding rear door)
- 1997 Chevrolet Camaro
  (w/ 3.8 l V6, 4 speed automatic)
- 1997 Ford Explorer
  (w/ 4.0 l V6, 4 wheel drive, 4 door, 5 speed automatic)
- 1998 Honda Accord (options to be determined)

Engine, drive-train, and air conditioning options will be selected based on the most popular selling options anticipated for that vehicle using published sales figures from previous model years. Other options will not be specified but kept constant for a given vehicle type (*e.g.* all Chevrolet Camaros tested will have the same option packages). Specific vehicle identification numbers and option packages will be documented in the subsequent technical reports on the results of the crash and fire propagation tests.

Market share of the specific models selected is shown in Appendix 1.

Crash Tests

To better represent the wide variety of crash conditions which may occur in the field, the four vehicle types will be tested in different crash conditions. The criteria used to develop these crash tests include the following:

- The crash tests are intended to be severe and do not represent current Federal Motor Vehicle Safety Standards. Crashes of low severity which do not result in substantial damage to the vehicle structure, the electrical system, or the fluid systems would provide little information about how post-collision fires start.
- The intent of the crash test matrix is not to compare the performance of vehicles or vehicle types.
- The test matrix will include both frontal and rear impacts per the terms of the Agreement.
- The crash tests should represent conditions which are field relevant.

An analysis of FARS (Fatal Accident Reporting System) data from 1979 through 1992 by the NHTSA [6] was reviewed to identify those conditions which are field relevant. This analysis suggested that frontal and rear impacts should be included in this testing.

Frontal impacts will be included because there were more frontal impacts than rear impacts, side impacts, or rollovers which resulted in a fire and a fatality. This was simply because frontal impacts in general were more common than rear or side impacts. See Table 3, which combines the reported incidents for cars, trucks and vans from the NHTSA analysis.

Table 3: A 1994 NHTSA analysis of 1979 - 1992 FARS data [6]
Car, Trucks, and Vans

Damaged Area	Number of Fatal Crashes	Number of Fires	Percent Fires	Number MHEF	Percent MHEF
Rollover	70189	2127	3.03	679	0.97
Front	212009	**4750**	2.24	**1319**	0.62
Rear	15608	717	**4.59**	294	**1.88**
Side	75697	1472	1.94	376	0.50
Other	14892	427	2.87	167	1.12

Also included in Table 3 are those incidents in which fire was judged to be the most harmful event (MHEF). Not only did frontal impacts result in the greatest number of fires, they also resulted in the greatest number of MHEF. As described in reference [6] the classification of fire as the most harmful event is based on the personal judgment of the FARS data analyst in each state. The fact that a fire was identified as the most harmful event does not necessarily mean that there was a fatality in the particular vehicle due to fire. Conversley, the fact that fire was not classified as most harmful event does not preclude a fire fatality for a particular crash analysis.

Even though there were fewer incidents of rear impact fatalities with a fire than frontal impact fatalities with a fire, the probability of a fire given a rear impact was about twice that for frontal impacts. Moreover, the probability of fire being the most harmful event given a rear impact was approximately three times greater than for frontal impacts. This supported including at least one rear impact in the test matrix.

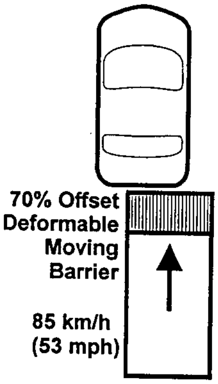
The NHTSA study [6] of incidents resulting in a fire and fatality suggested that the most common object struck is another vehicle, as indicated in Table 4. However, the likelihood of fire was greatest for impacts to narrow objects (*e.g.*, trees).

The four crash conditions initially developed for this research project, include three frontal and one rear impact. These crash conditions simulate either a vehicle-to-vehicle or vehicle-to-narrow object impact. The speeds were selected using engineering judgment rather than an analysis of field data, and are intended to produce significant damage to the vehicle's structure, electrical or fluid systems. All vehicle crash tests will be conducted at the General Motors Proving Ground in Milford, Michigan.

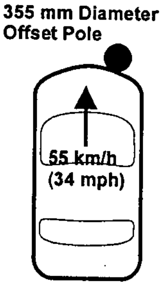
Table 4: A 1994 NHTSA analysis of 1979 - 1992 FARS data [6]
Car, Trucks, and Vans

Object Struck	Number Fatal Crashes	Number Fires	Percent Fires	Number MHEF	Percent MHEF
Vehicle	224560	**5098**	2.27	**1217**	0.54
Narrow	35899	1766	**4.92**	678	**1.89**
Fixed	45168	1938	4.29	737	1.63
Other	56925	332	0.58	95	0.17
Overturn	25784	355	1.38	108	0.42

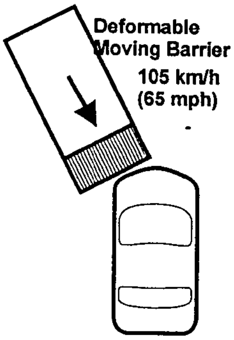
Deformable Rear Moving Barrier at 85 km/h. A moving barrier similar to the FMVSS 214 [7] vehicle impactor will be used to impact the stationary test vehicle in the rear with a 70% overlap on the filler neck side of the vehicle. The direction of impact will be parallel with the center line of the vehicle. And, unlike FMVSS 214, the wheels of the barrier will be aligned with the longitudinal axis of the barrier. The barrier will have an impact velocity of 85 km/h (53 mph). The offset will be set so that 70% of the vehicle will be engaged (measuring the width of the vehicle as the widest part of the body vertically in line with the rear axles.) The standard FMVSS 214 deformable face will be used and will be positioned at its standard height (bumper centerline 17" above grade.) The mass of the moving barrier will be 1367 kg (3015 lb).



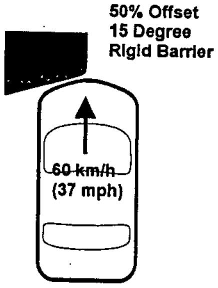
Frontal Offset Pole Impact at 55 km/h. The test vehicle will be towed into a fixed, rigid 355 mm (14") diameter steel pole at 55 km/h (34 mph). The impacted side will be vehicle specific and the offset will be 305 mm (12 in.), measured from the center of the pole to the centerline of the vehicle.



Oblique Moving Barrier Impact at 105 km/h. The test vehicle will be stationary and impacted with a moving barrier similar to the FMVSS 214 [7] vehicle impactor with a deformable face. The barrier will not be crabbed, but its approach will be aligned at a 20 - 30 degree angle (vehicle specific) relative to the test vehicle and will impact the front fender. To maximize the test severity, the vehicle will be positioned so that the trajectory of the center of gravity (CG) of the barrier passes through the CG of the test vehicle. The mass of the moving barrier will be 1600 kg (3600 lb.), which is greater than what is used for FMVSS 214 tests (1367 kg (3015 lb.)). The deformable face will be the standard FMVSS 214 face at the standard height (bumper centerline 17" above grade). The impact side will be vehicle specific, but will likely be opposite of the side impacted with the offset pole test.



Offset Rigid Barrier at 60 km/h. In a single test, a Dodge Caravan was towed into a rigid angled (15 degrees) barrier with a 50% overlap on the driver's side. The impact speed was 60 km/h (37 mph). As explained below, the other vehicles will not be subjected to this test.



The specific crash test configurations may be changed as testing progresses to best utilize available resources and meet the research objectives. For example, the crash tests of the Dodge Caravan have been completed and did not include a rear impact. The NHTSA (through its contractor, Transportation Research Corporation in East Liberty, Ohio) had conducted a similar rear impact crash test on March 2, 1996 using a Plymouth Voyager. These test results suggested that little new information about post-collision fire ignition sources would be gained by repeating the test with a Dodge Caravan.

After the initial crash tests and during the instrumentation of the vehicles for the fire propagation tests on the Dodge Caravan, it was realized that the initial testing matrix was too ambitious given the available resources. This was primarily due to the extensive instrumentation required on the fire propagation tests and the special instrumentation required on the crash tests. The level of instrumentation required could not be fully estimated until research began and the damage to the vehicle structures from these crash tests was fully determined. Therefore, NHTSA and GM researchers agreed to conduct only 2 frontal impacts on the remaining vehicles rather than the 3 initially proposed. The results of the Caravan crash tests indicated that the offset rigid barrier test resulted in the least amount of useful information to quantify possible post-collision ignition sources and this configuration will likely not be used for the subsequent tests.

Crash Test Instrumentation and Vehicle Set-up

The main objective of the crash tests is to identify potential fire ignition sources during a vehicle collision. Instrumentation to detect these events is not usually included on vehicle certification or engineering development crash tests. Following is a description of the instrumentation and test set-up, much of which is experimental and has been developed specifically for these tests.

Vehicle Condition New vehicles will be purchased for these tests. The test mass will be the mass of the vehicle as delivered (with full fluids) plus the mass of the anthropomorphic test devices (ATDs) and the crash-test instrumentation. More instrumentation than typically included in a crash test may be required and thus the test mass of the vehicle may be higher than what is specified for FMVSS 208 [8] testing. To retain the integrity of the vehicle for the fire propagation tests, no parts will be destroyed or cut prior to the test. The transmission will be in neutral and any electrical circuits which are being monitored will be activated during the impact. As an example, electric cooling fans frequently cycle on and off, and if these circuits will be monitored, then the vehicle impact will be timed such that the cooling fans are on at impact. Also, if the headlight circuits are being monitored, they will be on for the test. The front driver and passenger windows will be down for all tests.

The hood may be removed for some of the frontal tests to improve photographic coverage of the engine compartment. When this is done, the NIST will provide image analysis of the spray patterns of the under-hood fluids released during the crash. The presence of a vehicle hood may have little influence on the deceleration time history because it does not carry significant loads during an impact. However, the hood may play a more significant role in terms of vapor retention should fluid leaks develop during the crash. Flammable vapors from fluid leaks will disperse more quickly with the hood removed, thus resulting in an unrealistic high rate of vapor loss from the engine compartment. The absence of a hood also alters the dispersion patterns of fluid sprays in the engine compartment. This tradeoff will be judged on a test by test basis and it is likely that some tests may be conducted with the hood in place, while others will be conducted with the hood removed.

Engine. The test vehicle's engine will be allowed to run during all of the frontal crash tests with complete vehicle fluids (including battery electrolyte). Preliminary temperature measurements will be conducted to determine operating engine temperatures at various road speeds and loading conditions. It is unlikely that actual road-load temperatures throughout the engine will be matched because it is impractical to drive or somehow provide loading to the vehicle immediately before the crash. However, the engine will be allowed to run at higher than idle speeds to obtain higher than idle temperatures for the crash test. This warm up procedure may result in engine temperatures either hotter or cooler than actual road loads. Following a warm up time of approximately 20 to 30 minutes, the engine will be shut down for instrumentation calibration and set-up (approximately 5 minutes). The engine will be restarted and engine speed will again be increased to above idle speed. Gasoline will be supplied to the engine from an auxiliary fuel tank mounted inside the passenger compartment and connected to the gasoline supply line away from any anticipated vehicle crush. A production fuel pump system will be installed in this auxiliary tank and electrically connnected in place of the existing pump. The production gas tank will be filled to 95% of its usable capacity with Stoddard Solvent.

For the rear impact tests, the fuel tank will be filled to 95% of its usable capacity with Stoddard Solvent. The engine will not be running during the crash test, nor will it have been run prior to the test to minimize the probability of igniting spilled Stoddard Solvent if a fuel system-rupture should occur. However, the ignition will be on and the fuel lines charged. A plastic bag will be sealed around the filler cap to retain and detect the presence of Stoddard Solvent that has escaped from the cap during the impact. Normal collection procedures used for FMVSS 301 [9] testing will be used to quantify fuel system leaks after the impact.

Electrical Current and Voltage. Some, but not all, of the vehicle's electrical systems will be measured during the crash test to help identify potential electrical shorts which may result in ignition sources. These measurements may include both voltages and currents. The currents will be monitored using clamp-on non-intrusive current transducers, while voltages will be measured directly. It will be impractical to measure the condition of every engine compartment circuit, and so prudent engineering judgment will be used to help identify those circuits which are most likely to be damaged by the impact and possibly result in an ignition source. Electrical circuits to be monitored during the frontal tests may include the starter wire, the alternator wire, main battery feeds, the electric cooling fans, the headlights and other circuits specific to the vehicle. Circuits to be monitored for the rear impacts may include the rear taillights, the center high mounted stop light, the rear window defroster and other vehicle specific circuits.

Fluid Pressure. Pressure transducers (Model 8510B and 8510C Pressure Transducers, Endevco, San Jaun Capistrano, CA) will be installed to measure the dynamic pressures of key vehicle fluids during the frontal impacts. This will enable identification of the times at which fluid leaks may develop and correlate to structural damage during the crash. For the frontal tests, fluid pressures will be measured in the gasoline supply and return lines, the front brake lines, the engine coolant system, the power steering system, engine crankcase, and transmission. For the rear crash tests, fluid pressures will be measured only in the gasoline supply and return lines.

Fuel Pump. The fuel pump will be energized during the crash tests. For the frontal tests this will be the auxiliary fuel pump located in the auxiliary fuel tank. The electrical power to the fuel pump will be measured to determine when the fuel pump stops. In addition, the rotation of the engine will be measured either by monitoring the on-board engine-speed sending unit and/or by mounting a magnetic speed sensor (Model MP1A High Sensitivity Magnetic Pickup, Philips Technologies, Airpax Instruments, Chesire, CT) adjacent to the flywheel. Some vehicle fuel pumps are designed to shut down when the engine rotation stops, which typically occurs with severe frontal impacts. These two measurements allow the correlation of engine speed to fuel pump status.

Flammable Vapors. Two types of chemical analyses will be performed during the crash test to determine the contribution of fluid leaks to the development of a potentially flammable fuel/air mixture. The concentrations of flammable vapors will be measured with tin oxide semiconductor gas sensors (TGS 813, FIGARO USA, Inc, Wilmette, IL). These sensors are robust, have a fast response, require minimal electronic circuitry, but require careful calibration for accurate measurements.

In addition to the measurements of flammable vapor concentration, samples from each sensor-location will be collected on sorbent cartridges for analysis. The gases retained on the sorbent material in these cartridges will be identified by thermal desorption/gas chromatography (TD/GC) or by thermal desorption/gas chromatography/mass spectrometry (TD/GC/MS). Elucidation of the chemical composition of the gases at each location will help to identify the source of the flammable vapor.

Instrumentation to perform these measurements will be included in all the frontal crash tests. For the frontal crash tests, gas sensors and sampling tubes will be located near potential ignition sources (*e.g.*, hot surfaces and likely points of electrical arcing). Since the fuel tank will contain Stoddard Solvent, which has a significantly lower vapor pressure than gasoline, flammable vapor measurements will not be performed during the rear impact tests.

Vehicle Brakes. The dynamic brake fluid pressure will be monitored in the frontal tests in order to identify the times of potential brake fluid leaks.

For the offset pole and the offset barrier tests, the brake lines to the front wheels may be isolated from the brake calipers allowing the brake lines to be charged but still allowing the wheel to turn during the vehicle tow. This will be done so a steady state brake pressure can be measured and any drop in brake pressure during the impact will be easily identifiable. For typical crash tests, an auxiliary brake machine is sometimes used to apply the brakes remotely at or shortly after impact. During the initial application of the brakes, however, there is a time delay in the rise of brake pressure and a steady state pressure may not be realized during the time of any leaks. It is desirable to have the brake lines pre-charged during the vehicle tow to identify more clearly a drop in brake pressure. Also for these two tests, an auxiliary brake machine will be connected to the rear brakes and used only to abort the test, if necessary, during tow. For the oblique moving barrier test, the rear brakes will be disconnected from the brake lines and charged by an auxillary brake machine. The front brakes will be pressurized by loading the brake pedal and mechanically locking it down.

For the rear impacts, the front brakes will be activated with the auxiliary brake machine within 200 msec following the impact to help control the post-impact vehicle motion. The brake line pressure will not be monitored during these tests.

Crashworthiness of Experimental Fire Detection and Suppression Devices. Project "B.4 Evaluation of Potential Fire Intervention Materials and Technologies" involves evaluation of fire detection and suppression systems for automotive applications. The crash tests described here provide an excellent opportunity to evaluate the crashworthiness of several proposed detection or suppression technologies. Therefore, some experimental fire detection devices will be included on some of the crash tests. Examples of technologies to be evaluated include, thermal wire fire detectors, pneumatic fire detectors, and optical fire detection systems. The purpose of including some of these on the crash tests is to identify whether or not these devices would survive the crash and remain functional after the impact. This will be strongly dependent on the placement of the device in the engine compartment, and therefore, various locations will be evaluated.

Instrumented Anthropomorphic Test Devices. Instrumented 50th percentile male Hybrid III crash dummies will be placed in both outboard front seating positions and will be restrained by the vehicle's production seat belt and air bag restraint systems. Seat and dummy positioning will be done per FMVSS 208 [8] procedures. Instrumented ATDs will be included to represent the dynamic inertial loading of the occupant on the vehicle and also to assess the survivability of these selected crash conditions from an occupant trauma standpoint. For the frontal tests, full dummy instrumentation will be recorded which includes: the measurement of head accelerations, neck loads, chest accelerations, chest compression, pelvic acceleration, femur loads, and several lower leg load measurements. For the rear impacts only the head, neck and chest measurements will be recorded. Most of the injury assessment reference values for the Hybrid III ATD accepted by the automobile industry were developed for frontal loading, therefore, injury measurements recorded during the rear impacts will be interpreted accordingly and generally with less confidence in predicting injury risk than for frontal impacts.

Crash Test Instrumentation. These tests will use standard vehicle crash-testing instrumentation in addition to the specialized instrumentation developed to identify ignition sources. These standard measurements of the vehicle includes accelerations at various locations on the vehicle, linear displacements, and contacts. All vehicle and ATD channels will be recorded remotely (off-board) using drag-cables which connect the transducers to the signal conditioning and data acquisition equipment.

All transducer signals will be recorded using a digital data acquisition system (DSP Technology, Fremont, CA) at 10,000 samples per second with 12 bit resolution. These channels will use remote shunt emulation for instrumentation set-up and will be recorded for 28 seconds. Signal conditioning, filtering, and recording techniques will comply to SAE J211 [10].

Some channels, including the time-zero contact, the vapor measurements, and electrical measurements will also be recorded using a remote, PC-based digital data acquisition system for approximately 10 minutes after the impact. From the start of tow to the time of impact, the data acquisition rate will be 1,000 samples per second. The data acquisition rate will be switched to 10 samples per second after the impact.

Photo Coverage. Standard high speed movie coverage will be used to record the crash tests. Typically 15 - 30 high speed (500 or 1000 frames per second) cameras will be used depending on the test configuration. Coverage under the vehicle will be included for the rear impact, pole impact and offset barrier impact. Numeric film analysis will be done to measure vehicle motion. As an example, the dynamic pole penetration during the pole impact test will be measured using film analysis. In addition to high speed film, real time documentary video cameras will be used to record the vehicle condition for at least 10 minutes following the test.

Post-test Inspections. Following each crash test, the test vehicles will be partially disassembled to allow for a thorough inspection and documentation of possible ignition sources or fire paths into the passenger compartment. Fluid leaks, electrical shorts and structural damage to the vehicles will be photographed and documented.

Post-test Static Rollover. Static rollovers, similar to an FMVSS 301 [9] rollover will be conducted only after selected tests. A rollover will be completed for each of the rear impacts, but not for all of the frontal impacts. This will be decided on a test by test basis. The drawbacks to conducting a static rollover, especially for those vehicles which will be burned, is that the roll may distribute the engine compartment fluids into the passenger compartment. (For example, the vehicle used in the first frontal crash test of this program was rolled and the cracked windshield, the carpet, and the headliner were contaminated by a significant amount of leaking engine compartment fluids.) This contamination could serve as an accelerant, significantly altering fire propagation during the vehicle fire tests. For this reason, most of the frontal test vehicles will not be rolled.

2. Develop Standard Initiation Protocols

Potential ignition events observed during the crash tests will be the basis for the Standard Initiation Protocols. Simply stated, a Standard Initiation Protocol is a repeatable method for starting a fire for a vehicle fire test. To be useful for the vehicle fire tests, a standard initiation protocol should meet three requirements. First, it must result in an ignition. Second, the ignition must lead to a propagating fire; that is, a fire that does not self-extinguish before spreading from the site of ignition. Lastly, it must be a repeatable and controllable procedure. Thus, factors such as 1) the locations of potential fuel and energy sources in the vehicle, 2) the type, amount, and flammability properties of the fuel, 3) the type, intensity, and duration of the energy source, and 4) the flammability properties of combustible materials in close proximity to the site of ignition must be considered when examining the data from the crash tests and when developing the standard initiation protocols. Some of these parameters may be studied in small-scale test before developing the initiation protocols for the full-scale vehicle fire tests.

When appropriate, information about post-collision vehicle fires obtained from other sources (e.g., field incident data, crash data bases) will be considered when developing these initiation protocols.

Technical personnel from GM, NHTSA, NIST, and FMRC will work jointly to develop standard initiation protocols for ignition of combustible materials in the engine compartment and for ignition of a gasoline pool under the vehicle. These initiation protocols will be described in detail in future reports.

Ignition in the Engine Compartment

Possible ignition scenarios for engine compartment fires to be examined in small scale tests include:

- Ignition of combustible solids in the engine compartment by heat generated from an electrical short, which could include an internal short in the battery;
- Ignition of a combustible liquid sprayed onto a hot surface; or
- Ignition of gasoline leaking from a ruptured fuel line by an electrical arc.

These scenarios will be examined for possible development into a standard initiation protocol.

Ignition of a Gasoline Pool

The initiation protocol for vehicles struck in the rear will focus on ignition of gasoline leaking from a ruptured fuel system. There are two possible outcomes of the crash test with regards to fuel system integrity:

- The fuel system ruptures and leaking fluid is detected during the crash test or the vehicle roll, or
- The fuel system does not rupture and leaking fluid is not detected during the crash test or the vehicle roll.

When the crash test results in fluid leaking from a ruptured fuel system, the initiation protocol will recreate as accurately as possible the location of the leak, the leak-rate, and the size and location of the liquid pool relative to the stationary vehicle.

When the fuel system does not rupture and does not leak during the crash test, the ignition protocol will simulate a rupture of the fuel-system at the connection of the filler-neck to the fuel tank. Different procedures will be used for vehicles with steel and plastic fuel tanks. For vehicles equipped with plastic fuel tanks, a 3 mm diameter hole will be drilled at the base of the filler neck and the fuel tank will be partially filled with gasoline. For vehicles equipped with steel fuel tanks, gasoline will be pumped from an external reservoir through a grounded stainless steel tube with the outlet affixed to the base of the filler neck. For simplicity, the gasoline pool will be ignited with a pilot flame in these tests.

3. Design and Conduct Vehicle Fire Propagation Tests

Objectives

Understanding fire propagation in vehicles with the structure damaged in a crash is a first step in developing effective measures to reduce injuries and fatalities associated with post-collision vehicle fires. Both the probability of a post-collision vehicle fire and the probability of sustaining an incapacitating trauma injury or of being trapped in the vehicle after the crash increase as the severity of the crash increases [6]. In cases where a collision results in both a fire and surviving occupants being trapped in the vehicle, entry of the fire into the passenger compartment is the greatest, immediate threat to the occupants. The crash-tested vehicles will be burned in controlled tests to study propagation of a post-collision fire.

The literature contains several reports documenting investigations of motor vehicle fires. These reports generally fall into two categories: case studies of forensic investigations of motor vehicle fires [11-13], or technical reports describing the results of vehicle fire experiments using uncrashed vehicles [14-17]. The forensic investigations

[11-13] were generally concerned with determining the cause and origin of a motor vehicle fire after a crash or when arson is suspected. Forensic investigations focus on the ignition event and usually do not provide detailed information about how the fire propagated for two reasons. First, fire investigations occur after-the-fact; the investigators are not present to observe the fire. Second, much of the evidence needed to determine the fire paths was usually destroyed in the fires.

Most controlled vehicle fire tests have been concerned with determining the effect of a burning vehicle on surrounding structures [14-16], which involves measuring heat-transfer to surrounding objects. One study investigated propagation of an engine compartment fire through the forward bulkhead, using a series of front-half sections of uncrashed vehicles [18]. Neither the results of the fire investigations nor the controlled studies cited above can be generalized to propagation of post-collision vehicle fires.

The vehicle fire tests described below will focus on understanding how fire propagates in crashed vehicles. Data recorded during these tests will be used to (1) determine the paths for the spread of flame from the site of ignition to other locations in the vehicle, (2) measure the rate of flame-spread along each of these paths, (3) determine what components and materials burn, and (4) assess occupant survivability during the fire.

Fire Paths. Two of the objectives of these tests are to determine how the fire moves from the exterior of the vehicle into the passenger compartment, and to determine the time-line for this process. Possible fire paths into the passenger compartment include:

- polymer grommets used as seals in electrical, fluid, and mechanical feed-throughs in the sheet metal bulkheads around the passenger compartment;
- openings in the sheet metal structure of the vehicle created by the crush;
- the windshield, which can be shattered in the crash or by heat from the fire;
- windows, which may be open, or shattered in the crash or by heat from the fire;
- heat transfer through the sheet metal structures (e.g., the forward bulkhead and the floor pan) to combustible materials in contact with these structures (*e.g.*, the carpet pad).

A distinction is made here between the windshield and other windows in the vehicle. The windshield is a laminated structure consisting of a poly(vinyl butyral) sheet sandwiched by two outer-layers of tempered glass. Although the glass layers may shatter during the crash, the poly(vinyl butyral) sheet is less brittle and can hold a shattered windshield in place. In contrast, other windows in the vehicle typically consist of a single layer of tempered glass, and may not remain in place when shattered.

Component Temperatures and Thermal Environments. Another objective of these tests is to identify what components burn. In addition to flammable or combustible fluids, vehicles contain a number of components composed of organic polymers (plastics and elastomers). In general, all of these polymeric materials are combustible, and can be a fuel source in a post-collision fire.

Thus, the flammability of the constituent materials of the various components in the vehicle will affect both where and how fast the fire propagates. These fire tests will yield detailed information about what components burn, the sequence in which they ignite, the thermal environments around these components before and when they are burning, and the rate of growth and heat output of the fire.

Threat to Occupants. Another goal of these tests is to determine the threat to occupants posed by a post-collision fire. Fire can injure or kill by one or a combination of three basic mechanisms:

- Burns to the skin caused by hot gases and thermal radiation to the body or by flame directly contacting the skin;
- Burns to the lungs caused by inhalation of hot gases; or
- Acute toxicity caused by inhalation of toxic combustion products.

Instrumentation will be included in the vehicles to assess the threat from each of these mechanisms.

Fire Propagation Test Procedures

Eight fire propagation tests will be conducted at the Factory Mutual Test Center in West Glocester, Rhode Island. Two crash-tested vehicles per model will be selected for the fire propagation tests. The selection of the vehicles for fire propagation tests will be done by technical personnel from GM and NHTSA with input from technical personnel from the NIST and FMRC. The NIST will be responsible for all aspects of obtaining a detailed video record of each fire propagation test and analysis of these video records to determine the important events in the propagation of the fire from the site of ignition into the passenger compartment. FMRC will be responsible for preparing the fluid containment pan, weight-modules, and simulated road surface before each test, and for operation of the fire products collector during each test. GM will be responsible for all other aspects of the preparation and conduct of the fire tests described below.

One of the vehicles used in the frontal crash tests (offset pole test, deformable oblique moving barrier, or offset rigid barrier) will be selected for the engine compartment fire test. If one of the frontal crash tests results in a fire, then this vehicle will be selected for the fire test and the method of ignition will recreate as accurately as possible the cause of the fire observed in the crash test. If none of the frontal crash tests results in a fire for a given vehicle type, then the method of ignition for the fire test will recreate possible ignition scenarios determined after examination of the data from the crash test, disassembly and thorough inspection of the vehicle selected for the fire test. The vehicle used in the rear crash test will be used for the gasoline pool fire test.

Vehicle Condition. The condition of the vehicle for the fire test will approximate the condition of the vehicle after the crash test. For fire tests involving vehicles in which the hood was removed for the crash test, the hood will be crushed dynamically to simulate the crush that would have occurred in during the crash test and remounted on the vehicle. All intact windows will be raised to their fully closed or maximally closed positions. Windows broken during the crash test will not be replaced for the fire tests. Components which separate from the vehicle during the crash tests will be collected and placed in the same positions relative to the vehicle. The entire vehicle, including the engine compartment will be at ambient temperature at the start of the fire test. Automotive fluids will be spilled in the engine compartment and under the vehicle before the fire test to simulate fluid leaks that occurred during the crash test.

Fire Test Facility. The vehicles will be centered under a Fire Products Collector [19,20]. The Fire Products Collector is a large-scale calorimeter which will be used to obtain the release-rates of chemical, convective, and radiative heat, and of carbon dioxide, carbon monoxide, total hydrocarbons, and smoke during a fire test.

To prevent personal injury, fire damage to the test facility, and environmental contamination, the vehicle will be placed in a containment pan to prevent leaking automotive fluids from spreading in the test facility during and after the fire tests.

The bottom of the fluid containment pan will be lined with a simulated road surface consisting a layer of concrete construction board on top of a bed of sand. The purpose of the simulated road surface is to accurately recreate the effect of a semi-porous medium on fluid pool fires which may develop during these tests. The seams between boards will be sealed with latex construction caulk and the grade of the surface measured from the center to the edges along the major and minor axes will be no greater than 1% in all directions. This last specification is to minimize the effect of flaming fluid pools accumulating at low points in the surface.

Mass loss from the burning vehicle and any burning fluids retained by the containment pan will be measured with load cells. The fluid containment pan will be placed on top of an I-beam frame supported by weight-modules (KIS Series, BLH Electronics, Inc.) at each of its four corners. These weight-modules contain cylindrical, double cantilever strain gauge transducers that will not be affected by changes in the mass distribution in the containment pan.

Vehicle Instrumentation

Temperature. Thermocouples will be attached to metal bulkheads, and various components in the vehicles along anticipated fire paths or near combustible components in those paths. Temperature measurements obtained with these thermocouples will be used to track the spread of the fire and to define the thermal environments in the vehicle during the fire. The locations for thermocouple placement will be determined after disassembly and thorough inspection of the crashed vehicles.

Type-N thermocouples (Nicrosil/Nisil) will be used for these measurements. These thermocouples will have ungrounded junctions enclosed in an Inconel 600 sheath and insulated with magnesium oxide (Medtherm Corporation, Huntsville Alabama). The higher thermoelectric stability of Type-N thermocouple compared to the standard base-metal thermocouples [21] will yield more reliable temperature measurements in the extreme environment of the fire tests.

Each thermocouple will be connected to the data acquisition system with thermocouple duplex extension cable with a Teflon®-jacketed stainless steel over-braid. To minimize electromagnetic interference and to prevent ground-loops, the electronics chassis ground, the thermocouple shields, and the vehicle chassis will be connected to a common ground-bus at the data acquisition system. The ground-bus will be connected to earth-ground by a large gage cable.

Air Temperature. Two aspirated thermocouple probe assemblies (Medtherm Corporation) will be used to measure vertical air-temperature gradients at the front occupant positions. Each assembly will contain six Type-N thermocouples with bead-type junctions. The thermocouples will be housed in radiation shields with a vertical spacing of 75 mm (3 in.). The probes will be mounted to the roof of the passenger compartment so that the upper-most shielded thermocouple is approximately 12 mm (0.5 in.) below the lower surface of the head liner. Both probe assemblies will be connected to a vacuum pump to draw air into the radiation shields. The internal diameters of the interconnecting sections of the vacuum manifold will be sized to approximately balance the gas flow rate into each radiation shield, yielding a linear velocity of air flowing over the thermocouple junctions of 10 to 15 m/s. These conditions were chosen to minimize both the response-time of the thermocouples and error in the air temperature measurement due to radiative heat-transfer to the thermocouple bead [22].

Heat Flux. Dual heat-flux transducer/radiometer assemblies will be mounted to selected components and metal bulkheads in the vehicle to measure convection and radiation to objects in the anticipated fire paths. These assemblies will contain two Schmidt-Boelter thermopiles in a water cooled copper body (Medtherm Corporation). The faces of the heat flux transducers will be coated with high-temperature optical black paint. The radiometers will have sapphire windows (view-angle = 150°; optical transmittance range 0.4 to 4.2 μm). Both types of transducers will be calibrated to 10 W/cm^2 at a reference temperature of 80°C.

Dual heat-flux transducer/radiometer assemblies also will be located in the passenger compartment to measure convection and radiation to the occupant positions. These assemblies will contain two Schmidt-Boelter thermopiles in a water cooled copper body (Medtherm Corporation). The faces of the heat flux transducers will be coated with high-temperature optical black paint. The radiometers will have zinc selenide (ZnSe) windows (view-angle = 150°, optical transmitance range of 0.7 to 17 μm). Both types of transducer will be calibrated to 2 W/cm^2 at a reference temperature of 80°C.

Static Pressure. The static air pressures at several locations in the vehicle will be measured using bi-directional low differential pressure gages (Model C-264, Setra Systems, Acton, MA). The pressure gauges will be located outside of the fluid containment pan to protect them from the fire, and will be connected to stainless steel tubes terminating in the vehicle. For measurement of the static pressures, one port of the pressure gauges will be left open to the atmosphere so that these measurements will have a common, unchanging reference. For measurement of pressure differences across structural bulkheads, both ports of the pressure gauges will be connected to the stainless steel tubes terminating on opposite sides of the bulkhead. Pressure data will be recorded by the data acquisition system as analog inputs.

Bi-directional Flow. Directional gas flow velocity will be measured using a bi-directional flow probe connected to one of the low differential pressure gages described above. The differential pressure is related to the flow velocity by the relationship:

$$V = 0.070\sqrt{T\Delta p}$$

where V is the linear flow rate (m/s), T is the absolute temperature (K), and Δp is the pressure difference between the two openings in the probe (Pa). The probe will be placed near the top of an opening in the vehicle to measure the velocity of gas flow into or out-of the vehicle during the fire test [23,24].

Data Acquisition System. The data acquisition system to be used in the fire tests consists of a PC (ACER Inc., Taiwan R. O. C.) and a 100 kHz I/O board with 16 analog input channels (DaqBoard 200A, IOTech, Inc., Cleveland, OH). Four multiplexed analog-input expansion cards (DBK-12, IOTech) will be used for a maximum of 64 variable gain analog input channels for the heat flux transducers, radiometers, and pressure transducers. Twelve multiplexed thermocouple expansion cards (DBK-19, IOTech) will be used for a maximum of 168 thermocouple input channels. The expansion cards will be housed in a shielded metal cabinet with panel-mounted connectors.

The data acquisition software (DASYLab, Daten System Technik GmbH, Mönchengladbach, Germany) will be configured to sample each channel at a rate of 10 samples per second and store the data in 10-point block averages. Thus, data will be recorded at a rate of 1 sample per channel. To facilitate the decision to end the test, air temperature and heat fluxes at the occupant positions will be displayed in real-time during each test.

Video Camera Coverage. Hi-8 color camcorders will be positioned outside the vehicle to document each fire test. The cameras will be arranged around the vehicle to give partially overlapping views of the fire, with emphasis on anticipated fire propagation paths into the passenger compartment. The location of each camera relative to the vehicle will be mapped on a 3-dimensional coordinate system to facilitate the determination of the location of the flame on the vehicle and the rate of flame spread. One or more inexpensive CCD cameras mounted in fire-resistant housings may be located inside the passenger compartment to give views of the anticipated fire propagation paths.

Infrared Thermography. Infrared imaging equipment will be used to obtain estimates of flame and surface temperatures during the fire tests. Thermal imaging radiometers will be positioned outside the vehicle to give views similar to those of some of the video cameras. In addition, one camera protected by a fire-resistant housing will be mounted inside the vehicle to give a clear view of one of the anticipated fire paths into the passenger compartment.

The infrared imaging equipment to be used for these tests will include thermal imaging radiometers with spectral windows in the range of 3 to 5 micron (short-wave), 8 to 12 microns (long-wave), and 3 to 12 micron (broad-band). Flame filters with a cut-off wavelength of 3.9 microns may be used to eliminate radiation from the flame. An older, short-wave camera with a spectral range of 3 to 5 microns will be mounted inside the vehicles during the fire tests.

Chemical Analysis

Fourier Transform Infrared Spectrometry. Combustion gases accumulating in the passenger compartment during the fire test will be measured by Fourier transform infrared (FTIR) spectrometry. These gases include: ammonia (NH_3), benzene (C_6H_6), carbon dioxide (CO_2), carbon monoxide (CO), hydrogen chloride (HCl), hydrogen cyanide (HCN), methane (CH_4), nitric oxide (NO), nitrogen dioxide (NO_2), and styrene (C_7H_8). The spectrometer to be used for these measurements (Model I1000, MIDAC Corporation, Irvine, CA) will be equipped with a heated, stainless steel gas cell (path length = 10 m) with gold-surfaced mirrors and ZnSe windows, a liquid-nitrogen-cooled Mercury-Cadmium-Telluride detector, and a Michelson-Type interferometer with a Potassium Bromide beam splitter. The optical range of this instrument will be 5,555 to 645 cm^{-1}. The optical bench will be hermetically sealed and desiccated, isolating the internal optics and electronics from the harsh environment in the fire test facility and eliminating the need for continuous purge during the test.

During the fire tests, air from the passenger compartment will be drawn continuously into the gas cell through a stainless steel tube inserted into the breathing zone of the front occupants. Single-scan spectra with a resolution of 0.5 cm^{-1} will be acquired every 10 seconds. Gas concentrations will be determined using a Classical Least Squares algorithm. To facilitate the decision to end the test, the carbon monoxide concentration in the passenger compartment will be displayed in real-time during each test.

Gas Chromatography/Mass Spectrometry. Organic gases in the passenger compartment will be collected on sorbent cartridges packed with Graphitized Tenax® and analyzed by gas chromatography/mass spectrometry. Air from the passenger compartment will be sampled through a stainless steel tube inserted into the breathing zone of the front occupants. A series of five pairs of sequential samples will be acquired during the fire tests; one sample will be collected at a flow rate of 250 cm^3/min (corrected to standard temperature and pressure) and the other sample will be collected at a flow rate of 2.5 L/min (corrected to standard temperature and pressure).

The sorbent cartridges will be analyzed by TD/GC/MS. The instrument to be used for these analyses consists of a purge and trap concentrator (Model 6000 Purge and Trap Concentrator, CDS Analytical, Inc., Oxford, PA) connected to a GC/MS system (Model 5890 Series II Plus Gas Chromatograph and Model 5989B Quadrupole Mass Spectrometer, Hewlet Packard Corporation, Palo Alto, CA). Deuterated standards will be added to the sorbent cartridges before the analyses for quantitation by isotope dilution analysis.

Oxygen. The concentration of oxygen (O_2) in the passenger compartment will be measured using a galvanic-cell type sensor (GS Oxygen Sensor KE-25, Figaro U.S.A.). The oxygen sensor will be attached to the sample-line for the sorbent cartridges. The signal output from the sensor will be recorded by one of the analog input channels of the data acquisition system. The sensor will be calibrated for the effect of gas temperature and pressure on its response.

Particulate. Particulate from the passenger compartment will be collected on pre-weighed quartz fiber filters (o.d. = 47 mm). Stainless steel filter holders will be mounted on the roof of the vehicle, with stainless steel inlet tubes extending through the roof into the breathing zone of the front occupants. Five particulate samples will be acquired over the same time intervals as the sorbent tube samples. After the test, each filter will be weighed, then cut into four equal sections.

Cyanide anion (CN^-) in the particulate will be measured by ion exchange chromatography. One quarter section of each filter will be extracted with aqueous lithium hydroxide. The extracts will be analyzed by High Performance Liquid Chromatography (HPLC) using a DEAE Sephadex ion exchange column (Waters Chromatography, Milford, MA), an isocratic mobile phase (50 mM LiOH containing 0.25 mM Na_2EDTA) at a flow rate of 2 mL/min, and a pulsed electrochemical detector (Model 464, Waters Chromatography).

The anionic composition of the particulate will be measured by ion chromatography. One quarter section of each filter will be extracted with deionized water. The extracts will be analyzed by HPLC using an anion exchange column (IC-PAK Anion HC, Waters Chromatography), an isocratic mobile phase (a borate/gluconate buffer adjusted to pH 8.5 and modified with acetonitrile and n-butanol) at a flow rate of 2 mL/min, and a conductivity detector (Model 431, Waters Chromatography).

Semi-volatile organic compounds absorbed on the particulate will be identified by TD/GC/MS analysis of one quarter section of each filter. Non-volatile organic compounds in the particulate will be identified by GC/MS analysis of the methanol extracts of one quarter section of each filter. The insoluble residue remaining after extraction with methanol will be dissolved in *AquaRegia* and analyzed by inductively coupled plasma-atomic emission spectrometry to determine the metal content of the particulate.

Criteria for Ending the Test

To preserve evidence of fire paths, these tests will be stopped before all of the combustible material on the vehicle is consumed by the fire. These tests will be stopped and the fire will be extinguished when the environment in the passenger compartment is judged to be non-survivable by one of the following criteria:

- The air temperature in the passenger compartment at the breathing zone exceeds 200°C and is rising rapidly,
- The concentration of carbon monoxide in the passenger compartment exceeds 1% and is rising rapidly,
- Flames visibly impinge on one or both front seats,
- The head-liner is in flames over the forward occupant positions,
- Flash-over in the passenger compartment is evident.

As mentioned above, air temperature and carbon monoxide concentration will be monitored continuously to facilitate the decision to end each fire test. However, these decisions most likely will be based on a somewhat subjective evaluation of rapidly changing conditions inside the passenger compartment.

4. Proposed Test Schedule

The schedule for the crash and fire tests, which have been partially completed, is shown in Table 5.

5. Acknowledgments

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Table 5. Test ing Schedule

Completed	Model	Description	Speed km/h (mph)	Facility	Indoor or outdoor
16-May-96	Caravan	Offset Pole Crash Test	55 (34)	GM	Indoor
26-Jun-96	Caravan	Oblique Moving Barrier Crash Test	105(65)	GM	Outdoor
14-Aug-96	Caravan	Offset Rigid Barrier Crash Test	60(37)	GM	Indoor
25-Sep-96	Caravan	Offset Pole Crash Test	55(34)	GM	Indoor
13-Nov-96	Caravan	Front Vehicle Fire Propagation Test	n/a	FMRC	Indoor
15-Nov-96	Voyager	Rear Vehicle Fire Propagation Test	n/a	FMRC	Indoor
8-Jan-97	Camaro	Deformable Rear Moving Barrier Crash Test	85(53)	GM	Indoor
14-May-97	Camaro	Offset Pole Crash Test	55 (34)	GM	Indoor
18-Jun-97	Camaro	Oblique Moving Barrier Crash Test	105(65)	GM	Outdoor
	Explorer	Oblique Moving Barrier Crash Test	105(65)	GM	Outdoor
	Camaro	Front Vehicle Fire Propagation Test	n/a	FMRC	Indoor
	Camaro	Rear Vehicle Fire Propagation Test	n/a	FMRC	Indoor
	Explorer	Deformable Rear Moving Barrier Crash Test	85(53)	GM	Indoor
	Explorer	Offset Pole Crash Test	55 (34)	GM	Indoor
	Explorer	Front Vehicle Fire Propagation Test	n/a	FMRC	Indoor
	Explorer	Rear Vehicle Fire Propagation Test	n/a	FMRC	Indoor
	Accord	Offset Pole Crash Test	55 (34)	GM	Indoor
	Accord	Oblique Moving Barrier Crash Test	105(65)	GM	Outdoor
	Accord	Deformable Rear Moving Barrier Crash Test	85(53)	GM	Indoor
	Accord	Front Vehicle Fire Propagation Test	n/a	FMRC	Indoor
	Accord	Rear Vehicle Fire Propagation Test	n/a	FMRC	Indoor

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Appendix 1
January to November 1995
United States Market Share by Each Segment [5]

SEGMENT		MODEL	MARKET SHARE	
			% OF SEGMENT	% OF MARKET
small cars	lower	Neon	10.0	1.62
		Cavalier	7.0	1.10
		GEO Metro	3.0	0.47
	upper	Escort	13.0	2.04
		Saturn	12.3	1.94
		Corolla	7.8	1.34
	specialty	Eclipse	2.2	0.35
		Talon	1.0	0.16
		200SX	1.0	0.16
mid-size cars	lower	Grand Am/Skylark	6.9	2.00
		Corsica/Berretta	4.9	1.40
		Civic	4.7	1.37
	upper	Taurus/Sable	11.8	3.40
		Accord	***8.2***	***2.34***
		Lumina/Monte Carlo	6.6	1.92
	specialty	***Camaro/Firebird***	***3.3***	***0.95***
		Mustang	3.3	0.94
		Probe	1.5	0.43
large cars	large	Lesabre/Olds 88/Bonneville	30.0	1.94
		Intrepid/Concord	21.0	1.36
		Crown Victoria/Grand Marquis	19.8	1.28
	specialty	Thunderbird/Cougar	18.3	1.18
luxury cars	lower	Volvo 800 Series	5.0	0.40
		Toyota Avalon	4.7	0.38
		BMW 3 Series	4.2	0.34
	middle	Town Car/Continental	12.1	0.97
		Deville	9.3	0.45
		Park Avenue	4.5	0.36
	upper	Seville	3.0	0.24
		Mercedes E Class	1.9	0.15
		Lexus LS400	1.9	0.15
	specialty	Riviera G	2.1	0.17
		Eldorado	1.9	0.15
		Lincoln Mark VIII	1.6	0.13
	sport	Corvette	1.5	0.12
		Mitsubishi 3000 GT	0.9	0.08
		Mercedes SL Class	0.5	0.04

Appendix 1 (Continued)
January to November 1995
United States Market Share by Segment [5]

SEGMENT		MODEL	MARKET SHARE	
			% OF SEGMENT	% OF MARKET
sport-utility vehicle	**small**	JEEP Wrangler	4.0	0.46
		GEO Tracker	2.4	0.28
		Suzuki Sidekick	1.4	0.16
	mid-size	***Explorer***	***20.1***	***2.33***
		S-Blazer/Jimmy S	18.2	2.11
		Jeep Cherokee	6.7	0.78
	large	Suburban	6.9	0.79
		Tahoe/Yukon	4.5	0.53
		Bronco	2.0	0.24
	luxury	Jeep Grand Cherokee	14.5	1.68
		Toyota Land Cruiser	0.8	0.09
		Land Rover Discovery	0.6	0.07
vans	**small**	***Caravan/Voyager***	***26.1***	***2.91***
		Lumina/Silhouette/Trans Sport	5.8	0.64
		Villager	4.5	0.50
	mid-size	Windstar	13.8	1.54
		Astro/Safari	6.1	0.69
		Aerostar	5.5	0.61
	large	Econoline	9.9	1.10
		Chevrolet Van	5.2	0.59
		Dodge Ram Van	3.4	0.38
pickup trucks	**small**	Ranger	11.6	2.13
		S-10/Sonoma	10.2	1.86
		Nissan pickup	4.8	0.87
	large	Chevrolet C/K/GMC Sierra	25.3	4.63
		Ford F-Series	24.7	4.52
		Dodge Ram	9.4	1.71