Survey of the Fire Safety Research Conducted Under GM Settlement Agreements

Kennerly H. Digges
Motor Vehicle Fire Research Institute

ABSTRACT

This paper lists the research projects and the resulting reports that were published under two settlement agreements with General Motors. The research reports include the following subjects: fire statistics on crash modes; assessment of fire safety technology, the behavior of plastic gasoline tanks when subjected to fire and impact tests; tests and finite element analysis of fuel tanks subjected to crash conditions; assessments of automotive fuel components that relate to fire safety; underhood temperatures under driving conditions; flammability of underhood liners; ignition and flammability properties of plastics and underhood fluids; an analysis and synthesis of vehicle burn tests; fire suppression and mitigation technology, examination of fire safety aspects of future vehicle technologies such as 42-volt electrical systems and fire safety of hydrogen fueled vehicles.

INTRODUCTION

On March 7, 1995, the U.S. Department of Transportation (DOT) and General Motors Corporation (GM) entered into an administrative agreement, which settled an investigation that was being conducted by the National Highway Traffic Safety Administration (NHTSA) regarding an alleged defect related to fires in GM C/K pickup trucks [NHTSA 1994, NHTSA 1998 and NHTSA 1999].

Under the GM/DOT Settlement Agreement, GM agreed to support NHTSA's effort to enhance the current Federal Motor Vehicle Safety Standard (FMVSS) 301, regarding fuel system integrity, through a public rulemaking process. GM also agreed to expend $51.355 million over a five-year period to support projects and activities that would further vehicle and highway safety. Approximately ten million dollars of the funding was devoted to fire safety research [NHTSA 1998].

Subsequent to the GM/DOT Settlement, GM agreed to fund an additional $4.1 million in research related to impact induced fires. This latter research project was included under the terms of a judicial settlement. The fire safety project objectives are defined by the White, Monson and Cashiola vs. General Motors Agreement dated June 27, 1996 [Agreement 1996]. All research under the project has been made public for use by the safety community.

The Motor Vehicle Research Institute (MVFRI) was formed to administer and conduct this research. The work started in late 2001 and was completed in 2009.

The purpose of this paper is to document the research projects conducted under the two settlement agreements and list the reports that contain the research results. The paper is separated into two sections. The first lists the research projects and reports that were funded by MVFRI. The second section lists the projects and reports that were funded under the GM/DoT Agreement. The reports produced by each project are listed under the heading for the project. Related references that were not funded by the MVFRI or GM/DoT agreement are listed at the end of the paper.

To assist in understanding the research conducted in each of the projects brief summaries of some of the findings are included in the sections to follow. It is not possible to address all the findings or the limitations of the research. Therefore, the reader is encouraged to examine each the publications of interest and assess the results.

PART 1 MVFRI PROJECTS

The progress of the MVFRI research was reported annually from 2004 to 2007 at the SAE World Congress by Digges and Stephenson. The SAE numbers for the MVFRI progress reports are: 2004-01-0475, 2005-01-1425, 2006-01-0551 and 2007-01-0880. In addition, applications for some of the research findings were summarized at 2009 ESV Conference. These papers are as follows:

Digges, K. and Stephenson, R., “Fireworthiness: A Final Report on the Technology Base”, Paper Number 09-0211, *Proceedings of the 21st ESV Conference*, June 2009.

Digges, K., and Stephenson, R., “The Basis for a Fluid Integrity NCAP Rating”, Paper Number 09-0215, *Proceedings of the 21st ESV Conference,* June 2009.

The following sections address the ten major research projects conducted by MVFRI. Under each section, the research reports are listed along with the objectives and major findings.

Project A1: Fire Occurrence in Passenger Vehicles Based on NASS, FARS and State Data

The research under this MVFRI Project was conducted by the following: The George Washington University, Pacific Institute or Research and Evaluation, Dr. George Bahouth, Friedman Research and Associates and MVFRI. This research focused on identifying the conditions that produce crash induced fires. The studies

investigated a wide range of data sources including: FARS, NASS, State Data, NFIRS, and GES.

Studies of FARS 2001-2005 reported that the most frequent crash modes for FARS fatal crashes with fires as the Most Harmful Event (MHE) are frontal crashes at 44% followed by rollovers at 24% [Bahouth, 2007]. Fires in both crash modes have been increasing in recent years [Digges 2009 (b), Bahouth 2007]. Entrapments were documented in about 25% of FARS fatal crashes with fire as MHE [Bahouth, 2007]. Fires and entrapments appeared to be under-represented in FARS [Fell, 2009]. Seventy-five percent of FARS cases with documented rescue times reported rescue arrival within 12 minutes in urban areas and 24 minutes rural areas [Bahouth 2007].

Studies of NASS Major fires found that most frontal crash fires originate under the hood with no documented fuel spillage [Kildare 2006]. The fuel tank and engine compartment are about equally represented in rollover fires [Kildare 2006].

Studies of State data compared fire rates of V-8 engines I-6 engines in the same pickup model. The study also examined the fire rates of pickups with various safety features including fuel cut-off switches of different designs [Friedman October, 2005].

The results of research conducted under this project are contained in the following reports:

Bahouth , G., "Analysis of Fire Related Crash Fatalities and Crashed Vehicle Rescue Times", Report prepared for MVFRI, March 30, 2007. www.mvfri.org

Bahouth, G., "Post Crash Exterior Crush Patterns and Motor Vehicle Fire Occurrence" SAE Paper 2006-01-0789, April, 2006.

Bahouth, J., and Kuzentsov, A., "Automotive and Fire Safety Research", prepared for MVFRI by The George Washington University, January, 2005. www.mvfri.org

Digges, K., "Fire Occurrence in Crashes Based on NASS/CDS, MVFRI Report, August 2009 (a). www.mvfri.org

Digges, K., "Crashes that Result in Fires", Paper Number 09-0214, *21st ESV Conference,* June 2009 (b). www.mvfri.org

Digges, K., "Fire Occurrence in Side Crashes Based on NASS/CDS", SAE Paper 2009-01-0008, April, 2009 (c).

Digges, K., "Fire Occurrence in Frontal Crashes Based on NASS/CDS", SAE Paper 2008-01-0256, April, 2008.

Digges, K., and Kildare, S., "Fire Occurrence in Rollover Crashes Based on NASS/CDS", SAE Paper 2007-01-0875, April, 2007.

Digges, K. and Stephenson, R. "A Research Program to Study Impact Related Fire Safety", *19th ESV Conference* May, 2005.

Fell, J., Tippets, S., and Bahouth, G., "A Further Analysis of Fire Occurrence and Rollover Rates in the Fatality Analysis Reporting System (FARS)", Report prepared for MVFRI by Pacific Institute for Research and Evaluation, October, 2009. www.mvfri.org

Fell, J., Tippets, S., and Bahouth, J., "An Analysis of Vehicle Fire Rates in Fatal Crashes: Is there an Indication of Underreporting?" SAE Paper 2007-01-0876, April, 2007.

Fell, J., "Interim Report to MVFRI on FARS Missing Data", Pacific Institute for Research and Evaluation, prepared for MVFRI, November 2004. www.mvfri.org.

Friedman, K., Holloway, E., and Kenny, T., "Impact Induced Fires: Pickup Feature Design Analysis", SAE Paper 2006-01-0550, April, 2006.

Friedman, K., Holloway, E., and Kenny, T., "Impact Induced Fires: Statistical Analysis of FARS and State Data Files (1978-2001)", SAE Paper 2005-01-1421, April, 2005.

Friedman, K., Holloway, E., and Kenny, T.., "Impact Induced Fires: Pickup Design Feature Analysis", prepared for MVFRI by Friedman Research Corporation, October 2005. www.mvfri.org

Friedman, K., Holloway, E., and Kenny, T., "Final Report, Impact Induced Fires & Fuel Leakage: Statistical Analysis of FARS and State Data Files (1978-2001)", prepared for MVFRI by Friedman Research Corporation, July 2003. www.mvfri.org

Kildare, S, and Digges, K., "Analysis of Fire Occurrence in Automotive crashes Using NASS CDS Data (1994-2004), prepared for MVFRI by The George Washington University, November, 2006. www.mvfri.org

Shields, L., and Scheib, R., "Computer-Based Training in Vehicle Fire Investigation Part 1 : Ignition Sources", SAE Paper 2006-01-0547, April, 2006.

Shields, L., and Scheib, R., "Computer-Based Training in Vehicle Fire Investigation Part 2 :Fuel Sources", SAE Paper 2006-01-0548, April, 2006.

Shields, L., "Emergency Response Time in Motor Vehicle Crashes: Literature and Resource Search," Report prepared for MVFRI by Leland E. Shields, Inc., January 2004.

Stephenson, R., "CNG Tank Burst During Filling", SAE Paper 2008-01-0557, April, 2008.

Project A2: Survey of the State-Of-The-Art in Fuel System Fire Safety

This MVFRI project was conducted by Biokinetics and Associates, Ltd.

The project examined new vehicles and documented the state-of-the-art in fuel systems has been undertaken with a focus on identifying fire safety technologies that may be in use today for the purpose of preventing and/or mitigating post-crash fires. A database that shows the fire safety features on most MY 2003 vehicles was entered on-line at www.mvfri.org.

Selected fire safety technologies on existing vehicles include the following:
Tank placement away from crush zones
Tank and exhaust shielding
Tank protection from drive shaft deformation
Tank protection from aggressive surrounding objects
Appropriate ground clearance
Fuel pump shutoff
Battery to starter disconnect
Battery placement away from crush zones
Battery terminal shielding
Fuel line routing and flexibility to provide for integrity in crashes
Filler tube check valve
Rollover check valve
Anti-siphon design features
Check valves and design features to prevent fuel leakage in the event of ruptured lines from the tank.
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The results of research conducted under this project are contained in the following reports:

Digges, K., Stephenson, R., and Bedewi, P., "Fire Safety Performance of Motor Vehicles in Crashes", *18th ESV Conference*, May, 2003. www.mvfri.org

Fournier, E., Kot, J., Sullivan, D., "Assessment of Fuel System Safety Technology Use in 2003 Model Year Vehicles", SAE Paper 2005-01-1423, April 2005.

Fournier, E., Kot, J., "Comparison of Internal Tank Components – 20 Fuel Systems", Prepared for Motor Vehicle Fire Research Institute by Biokinetics and Associates, Ltd. Report R04-06c, July, 26 2004. www.mvfri.org

Fournier, E., and Kot, J. "Summary Report: Expansion of the Vehicle Fuel System Database and Overview of Pickup Truck History", Prepared for Motor Vehicle Fire Research Institute by Biokinetics and Associates, Ltd. Report R04-02-V02, May 10, 2004. www.mvfri.org

Fournier, E., Bayne, T., and Kot, J., "Eighty-eight Vehicle MY 2002/03 Database for Fuel System Fire Safety", Prepared for Motor Vehicle Fire Research Institute by Biokinetics and Associates, Ltd,. March 31, 2004. www.mvfri.org

Fournier, E., and Keown, M. "Preliminary Analysis of the Vehicle Fuel System Database", Prepared for Motor Vehicle Fire Research Institute by Biokinetics and Associates, Ltd. Report R03-16, August 18, 2003. 2004. www.mvfri.org

Fournier, E., Bayne, T., and Kot, J., "Survey of the State-Of-The-Art in Fuel System Fire Safety – Phase II", Prepared for Motor Vehicle Fire Research Institute by Biokinetics and Associates, Ltd. Report R03-01, May 12, 2003. www.mvfri.org

Project A3: Test and Evaluation of the State-Of-The-Art in Fuel Leakage Prevention

This MVFRI project was conducted by Biokinetics and Associates, Ltd.

This project conducted two types of evaluations of fire safety features present in on-the-road vehicles. First, the leakage prevention technology was evaluated through component testing of fuel systems in rollovers with severed fuel and vent lines. Second, tests were undertaken to evaluate and document anti-siphoning technology.

The project found that some on-the-road vehicles have incorporated technology to minimize fuel spillage in the event of a rupture on any of the lines that enter the tank. This includes the filler tube, the fuel and return lines and the vent lines. The tests and technologies were documented in the reports to follow.

Digges, K., "Technologies to Improve Impact Related Fire Safety", *20th ESV Conference*, June 2007. www.mvfri.org

Fournier, E., Bayne, T., "Automotive Fuel System Anti-Siphoning and Leak Prevention Technology Review", Prepared for Motor Vehicle Fire Research Institute by Biokinetics and Associates Ltd. Report R06-20, September 28, 2006. www.mvfri.org

Project A4: Analysis of Vehicle Fire Tests – GM/DoT and Others

The research under this project was conducted by FM Global, Southwest Research Institute, MVFRI, and several consultants to MVFRI. The consultants included: K. Digges, R. Gann, S. Grayson, M. Hirschler, R. Lyon, D. Purser, J. Quintiere, R. Stephenson and A. Tewarson.

Under this project, the GM/DOT Settlement research program in motor vehicle fire safety was reviewed by a team of experts led by FM Global. Of particular interest was the analysis of eleven, highly instrumented burn

tests using crashed vehicles. In addition, the results of 34 different vehicle burn tests were collected and summarized by Janssens. Finally, the fire properties of materials research conducted under the GM/DoT Settlement were collected and summarized by a team led by A. Tewarson at FM Global.

The reports generated under this project summarize a large amount of fire test data. Some observations from the GM/DoT crash and burn tests will follow.

In one frontal crash test, an engine compartment fire originated as a result of an electrical fault. The burn tests found that the survival time after a fire entered the occupant compartment either from underneath the vehicle was as little as 30 seconds. The time for an underhood fire to penetrate the occupant compartment ranged from 10 minutes for two of the vehicles tested to 23.5 minutes for a third.

The results of this MVFRI project are contained in the following reports:

Digges, K., Gann, R., Grayson, S., Hirschler, M., Lyon, R., Purser, D., Quintiere, J., Stephenson, R., and Tewarson, A., "Improving Survivability in Motor Vehicle Fires", Fire and Materials Conference, January, 2007. www.mvfri.org

Janssens, M., "Development of a Database of Full-Scale Calorimeter Tests of Motor Vehicle Burns", Report prepared for MVFRI by SwRI; 01.096939.01.003, March 11, 2008. www.mvfri.org

Tewarson, A., Quintiere, J., and Purser, D., "Post Collision Motor Vehicle Fires.", Report prepared for MVFRI by FM Global Technical Report #0003018009, Volume I, October 2005. www.mvfri.org

Tewarson, A., Quintiere, J., and Purser, D., "Theory and Testing for the Fire Behavior of Materials for the Transportation Industry", Report prepared for MVFRI by FM Global Technical Report #0003018009, Volume II, October 2005. www.mvfri.org

Tewarson, A., Quintiere, J., and Purser, D., "Thermophysical and Fire Properties of Automobile Plastic Parts and Engine Compartment Fluids", Report prepared for MVFRI by FM Global Technical Report #0003018009, Volume III, October 2005. www.mvfri.org

Tewarson , A., Quintiere , J., and Purser, D., "Fire Behavior of Materials in Vehicle Crash Fires and Survivability of the Passengers", SAE paper 2005-01-1555, April 2005.

Project A5: Fire Exposure, Impact Tests, and Finite Element Modeling of Plastic Fuel Tanks

This project was conducted by contracts with Southwest Research Institute and Dr. Nabih Bedewi.
The purpose of this program was to conduct comparison evaluations of new and in service plastic fuel tanks to performance standards applied in Europe and to standards applied to tanks for trucks in the US. The tests included exposure to pool fires, impacts at low temperatures, and drop tests. The drop tests with 90% fluid containment revealed that tank failures originated at the seam. A finite element analysis of fuel tanks under dynamic loading provided a better understanding of the test conditions needed to evaluate the seam integrity.
The results of this MVFRI project are reported in the following:

Bedewi, N., and Tarek, O., "Modeling of Automotive Fuel Tanks Using Smoothed Particle Hydrodynamics", SAE Paper 2007-01-0682, April 2007.

Bedewi, N., "Evaluation of Fuel Tank Drop Tests and ASTM Tensile Tests conducted by Southwest Research Institute", Prepared for Motor Vehicle Fire Research Institute, Final Report December 13, 2004. www.mvfri.org

Buyuk, M., Marzougui, d., Digges, K., Kan, C. "Impact Performance Evaluation of Thermo-Plastic Fuel Tanks by Using Meshfree Methods", Proceedings of the 10th US National Congress on Computational Mechanics, Columbus, Ohio, July 16-19, 2009.

Digges, K., Stephenson, R., and Bedewi, P., "Fire Safety Performance of Motor Vehicles in Crashes", *18th ESV Conference*, Paper 442, May, 2003. www.mvfri.org

Griffith, J., Machado, C., Bendele, B, "Comparative Evaluation of Automotive Fuel Tanks in General Accordance with ECE R34.01, Annex 5 Section 5.0 "Resistance to Fire," SAE Paper 2005-01-1561, April 2005.

Machado, C., "Automotive Fuel Tank Evaluation", Prepared for Motor Vehicle Fire Research Institute, by Southwest Research Institute, Report on Project 01.06081.01.001, August 2003. www.mvfri.org

Project A6: Fire and Toxicity Properties of Underhood Fluids and Plastics

This research was based on contracts with Southwest Research Institute, FM Global, Galaxy Scientific and TRACE Technologies, and Biokinetics and Associates, Ltd.

The research deals with the fire and toxicity properties of under-hood fluids and plastics. It also examines

alternative ways of measuring these properties. The results are documented in the following reports:

Battipaglia, K., Griffith, A., Huczek, J., Janssens, M., Miller, M., and Willson, K., "Comparison of Fire Properties of Automotive Materials and Evaluation of Performance Levels", Report prepared for NHTSA and the Motor Vehicle Fire Research Institute by Southwest Research Institute, Project Report 01.05804, October, 2003. www.mvfri.org

Fournier, E., and Bayne, T., "Flammability of Under Hood Insulation Materials," Biokinetics and Associates, Ltd. SAE Paper 2006-01-1011, April, 2006.

Fournier, E. and Bayne, T., "Cone Calorimeter Testing of Under Hood Insulation", Report prepared for MVFRI by Biokinetics and Associates, Ltd., Report R05-13b, August 2005. www.mvfri.org

Lyon, R., and Walters, R., "Flammability of Automotive Plastics", SAE Paper 2006-01-1010, April 2006.

Lyon, R., and Walters, R., "Flammability of Automotive Plastics", Report prepared for MVFRI by Lyon (FAA), Walters (Galaxy Scientific Corporation) and TRACE Technologies LLC, August 2005. www.mvfri.org

Tewarson , A., "Thermophysical and Fire Properties of Engine Compartment Fluids", SAE Paper 2005-01-1560, April 2005.

Project A7: Underhood Temperature Measurements

This research was conducted by Biokinetics and Associates, Ltd.

This research measured the temperature of hot surfaces along the exhaust systems of four vehicles. The variation of temperature with driving conditions and after engine shut-off was measured and reported. The following reports were produced under the project:

Fournier, E. and Bayne, T., "Underhood Temperature Measurements", SAE Paper 2007-01-1393, April 2007.

Fournier, E., Bayne, T., "Assessment of Thermocouple Attachment Methods for Measuring Vehicle Exhaust Temperature", Prepared for Motor Vehicle Fire Research Institute by Biokinetics and Associates, Ltd., Report R06-23b for MVFRI, August 19, 2006. www.mvfri.org

Fournier, E. and Bayne, T., "Underhood Temperature Measurements of Four Vehicles", Prepared for Motor Vehicle Fire Research Institute, by Biokinetics and Associates, Ltd., Report R04-13, September 2004. www.mvfri.org

Project A8: Research in Automotive Fire Suppression

This MVFRI project was conducted by the University of Maryland with the consulting assistance of Dr. Anthony Hamins at National Institute of Standards and Technology (NIST)

The goal of the research was to suppress an 80 kw gasoline pool fire in an undamaged engine compartment for a period in the order of 20-30 minutes. A prototype foam based system achieved the project goals. However, the project did not involve a crash so that the dynamic factors were not evaluated. Additional research would be required to demonstrate the system's effectiveness over a large range of crash conditions. Dr. Hamins led a seminar at on fire suppression at the 2005 SAE World Congress and authored a report on research needs. This report also contains a description of the fire suppression system offered by Ford on a police version of the 2005 Crown Victoria [Hamins, 2007]. The results of the fire suppression project were documented in the following reports:

Gunderson, J., and DiMarzo, M., "Vehicle Post-crash Under-hood Nitrogen Foam Fire Suppression System", SAE Paper 2005-01-1789, April 2005.

Gunderson, J., and DiMarzo, M., "Nitrogen Foam Fire Suppression System for Automobile Under-hood Post-collision Fire Protection", Prepared for Motor Vehicle Fire Research Institute by Fire Protection Engineering Department, University of Maryland, August, 2004. www.mvfri.org

Hamins, A., "Vehicle Fire Suppression Research Needs", Prepared for Motor Vehicle Fire Research Institute", National Institute of Standards and Technology, February 20, 2007. www.mvfri.org

Project A9: Fire Safety in Motor Vehicles with High Voltage Electrical Systems

This MVFRI research project was based on contracts with Underwriters Laboratories, Chilworth Technology, and Southwest Research Institute

The research under this project explored fire safety issues associated with higher voltage electrical systems applied to automotive use. The issues included the carbon tracking that increases the conductivity of insulators when exposed to road salt and higher voltage direct current, the short circuit response of 36 volt batteries when abused during a crash, and the conductivity of engine compartment fluids.

The results of research conducted under this project are contained in the following reports:

Dey, W., "Conductivity Measurements for New Engine Compartment Fluids," Prepared for Motor Vehicle Fire

Research Institute, by Chilworth Technologies, Inc, April 2004. www.mvfri.org

Stephenson, R., "Physics of DC Carbon Tracking of Plastic Materials," Fire and Materials Conference, San Francisco, California, Jan. 2005. www.mvfri.org

Wagner, R., Stimitz, J., "Properties of Plastic Materials for Use in Automotive Applications: Study of Arc Track Properties of Plastic Materials when Subjected to DC Voltages Ranging from 12 V DC - 150 V DC; Prepared for Motor Vehicle Fire Research Institute and USCAR by Underwriters Laboratories, December 15, 2003. www.mvfri.org

Wagner, R., "Development of a DC High-Current Arc Ignition Tester", SAE 2007-01-1042, April 2007.

Weyandt, N., "Comparative Abuse Testing of 36V and 12V Battery Designs in General accordance with SAE J2464, Prepared for Motor Vehicle Fire Research Institute by Southwest Research Institute Report 01.06939.01,002, May 2005. www.mvfri.org

Weyandt, N., "Comparative Abuse Testing of 36V and 12V Battery Designs" SAE 2006-01-1274, April, 2006.

Project A10: Research in Fire Safety for Hydrogen-Fueled Vehicles

This research was based on contracts with Southwest Research Institute and Dr. Robert Zalosh (FIREXPLO).

Fire safety issues that may be associated with hydrogen fueled vehicles were examined. These included evaluating fire hazards from leaking hydrogen fuel lines and from malfunctioning pressure relief devices (PRD). In one project a typical composite 5000 psi compressed hydrogen tank was exposed to a bonfire to evaluate the consequence of fire induced tank rupture [Zalosh 2005]. The tank was tested without a pressure relief device. The composite tank material supported combustion after about 45 seconds of exposure to the bonfire and ruptured after about 6.5 minutes. At the time of tank rupture, the pressure inside the 5,000 psig tank had only increased by 180 psi and the temperature at the cylinder ends had risen only to 103 ^{o}F. These test results illustrate the importance of a functioning pressure release device and the challenges of sensing incipient tank failure from external fires.

The following reports document the results of this research project.

Weyandt, N., "Ignited Hydrogen Release from a Simulated Automotive Fuel Line Leak," Report prepared for MVFRI by SwRI, report 01.06939.01.004, December 2006. www.mvfri.org

Weyandt, N., "Catastrophic Failure of a 5,000-psig Hydrogen Cylinder Installed on a Typical SUV," Report prepared for MVFRI by SwRI; Report 01.06939.01.005, November 2006. www.mvfri.org

Weyandt, N., "Ignition of Underbody and Engine Compartment Hydrogen Releases", SAE Paper 2006-01-0127, April 2006.

Weyandt, N., "Analysis of Induced Catastrophic Failure of a 5000 psig Type IV Hydrogen Cylinder," SwRI, Report 01.0639.01.001, February 2005. www.mvfri.org

Zalosh, R., Weyandt, N., "Hydrogen Fuel Tank Fire Exposure Burst Test," SAE paper 2005-01-1886, April 2005.

Zalosh, R., "Hydrogen Vehicle Post-Crash Fire Research Recommendations", Report Prepared for MVFRI, February 2003. **www.mvfri.org**

PART 2 GM/DOT SETTLEMENT PROJECTS

The projects listed in this section were conducted by General Motors in collaboration with NHTSA. NHTSA published reports on the progress. The reports for the fourth and fifth year summarized some of the findings. In the summaries below, the findings were extracted from the NHTSA progress reports [NHTSA 1998 and 1999].

DOT/GM Project B.1
Analysis of Motor Vehicle Accident Data

This project involved two different contractors, Texas Transportation Institute and Failure Analysis. The contractors studied vehicle fire data from three sources: the Fatality Analysis Reporting System (FARS), the National Fire Incident Reporting System (NFIRS), and the Crash Outcome and Data Evaluation Study (CODES).

NHTSA's evaluation of this research was: "Reports from FA and TTI indicate that the information in existing state and federal traffic safety databases is neither reliable nor sufficient for purposes of describing the likely causes and consequences of collision related vehicle fires. Enhancement of our understanding of collision fire events requires information from other sources (e.g. detailed case study investigations and forensic evaluations in conjunction with controlled laboratory crash and fire testing)."[NHTSA 1998]

Based on these results, MVFRI research studied the reasons for underreporting of fires and made recommendations to improve FARS, developed a computer based course for fire investigators, and conducted case studies of fires in the National Analysis Sampling System/ Crashworthiness Data System (NASS/CDS). The final reports are contained in the

section, “Fire Occurrence in Passenger Vehicles Based on NASS, FARS and State Data”.

The results of research conducted under this GM/DoT project are contained in the following reports:

Davies, Becky T., and Griffin, Lindsay I., “A Clinical Evaluation of the Death Investigations for 206 Decedents Who Died in Passenger Vehicles that Experienced Post-Crash Fires,” (January 2002) Docket # NHTSA-98-3588-170, Texas Transportation Institute.

Griffin, Lindsay I., Davies, Becky T., and Flowers, Robert J., “Studying Passenger Vehicle Fires with Existing Databases,” (January 2002) Docket # NHTSA-98-3588-169, Texas Transportation Institute.

Griffin, Lindsay I., “Comparisons of Crash-Involved Passenger Vehicles [Containing One or More Fatally-Injured Occupants] that Did or Did Not Experience Fires (FARS 1994-1996),” (April 2001) Docket # NHTSA-98-3588-165, Texas Transportation Institute.

Griffin, Lindsay I., and Flowers, Robert J., “An Evaluation of Fatal and Incapacitating Injuries to Drivers of Passenger Vehicles that Experienced Post-Crash Fires in North Carolina (1991-1996),” (April 2001) Docket # NHTSA-98-3588-145, Texas Transportation Institute.

Griffin, Lindsay I., “An Assessment of the Reliability and Validity of the Information on Vehicle Fires Contained in the Fatal Accident Reporting System (FARS),” (November 1997) Docket # NHTSA-98-3588-40, Texas Transportation Institute.

Lavelle, Joseph P., Kononen, Douglas W., and Nelander, James R., “Field Data Improvements for Fire Safety Research,” (August 1998) Docket # NHTSA-1998-3588-29, General Motors Corporation, ESV Paper Number 98-S6-W-45.

Ray, Rose and Lau, Edmund, “Identification and Evaluation of Sources of Statistical Data on Collision and Non-Collision Fires in Passenger Vehicles,” (November 1996) Docket # Unknown, Failure Analysis Associates.

DOT/GM Project B.2
Case Studies of Motor Vehicle Fires

This project, conducted by the University of Washington Transportation Center (TRAC), consisted of in depth investigations of approximately 35 collision related vehicle fires to determine the causes of the fire and of the occupant injuries. NHTSA’s comments on this research were as follows: “ …vehicle fires are associated with a variety of crash scenarios and may result from a variety of potential ignition sources and involve a wide range of combustible materials (including both liquid and solid combustibles). Because of the inherent complexities of these events, a combination of fire mitigation and design strategies may be needed to reduce the likelihood and consequence of these events.” [NHTSA 1998]

Based on the expertise of these investigators, MVFRI engaged Shields and Scheib to develop a computer based training program to guide the investigation of crash related fires. This training course was donated to NHTSA and is available to the public by way of a link on the MVFRI website.

The reports generated under the project are listed below:

Scheibe, Robert R., Shields, Leland E., and Angelos, Timothy E., "Field Investigation of Motor Vehicle Collision-Fires," (1999) Docket # NHTSA-1998-3588-70, Washington State Transportation Center, SAE Paper Number 1999-01-0088.

Shields, Leland E., Scheibe, Robert R., Angelos, Timothy E., and Mann, Robert, "Case Studies of Motor Vehicle Fires," (January 2001) Docket # NHTSA-1998-3588-164, Washington State Transportation Center.

Shields, Leland E., Scheibe, Robert R., and Angelos, Timothy E., "Motor-Vehicle Collision-Fire Analysis Methods and Results," (November 1998) Docket # NHTSA-1998-3588-77, Washington State Transportation Center.

Shields, Leland E., "Case Studies of Motor Vehicle Collision Fires," (April 21, 1998) Docket # NHTSA-1998-3588-98, SAE (Society of Automotive Engineers) Government/Industry Meeting, Washington, DC.

DOT/GM Project B.3
Fire Initiation and Propagation Tests

This project involved three research organizations and three tasks. The research organizations were: General Motors R&D, National Institute of Standards and Technology (NIST) and Factory Mutual Research Corporation (FMRC). The three tasks were: (1) develop and conduct vehicle crash tests that evaluate the potential for fire initiation, (2) develop and conduct vehicle fire spread tests using selected crash tested vehicles and (3) develop realistic fire initiation protocols for under-hood and rear end fuel fed fire tests. This series was generally known as the “crash and burn tests”.

Selected points from NHTSA’s report were as follows: “Potential ignition mechanisms for fires in the engine compartment may include:

- Electrical shorts to the chassis, which can generate sufficient heat to ignite combustible solid materials in contact with resistively heated surfaces.
- Hot surface ignition of combustible fluids (eg. Motor oil, power steering fluid, brake fluid, or automatic transmission fluid spilled onto the exhaust system.

- Piloted ignition of combustible vapor, such as the methanol vapor above the windshield washer fluid, when the temperature is greater than the flash point.
- Fire propagation pathways into the passenger compartment generally involve flame spread through openings in the vehicle structure. Heat conducted through the floor pan wheelhouse panels or dash panel can result in the ignition of combustible materials in contact with these metal surfaces (frying pan effect). Engine compartment fluids are frequently released during frontal crash tests.
- Occupants of burning vehicles may suffer thermal injury and inhale toxic combustion gasses accumulating in the passenger compartment. Self propagating underhood fires can be life threatening within 10-12 minutes after fire initiation.
- Underbody gasoline pool fires can rapidly propagate through very small openings in the body structure and pose an immediate threat to occupants within 2-3 minutes post-ignition." [NHTSA 1998]

MVFRI engaged personnel at Factory Mutual Research Corporation (FMRC) who conducted the burn tests to further analyze and summarize the results of this extensive test project. See the MVFRI project, "Analysis of Vehicle Fire Tests – GM/DoT and Others".

The results of research conducted under this project are contained in the following reports:

Ieradi, James A., and Barnett, Jonathan R., "Computer Model of Fire Spread from Engine to Passenger Compartments in Vehicle Fires," Worchester Polytechnic Institute (December 1998), Docket # NHTSA-1998-3588-206, General Motors Corporation.

Ohlemiller, T. J., "An Overview of Fire Test Results On Certain Automotive Components," NIST (December 2001) Docket # NHTSA-1998-3585-542, National Institute of Standards and Technology. - Also applies to Projects B.4 and B.10

Jensen, Jack L., and Santrock, Jeffrey, "Evaluation of Motor Vehicle Fire Initiation-and Propagation, Vehicle Crash and Fire Propagation Test Program," (May 1998) Docket # NHTSA-1998-3588-38, General Motors Corporation, ESV Paper Number 98-S4-O-04.

Jensen, Jack L., and Santrock, Jeffrey, "Evaluation of Motor Vehicle Fire Initiation and Propagation Part 1: Vehicle Crash and Fire Propagation Test Program," (July 1997) Docket # NHTSA-1998-3588-30, General Motors Corporation.

Jensen, Jack L., and Santrock, Jeffrey, "Evaluation of Motor Vehicle Fire Initiation and Propagation Part 2: Crash Tests on a Passenger Van," (September 1998) Docket # NHTSA-1998-3588-30, General Motors Corporation.(4 Frontal crashes of a 1996 Dodge Caravan)

Santrock, Jeffrey, "Evaluation of Motor Vehicle Fire Initiation and Propagation Part 3: Propagation of an Engine Compartment Fire in a 1996 Van Passenger," (August 2001) Docket # NHTSA-1998-3588-119, General Motors Corporation. (1996 Dodge Caravan, Frontal crash, engine compartment fire)

Santrock, Jeffrey, "Evaluation of Motor Vehicle Fire Initiation and Propagation Part 4: Propagation of an Underbody Gasoline Pool Fire in a 1996 Passenger Van," (January 2002) Docket # NHTSA-1998-3588-143, General Motors Corporation. (1996 Plymouth Voyager, Rear impact, underbody pool fire)

Jensen, Jack L., and Santrock, Jeffrey, "Evaluation of Motor Vehicle Fire Initiation and Propagation Part 5: Crash Tests on a Rear Wheel Drive Passenger Car," (September 2001) Docket # NHTSA-1998-3588-131, General Motors Corporation. (1997 Chevrolet Camaro, 2 Frontal and one Rear crash)

Jensen, Jack L., and Santrock, Jeffrey, "Evaluation of Motor Vehicle Fire Initiation and Propagation Part 6: Propagation of an Underbody Gasoline Pool Fire in a 1997 Rear Wheel Drive Passenger Car," (June 2002) Docket # NHTSA-1998-3588-158, General Motors Corporation. (1997 Camaro, Rear impact, underbody pool fire)

Jenson, Jack L., and Santrock, Jeffrey, "Evaluation of Motor Vehicle Fire Initiation and Propagation Part 6: Propagation of an Underbody Gasoline Pool Fire in a 1997 Rear Wheel Drive Passenger Car," (June 2002) Docket # NHTSA-1998-3588-581, General Motors Corporation. (Corrected pages filed May 10, 2002)

Santrock, Jeffrey, "Evaluation of Motor Vehicle Fire Initiation and Propagation Part 7: Propagation of an Engine Compartment Fire in a 1997 Rear Wheel Drive Passenger Car," (August 2002) Docket # NHTSA-1998-3588-178, General Motors Corporation. (1997 Camaro, Frontal pole crash, engine compartment fire)

Jensen, Jack L., and Santrock, Jeffrey, "Evaluation of Motor Vehicle Fire Initiation and Propagation Part 8: Crash Tests on a Sport-Utility-Vehicle," (January 2002) Docket # NHTSA-1998-3588-139, General Motors Corporation. (1997 Ford Explorer, 2 Frontal crashes and one Rear)

Santrock, Jeffrey, "Evaluation of Motor Vehicle Fire Initiation and Propagation Part 9: Propagation of a Rear-Underbody Gasoline Pool Fire in a 1998 Sport Utility Vehicle," (May 2002) Docket # NHTSA-1998-3588-188, General Motors Corporation. (1998 Explorer, Rear impact, rear pool fire)

Santrock, Jeffrey, "Evaluation of Motor Vehicle Fire Initiation and Propagation Part 10: Propagation of a Mid-Underbody Gasoline Pool Fire in a 1998 Sport Utility Vehicle," (May 2002) Docket # NHTSA-1998-3588-189,

General Motors Corporation. (1998 Explorer, Frontal crash, mid-body pool fire)

Jensen, Jack L., and Santrock, Jeffrey, "Evaluation of Motor Vehicle Fire Initiation and Propagation Part 11: Crash Tests on a Front-Wheel Drive Passenger Vehicle," (August 2002) Docket # NHTSA-1998-3588-179, General Motors Corporation. (1998 Honda Accord, 2 Frontal and one Rear impact)

Santrock, Jeffrey, "Evaluation of Motor Vehicle Fire Initiation and Propagation Part 12: Propagation of an Underbody Gasoline Pool Fire in a 1998 Front-Wheel Drive Passenger Vehicle," (November 2003) Docket # NHTSA-1998-3588-201, General Motors Corporation. (1998 Accord, Rear impact, rear fire)

Santrock, Jeffrey, "Evaluation of Motor Vehicle Fire Initiation and Propagation Part 13: Propagation of an Engine Compartment Fire in a 1998 Front-Wheel Drive Passenger Vehicle," (November 2003), Docket # NHTSA-1998-3588-203, General Motors Corporation. (1998 Accord, Frontal impact, engine compartment fire)

White, Robert E., Weyandt, Nathan C., Silvus, H. Stanley, Jr., Jannsens, Marc L., and Miller, Michael A., "Experimental Determination of Electrical and Physical Conditions for Ignition During Electrical Arcing," Southwest Research Institute (March 2004) Docket # NHTSA-1998-3588-207, General Motors Corporation.

Wittasek, Nathan B., Pehrson, Richard D., and Barnett, J.R., "Computational Fluid Dynamics Modelling of Post-Crash Vehicle Fires," (Volume 1: Bulkhead) Worchester Polytechnic Institute (May 1997), Docket # NHTSA-1998-3588-209, General Motors Corporation.

DOT/GM Project B.4
Evaluation of Potential Fire Intervention Materials and Technologies

The research organizations for this project were: General Motors R&D and National Institute of Standards and Technology (NIST). The project involved surveying suppliers to identify promising fire suppression candidates and laboratory testing selected concepts when exposed to engine compartment and under-vehicle fire scenarios. The laboratory testing was conducted by NIST.

NHTSA's evaluation of the project was as follows: "Although many suppressant types are impractical for post-collision engine compartment applications, a unique pyrotechnic device developed primarily for military use shows promise for vehicle applications." [NHTSA 1998]

General Motors subsequently crash tested an engine compartment fire suppression approach that appeared to offer promise in the NIST laboratory tests [Santrock, 2005]. The offset frontal crash tests, conducted with engines hot and running, induced engine compartment fires. The researchers concluded that the dynamic crash factors such as vehicle crush, vehicle movement, wind, and re-ignition of the fuel after release of the dispersal agent can substantially reduce the effectiveness of an automatic fire suppression system.

The results of research conducted under this project are contained in the following reports:

Hamins, Anthony ,"Evaluation of Active Suppression in Simulated Post-Collision Vehicle Fires," (November 2000) Docket # NHTSA-1998-3588-132, National Institute of Standards and Technology (NIST).

Hamins, Anthony, "Evaluation of Intumescent Body Panel Coatings in Simulated Post-Accident Vehicle Fires," (August 1998) Docket # NHTSA-1998-3588-24, National Institute of Standards and Technology (NIST).

Ohlemiller ,T. J ., "An Overview of Fire Test Results On Certain Automotive Components ," (December 2001) Docket # NHTSA-1998-3585-542, National Institute of Standards and Technology (NIST). – (Also contains information related to B.3 and B.10)

DOT/GM Project B.5
Development of Crash Test Protocols

Under this project, General Motors R&D conducted rear crash tests of five small cars – 1998 Ford Escort, 1998 Honda Civic, 1998 Nissan Sentra, 1998 Volkswagen Jetta, and 1998 Chevrolet Cavalier. The test conditions were: 70% overlap, 50 mph collinear impact by the FMVSS 214 barrier lowered by 2 inches.

NHTSA's evaluation of these tests were as follows: "Three of these tested vehicles did not meet the fuel spillage limits specified for the lower impact energy test of the current FMVSS 301. Detailed inspection and analysis of the crash tested vehicles that component subsystem and structural design details can contribute to performance in this configuration." [NHTSA 1998]

The results of research conducted under this project are contained in the following reports:

Eichbrecht, Paul T., "Crash Test Protocol Development for Fuel System Integrity Assessment," (December 1999) Docket # NHTSA-1998-3588-72, General Motors Corporation.

Eichbrecht, Paul T., "Overview of FMVSS 301 Upgrade Testing at GM ," (April 1998) Docket # Unknown, SAE Government/Industry Meeting, General Motors Corporation.

Rear Impact of 1998 Volkswagen Jetta (Reference GM test #C11816) *Test Report #3427*
Rear Impact of 1998 Honda Civic (Reference GM test #C11817*Test Report #3428*
Rear Impact of 1998 Ford Escort (Reference GM test #C11818) *Test Report #3429*
Rear Impact of 1998 Nissan Sentra (Reference GM test

#C11828)*Test Report #3430*
Rear Impact of 1998 Chevrolet Cavalier (Reference GM test #C11829) *Test Report #3431*

DOT/GM Project B.6
Analyses of Failure Modes and Effects for Alternatively Fueled Vehicles

This project, by Exponent/Failure Analysis Associates, conducted an analysis of failure modes and effects associated with normal use and operation of CNG fuel systems.

The results reported by NHTSA were as follows: "Results of this FMEA revealed the need to: 1) review the broad leak control strategies of existing systems (insofar as they are comprehended by the generic system analyzed in this study) and 2) revisit some basic engineering of these systems to help minimize the possibility of a system-wide risk of gas release." [NHTSA 1998] The following report was issued.

"Failure Modes and Effects Analysis of Compressed Natural Gas Fuel Systems for Cars and Trucks ," (August 1998) Docket # NHTSA-1998-3588-28, Exponent/Failure Analysis Associates

DOT/GM Project B.7
Development of Criteria and Methodologies for In-Service Inspections of Gaseous Fuel Pressure Vessels

This project, by Exponent/Failure Analysis Associates, evaluated acoustic emissions as a promising candidate non-destructive testing (NDT) technology for in-service inspections of CNG fuel system integrity. NHTSA's analysis was as follows: "..a wider variety of tank designs using a larger sample of size per tank design is required before a viable NDT inspection method using this technique can be developed." [NHTSA 1998] The reports for the project follow.

"Development of Inspection Technology for NGV Fuel Tanks - Revision ," (September 1998) Docket # NHTSA-1998-3588-57, Exponent/Failure Analysis Associates.

"Development of Inspection Technology for NGV Fuel Tanks ," (September 1997) Docket # NHTSA-1998-3588-13, Exponent/Failure Analysis Associates .

DOT/GM Project B.8
Search of Scientific Literature

Michigan State University was the contractor for this project. Under this project a searchable transportation Fire Safety Bibliography was created as a stand-alone, PC-based software package that contains information regarding more than 1000 scientific and technical articles relating to different aspects of transportation fires (e.g., the causes, propagation, severity, and extinguishment of fires in passenger carriers, flammability properties of interior and exterior materials used in motor vehicles and other modes of transportation, chemistry of flame retardants and their combustion products, and toxic effects of combustion gases).
The searchable bibliography was placed on the MVFRI website. The results of research conducted under this project are contained in the following reports:

LaDue, Douglas E. and Kononen, Douglas W. "A Searchable Transportation Fire Safety Bibliography," General Motors Global Research and Development Operations, Paper Number 98-W-46, 16th ESV Conference, (1998) General Motors Corporation

Wichman, Indrek S., "Material Flammability, Combustion, Toxicity and Fire Hazard in Transportation," (March 2003) *Progress in Energy and Combustion Science*, pp. 247-299, Elsevier Ltd., Docket # NHTSA-1998-3585-605, Michigan State University.

Wichman, Indrek S., "A Review of the Literature of Material Flammability, Combustion and Toxicity Related to Transportation," (January 2002) Docket # NHTSA-1998-3585-605, Michigan State University.

DOT/GM Project B.9
Inspection of Aging Vehicles and Testing of Components

This Southwest Research Institute (SwRI) study examined the effects of aging and environmental degradation on the integrity of fuel system components (eg. Fuel tanks, fuel lines and their connections) in 8-12 year old passenger vehicles. This project was not completed at the time the NHTSA Year 5 task was published. However, based on the SwRI experience, MVFRI engaged their research team to conduct fire and impact tests of representative plastic fuel tanks, both new and aged. The tests showed some degradation in the seams of the older tanks.
The results of research conducted under this project are contained in the following report:
Miller, Michael A., Brown, Robert D., Page, Richard A., and Orvis A. Leigh, "Inspection of Aging Vehicles and Testing of Components ," (September 2001) Docket # NHTSA-1998-3588-177, Southwest Research Institute.

DOT/GM Project B.10
Study of Flammability of Materials

This project of flammability research involved three research organizations: General Motors R&D, National Institute of Standards and Technology (NIST) and Factory Mutual Research Corporation (FMRC). The research investigated the fundamental materials flammability properties as well as the combustion chemistry of automotive materials. NHTSA's evaluation of this research was as follows: "New material flammability test methods have been developed that appear to be superior to existing FMVSS 302 Materials Flammability Test Methods." [NHTSA 1998]

MVFRI engaged FMRC to develop reports summarizing the improved test methods and the fire properties of the automotive materials tested under the GM/Dot Project.

The results of research conducted under this project are contained in the following reports:

Abu-Isa, Ismat A., Cummings, David R., and LaDue, Douglas E., "Thermal Properties and Flammability Behavior of Automotive Polymers," (May 1998) Docket # NHTSA-1998-3588-62, General Motors Corporation, ESV Paper Number 98-54-P-17.

Abu-Isa, Ismat A., "Thermal Properties of Automotive Polymers II – Thermal Conductivity of Parts Selected From A Dodge Caravan," (March 1999) Docket #NHTSA-1998-3588-39, General Motors Corporation.

Abu-Isa, Ismat A., and Jodeh, Shehdeh, "Thermal Properties of Automotive Polymers III – Thermal Characteristics And Flammability of Fire Retardant Polymers," (March 1999) Docket # NHTSA-1998-3588-84, General Motors Corporation.

Abu-Isa, Ismat A., Jodeh, Shehdeh, and LaDue, Douglas E., "Thermal Properties of Automotive Polymers IV – Thermal Gravimetric Analysis and Differential Scanning Calorimetry of Selected Parts from a Chevrolet Camaro," (April 2001) Docket # NHTSA-1998-3588-104, Delphi Central R&D.

Abu-Isa, Ismat A., and Jodeh, Shehdeh, "Thermal Properties of Automotive Polymers V – Flammability Test for Fire Retardant Polymers," (September 2001) Docket #NHTSA-1998-3588-130, Delphi Central R&D.

Ohlemiller, Thomas J., and Shields, John R., "Burning Behavior of Selected Automotive Parts from a Sports Coupe," (April 2001) Docket # NHTSA-1998-3588-138, National Institute of Standards and Technology.

Ohlemiller, Thomas J., and Shields, John R., "Burning Behavior of Selected Automotive Parts from a Minivan," (September 1998) Docket # NHTSA-1998-3588-26, National Institute of Standards and Technology.

Santrock, Jeffrey, Tewarson, Archibald and Wu, Peter, "Flammability Testing of Automotive Heating Ventilation and Air Conditioning Modules Made from Polymers Containing Flame Retardant Chemicals," *SAE* Paper 2002-01-3091 (2002) Docket # NHTSA-1998-3585-58, General Motors Corporation and Factory Mutual Research Corporation.

Santrock, Jeffrey, Tewarson, Archibald, and Wu, Peter, "Flammability Testing ofAutomotive Heating Ventilation and Air Conditioning Modules Made from Polymers Containing Flame Retardant Chemicals," (August 2002) Docket # NHTSA-1998-3588-180, General Motors Corporation.

Santrock, Jeffrey, "Identification of the Base Polymers in Selected Components and Parts from a 1997 Chevrolet Camaro by Pyrolysis / Gas Chromatography / Mass Spectroscopy," (August 2002) Docket # NHTSA-1998-3588-181, General Motors Corporation.

Santrock, Jeffrey, "Identification of the Base Polymers in Selected Components and Parts from a 1997 Ford Explorer by Pyrolysis / Gas Chromatography / Mass Spectroscopy and Attenuated Total Reflectance / Fourier Transform Infrared Spectroscopy," (August 2002) Docket # NHTSA-1998-3588-182, General Motors Corporation.

Santrock, Jeffrey, "Determination of Mol-% Ethylene in Propylene / Ethylene Copolymer Samples by Pyrolysis / Gas Chromatography / Mass Spectroscopy Analysis," (August 2002) Docket # NHTSA-1998-3588-183, General Motors
Corporation.
Silvus, H. S., and White, Robert E., "Inductances of Automotive Electromagnetic Devices," (March 2002) Docket # NHTSA-1998-3585-544, Southwest Research Institute, SAE Paper #2002-01-0143.

Tewarson, Archibald, "Fire Behavior of Automotive Polymers," *International Fire and Materials Conference*, January (2003) Docket # NHTSA-1998-3585-597, FM Global Research.

Tewarson, Archibald, "Characterization of the Ignition Behavior of Polymers Commonly Used In the Automotive Industry," (December 1999) Docket # NHTSA-1998-3588-71, Factory Mutual Research, Sixth International Symposium on Fire Safety Science, July 5-9, 1999.

Tewarson, Archibald, "A Study of the Flammability of Plastics in Vehicle Components and Parts," (October 1997) Docket # NHTSA-1998-3588-1, Factory Mutual Research.

DOT/GM Project B.11
Study of Component Influence on Vehicle Fires

This research conducted by SEA, Columbus Ohio, investigated safety issues associated with non-enhanced evaporative emission canisters and proposed onboard refueling vapor recovery canisters (ORVR). NHTSA's analysis was as follows: "..all data collected to date indicate that ORVR's in rear or mid-mounted positions are at least as safe (in terms of risk of post-impact fires) as current front-mounted emission canisters" [NHTSA 1998]

The results of research conducted under this project are contained in the following reports:

Andreatta, Dale A., Heydinger, Gary J., Bixel, Ronald A., Park, Joonhong, and Jorgensen, Scott W., "Evaluation of the Ignition Hazard Posed by Onboard Refueling

Vapor Recovery Canisters," (August 2002) Docket # NHTSA-1998-3588-176, SAE Paper Number 2001-01-0731.

Heydinger, Gary J., Andreatta, Dale A., and Bixel, Ronald A., "ORVR Vapor Canister Testing and Evaluation - Revision," (November 2000) Docket # NHTSA-1998-3588-91, S.E.A. Inc.

Heydinger, Gary J., Andreatta, Dale A., and Bixel, Ronald A., "ORVR Vapor Canister Testing and Evaluation," (March 2000) Docket # NHTSA-1998-3588-86, S.E.A. Inc .

DOT/GM Project B.12
Development of NASS Electronic Imaging System

This project was initiated in the first year of the settlement agreement to develop a state-of-the-art high volume imaging system for crash data. However, this project was discontinued the second year. No reports were generated [NHTSA 1999].

DOT/GM Project B.13
Development of Technical Information for Dissemination to First Responders

The project objective was to evaluate the potential usefulness of information developed in the other fire safety research projects for the first responder community and to develop effective ways of communicating that selected information to the emergency response community. There have been no reports on this project submitted to the NHTSA public docket. NHTSA's evaluation stated: "No significant progress has been made on this project as of the second quarter of year 5" [NHTSA 1999].

DOT/GM Project B.14
Demonstration of Enhanced Fire Safety Technology

This project was conducted by General Motors R&D. The objective was to evaluate the performance of some of the fire intervention technologies and materials identified in other fire safety research projects that might be adapted for use in automotive environments. The project was conducted after Year 4 and the complete results were not included in any NHTSA report. The test results generally highlighted real world conditions under which the effectiveness of the systems under evaluation were substantially reduced. In the Year 5.5 report NHTSA stated: "Preliminary findings indicate that the two prototype active suppression systems tested did not suppress the underhood and underbody fire scenarios developed for this study. There are considerable technical challenges associated with reliable detection and suppression of fire in vehicles." [NHTSA 1999]

The results of research conducted under this project are contained in the following reports:

Santrock, Jeffrey, "Part 1: Full Scale Vehicle Fire Tests of a Control Vehicle and a Test Vehicle Containing an HVAC Module Made from Polymers Containing Flame Retardant Chemicals ," (June 2002) Docket # NHTSA-1998-3588-190, General Motors Corporation.

Santrock, Jeffrey, and Hodges, Steven E., "Part 2A: Evaluation of a Fire Suppression System in a Full Scale Vehicle Fire Test and Static Vehicle Fire Tests - Engine Compartment Fires," (November 2003) Docket # NHTSA-1998-3588-202, General Motors Corporation.

Santrock, Jeffrey, and Hodges, Steven E., "Part 2B: Evaluation of a Fire Suppression System in a Full Scale Vehicle Crash Test and Static Vehicle Fire Tests - Underbody Gasoline Fires," (December 2003) Docket # NHTSA-1998-3588-205, General Motors Corporation.

Santrock, Jeffrey, and LaDue III, Douglas E., "Part 3: Full Scale Vehicle Fire Tests of a Control Vehicle and a Test Vehicle Containing an Intumescent Paint on its Underbody," (November 2003) Docket # NHTSA-1998-3588-204, General Motors Corporation.

DOT/GM Project B.15
Theoretical and Experimental Study of Thermal Barriers Separating Automobile Engine and Passenger Compartments

This project examined various thermal insulations for their roll in retarding fire and heat transfer from the engine compartment to the passenger compartment through the bulkhead. NHTSA's evaluation was as follows: "Results indicate that certain insulating materials were able to reduce heat transmission by up to a factor of ten compared to commonly used materials" [NHTSA 1998].

The results of research conducted under this project are contained in the following reports:

Ierardi, James A., Pehrson, Richard D., and Barnett, Jonathan R., "Applications of the Finite Volume Radiation Model to Predict Fire Behavior in Occupied Spaces ," (March 1999) Docket # NHTSA-1998-3588-36, Worcester Polytechnic Institute .

McMasters IV, Robert L., and Wichman, Indrek S., "Compound Material Thermal Parameters for a Layered Material Resembling an Automobile Firewall," (July-August 2002) *Heat Transfer Engineering*, Volume 23, Number 4, Docket # NHTSA-1998-3585-585.

Wichman, Indrek S., Beck, James V., Oladipo, A. Bukola, McMasters, Robert L., and Little, Erica, "Theoretical and Experimental Study of Thermal Barriers Separating Automobile Engine and Passenger Compartments ," (April 2001) Docket # NHTSA-1998-3588-105, Michigan State University.

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National Highway Traffic Safety Administration, "U.S. DOT/General Motors Settlement Agreement Status Report, Mid-Year 5", Undated (1999).

National Highway Traffic Safety Administration, Office of Defects Investigation, "Engineering Analysis Report and Initial Decision that the Subject Vehicles Contain A Safety Related Defect", National Highway Traffic Safety Administration, Engineering Analysis EA92-041, October 17, 1994.

Santrock, J., and Hodges, S., "Evaluation of Automatic Fire Suppression Systems in Full Scale Vehicle Fire Tests and Static Vehicle Fire Tests," SAE paper 2005-01-1788, April, 2005.

DEFINITIONS, ACRONYMS, ABBREVIATIONS

CDS: Crashworthiness Data System
ESV: International Technical Conference on the Enhanced Safety of Vehicles,
FARS: Fatality Analysis Reporting System
MHE: Most Harmful Event
MVFRI: Motor Vehicle Research Institute
NASS: National Automotive Sampling System
NHTSA: National Highway Traffic Safety Administration
SwRI: Southwest Research Institute