Review of the State-of-the-art In Fuel Tank Systems – Phase II

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Preface

This report constitutes the final deliverable for the Review of the State-of-the-art in Fuel Systems in Use in the North American Fleet. The work was performed under contract to Dr. Ken Digges of the Motor Vehicle Fire Research Institute and is a continuation of a previous project which specified the procedures for performing the fuel system survey contained in this report.

The opinions expressed herein are those of Biokinetics and Associates Ltd. and do not necessarily reflect those of Dr. Digges or the Motor Vehicle Fire Research Institute.

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1. Introduction

Post crash vehicle fires result from the ignition of flammable materials or fuels that may be expelled during and after a collision. Gasoline, the most volatile of such fuels, may leak directly from a damaged fuel tank or from torn or severed fuel lines. In the presence of an ignition source, this poses the greatest risk of rapid conflagration. The crash environment presents several possible ignition sources, including:

- Hot vehicle components such as the exhaust system.
- Sparks generated from steel vehicle components scraping the ground.
- Sparks generated from metal to metal contact with an opposing vehicle.
- Heat and sparks generated by the crush of a vehicle’s structure.
- Electrical arcing from broken or exposed wires.
- Electrical heat generated from short circuits of primary and secondary wiring.
- Electrical heat generated from internal shorting of battery plates.

Although it is difficult to determine the causes of vehicle fires or the incidents of fire related fatalities or injuries from existing accident statistics [Ref. 1 and Ref. 2], burn injuries can be disfiguring, requiring long recuperation and rehabilitation. The design criteria for a fuel system should include considerations for reducing the possibility of post crash vehicle fires. Features such as structural crashworthiness design, material selection, fuel tank location in the vehicle, and add-on technologies must all be considered.

In 1967, the National Highway Traffic Safety Administration (NHTSA) introduced the Federal Motor Vehicle Safety Standard (FMVSS) No. 301 “Fuel System Integrity”. The intent of the standard was to reduce the incidence of deaths and injuries resulting from post crash vehicle fires by ensuring that the fuel systems in new vehicles met a minimum integrity requirement under three crash test configurations. These test configurations included a frontal collision into a rigid wall and a lateral and a rear impact from a rigid flat faced moving barrier. In 2000, a notice of proposed rulemaking (NPRM) [Ref. 3] was issued by NHTSA to upgrade the existing impact configurations in the FMVSS 301 standard to be more representative of crashes involving fires. A summary of the proposed changes to the standard is presented in Table 1.

Table 1: Proposed changes to FMVSS 301 Fuel System Integrity standard.

Impact Direction	Test Parameter	FMVSS 301	Proposed FMVSS 301
Frontal	Barrier	fixed / rigid	No changes
	Impact speed	48 km / h (30 mph)	No changes
Rear	Barrier	Moving / rigid	Moving / deformable
	Barrier mass	1,814 kg (4,000 lbs)	1,368 kg (3,015 lbs)
	% vehicle contact	100	70
	Impact speed	48 km / h (30 mph)	80 km / h (50 mph)
Side	Barrier	Moving / rigid	Moving / deformable
	Barrier mass	1,814 kg (4,000 lbs)	1,368 kg (3,015 lbs)
	Impact site	Centred at the driver's seating reference point	As defined in FMVSS 214
	Impact direction	90^{o}	Crabbed
	Impact speed	32 km / h (20 mph)	53.6 km / h (33.5 mph)
Note: The proposed side impact test is the same as the FMVSS 214 test and thus does not have to be repeated.			

Compliance with the existing standard is still required and presumably the fuel systems in the 2002 and 2003 North American fleet of vehicles all meet the FMVSS 301 requirement. Furthermore, the tank systems of many of these vehicles employ counter measures that would aid in the prevention or mitigation of post crash vehicle fires under varied crash configurations and may aid in compliance with the more stringent requirements of the proposed FMVSS 301 standard.

An investigation of the state-of-the-art in automotive fuel systems has been conducted to establish the best practices in fuel system design and implementation in the current North American fleet of vehicles. The investigation consisted primarily of an in-vehicle inspection of 74 fuel tank systems and a complete tear down and inspection of 18 fuel tanks and their associated components.

The investigation was divided into two phases. Phase 1 defined the overall scope of the review and established procedures for carrying out the more specific inspection of individual vehicles and their tank systems. A review of fuel system standards was also performed. Phase 2 comprised the actual inspection of vehicles and their tank systems and further investigation of fuel tank fire safety technologies.

Details of Phase 2 of the review of the state-of-the-art in fuel system technology is described herein while the work performed in Phase 1 is reported on in Biokinetics and Associates Ltd Report R02-04 [Ref. 4].

2. Vehicle Selection

The investigation of the state-of–the-art in fuel systems included the inspection of 74 vehicles from the over 300 makes and models of vehicles represented in the 2002 and 2003 North American fleet. The selected vehicles were intended to highlight the best practices employed in current fuel system design.

Initially, vehicles were included in the review if they were known to incorporate or suspected of incorporating fire preventative technologies or design strategies. Furthermore, vehicles that had been involved in fuel system fire safety related recalls were also included, as the improvements to their fuel systems would highlight considerations for a fuel system's design. Additionally, 9 of the 13 vehicles that were tested in the development and evaluation of the proposed FMVSS 301 upgrade were also included. The resulting list consisted of vehicles included for reasons indicated above plus a sampling of vehicles representative of various manufacturers, price ranges and classes, such as SUVs, pickup trucks, vans and passenger cars.

A summary of the types of vehicles selected is presented in Table 2 to Table 4 with the complete list of inspected vehicles presented in Appendix A.

Table 2: Number of vehicles inspected by manufacturer.

Manufacturer	No. of vehicles	Manufacturer	No. of vehicles
General Motors	12	BMW	3
Ford	10	Volvo	3
Chrysler	9	Audi	2
Toyota	9	Hyundai	2
Honda / Acura	8	VW	2
Nissan / Infinity	5	Mercedes	2
Mazda	3	Subaru	1
KIA	3		

Table 3: Number of vehicles inspected per class.

Vehicle type	No. of vehicles	Vehicle type	No. of vehicles
Sedan / Coupe / Wagon	41	Mini-van	7
SUV	15	Full-size van	3
Pickup truck	8	-	-

Table 4: Number of vehicle from various price ranges.

Vehicle Price (USD)	No. of vehicles	Vehicle Price	No. of vehicles
Under $15,000	14	$25,000 to $30,000	9
$15,000 to $20,000	22	$30,000 to 50,000	9
$20,000 to 25,000	18	Over $50,000	2

3. Fuel System Inspection Procedure

The fuel system inspections comprised an in-vehicle inspection of the fuel system installation. For a select number of vehicles the fuel system components were purchased and evaluated in more detail.

3.1 Vehicle Inspections

The selection of 74 subject vehicles included in the review was made available for inspection through the co-operation of many automotive dealerships that not only provided the vehicles for the inspections but also the service bay facilities for inspecting the fuel system installations from underneath the vehicles.

The fuel system inspections comprised a visual inspection of the installation, and size and positioning measurements of the various fuel system components within the vehicle. During the course of the inspection, none of the vehicles' components was altered or removed in any way to obtain a better view or to determine the use a particular fire safety technology that may have been occluded.

Generally, the information pertaining to the fuel system that was obtained through the vehicle inspections included:

- The placement of the tank relative to the extents of the vehicle.
- The presence of fire safety related technologies.
- The routing of fuel lines.
- The proximity of aggressive components which could potentially be damaging to the fuel system in a collision.

The parts list[1] for the fuel systems and, when available, the shop manuals for each vehicle were also reviewed with emphasis on obtaining additional information pertaining to the fuel systems' components and installation. The parts lists were very useful in determining the components of a particular fuel system, many of which were not visible during the inspection. On the other hand, the shop manuals that were reviewed did not provide additional information related to the fire safety features of a fuel system that were not already determined during the vehicle inspections or the review of the fuel systems' part lists.

[1] The fuel system parts lists were obtained using Mitchell International Inc.'s "PartsPoint", an electronic part look-up database.

An inspection checklist/summary report was used to ensure consistent data collection from each vehicle inspected. The data collected included information regarding:

- The vehicle in general.
- The battery placement.
- The fuel system, which comprises the fuel tank, fuel lines, fuel filler, canister and the fuel filter.
- Specific fire safety related features.

If a specific feature was not apparent or could not be determined it was classified as unknown.

A copy of the inspection checklist is presented in Appendix B.

The data recorded was transcribed into an electronic database that was created using Microsoft Access®.

Forty-four predefined photographs of each vehicle were also taken to provide visual documentation of the inspected vehicles and their fuel systems. These photographs were catalogued and included in the electronic database. A blank image was used to record the instances when a feature was not visible.

3.2 Tank Component Inspection

The complete fuel systems from 18 of the inspected vehicles were purchased for further detailed inspection and measurement. Included in the components purchased were the tank, sending unit, vapour canister, filler tubes and filters. The tank systems are listed in Appendix C along with the reason for their selection.

Similarly to the vehicle inspections, a checklist/summary report was followed for the tank inspections to ensure consistency of the data collected. The tank inspection checklist is contained in Appendix D for reference. In general, information pertaining to the fuel tank's dimensions, capacity, construction and components were recorded in the summary reports and later transcribed into the electronic database. Additionally, 22 photographs of the tank and its components were included in the electronic database.

4. Tank Design Considerations

Many issues must be considered in the design of a fuel system to optimize its crashworthiness. For example, features such as vehicle structural integrity, tank placement, fuel line routing, materials selection, filler connections, grounding and battery location all need to be considered. Each of these issues is discussed briefly in the following sections.

4.1 Structural Crashworthiness Design

The structural design of a vehicle is undoubtedly very important in preventing or mitigating fuel system damage and possibly loss of integrity in a crash. An otherwise well designed tank system may exhibit poor crashworthiness if the vehicle structure does not provide adequate protection from crash loads or from impingement into the tank space. Conversely, a less robust tank design may perform favourably if afforded sufficient protection by the vehicle structure. The performance of a vehicle's structural design in a crash, however, could not be ascertained simply by the vehicle inspections that were performed. Structural integrity in a crash environment can only be evaluated with integral knowledge of the structural design, through crash testing or analysis of field data. Consequently, the implementation or lack thereof of other tank technologies or design considerations is in itself insufficient to evaluate the crashworthiness of a tank system.

The combination of tank technologies and vehicle structure is ultimately what will dictate the integrity of a tank system in a crash. To this end manufactures are known to test tank designs under full-scale crash conditions that are more severe than those in FMVSS 301 and may involve a variety of crash configurations, crash speeds and impacting surfaces other than those specified in FMVSS 301.

4.2 Tank Placement

In an ideal fuel system installation the tank would be situated in a location where the damaged sustained would be minimal under various crash configurations that include frontal, rear and lateral collisions. Therefore, the tank should be placed in a location best protected by surrounding structures designed to mitigate crash forces. The immediate area around the tank should also be free of components that may be intrusive to the tank, such as hard edges or protruding bolts. During a crash, these items could be damaging to the tank if they are displaced sufficiently by the vehicle crush to the extent of piercing or tearing open the tank.

The structure of the vehicle can also be used to enhance the protection afforded the tank by virtue of its location in the vehicle. For example, the forward region proximal to the rear axle may have added protection against lateral intrusion offered by the rigid structure of the axle. Similarly, in pickup trucks the substantial frame rails might effectively improve the protection of the fuel tank.

In addition to protecting the tank from severe crash type loading, consideration can also be given to reducing wear and tear on the tank from such road hazards as dirt, rocks and other road debris that may be encountered in daily or specialized driving conditions. Depending on the use of the vehicle, the ground clearance of a fuel tank placed underneath the vehicle can be optimized. Technologies such as debris shields can be incorporated to protect under certain conditions. These are most often considered for significant off-road driving of utility vehicles.

4.3 Fuel Line Routing

In routing the fuel lines from the tank to the engine, consideration must be given to providing them with the maximum amount of protection from damage in a crash. This may be accomplished by routing the lines along structural components or providing additional shielding to protect against potentially aggressive edges on an impacting vehicle or intruding structures. The routing of the fuel lines should avoid the proximity of the exhaust components or hot engine components. If the lines are severed in a crash it is best to keep any possible leaking fuel from coming into contact with a hot component. Additionally, a design consideration may be to add compliance in the fuel lines to allow for elongation of the routing path as a result of vehicle crush and deformations from a collision and relative motion between the engine and the vehicle frame.

4.4 Materials Selection

The choice of material for the fabrication of a fuel tank can affect the vapour emissions, the crashworthiness, the manufacturability and the long term durability of a tank system. The points listed below are not intended to recommend one material over another but instead to highlight the need to carefully evaluate the environment the tank may experience during normal operation or in a crash and to select a material that is most appropriate for a specific application or tank design.

- With ever increasing environmental concerns, minimizing evaporative emissions has become a very important issue governing the selection of materials for use in a fuel tank system. Steel is inherently impermeable to fuel vapour and new plastic formulations have been developed that reduce the vapour permeation in plastic tanks.

- Steel and plastic tanks may have different resistance to damage by virtue of their material properties. In selecting a material for fabricating a tank the environment to which the tank may be exposed must be considered.
- In terms of fabrication, plastic manufacturing methods allow for complex geometries to be moulded to maximize the space available to the fuel tank installation. Newer, highly formable steels and steel manufacturing methods, however, do allow for stamping steel into more complex shapes than previously possible.
- Plastic tanks are corrosion resistant and, therefore, should not suffer degradation of their structural integrity, as would an improperly treated steel tank. However, results of limited tests sponsored by the Motor Vehicle Fire Research Institute suggest some degradation of aged plastic tanks may occur particularly at the pinch-off [Ref. 5].
- According to the Strategic Alliance for Steel Fuel Tanks (SASFT), with the proper treatment steel tanks can effectively resist corrosion for over 15 years.

4.5 Filler Connection

Although a fuel tank may be well positioned in a vehicle to avoid direct contact from an impacting vehicle, an unavoidable requirement of any fuel system is the provision for refuelling. In a vehicle, this is typically accomplished through a filler tube connected to a rear quarter panel. Even though the tank itself may be well removed from direct impact in a collision, the filler tube is susceptible to damage and/or possible displacement from its design position. If the filler tube is rigidly attached to the tank the crash forces can be transmitted through the tube, to the tank, potentially damaging the tank and causing fuel leakage. It is, therefore, prudent to ensure a compliant connection of the filler tube to the tank. In an extreme case where the filler tube has been severed, provisions should be incorporated in the fuel system design to prevent fuel loss. This is most easily accomplished with a check valve installed at the tank where the fuel filler tube meets the tank. Check valves are discussed further in Section 5.1.

4.6 Grounding

The individual components of a fuel system should be commonly grounded to avoid the possibility of an electrostatic discharge (ESD) occurring. Under the right circumstances of humidity and fuel vapour concentration, a build up of static electricity can discharge between two objects of different electrical potential creating a spark that can ignite fuel vapours. This may not necessarily be associated with a crash event. Refuelling, for example, is a non-crash-related environment where fuel vapours may be present. The flow of fuel itself, through the filler tube for example, can generate a static charge on the system's components. Each component associated with a fuel system should, therefore, be commonly grounded to dissipate such build up of electrical charge.

4.7 Battery Location

Although it is not directly related to fuel systems, and therefore it is somewhat outside the scope of the current review, the installation of the battery may be an important consideration concerning the prevention of vehicle fires in general.

The service battery in a vehicle is the only source of electrical current that may cause arcing if the engine is not in operation. Following a collision, electrical arcing from damaged electrical wiring is a potential source of ignition for spilled fuel, which of course includes gasoline, the most volatile of automotive liquids. To mitigate this possibility, a battery disconnect/cut-off can be employed to disconnect current to the vehicle's electrical systems in the event of a collision. Battery disconnects are discussed further in Section 5.5.

Regardless of whether or not other fuels are spilled in a crash, electrical shorting within the battery itself or of the positive battery terminal can ignite the battery case which may also result in fire. Ideally, the battery should be situated so as to minimize or avoid damage in a collision and an insulated cap may be placed over the positive battery terminal to minimize the possibility of electrical arcing with displaced metal components.

In addition to the service battery, consideration must also be given to the installation of secondary battery systems such as those found in electrical vehicles. The potential problems associated with typical service batteries are only exacerbated with the increased current and voltages that are associated with the battery packs used in these vehicles.

5. Tank Fire Safety Technologies

A review of fuel system fire safety technologies with applications in the automotive, aviation and military industries was undertaken and is described in the following sections. In principle, all these technologies can be incorporated into a fuel system's design to potentially mitigate post crash fuel fires, although, the implementation of some of the technologies may be impractical due to prohibitive costs, reliability or suitability for a given application.

Promotional information for some of the technologies discussed is contained in the appendices; however, the inclusion of this information does not constitute an endorsement of a particular product or company.

Neither the design intent nor the described efficacy of the technologies discussed in this section has been supported with field data or independent testing.

5.1 Fuel Filler Check Valves

The function of a fuel filler check valve is to prevent fuel spillage in the event the fuel cap or the filler tube is damaged in a crash. Depending on the final resting position of the vehicle and the severity of damage to the cap or the filler tube, large quantities of fuel may be spilled.

Check valves are designed to allow fuel flow in one direction and to restrict flow in the opposite direction. These valves are normally closed but will open under fuel pressure to allow tank filling to occur. However, under reverse flow conditions the fuel pressure acts to maintain the valves closed, thus preventing or minimizing fuel spillage through the filler pipe.

Ideally, the valve would be installed as close as possible to the tank to minimize the potential of the valve itself being damaged in a crash. Two valves are shown in Figure 1. One is typical of that used in consumer vehicle applications and the other for automotive racing applications.

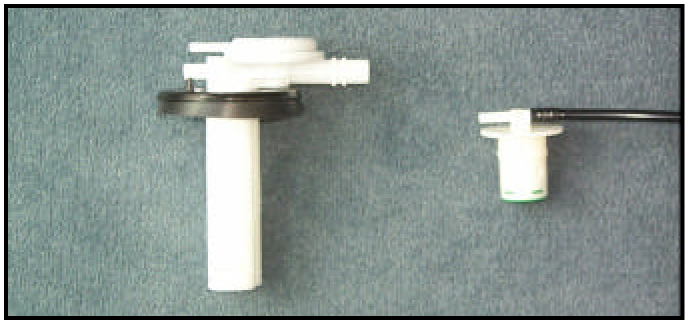
a) b)

Figure 1: Check valve from: a) consumer vehicle and b) auto racing fuel tank.

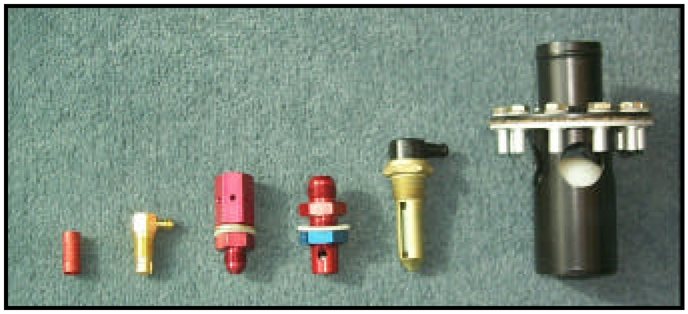
5.2 Roll-over Valves

A roll-over valve prevents fuel from entering a tank's vent lines if a vehicle is overturned during a collision. Under normal operating conditions the roll-over valve is normally open permitting the flow of air or fuel vapour into or out of the tank through the vent hoses connected to the tank.

The valves which are gravity actuated are orientation sensitive and must exceed a minimum rotation from their upright orientation before the valves engage to prevent fuel from flowing into the vent lines. Typical examples of roll-over ball type valves from consumer automotive fuel tanks and from auto racing applications are shown in Figure 2.



a)



b)

Figure 2: Roll-over valves from a) consumer automotive and b) auto racing applications.

5.3 Fuel Pump Shut-off

With fuel injected vehicles it is conceivable that the electric fuel pump may continue to function following a collision. If the fuel delivery line is severed, the pump would continue to expel fuel from the severed line. In a crash, a fuel pump shut-off disables the pump and prevents this from happening.

The fuel pump shut-off switch can be either inertially or electronically activated. Mechanical fuel shut-off switches are sensitive to vehicle accelerations. A sufficiently high acceleration would be indicative of a crash and would result in deactivation of the fuel pump. Electronic fuel shut-off systems are activated by sensors that monitor for a crash or engine rotation.

In an inertial type switch, a crash pulse causes a mass within the switch to shift, breaking the electrical connection to the fuel pump. An example of an inertial switch, produced by First Technology and known to be used in the Ford Focus, is shown in Figure 3 along with a cutaway view of the switch in its normal and activated state. The switch is described in more detail in Appendix E.

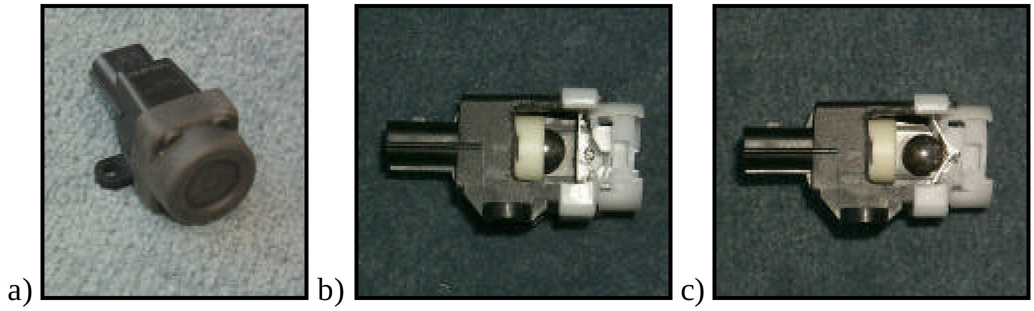


Figure 3: a) Inertia activated fuel shut-off switch, b) cutaway view showing normal state and c) cutaway view showing activated state.

An electronic fuel pump shut-off system is controlled by an onboard computer that monitors for a crash using accelerometers mounted in the vehicle or engine rotation sensors. Internal algorithms monitor the outputs from these sensors for indications that a crash has occurred. Once a crash is detected power to the fuel pump is disconnected.

5.4 Returnless Fuel Systems

In recent years, emphasis has been placed on reducing the emissions of fuel vapours in automobiles. A development in this regard has been an electronic returnless fuel system (ERFS), see Figure 4. Conventional fuel pump systems provide more fuel than the engine requires resulting in a constant circulation of fuel to the engine, through the fuel delivery line, and returning back into the fuel tank via a return fuel line. The ERFS makes the return fuel line obsolete by only producing exactly what the engine requires through the use of an electronic pressure regulator located in the pump housing, which in turn is located in the fuel tank. The elimination of the return line prevents hot fuel vapours from returning to the fuel tank, resulting in reduced evaporative emissions.

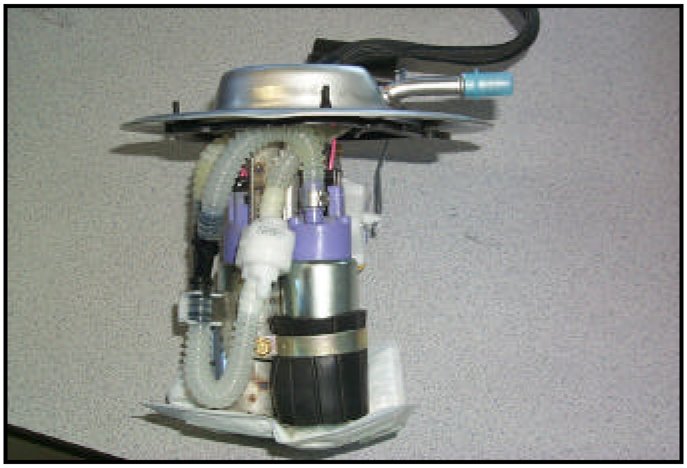


Figure 4: Ford Mustang Electronic Returnless Fuel Pump.

With the implementation of the ERFS, two secondary fuel system safety related benefits have arisen. First, the absence of the return fuel line means there is one less line containing fuel that can be severed in a collision and secondly, there is less fuel being pumped to the engine. Regardless of the quantity of fuel being pumped, the fuel pump shut-off described in Section 5.3 should disconnect the pump in a collision.

5.5 Battery Disconnect/Cut-off

In a sufficiently severe collision a battery disconnect or cut-off disconnects power to the vehicle's electrical systems directly by severing the electrical connection to the positive battery terminal. This is done to minimize the chances of electrical shorts and arcing from damaged wiring following a crash. Such arcing or hot wires could act as an ignition source in the presence of spilled fuel, from a damaged fuel tank for instance.

Two mechanisms for disconnecting the battery were identified. The first employed a pyrotechnic charge to disconnect power and the second disconnected the power electronically. With both systems the power from the battery is interrupted within 3 ms of a crash being detected.

5.5.1 Battery Cable Squib

The battery cable squib employs a small pyrotechnic charge to disengage the main voltage supply to the vehicle's electrical system. Power to essential vehicle functions, such as the door locks and electric window mechanisms, is maintained.

Similarly to the electronic fuel shut-off switch, the battery squib is activated by the onboard computer which monitors for crash conditions by means of transducers mounted on the vehicle.

The positive voltage battery cable from a BMW, with the integral squib on battery post end of the cable, is shown in cutaway view in Figure 5 before and after the discharge of the squib.

a) b)

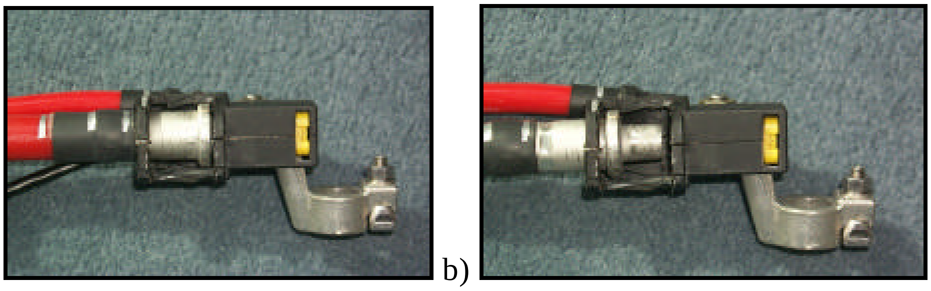


Figure 5: Cutaway view of the BMW battery connector squib (a) before and (b) after the squib discharge.

5.5.2 Electronic Battery Disconnect

The electronic battery cut-off functions similarly to the battery squib. However, instead of using a pyrotechnic charge to disengage the battery cable, the electronic cut-off uses a fusible switch that is activated from a remote signal that can be derived from crash sensors mounted in the vehicle. Unlike the battery squib, the electronic battery cut-off can be reset. Information regarding this type of disconnect is found in Appendix F.

5.6 Collapsible Drive Shaft

Although not a component of the fuel system, the drive shaft in rear wheel drive vehicles may pose a potential threat to the crashworthiness of a fuel tank. In a frontal collision the drive shaft may be pushed rearward and if this motion is resisted sufficiently, buckling of the drive shaft may occur. Depending on the positioning of the fuel tank relative to the drive shaft and the buckling mode of the shaft, contact with the tank may result. The collapsible drive shaft absorbs energy by incorporating compliance in the shaft design that would aid in mitigating the possibility of the drive shaft buckling, thereby reducing the possibility of undesirable contact with the fuel tank.

5.7 Self-sealing Breakaway Connectors

Self-sealing breakaway connectors on the fuel lines are used in the auto racing industry. They are designed to disengage when a predefined tensile load limit is exceeded. Once disconnected, the resulting free ends of tubing are instantly sealed to prevent fluid loss. If a tank experiences excessive displacement during a collision or if its mounting hardware fails and the tank is ejected, the self-sealing connectors would help to prevent the fuel lines from severing and causing excessive fuel spillage. An example of the self-sealing breakaway connector, installed on the fuel delivery and return line on an automotive racing fuel cell, is shown in Figure 6. Specification for the breakaway connectors shown in Figure 6 can be found in Appendix G.

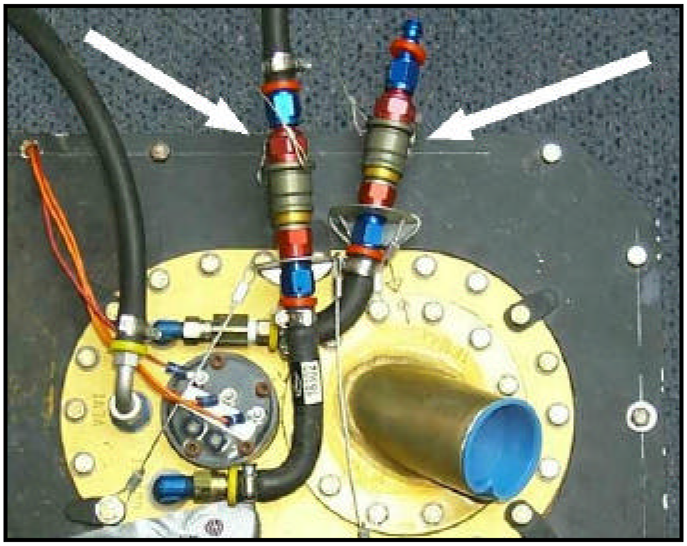


Figure 6: Self-sealing breakaway connectors installed on an automotive racing fuel cell.

5.8 Active Fire Suppressant Systems

Active fire suppressant systems are widely used in commercial, marine, military and aircraft applications. Upon sensing the presence of a fire, an active fire suppressant system, installed in a vehicle, would disburse a fire suppressant agent to extinguish the fire. There are no known automotive applications of such a system although research has been conducted into their use under simulated engine compartment and under body fire scenarios [Ref. 6].

5.9 Passive Fire Suppressant Systems

5.9.1 Fire Retardant Blankets

Although not directly related to the fuel system, the presence of fire retardant blankets was recorded during the vehicle inspections. The premise behind the use of fire retardant blankets in the engine compartment is that the heat from a fire would melt the blanket's mounting lugs causing it to drop down from the under side of the hood and smother the fire. Numerous vehicles also employ sound dampening material on the underside of the hood to reduce vehicle noise.

It was not possible to determine from the vehicle inspections whether the material observed inside the engine compartment had fire retardant properties, however, its presence was recorded as a fire retardant blanket.

5.9.2 Powder Panel

Powder panels were originally developed by the military, both for aircraft and ground vehicles, to prevent fuel fires following a ballistic strike to a fuel tank. They are constructed of hollow panels filled with a dry chemical fire suppressant and then sealed. When the panels are compromised, a cloud of fire suppressant powder is emitted to extinguish or prevent ignition of spilled fuel.

In an automotive application, the panels would be affixed to the exterior of a fuel tank. If the fuel tank is ruptured in a collision, the intimate proximity of the fire panels ensures the simultaneous rupture of the panels and the release of the fire suppressant at the site of damage and of the potential ignition source. Following the initial release of the fire suppressant, a cloud of suppressant remains for an extended period and may prevent delayed ignition.

FIREPANEL has developed a powder panel specific for use in the Crown Victoria Police Interceptor (CVPI) that has been reported to be at risk of fire in the event of a high speed rear end collision. The powder panel is affixed to the axle side of the gas tank. If sufficient intrusion into the tank's space occurs, the panels are supposed to fracture and disperse the fire suppressant.

The information pertaining to intended functioning of the powder panels was provided by FIREPANEL and is contained in Appendix H

5.10 Explosion Suppressant Tank Fillers

Explosion suppressant arresting foam (ESAF) was developed for use in bladder type fuel tanks such as those used in military aircraft and auto racing. If a fuel tank is damaged in a crash the ESAF works to prevent or mitigate the chance of an ensuing fuel fire. Additionally, in military applications the ESAF prevents explosion if a fuel tank is compromised by weapons fire.

The ESAF is manufactured from reticulated polyurethane foam whose structure is 98% void. The foam is either made or cut to conform to the internal geometry of a fuel tank with allowances made to accommodate internal tank components such as sending units or fuel level meters.

The ignition of fuel vapours in the ullage[2] of a tank may be the result of electrical arcing, heated components, static discharge, and weapons fire in military applications. In these circumstances violent explosion of the vapour is

[2] The tank ullage refers to the pocket of space in a fuel tank that is not occupied by liquid fuel.

suppressed by confining the ignition of fuel vapour, in the ullage of a tank, to the immediate area of the ignition source.

A secondary benefit of ESAF is that it acts as baffling and eliminates sloshing inside a tank.

Promotional information from Engineered Inerting Systems, a supplier of ESAF, is contained in Appendix I.

Anti-explosion characteristics are also achieved with a similar technology that uses matted aluminum mesh instead of reticulated foam. The mesh can be installed as a net-roll during manufacturing or it can be added to the finished product in the form of aluminum mesh spheres. Similarly to the ESAF, the aluminum mesh is 98% void and thus occupies very little volume. More details pertaining to this technology are presented in Appendix J.

5.11 Tank Bladder

A bladder tank consists of a tough rubberized membrane that by virtue of its compliance is resistant to impact. These tanks are used in the transportation and storage of liquids, and in aviation, marine and auto racing fuel systems. Typically, in an auto racing application the bladder is contained within a metal outer container which affords additional protection from impact.

In addition to the inclusion of a bladder, auto racing fuel cells incorporate several of the fuel tank technologies discussed in previous sections, such as, ESAF, check-valves and roll-over valves. A description of a fuel cell system that incorporates a bladder is presented in Appendix K.

5.12 Self Sealing Fuel Tank

The primary use of self sealing technology is to prevent fuel loss due to tank punctures resulting from ballistic impact from small arms fire. Typical applications of this technology include military vehicles and dignitary limousines.

There are many variations to the construction methods used to fabricate a self sealing tank. Each method typically encapsulates a tank with multi-layers of material that are vulcanized to the tank's outer surface. Rubberized inside and outside layers surround a fuel activated sealant layer. If the fuel cell is penetrated by a projectile or some other object, two sealing mechanisms occur. Firstly, the outer and inner rubber layers quickly close around the hole to minimize fuel leakage created by the intrusion. Secondly, the fuel that leaks through the hole in the inner layer reacts with the sealant causing it to swell several times it normal size providing an effective means of stopping further fuel leakage.

An example of a self sealing tank system is presented in Appendix L.

5.13 Inerting Systems

Fuel vapour is a leading contributor to fuel tank explosions due to excessive heat build-up, static discharge or penetrating projectiles. The aircraft industry, primarily with regards to military applications, has adopted an onboard system that reduces the presence of oxygen from the ullage that when mixed with the fuel vapours results in a highly flammable mixture. An on-board inert gas generating system (OBIGGS) draws in ambient air and filters out approximately 98% of the oxygen molecules and the remaining nitrogen enriched air is pumped into the ullage of the fuel tank, see Figure 7[3]. The presence of the nitrogen in the ullage will prevent the explosive oxygen/vapour concentration from occurring and therefore will mitigate the possibility of ignition.

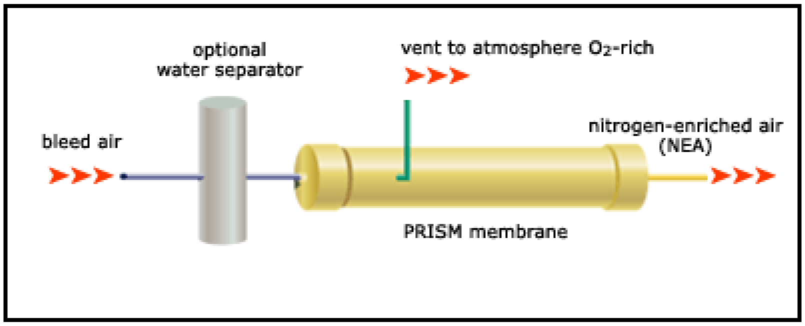


Figure 7: OBIGGS.

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[3] Photo was obtained from the following web site:
http://www.airproducts.com/membranes/page02.asp

6. Vehicle Inspection Findings

The following sections summarize some of the findings from the in vehicle fuel system inspections and the detailed tank inspections as they relate to the tank design strategies and technologies described in Sections 4 and 5.

6.1 Tank Placement

The placement of the fuel tank was categorized relative to the rear axle and the medial plane of the vehicle. If a physical axle was not present, the placement of the tank was taken relative to the axis joining the hubs of the rear wheels.

The tank placement results, including the minimum and maximum clearances to the rear bumper, are summarized in Table 5.

Table 5: Fore-aft placement of fuel tanks relative to the rear axle.

Tank Fore-Aft Position	**No. of Tanks**	**Clearance from rear bumper (cm)**	
		min	**max**
Ahead of axle	64	86	195
Over axle	6	58	108
Behind axle	4	31	97

6.1.1 Tank Placement Ahead of Rear Axle

For the 64 vehicles with their tank mounted ahead of the rear axle, the placement of the tank was further categorized relative to the medial plane of the vehicle as summarized in Table 6. Also included in Table 6 is the distance of the tank edge to the closest side of the vehicle.

Table 6: Lateral position of tanks forward of the rear axle.

Tank Lateral Position	**No. of Tanks**	**Clearance from the sides of the vehicle (cm)**	
		min	**Max**
Left side	20	21	54
Mid-ship	40	17	67
Right side	3	30	39
Both sides	1	30	30

Referring to Table 6, the only vehicle with a tank on both sides was the Chevrolet Corvette which has a dual fuel tank system.

In general, a mid-ship tank configuration was employed in passenger cars, whereas the vehicles with their tank on either the left or right side, with the exception of the Audi A4 and the Corvette, were either trucks or vans.

6.1.2 Tank Placement Over the Axle

All six tanks that were situated over the axle, extend both forward and aft of the axle and were somewhat centred about the medial plane of the vehicle. Although extending towards the rear of the vehicle, the distance of the tank to the rear bumper was maintained between 91 cm to 108 cm, except for the VW Passat that had a tank clearance distance of 58 cm from the rear bumper. A typical over the axle tank placement is shown in Figure 8.

Figure 8: Typical over the axle tank placement.

6.1.3 Behind the Rear Axle

Four of the 74 vehicles inspected had their tank situated behind the rear axle. However, of the four, the Grand Marquis' (Crown Vic) tank was installed vertically which allowed for a large clearance of 97 cm from the rear bumper. This clearance is similar to that of the tanks that were located above the axle and to some of the tanks installed ahead of the axle.

Fuel tanks from the other three vehicles, that included the Jeep Liberty, the Jeep Grand Cherokee and the Ford Mustang, essentially extended to the rear bumper. These vehicles maintained a tank distance between 29 cm and 31 cm from the rear bumper.

The placement of the Grand Marquis tank and the Grand Cherokee tanks are shown in Figure 9.

a) 

b) 

Figure 9: Behind the axle placement of the Grand Marquis tank (a) and the Grand Cherokee tank (b).

6.2 Ground Clearance

Ground clearance of the fuel tank was measured from the lowest point of the tank. If a secondary shield was in place over the tank, the clearance was measured to the shield. The clearances are summarized in Table 7 for the different class of vehicles.

Table 7: Range of ground clearance for different class of vehicles.

Vehicle Type	Ground Clearance (cm)	
	Minimum	**Maximum**
Coupe/hatchback	14	32
Minivan	19	24
Pickup	28	41
Sedan	17	24
SUV	23	35
Van	34	40

Of all the vehicles, the Chevrolet Corvette presented the lowest ground clearance. The largest measured ground clearance was found on the Toyota Tundra pickup truck.

Surprisingly, the tank clearance of the Mazda Miata, measuring approximately 32 cm, was the largest of the passenger cars surveyed, including coupes, hatchbacks and sedans.

6.3 Fuel Line Routing and Shielding

In all the vehicles the fuel lines were predominantly made of steel and were generally routed such that they derived protective benefits from a vehicle's structure. Typically, the fuel lines were routed along a frame rail or unibody frame rail. To varying extents, supplemental shielding of the lines afforded additional protection in 28 of the 74 vehicles inspected. An example of partial fuel line shielding is shown in Figure 10 for a Volvo XC 90.

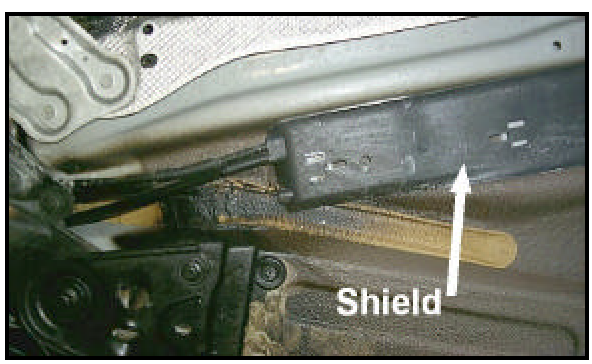


Figure 10: Partial fuel line shielding from a Volvo XC 90.

6.4 Tank Materials

Either plastic or steel are the materials of choice for the fabrication of fuel tanks. The incidence of their use in the 74 subject vehicles is presented in Table 8.

Table 8: Incidence of material used in the manufacture of fuel tanks.

Tank Material	No. of Vehicles
Plastic	44
Steel	29
Combined	1

Referring to Table 8, the Toyota Prius was the one vehicle whose tank was classified as being fabricated with a combination of plastic and steel. The fuel tank in the Prius is fabricated with a steel outer shell and an internal plastic tank as shown in the cut-away view of the tank in Figure 11.

Figure 11: Cutaway view showing the plastic tank inside the steel outer shell of the Toyota Prius tank.

To better determine the ratio of plastic tanks to steel tanks, a quick survey of 64 additional vehicles displayed at a local auto show was conducted and the findings are summarized in Table 9.

Table 9: Survey of fuel tank materials used in 64 additional vehicles.

Tank Material	No. of Vehicles
Plastic	39
Steel	18
Could not be determined	7

The fuel tanks of the 7 vehicles in Table 9, for which the material could not be determined, were either inaccessible or they were coated, making it difficult to determine the tank material with certainty.

Combining the results from the vehicle inspections and the auto show survey, but omitting tanks where the material could not be determined with certainty, it was found that 63% of the fuel tanks were fabricated from plastic and 37% were fabricated from steel.

6.5 Tank Shielding

The use of tank shielding amongst the inspected vehicles is summarized in Table 10.

Table 10: Use of shielding on fuel tanks.

Tank Shielding	No. of Vehicles
Full coverage	13
Partial coverage	48
No coverage	13

Of the 12 vehicles that did not have shielding around the fuel tank only one, the Jeep Liberty, could conceivably be used for off-road driving and a skid plate package is available for that purpose. This optional package includes a tank shield.

In the initial review, the Toyota Prius tank was considered non-shielded, however, referring back to Figure 11, it is likely the most shielded of all the tanks. The tank is composed of a plastic tank system that is completely enclosed in a steel container.

Additional steel shielding was installed between the exhaust components and the tank in 67 vehicles where the exhaust system components were in close proximity to the fuel tank.

6.6 Fuel Pump Shut-off

There was no incidence of fuel pump shut-off usage determined directly from the vehicle inspections, as these devices may be installed anywhere in a vehicle and are not apparent from a visual inspection alone. The Ford Focus, however, was ascertained to have an inertial shut-off device which is shown in Figure 12. A similar type sensor is also used by Renault, Fiat and Hyundai.

Figure 12: Fuel shut-off from a Ford Focus.

It was also discovered that BMW deactivates the fuel pump when the onboard computer senses a crash. The same sensors used to determine airbag deployment and battery disconnect are used for fuel pump shut-off.

From published feedback regarding the advanced notice of proposed rulemaking announcing plans for upgrading of the FMVSS 301 fuel integrity standard [Ref. 3], Ford has claimed that it uses both an inertia type switch and an engine speed sensing device to shut off the fuel pump. General Motors, Chrysler and Volkswagen all claim to use engine rotation sensing device for fuel pump shut-off.

6.7 Battery Disconnect

The BMWs and the Toyota Prius are the only vehicles from the subject group that are known to use a battery disconnect. In the Prius the onboard computer will disconnect both the service battery and the high voltage battery for the electric motor. Although not included in the inspected vehicles, it was discovered that the GM Silverado (24 volt models) uses an electronic battery disconnect.

6.8 Battery Placement

Typically, the 12 volt service battery in a vehicle is located under the hood, in the engine compartment of a vehicle. As shown in Table 11, this was the case in the vast majority of the vehicles inspected.

Table 11: Battery location.

Battery Location	No. of Vehicles
Under hood in the engine compartment	64
Batteries in the trunk	7
Other locations	3

Of the 64 batteries located under the hood, 14 were installed towards the rear of the engine compartment.

The service batteries in the Chrysler Sebring, Pontiac Bonneville and the Cadillac Deville were installed in locations other than under the hood or in the trunk. The battery in the Sebring was located in the left front bumper, with access to the battery gained through the wheel well as shown in Figure 13. It appears that in this location the battery would be susceptible to impact even in a minor left front end collision. Both the Bonneville's and the Cadillac's battery were located inside the passenger compartment under the rear seat.

Figure 13: Sebring battery located in the front left bumper.

Three hybrid, gasoline / electric, vehicles were included in the vehicle inspections. They included the Toyota Prius, the Honda Insight and the Honda Civic HEV. In addition to the service battery, each of these vehicles employed an additional high voltage battery to power their auxiliary electric motor (280 volt from the Prius battery and 144 volt from both Honda batteries). In all three instances this battery was located in the truck behind the rear seat and was electrically isolated from the remainder of the vehicle.

A recognized countermeasure for reducing electrical fires is an insulated cap placed over the positive battery terminal. Although not noted during the vehicle inspection, a summary of battery cap usage was determined from the database photographs and is presented in Table 12.

Table 12: Summary of battery cap usage on the positive battery terminal.

Insulated Cap Over Positive Battery Terminal	**No. of Vehicles**
Yes	56
No	8
Unknown	10

Of the 8 vehicles without an insulating cap over the positive battery terminal, 1 was from a North American manufacturer and the remaining 7 were imports.

7. Detailed Tank Inspections

A detailed inspection of 18 tank systems from the 74 inspected vehicles was carried out and a summary of the tank features that could not be fully ascertained during the vehicle inspections is presented below. A list of the tanks that were reviewed in more detail is presented in Appendix C.

7.1 Corrosion Protection

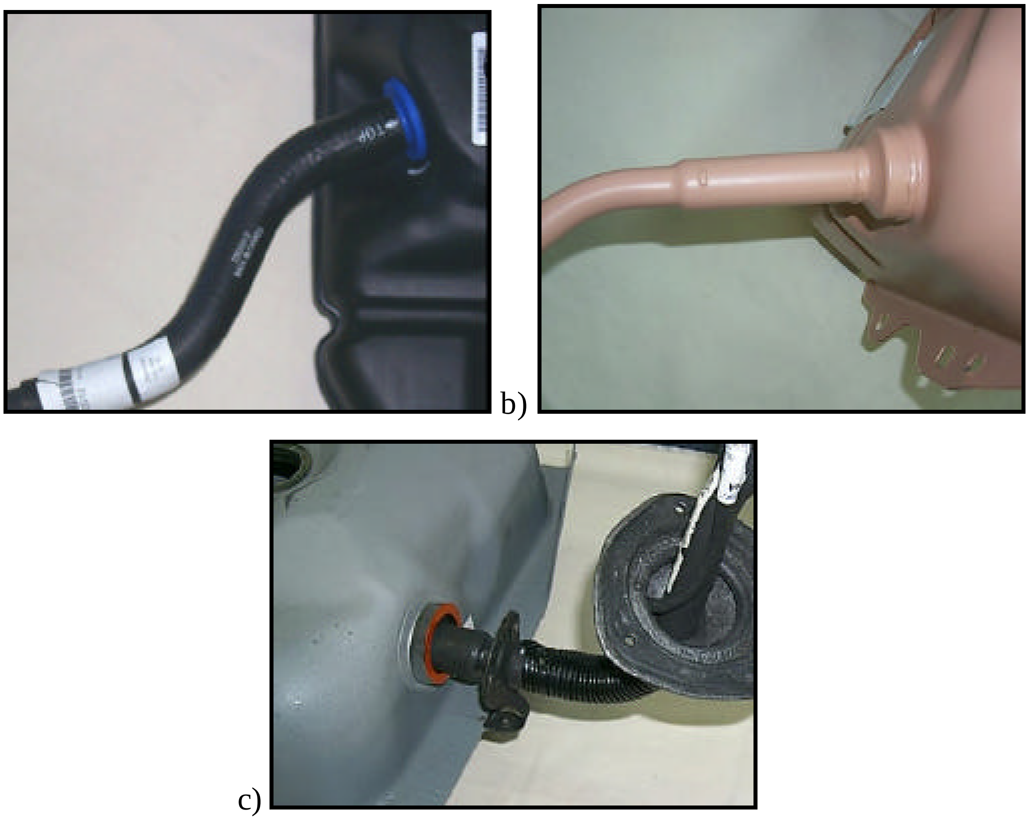
The application of corrosion inhibitors in itself is not considered a fire safety feature, however, it may affect the integrity of the tank over time, which could affect fire safety in a collision. Of the 18 tanks inspected 8 were fabricated from steel. A summary of corrosion protection on these tanks is presented in Table 13.

Table 13: Summary of application of corrosion resistance.

Tank Surface	Outside	Inside
Painted	8	1
Galvanized	0	5
None	0	2

7.2 Filler Tube Connection

The filler tube connection to the tank was classified as positive, integral or loose. In a positive connection the filler tube is mechanically fastened to the tank. An integral filler tube is moulded simultaneous with the tank or welded on. With a loose connection, the filler is not mechanically fastened or integral with the tank. The filler tube itself was further classified as flexible or rigid. Examples of these connections are shown in Figure 14.



a) b) c)

Figure 14: Examples of (a) positive / flexible (b) integral / rigid and (c) loose / rigid filler tube connections to the fuel tank.

The type of filler tube connection is summarized in Table 14 for the 18 tank inspections.

Table 14: Summary of filler tube connection to the tank.

Filler Tube Characteristics	**Number of Tanks**
Positive connection to tank	13
Integral connection to tank	3
Loose connection to tank	2
Rigid filler tube	5
Flexible filler tube	13

7.3 Check Valves and Roll-over Valves

The presence of a filler neck check valve could not be determined during the vehicle inspections because disassembly of the tank system would have been required and the use of roll-over valves could not be determined with certainty because the top of an installed tank is not visible. The in depth tank inspection provided the opportunity to dissemble and inspect individual tank components directly without hindrances. The incidence of use of these valves is presented in Table 15.

Table 15: Presence of roll-over and check valves amongst the 18 detailed tank inspections.

Tank Feature	**Check Valve**	**Roll-over Valve**
Yes	16	18
No	2	0

Although it can not be positively confirmed without a detailed inspection of the tank components, it is believed that all vehicle tanks have a roll-over valve.

8. Summary

Seventy four subject vehicles from the 2002 and 2003 North American fleet, representing various manufacturers, price ranges and classes were selected for inspection and investigation with respect to fuel systems fire safety. Included were nine of the vehicles tested in the development and evaluation of the proposed FMVSS 301 upgrade. The inspections comprised a visual examination of the fuel system components' installation, size and positioning measurements within the vehicle.

A subset of eighteen fuel systems from the seventy four subject vehicles was purchased and an additional component inspection was performed. Information pertaining to a tank's dimensions, capacity, construction and sub-components were recorded.

An electronic vehicle inspection database was compiled from the information and photographs gathered from the vehicle and the component inspections.

In many instances, the use of tank safety features could not be ascertained with certainty due to the non disruptive nature of the vehicle inspections. Nevertheless, the fuel system inspection database may be used as a useful tool in comparing the safety features and tank installation features of the subject vehicles contained within.

Fuel system design considerations and technologies that may be beneficial in mitigating post crash vehicle fires were identified and reviewed. The design considerations discussed included:

- Structural crashworthiness of the vehicle frame.
- Tank placement.
- Fuel line routing / compliance.
- Tank materials selection.
- Fuel filler connections.
- Electrical grounding.
- Battery placement.

The technologies that were reviewed included:

- Check valves for the tank filler tube.
- Roll-over valves.
- Shut-off mechanisms for electronic fuel pumps.

- Returnless fuel systems that reduce the total length of fuel line that can potentially be damaged.
- Crash sensing battery disconnects or cut-offs.
- Collapsible drive shafts.
- Self-sealing breakaway connectors.
- Fire retardant blankets.

More exotic fuel system safety technologies were also reviewed, many of which are used in aviation and military applications. Some, however, have found use in the special application automotive fuel tank systems whereas others may still be too costly or impractical for consumer vehicle use. These technologies include:

- Active fire suppressant systems.
- Tank filler material for explosion suppression.
- Bladder tanks.
- Self sealing tank systems.
- Tank inerting systems.

9. References

Ref. 1 Griffin, L. I.,"An Assessment of the Reliability and Validity of the Information on Vehicle Fires Contained in the Fatal Accident Reporting System (FARS)", Safety Division Texas Transportation Institute, November 1997.

Ref. 2 Lavelle, J. P., Kononen, D. W., Nelander, J. R., "Field Data Improvements for Fire Safety Research", General Motors Corporation, Paper 98-S6-W-45.

Ref. 3 Notice of Proposed Rulemaking, "Federal Motor Vehicle Safety Standards; Fuel System Integrity", National Highway Traffic Safety Administration, 49 CFR Part 571, Docket No. NHTSA-00-8248.

Ref. 4 Fournier, E., Keown, M., "Survey of the State-of-the-art In Fuel System Design", Biokinetics report R02-04, April 19, 2002.

Ref. 5 Digges, K. H., Stephenson, R., Bedewi, P., "Fire Safety Performance of Motor Vehicles In Crashes", Proceedings of the 18th International Technical Conference on the Enhanced Safety of Vehicles, Paper number 18ESV-000422, Nagoya, Japan, May 2003

Ref. 6 Hamins, A, "Evaluation of Active Suppression in Simulated Post-Collision Vehicle Fires" Building and Fire Research Laboratory, National Institute of Standards and Technology, NISTR 6379, November 2000.

Appendix A: List of Inspected Vehicles

Make	Model	Make	Model	Make	Model
Acura	RSX	Ford	Taurus	Nissan	Altima
Acura	MDX	Ford	Windstar	Nissan	Pathfinder
Acura	3.2 TL	GM Cadillac	Deville	Nissan	Sentra
Audi	A4	GMC	Yukon	Nissan	Maxima
Audi	A8	GMC	Savana	Pontiac	Montana
BMW	X5	GMC	Jimmy	Pontiac	Sunfire
BMW	320I	GMC	Sierra	Pontiac	Bonneville
BMW	Z4	Honda	Odyssey	Pontiac	Grand am
Chevrolet	Corvette	Honda	CRV	Saturn	SL
Chevrolet	S-10	Honda	Insight	Subaru	Outback
Chrysler	Sebring	Honda	Civic Hybrid	Toyota	Rav 4
Dodge	Durango	Honda	Accord	Toyota	Sienna
Dodge	Neon	Hyundai	Elantra	Toyota	Prius
Dodge	Grand Caravan	Hyundai	Tiburon	Toyota	Tacoma
Dodge	Ram 1500	Infiniti	G35	Toyota	Camry
Dodge	Dakota	Jeep	Grand Cherokee	Toyota	Echo
Dodge	Ram	Jeep	Liberty	Toyota	4 Runner
Ford	E350	Kia	Sedona	Toyota	Corolla
Ford	Mustang	Kia	Sportage	Toyota	Tundra
Ford	Grand Marquis	Kia	Spectra	Volvo	XC90
Ford	F150	Mazda	Miata	Volvo	V-40
Ford	Explorer	Mazda	Protege5	Volvo	S60
Ford	Focus	Mazda	MPV	VW	Jetta
Ford	Ranger	Mercedes	C320	VW	Passat
Ford	Expedition	Mercedes	S430	---	---

Appendix B: Vehicle Inspection Checklist/Summary Report

VEHICLE FUEL SYSTEM REVIEW CHECKLIST/REPORT

VEHICLE:___________________

COMPLETED BY:__________________

DATE (YY/MM/DD) :_____________

Prepared for:	Dr. Ken Digges Motor Vehicle Fire Research Institute
Author:	Ed Fournier Matthew Keown
Date:	September 2002
Report No. :	R02-06 d

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1. GENERAL VEHICLE INFORMATION

Make:				
Model:				
Trim level:				
Type:	☐ Coupe	☐ Sedan	☐ Hatchback	☐ Wagon
	☐ Mini-van	☐ SUV	☐ Pickup	☐ Van
Class:	☐ Compact		☐ Full-sized	
Number of doors:	☐ 2	☐ 3	☐ 4	☐ 5
V.I.N.:				
Date of Manufacture (YY / mm)				
GVW:				
Number of Tanks:	☐ 1	☐ 2	☐ 3	☐ 4
Tank Options				

2. Battery Location

Battery: 1 of ________	
Location	
Battery location (check all that apply)	☐ Inside the engine compartment ☐ Inside the trunk compartment ☐ Left side ☐ Mid-ship ☐ Right side ☐ Toward the front of the compartment. ☐ Toward the rear of the compartment. ☐ Other ____________
Voltage	
Ampere	
CC-amps	
Ampere - hours	
Size designation	

Battery: 2 of 2	
Location	
Battery location (check all that apply)	☐ Inside the engine compartment ☐ Inside the trunk compartment ☐ Left side ☐ Mid-ship ☐ Right side ☐ Toward the front of the compartment. ☐ Toward the rear of the compartment. ☐ Other ____________
Voltage	
Ampere	
CC-amps	
Ampere - hours	
Size designation	

3. *FUEL TANK 1: INFORMATION*

Tank No.:	1 of________		
Capacity (litres):			
Material:	☐ Steel ☐ Plastic ☐ Other ______________________		
General Shape:	☐ Long ☐ Short	☐ Wide ☐ Thin	☐ Deep ☐ Shallow
Dimensions (cm):	Length:_________	Width:__________	Depth:__________
Layers:	☐ Single ☐ Multi ______________________ ☐ Unknown		
Layer Notes:			
Baffles:	☐ Yes ☐ No ☐ Other ______________________		
Baffle Notes:			
Internal Components:			
Notes:			

4. FUEL TANK SYSTEM 1: INFORMATION

Tank No.:	1 of _____	
Location		
Tank Location (relative to rear axle):	☐ Behind axle ☐ Over axle ☐ Ahead of axle ☐ Other ______________________	
Tank Location (relative to vehicle centreline):	☐ Left side ☐ Mid-ship ☐ Right side ☐ Other ______________________	
Vehicle Measurements (cm):	Front bumper to rear axle:	
	Front of tank to front bumper:	
	Rear of tank to rear bumper:	
	Left side of tank to vehicle left side:	
	Right side of tank to vehicle right side:	
	Bottom of tank to ground (min.) :	
	Fuel line to ground (min.) :	
Identify Possible Intrusive Components:		
Distance of Closest Intrusive Components (cm):		
Filler		
Filler Location:	☐ Left side ☐ Rear ☐ Right side ☐ Other ______________________	
Filler Location Measurements (cm):	Height of filler opening (from ground):	
	Distance forward of rear axle:	
Filler door type:	☐ Lockable ☐ Non-lockable ☐ Automatic Release	
Other		
Tank Shield:	Coverage:	☐ Full ☐ Partial ☐ None
	Material:	☐ Steel ☐ Plastic ☐ Other ___________
Tank Shielded from the Exhaust	☐ Yes ☐ No	
	If "Yes" closest distance of shield to tank (cm):________________	
Distance of Closest Exhaust Component to Tank (cm):		
Fuel Lines:	Shielded:	☐ Full ☐ Partial ☐ None
	Material:	☐ Rubber ☐ Steel ☐ Braided
Fuel return line from engine	☐ Yes ☐ No	
Fuel Line Routing Notes:		

Other (continued)				
Drive Shaft Clearance Rear Wheel Drive (cm):				
Grounding of Fuel System Components	☐ Tank	☐ Yes	☐ No	☐ Unknown
	☐ Sending Unit	☐ Yes	☐ No	☐ Unknown
	☐ Canister	☐ Yes	☐ No	☐ Unknown
	☐ Filler Neck	☐ Yes	☐ No	☐ Unknown
	☐ other	☐ Yes	☐ No	☐ Unknown

Canister: 1 of _____		
Location		
Canister location relative to rear axle:	☐ Behind axle ☐ Over axle ☐ Ahead of axle ☐ Other ______________________	
Canister location relative to vehicle centreline:	☐ Left side ☐ Mid-ship ☐ Right side ☐ Other ______________________	
Canister location measurements (cm):	Front of canister to front bumper:	
	Rear of canister to rear bumper:	
	Left side of canister to vehicle left side:	
	Right side of canister to vehicle right side:	
Identify possible intrusive components:		
Routing notes for vapour hoses:		

Fuel Filter: (other than filter inside tank) 1 of________	
Location	
Filter location (check all that apply)	☐ Left side ☐ Mid-ship ☐ Right side ☐ Under vehicle ☐ Above tank ☐ Inside the engine compartment ☐ Other _____________

5. FUEL TANK 2: INFORMATION

Tank No.:	1 of________		
Capacity (litres):			
Material:	☐ Steel ☐ Plastic ☐ Other _______________________		
General Shape:	☐ Long ☐ Short	☐ Wide ☐ Thin	☐ Deep ☐ Shallow
Dimensions (cm):	Length:_________	Width:__________	Depth:__________
Layers:	☐ Single ☐ Multi _______________________ ☐ Unknown		
Layer Notes:			
Baffles:	☐ Yes ☐ No ☐ Other _______________________		
Baffle Notes:			
Internal Components:			
Notes:			

6. FUEL TANK SYSTEM 2: INFORMATION

Tank No.:	1 of _____	
Location		
Tank Location (relative to rear axle):	☐ Behind axle ☐ Over axle ☐ Ahead of axle ☐ Other ______________________	
Tank Location (relative to vehicle centreline):	☐ Left side ☐ Mid-ship ☐ Right side ☐ Other ______________________	
Vehicle Measurements (cm):	Front bumper to rear axle:	
	Front of tank to front bumper:	
	Rear of tank to rear bumper:	
	Left side of tank to vehicle left side:	
	Right side of tank to vehicle right side:	
	Bottom of tank to ground (min.) :	
	Fuel line to ground (min.) :	
Identify Possible Intrusive Components:		
Distance of Closest Intrusive Components (cm):		
Filler		
Filler Location:	☐ Left side ☐ Rear ☐ Right side ☐ Other ______________________	
Filler Location Measurements (cm):	Height of filler opening (from ground):	
	Distance forward of rear axle:	
Filler door type:	☐ Lockable ☐ Non-lockable ☐ Automatic Release	
Other		
Tank Shield:	Coverage:	☐ Full ☐ Partial ☐ None
	Material:	☐ Steel ☐ Plastic ☐ Other ___________
Tank Shielded from the Exhaust	☐ Yes ☐ No	
	If "Yes" closest distance of shield to tank (cm):________________	
Distance of Closest Exhaust Component to Tank (cm):		
Fuel Lines:	Shielded:	☐ Full ☐ Partial ☐ None
	Material:	☐ Rubber ☐ Steel ☐ Braided
Fuel return line from engine	☐ Yes ☐ No	
Fuel Line Routing Notes:		

Other (continued)				
Drive Shaft Clearance Rear Wheel Drive (cm):				
Grounding of Fuel System Components	☐ Tank	☐ Yes	☐ No	☐ Unknown
	☐ Sending Unit	☐ Yes	☐ No	☐ Unknown
	☐ Canister	☐ Yes	☐ No	☐ Unknown
	☐ Filler Neck	☐ Yes	☐ No	☐ Unknown
	☐ other	☐ Yes	☐ No	☐ Unknown

Canister: 1 of _____		
Location		
Canister location relative to rear axle:	☐ Behind axle ☐ Over axle ☐ Ahead of axle ☐ Other ______________________	
Canister location relative to vehicle centreline:	☐ Left side ☐ Mid-ship ☐ Right side ☐ Other ______________________	
Canister location measurements (cm):	Front of canister to front bumper:	
	Rear of canister to rear bumper:	
	Left side of canister to vehicle left side:	
	Right side of canister to vehicle right side:	
Identify possible intrusive components:		
Routing notes for vapour hoses:		

Fuel Filter: (other than filter inside tank) 1 of________	
Location	
Filter location (check all that apply)	☐ Left side ☐ Mid-ship ☐ Right side ☐ Under vehicle ☐ Above tank ☐ Inside the engine compartment ☐ Other _____________

7. FIRE SAFETY RELATED FUEL SYSTEM FEATURES

Select all that apply and photograph where applicable.

YES	NO	Unknown	
☐	☐	☐	Filler check valve.
☐	☐	☐	Fuel shut off valves (ie 7g valve).
☐	☐	☐	Shielding of tank.
☐	☐	☐	Shielding of other fuel system components.
☐	☐	☐	Multiple layered tanks.
☐	☐	☐	Tank bladders.
☐	☐	☐	Tear away fuel line connections with cut-off valves.
☐	☐	☐	Fire shields / blankets in the engine compartment.
☐	☐	☐	Anti-siphoning.
☐	☐	☐	Electrical isolation.
☐	☐	☐	Battery disconnect
☐	☐	☐	Tank additives (such as Explosafe or foams).
☐	☐	☐	Slip-in-tube drive shaft.
☐	☐	☐	EFI Fuel Pump shut off.
☐	☐	☐	Active fire suppression system.
☐	☐	☐	Tank Grounding
☐	☐	☐	Roll-over valve
☐	☐	☐	Other: ________________________________
☐	☐	☐	Other: ________________________________

8. *PHOTOGRAPH CHECKLIST*

Important: If a detail is not visible DO NOT skip the photograph, instead take a photograph of the notice page contained in Appendix A. A skipped photograph may lead to confusion when the digital files are renamed.

Check	Photograph	Filename (XXX – vehicle number)
	General Vehicle Photographs	
☐	1- Front.	XXX-01-front-general.jpg
☐	2- Left Side.	XXX-02-left-general.jpg
☐	3- Rear.	XXX-03-rear-general.jpg
☐	4- Right side.	XXX-04-right-general.jpg
☐	5- Underside of hood.	XXX-05-under-hood.jpg
	Engine Compartment	
☐	6- From left side.	XXX-06-engine-left.jpg
☐	7- From front.	XXX-07-engine-front.jpg
☐	8- From Right.	XXX-08-engine-right.jpg
☐	9- Connection to fuel injection unit.	XXX-09-fuel-line-injector-1.jpg
☐	10- Connection to fuel injection unit.	XXX-10-fuel-line-injector-2.jpg
	Fuel Filler Door and Cap	
☐	11- Filler door closed.	XXX-11-filler-closed.jpg
☐	12- Filler door opened.	XXX-12-filler-open.jpg
☐	13- Filler cap outside.	XXX-13-cap-open.jpg
☐	14- Filler cap inside.	XXX-14-cap-underside.jpg
	Vehicle Underside	
☐	15- Tank ground clearance (show scale).	XXX-15-ground-clearance.jpg
☐	16- Full from front.	XXX-16-full-under-front.jpg
☐	17- Full from front left side.	XXX-17-full-under-front-left.jpg
☐	18- Full from rear left.	XXX-18-full-under-rear-left.jpg
☐	19- Full from rear.	XXX-19-full-under-rear.jpg

Check	Photograph	Filename (XXX – vehicle number)
☐	20- Full from rear right.	XXX-20-full-under-rear-right.jpg
☐	21- Full from right side.	XXX-21-full-under-right.jpg
☐	22- Front from directly underneath.	XXX-22-front_under.jpg
☐	23- Mid front, directly underneath.	XXX-23-front-mid-under.jpg
☐	24- Mid rear, directly underneath.	XXX-24-rear-mid-under.jpg
☐	25- Rear from directly underneath.	XXX-25-rear-under.jpg

Fuel Tank and Surroundings

☐	26- Front of tank.	XXX-26-tank-front.jpg
☐	27- Left side.	XXX-27-tank-left.jpg
☐	28- Rear of tank	XXX-28-tank-rear.jpg
☐	29- Right side.	XXX-29-tank-right.jpg
☐	30- Full tank and surroundings from directly underneath.	XXX-30-tank-under.jpg
☐	31- Most aggressive component.	XXX-31-aggressive-comp.jpg
☐	32- Distance most aggressive component to tank (show scale).	XXX-32-dist-aggressive-comp.jpg

Fuel Line Routing

☐	33- Fuel line at tank.	XXX-33-fuel-line-tank.jpg
☐	34- Routing photo 1.	XXX-34-fuel-line-routing-1.jpg
☐	35- Routing photo 2.	XXX-35-fuel-line-routing-2.jpg
☐	36- Routing Photo 3.	XXX-36-fuel-line-routing-3.jpg
☐	37- Fuel line at engine.	XXX-37-fuel-line-engine.jpg
☐	38- Connection to filter.	XXX-38-fuel-line-filter.jpg
☐	39- Filler tube from underside.	XXX-39-filler-tube-underside.jpg
☐	40- Filler tube from side.	XXX-40-filler-tube-side.jpg

Miscellaneous Photographs

☐	41- Canister photo 1	XXX-41-Canister -1.jpg
☐	42- Canister photo 2	XXX-42-Canister –2.jpg

Check	Photograph	Filename (XXX – vehicle number)
☐	43- Battery Photo 1	XXX-43-Battery-3.jpg
☐	44- Battery photo 2	XXX-44-Battery-4.jpg
☐	45- Misc. photo 1	XXX-45-Misc-1.jpg
☐	46- Misc. photo 2	XXX-46-Misc-2.jpg
☐	47- Misc. photo 3	XXX-47-Misc-3.jpg
☐	48- Misc. photo 4	XXX-48-Misc-4.jpg
☐	49- Misc. photo 5	XXX-49-Misc-5.jpg
☐	50- Misc. photo 6	XXX-50-Misc-6.jpg

9. GENERAL COMMENTS

10. TANK COMPONENTS

Please attached the component list for the vehicles fuel system.

APPENDIX A : BLANK PHOTOGRAPH FORM

DETAIL
IS NOT
VISIBLE

Appendix C: List of Tank Systems Purchased

Make	Model	Reason for selection
Mercedes Audi BMW	S430 A8 320I	Believed to be leaders in technology.
GMC	Sierra	Successor to the C/K trucks with the side saddle tanks systems.
Chevrolet	Corvette	Employs a dual tank system.
Ford	Crown Vic	Employs an upgrade in tank safety.
Plymouth Saturn Jeep Pontiac	Grand Voyager SL Grand Cherokee Sunfire	These tanks were burn tested at South West Research Institute. The tank from the Chevrolet Cavalier that was burn tested is the same as the Sunfire.
Mazda Toyota Acura Honda Ford	MPV Camry TL Odyssey Mustang	Known to have at least one of the following: ▪ One way valves. ▪ Check valves. ▪ Fuel cut-off
Kia	Spectra	Entry level vehicle with many tank safety features.
VW	Jetta	Fuel tank incorporates an integrally moulded filler tube.
Toyota	Prius	Fuel tank incorporates a bladder. (*)

* This was initially believed to be a bladder system. The Prius in fact had a complete plastic fuel tank system installed inside a steel container.

Appendix D: Tank Inspection Checklist

Biokinetics
AND ASSOCIATES LTD.

Gas Tank Tear Down – Measurements and Obsevations

Vehicle :

Date:
[2002-05-28]

Inspected by:

Prepared for:
Dr. Ken Digges

Motor Vehicle Fire Research Institute

Authors:

Biokinetics and Associates Ltd.
2470 Don Reid Drive
Ottawa, Ontario, K1H 1E1
Canada

tel: (613) 736-0384
fax: (613) 736-0990
www.biokinetics.com

1. Tank Inspection

Vehicle	Make	
	Model	
	Year	
Tank capacity (litres)		
Max Dimensions (cm)	Length____________ Width______________ Height_____________	
Material	Type: Plastic ________________________ Steel ________________________ Other ________________________	
	Specification________________________ or Unknown	
Tank layers	Yes No If yes number of layers_______________	
For steel tanks is there corrosion protection	Inside: Painted Galvanised none	Outside: Painted Galvanised none
Grounded	Tank	Yes / No / Unknown
	Sending unit	Yes / No / Unknown
	Canister	Yes / No / Unknown
	Filler Neck	Yes / No / Unknown
Baffles	Yes No	
Sending unit	Type	Carbureted Fuel injected
	Connections	Fuel delivery Return Vent
	Mounting to tank	Bolted ¼ turn locking collar. Threaded locking collar.
Level Sensor – integral with sending unit	Yes No	
Material Thickness (mm)	Top	Rear
	Front	Left side
	Right side	Bottom
Tear away filler cap design	Yes No Unknown	
Indication of compliance with standards	Yes No	
	If yes indicate standard designation	______________________________ ______________________________ ______________________________
Filler tube	Integral with tank	Flexible
	Positive attachment	Rigid
	Loose attachment	
Spillage prevention	Filler check valve	Yes No Unknown
	Roll-over valve	Yes No Unknown
	Anti-siphon valves	Yes No Unknown

2. Notes:

3. Photograph Check List

Important: If a detail is not visible DO NOT skip the photograph, instead take a photograph of the notice page contained in Appendix A. A skipped photograph may lead to confusion when the digital files are renamed.

	1- Tank and all components	XXX-71-tank-components.jpg
	2- Tank - filler connection	XXX-72-filler-connect.jpg
	3- Tank - sending unit attachment	XXX-73-sender-unit-attach.jpg
	4- Tank - miscellaneous 1	XXX-74-tank-misc-1.jpg
	5- Tank - miscellaneous 2	XXX-75-tank-mist-2.jpg
	6- Filler assembly 1	XXX-76-filler-1.jpg
	7- Filler assembly 2	XXX-77-filler-2.jpg
	8- Filler assembly 3	XXX-78-filler-3.jpg
	9- Sending unit 1	XXX-79-sender-1.jpg
	10- Sending unit 2	XXX-80-sender-2.jpg
	11- Sending unit 3	XXX-81-sender-3.jpg
	12- Canister 1	XXX-82-canisterpart-1.jpg
	13- Canister 2	XXX-83-canisterpart-2.jpg
	14- Canister 3	XXX-84-canisterpart-3.jpg
	15- Fuel filter 1	XXX-85-fuel-filter-1.jpg
	16- Fuel filter 2	XXX-86-fuel-filter-2.jpg
	17- Assembled fuel system 1	XXX-87-system-1.jpg
	18- Assembled fuel system 2	XXX-88-system-2.jpg
	19- Assembled fuel system 3	XXX-89-system-3.jpg
	20- Assembled fuel system 4	XXX-90-system-3.jpg

DETAIL IS NOT VISIBLE

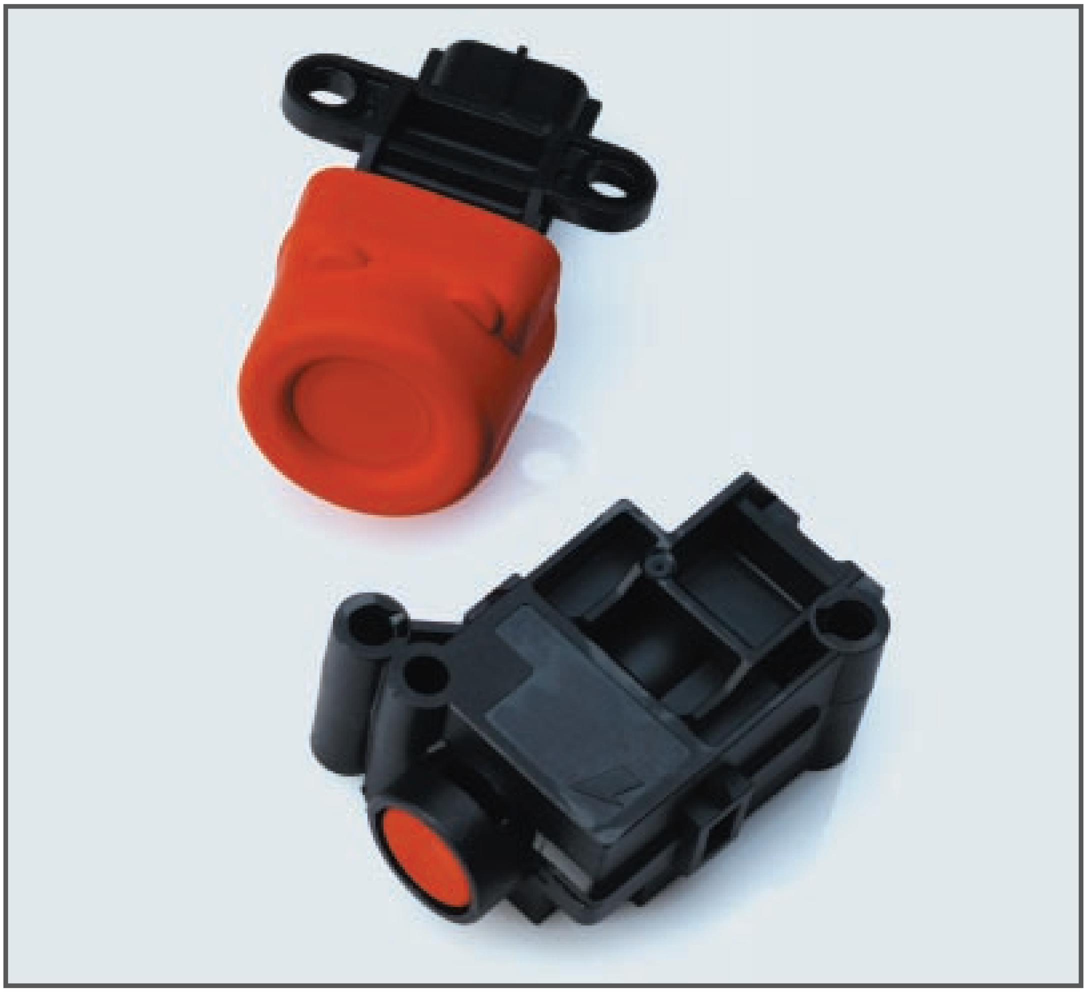
Appendix E: Fuel Pump Shut-off Switch

First Technology
Innovative Solutions

Resettable Crash Sensors

First Technology's Resettable Crash Sensors were designed to directly shut down the fuel pump or main contactor upon impact. Our Resettable Crash Sensors reduce the risk of fires and electrical shock in post-crash situations. The First Technology Resettable Crash Sensors are a low-cost solution to vehicle safety requirements, i.e. FMVSS301, and approved for vehicle installation by major automotive manufacturers worldwide.

First Technology is an ISO and QS Registered company. We provide world-class quality products *error free and on time.*



Proven Reliability

- Extensive accelerated life testing performed to insure operation under extreme conditions
- Meets or exceeds demanding automotive performance requirements
- Over 80 million produced

Advanced Features

- Ball and magnet inertia mechanism
- Loads rated up to 10 Amps
- Manual reset
- Ranges from 8g to 30g
- Stops fuel pump operation (EV electric systems)

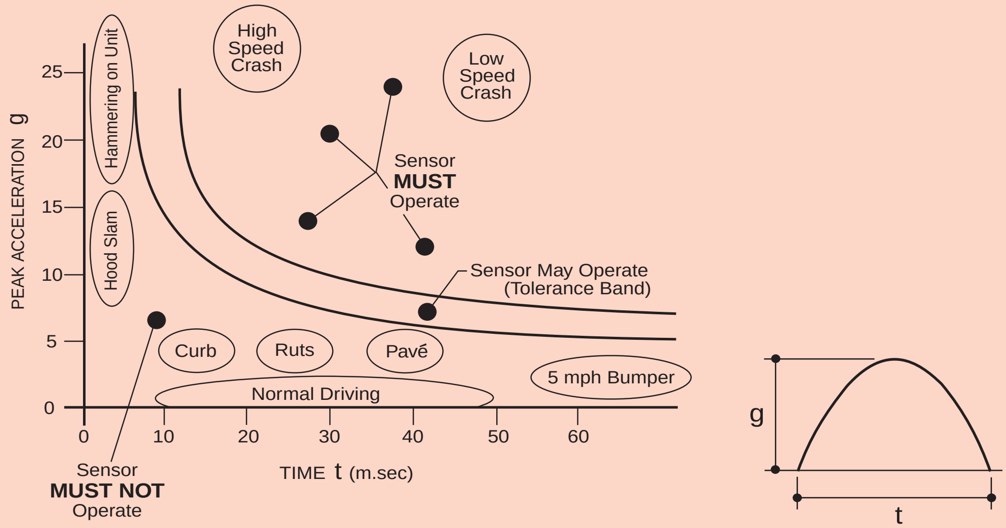
Design Benefits

- Responsive to impact in all horizontal directions
- Capable of carrying fuel-pump load
- Sensory feedback
- Customized for various installations
- Reduces the risk of fires (shock)

DOCUMENTED QUALITY
ISO 9001
QS-9000
REGISTERED

Automotive Electronics • Control Devices • Electronic Ceramics

Resettable Crash Sensors



Typical Acceleration Loads for an Average-Size Passenger Vehicle

Applied Test Pulse (Half Sine)

Type	No Operation (60 ms Pulse)	Will Operate (60 ms Pulse)	Contacts	Height (mm)	Width (mm)	Depth (mm)
505	8 g 10 g	14 g 16 g	Normally Open and Normally Closed	70 Max 70 Max	48 Max 62 Max with adaptor	40 Max 43 Max with adaptor

23824 Iss.A (1) A859

First Technology
28411 Northwestern Highway, Suite 115, Southfield, MI 48034, USA
Tel. (800) 392-3908 • (248) 353-6200 • Fax (248) 353-8333
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5-7, allée Louis Bréguet, 93421 Villepinte cédex, France
Tel. +33 (0) 1 49 63 12 72 • Fax +33 (0) 1 49 63 56 66

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Seo-Chang Building, Suite 301, Banpo-Dong 94-5, Seocho-Ku, Seoul, Korea 137-044
Tel. +82 (0) 2 595 0496 • Fax +81 (0) 2 595 0498

First Technology
Innovative Solutions

Automotive Electronics • Control Devices • Electronic Ceramics

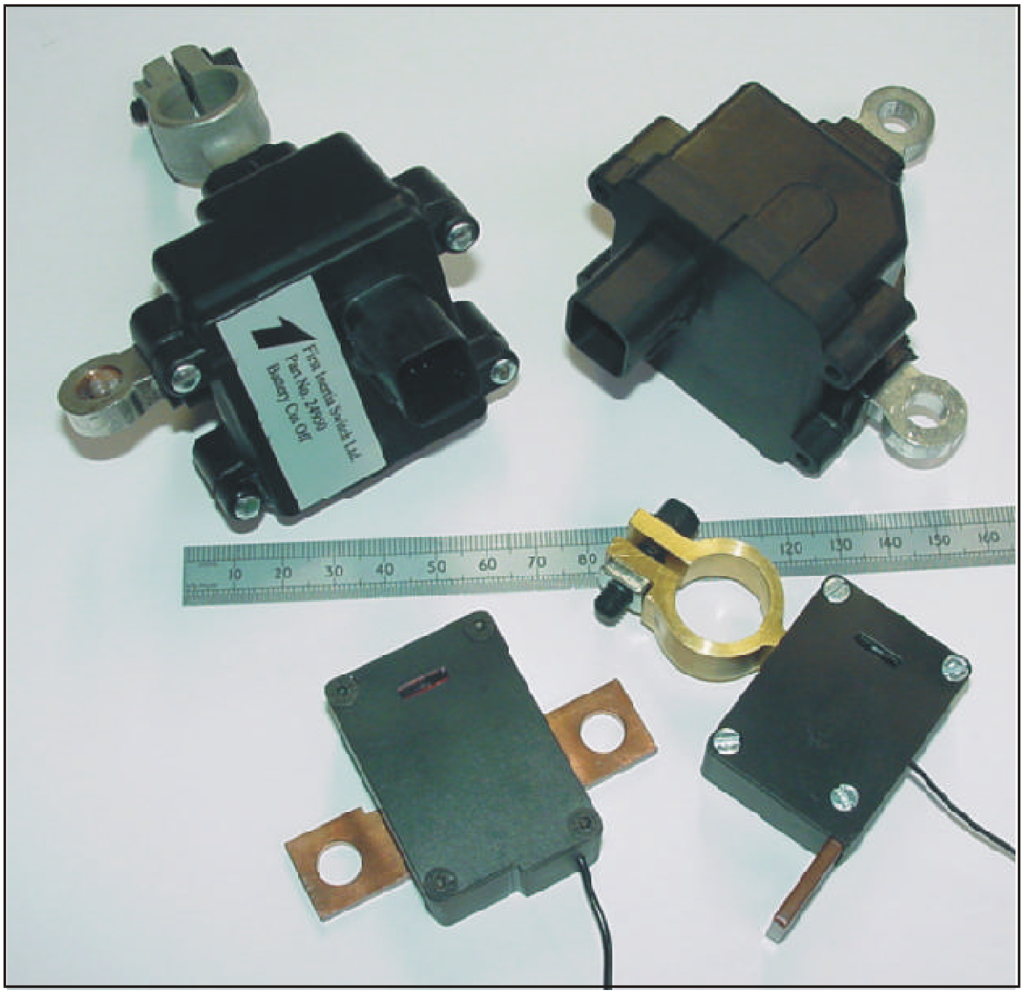
Appendix F: Battery Cut-off

First Technology
Innovative Solutions

Battery Cut-Off

First Technology's Battery Cut-off Switch was designed primarily for motor vehicles where the electrical system is to be disconnected in a collision. Following a crash situation, the Battery Cut-off Switch responds from a remote signal in ≤3mS, disabling the electrical system. Certain circuits identified by the customer will retain battery power (i.e. door locks, power windows, hazards, etc.).

First Technology is an ISO and QS Registered company. We provide world-class quality products error free and on time.



DOCUMENTED QUALITY
ISO 9001
QS-9000
REGISTERED

Proven Reliability

- Meets or exceeds demanding automotive performance requirements

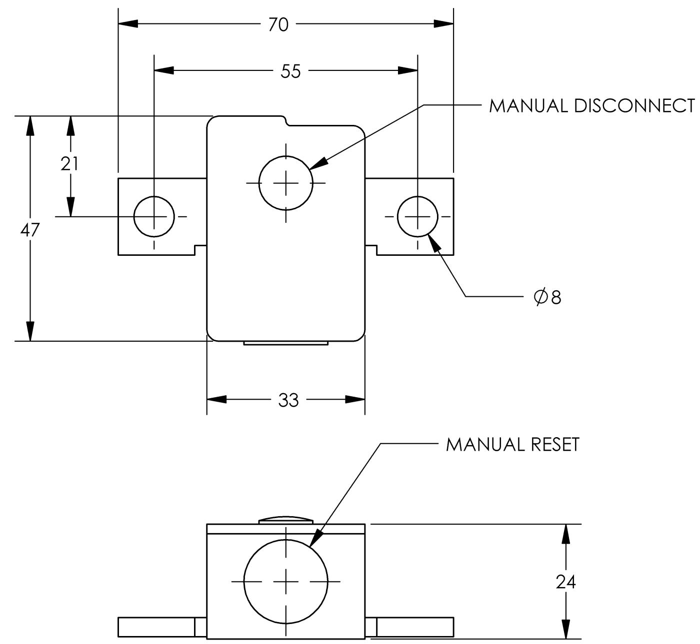
Design Features

- Battery power disconnect
- 12/24/42 Volt usage
- Manual/Electric disconnect
- Manual/Electric reset
- Short circuit protection
- Voltage/Current monitoring
- Visual Status Indicator
- Battery saver
- Non-destructive
- Response time of ≤3mS from a remote signal

Design Benefits

- Reduces the potential for electrical fires in a crash
- Disconnect during service or transit
- Fast-acting response for safety enhancement
- Flat Battery protection
- Enhances anti-theft
- Customer convenience

Battery Cut-Off



Manual Reset BCO **Example of Dimensions**

General Specifications

Operating Temperature	-40 ℃ to 125 ℃
Continuous Current	150 to 220 Amps
Peak Current	1000 Amps for 10 seconds
Activation Current	1A ≤3ms or logic ≤10ms
Resettable	Electric/Manual Reset
Maximum Contact Resistance	0.4 milliohms
Current Monitoring Accuracy	2%

First Technology
28411 Northwestern Highway, Suite 115, Southfield, MI 48034, USA
Tel. (800) 392 3908 • (248) 353 6200 • Fax (248) 353 8333
E-mail: service@firsttech.com • http://www.firsttech.com

5-7, Allée Louis Bréguet, 93421 Villepinte Cedex, France
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Monzennakacho Building, 9th Floor, 1-13 Etchujina, Koto-Ku, Tokyo 135, Japan
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Tel. +82 (0) 2 336 7872 • Fax. +82 (0) 2 336 7803

Appendix G: Self Sealing Breakaway Connector

Quick-release coupling RMI 09 / EA - Racing

NEW !

Applications

- Fuel line.
- Fuel sampling.
- Fuel line safety break-away.

Features

- Compact size, light weight combined with high strength aluminium construction provide optimum performance.
- Positive valve design prevents fluid spillage during connection.
- Double shut-off system offers a minimum fluid loss while disconnecting.
- Lanyard release feature ensures a safe fuel line break-away in a crash situation.
- Take advantage of STAUBLI reliability: over 40 years of experience in Design and Manufacturing of quick-release couplings.

STÄUBLI

RMI 09 / EA

W 650.00 e A

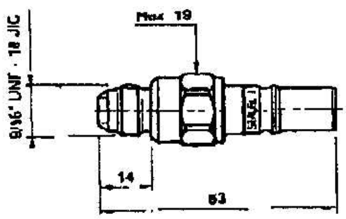
Technical features

■ Nominal diameter	(mm):	9
■ Cross section	(mm²):	63.60
■ Max. working pressure	(bar):	16
■ Max. working temperature	(°C):	-10 to + 200
■ Double shut-off		-◯>—<◯-
Construction	Coloured high resistance aluminium	
Tightness	Fluorocarbon seals FPM (Viton ®) compatible with unleaded fuel	

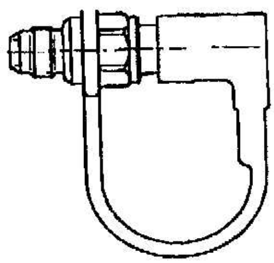
GOODRIDGE INDY
101B N. Gasoline Alley
Indianapolis, IN 46222
(317) 244.1000

Part-numbers

DASH 6 male thread plug

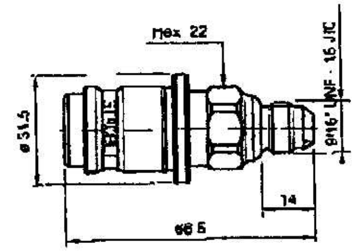


PART-NUMBER
RMI 09.7655/L/EA/JV



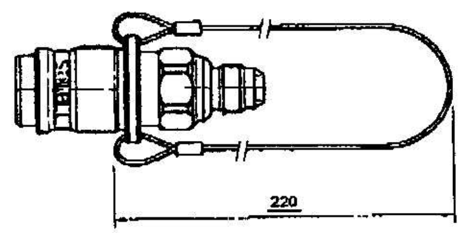
Plug is systematically delivered with dust cap

DASH 6 male thread socket

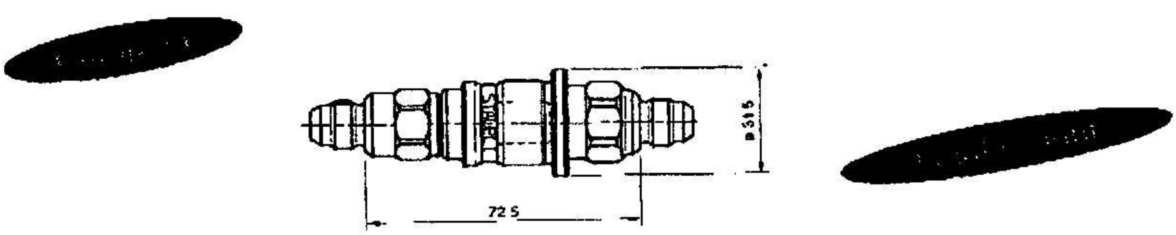


PART-NUMBER
RMI 09.1655/L/EA/JV

DASH 6 male thread socket with safety break-away lanyard



PART-NUMBER
RMI 09.3655/L/EA/JV



Weight socket + plug = 66 g.

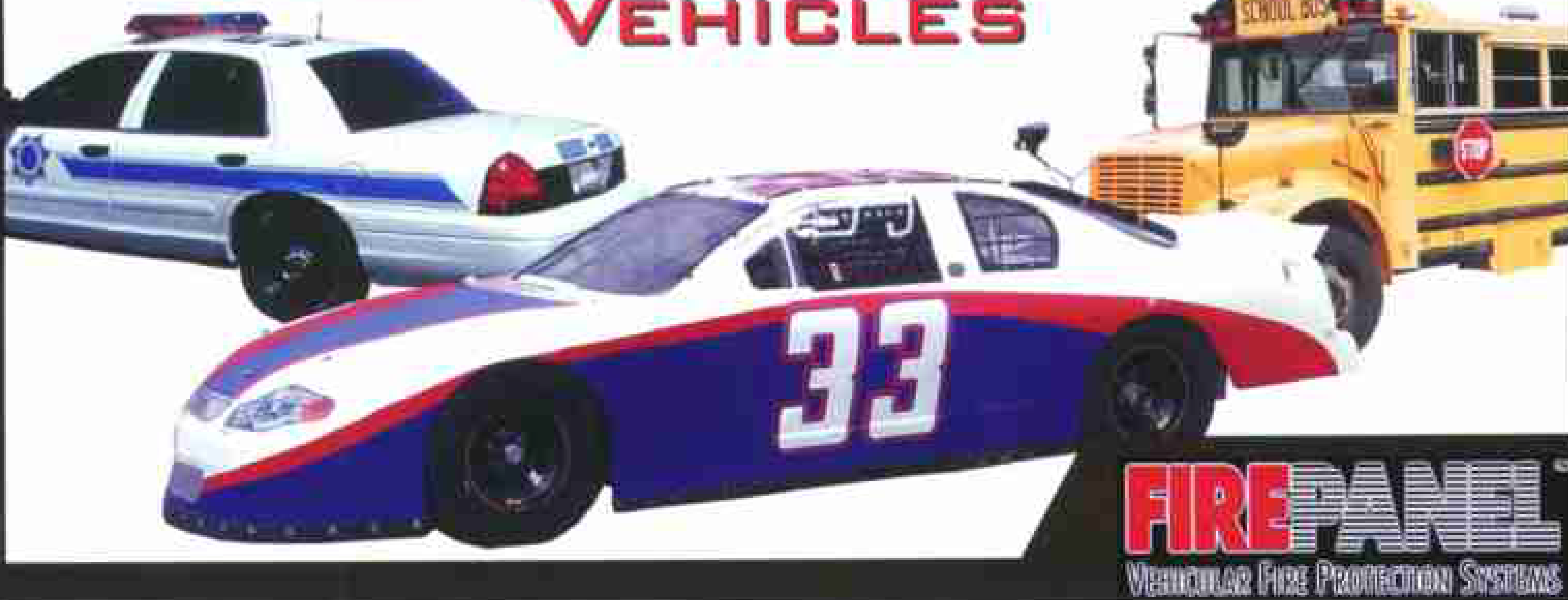
14/12/96

STÄUBLI®

STÄUBLI FAVERGES
F-74210 FAVERGES ☎ 04 50 65 60 60 - TELEX 385 380 F - FAX 04 50 65 60 69
Internet: http://www.staubli.com/ E-mail: connectors.sales@staubli.com

Appendix H: Powder Panels

Fire Protection For Vehicles



The FIRE Panel is the latest in fuel cell fire protection technology that comes from a proven military application background. This patented product provides the same fire protection for vehicle fuel cells that it does for the fuel tanks of some of the most sophisticated military aircraft and helicopters.

The premise of the FIRE Panel is this: In order to reach the fuel cell with some object that would puncture or ignite the fuel, that object must first pass through a breakable, protective wrap containing fire suppressing powder, which is installed around the exterior of the fuel cell. The puncturing of this protective wrap releases a "cloud" of fire suppressing powder, which "inerts" the space around the fuel cell, thereby preventing the ignition of the fuel or quickly suppressing the fire.

Crash test showing that impact instantly creates a "cloud" of powder that follow the vehicles.

Already proven in military applications, this technology has now been used on the racetracks of professional motorsports. Earlier versions of the FIRE Panel were road tested in competition using racing vehicles from the SCCA® Trans-Am® Series. The FIRE Panel's durable construction withstood the rigors of the high-speed track racing. Plus, the lightweight characteristic of the FIRE Panel added virtually no weight to the racing vehicles.

Fire Panels are also being used today to protect our nation's law enforcement professionals. Well documented in the national news, fires that have occurred from high-speed, rear end impacts have cost police officers their lives from otherwise survivable collisions. A new version of the FIRE Panels was specifically designed to perfectly fit the contours of the police car's fuel tank, thus adding a strong layer of fire protection for the officers.

The FIRE Panel's channel design makes it easy to customize and fit any fuel cell. With a fuel cell custom wrapped in the FIRE Panel, collisions or impacts that may send vehicle components or debris into the fuel cell will not result in a fire, even at high speeds.

The FIRE panel technology is also available for public transportation vehicles such as school or city buses. Although these vehicles are designed to be safe, accidents can occur from any angle, and a fuel spill is always a concern. Now, there is an affordable means to protect these vehicles from a fire.

FIRE Panels have many benefits including:

- Proven, patented fire protection that is cost-effective
- Lightweight, yet rugged design to withstand tough road conditions
- Fast, easy installation directly over fuel cells

So don't delay, call us, toll-free, at **866.607.0747** or visit www.firepanelllc.com and learn how a FIRE Panel could make the difference between a devastating fire and a survivable crash.

F.I.R.E. Panel LLC 7898 E. Acoma Drive, Suite 106, Scottsdale, AZ 85260 USA Tel: 480.607.0595 Fax: 480.778.1773 E-mail: info@firepanelllc.com Web site: www.firepanelllc.com

ONE IS TOO MANY!

The potential for a fire to occur during a high-speed collision involving a police car is of great concern today. Well documented in the news, fires that have occurred after a high-speed, rear end impact have cost police officers their lives from otherwise survivable collisions. Now, a FIRE Panel installed directly on the fuel tank provides a strong layer of fire protection for officers.

The FIRE Panel product, which is patented technology, is the civilian embodiment of a fire protection concept used by the military for decades. This military technology has enhanced the survivability of aircraft fuel tanks during combat. Military aircraft have often encased the fuel tanks with hollow shields filled with fire suppressing agents. Currently, helicopters and some of the most advanced aircraft in development employ this type of fuel tank protection.

The FIRE Panel pedigree also includes motorsports. Earlier versions of FIRE Panels have been road tested in competition using professional racing vehicles from the SCCA® Trans-Am® Series. This motorsports background demonstrates the durability of the FIRE Panel as it stood up to the rigors of professional racing.

The premise of the FIRE Panel fire protection is this: In order to reach the fuel tank with some object that would puncture or ignite the fuel, that object must first pass through a breakable, protective wrap containing fire suppressing powder, which is installed around the exterior of the fuel tank. As the protective wrap is shattered by the puncturing object, a "cloud" of fire suppressing powder is released, which "inerts" the space around the fuel tank, thereby preventing the ignition of the fuel or quickly suppressing the fire.

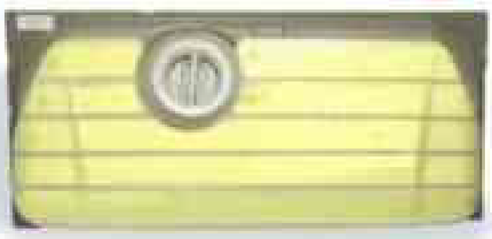
The sequence below, taken from an actual high-speed rear end collision, documents the deployment of the fire suppressing powder around a police cruiser.

FIRE Panels have many features that add to their powerful fire suppression properties:

- FIRE Panels have no moving parts to fail — they will always be ready to provide fire protection
- FIRE Panels are made of a rugged yet lightweight polymer for durability during regular use
- FIRE Panels install in minutes on the outside of fuel tanks, which minimizes vehicle downtime
- FIRE Panels work automatically and will not be affected by low speed "fender benders"
- FIRE Panels are cost-effective

1

The FIRE Panel wraps around the axle side, as well as both left and right sides, of the fuel tank.



2

"Image of fuel tank superimposed over CVPI is for general placement information only and is not to scale nor intended to be a technical representation."

To test the FIRE Panel in a "real world" collision, a normally functioning 1999 Crown Victoria Police Interceptor (CVPI) was equipped with two safety enhancements. A FIRE Panel was mounted on the axle side of the fuel tank *(see Images 1 & 2)*, and a bladder was installed inside the fuel tank. The fuel tank was filled with 14 gallons of unleaded gasoline, and the vehicle's flashers were operating. A pickup truck was then crashed into the rear of the CVPI at 81.9 mph.

3 Post-crash CVPI

Image 3 shows that the impact of the high-speed, rear end collision was quite severe. As the trunk compartment of the CVPI compressed to absorb the impact, the fuel tank was thrust forward and up into the other components of the CVPI's underside. The safety enhancements used in the test lead to a most important and obvious result — there was NO fire. In this test, the FIRE Panel was immediately shattered (by design) at the onset of the collision by the impacting CVPI's rear end components.

In a subsequent test conducted by the Automotive Safety Research Institute, a GMC® Sierra pickup truck, featuring conventional "side-saddle" fuel tanks mounted outside of the frame, was outfitted with the same two safety enhancements, a FIRE Panel and a bladder. A Chevrolet® Caprice Classic was crashed into the side of the GMC pickup at 50 mph *(see Image 4)*. Just as in the CVPI test, a large "cloud" of fire suppressing powder instantly formed around the fuel tank to "inert" the surrounding air *(see Image 5)*.

What's more, FIRE Panels are not limited to police vehicles. As mentioned earlier, professional and amateur motorsports continue to use and evaluate FIRE Panel for fire protection. Mass transportation vehicles such as city and school buses can also add a proven layer of safety by installing FIRE Panels on their fuel tanks.

4 Impact instantly creates "cloud"

5 "Cloud" of fire suppressing powder

Call us today, toll-free, at 866.607.0747 and learn how a FIRE Panel could make the difference between a devastating fire and a survivable crash.

FIREPANEL™

VEHICULAR FIRE PROTECTION SYSTEMS

F.I.R.E. Panel LLC
7898 E. Acoma Drive, Suite 106
Scottsdale, AZ 85260 USA
Tel: 480.607.0595
Fax: 480.778.1773

www.firepanelllc.com
E-mail: info@firepanelllc.com

Appendix I: Explosion Suppressant Arresting Foam

ESAF

Explosion Suppressant Arresting Foam

- Fuel Tank Inerting
- Explosion Suppression
- Surge Mitigation

EIS

Engineered Inerting Systems, LLC

ESAF Explosion Suppressant Arresting Foam

Proven safety and security for fuel tank inerting, and surge and slosh mitigation

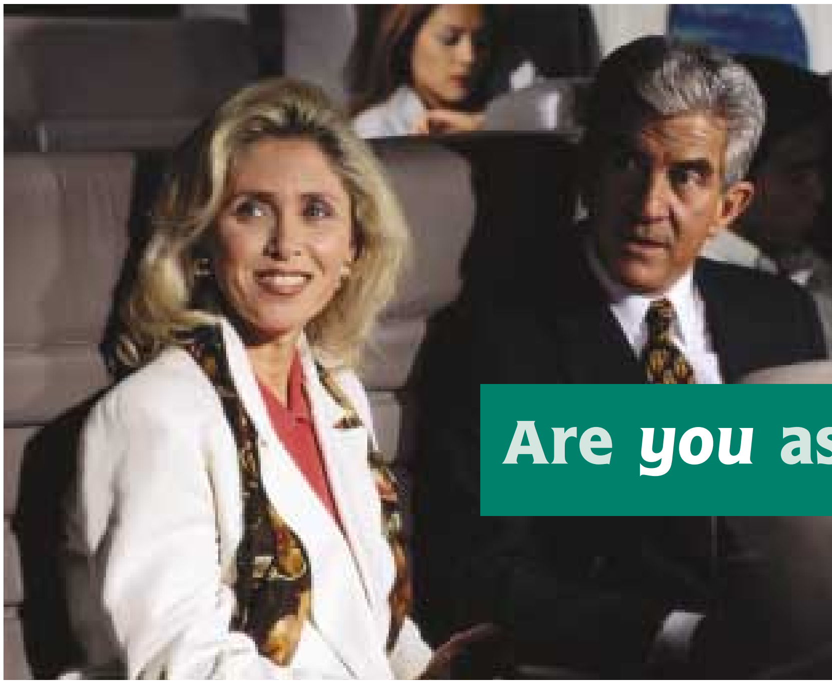
ESAF protects...

- Aircraft of all types including business/commercial
- Fuel tanker trucks
- Emergency and special use vehicles
- Commercial and recreational powerboats
- All terrain vehicles (ATVs)
- Personal watercraft (PWCs)
- Stationary and portable fuel storage tanks, auxiliary tanks

ESAF explosion suppressant arresting foam prevents catastrophic explosions of ignited fuel vapors caused by electrical arcing, overheating of internal components, lightning strikes, small arms fire, or other similar ignition sources. It also mitigates the rapid movement of fuel, significantly reducing surging and sloshing.

ESAF offers a unique combination of advantages for rigid and flexible fuel tanks

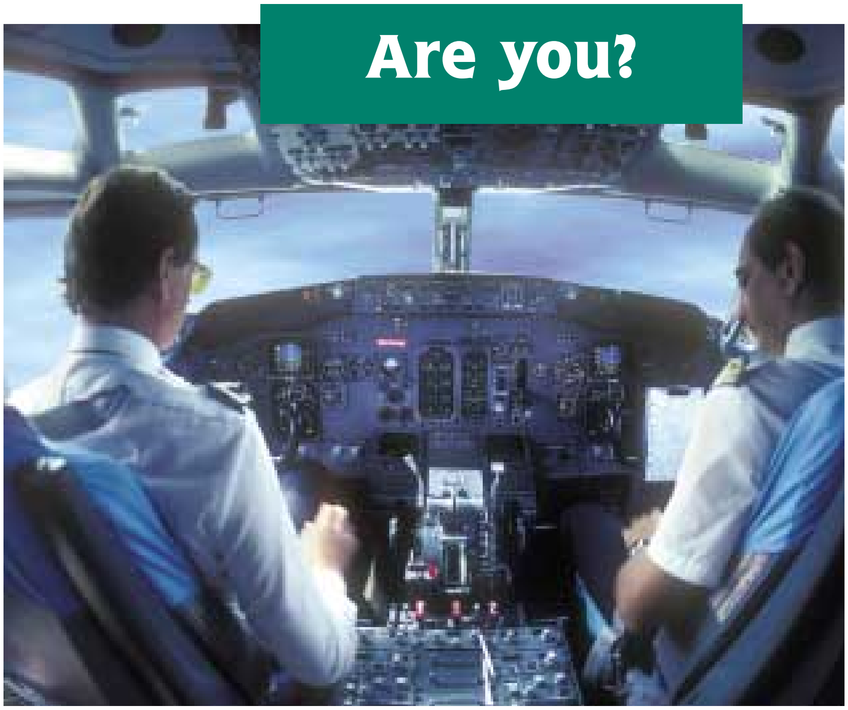
- ESAF is easily fabricated into any configuration to conform inside a complex rigid or flexible bladder-type fuel tank
- ESAF is specified to remain in service for up to 20 years
- ESAF is maintenance free and completely passive; no crew action is required
- ESAF has no mechanical or electrical parts to fail; it protects fuel tanks at all times
- ESAF offers low initial costs and no maintenance costs over its entire life cycle
- ESAF is static dissipative and will not hold an electrical charge when properly installed



Are *you* as safe as you can be?

You *could be* with

ESAF



Are you?

Explosion Suppressant Arresting Foam in your fuel tanks

ESAF may be used in any aircraft, vehicle, or vessel where the possibility of fuel tank explosion exists, or where fuel surge/noise mitigation is required

ESAF also considerably reduces the spraying and spewing of fuel, should the fuel tank be catastrophically impacted.

Explosion suppressant foam (fuel tank inerting foam) has been protecting military aircraft for more than 30 years. It also helps protect world class racing cars and boats and many special use vehicles. ESAF is designed for use virtually anywhere the possibility of explosion exists or fuel surge/slosh mitigation is needed.

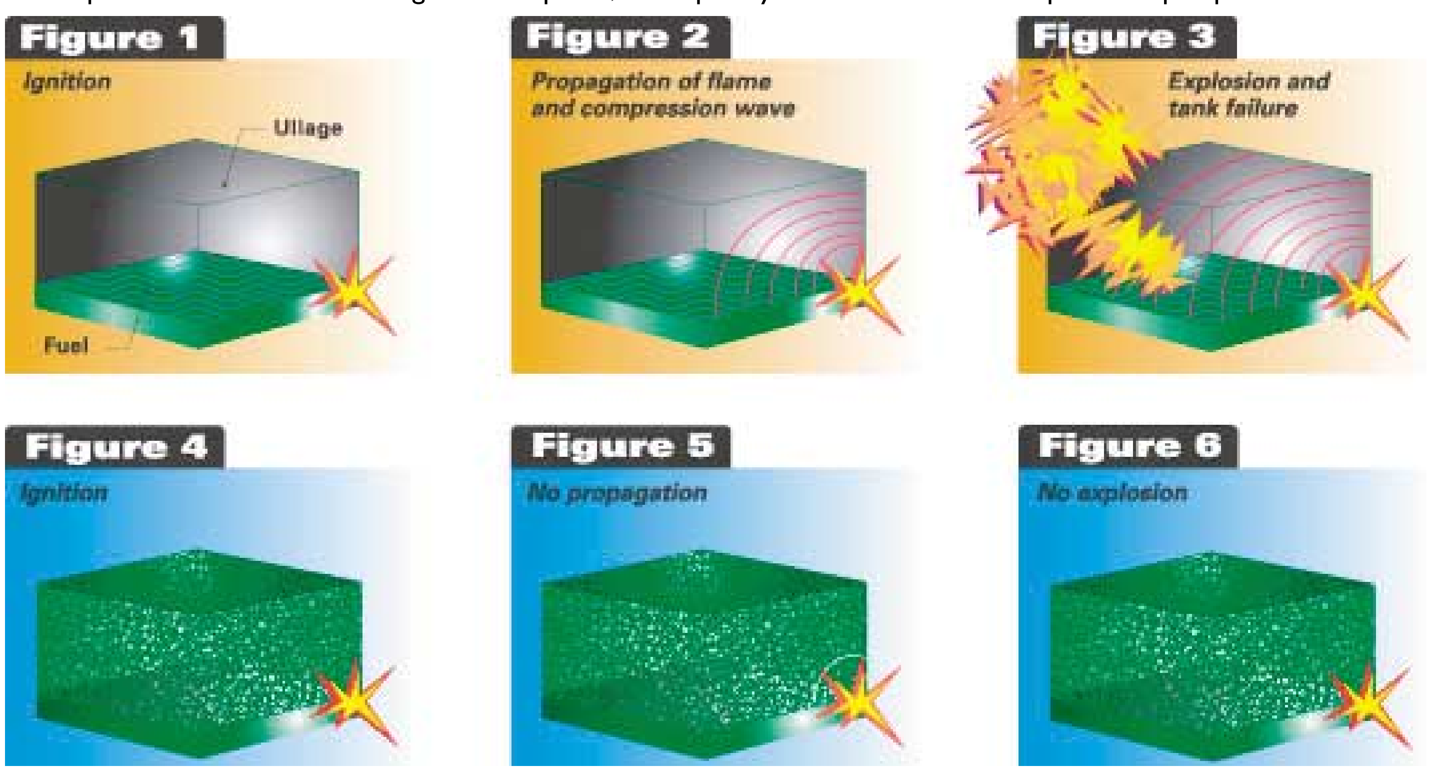
ESAF prevents catastrophic fuel tank explosions—regardless of their source

More than three decades of safety and security for military aircraft around the world

Add safety, security, and peace of mind for virtually all fuel tank applications…quickly, efficiently, and economically. Explosion suppressant foam has an impressive track record of success. It is currently used in military transport and reconnaissance aircraft such as C-130 Hercules and P-3 Orions, fighter aircraft such as F-4s, F-5s, F/A-14s, F-15s, F/A-18s, A-10s, A-37s, and the T-1A trainer (the military version of the popular BeechJet series of corporate aircraft), as well as military helicopters, battle tanks, and transport vehicles.

How ESAF protects against catastrophic explosions

In a fuel tank, the empty space above the fuel level (known as the ullage) may readily contain an explosive mixture of fuel vapor and air. It is in this ullage area where an explosion can occur, should it be ignited by any source. Since the liquid fuel itself does not explode, a completely filled tank is far less likely to explode than one that is not full. Conversely the lower the fuel level in the tank, the greater amount of explosive vapor present.



When an ignition source is present (perhaps from a spark), the vapor adjacent to the spark ignites rapidly (Figure 1). This ignition, in turn, ignites the vapor around it, creating a "chain reaction" as the ignition, or "flame front" gets larger and moves faster as it propagates through the vapor (Figure 2). The rapid ignition and propagation of the flame results in an ever growing compression wave in front of it, compressing the unignited vapor, thus adding even greater force to an explosion (Figure 3). This sequence occurs in milliseconds. ESAF prevents this chain reaction from occurring; instead, vapor ignition is confined to the area immediately around the ignition source (Figure 4). Flame and wave propagation are mitigated by the foam to below propagation levels (Figure 5), thus preventing a catastrophic explosion (Figure 6).

ESAF

Enhanced safety, security, and peace of mind in an uncertain world

ESAF adds an unprecedented level of protection—virtually everywhere

Tell us about your application today...

Tell us about your application for ESAF Explosion Suppressant Arresting Foam.
We'll be pleased to discuss your requirements in detail, and provide full technical data and samples for your review. Let us hear from you today.

EIS
Engineered Inerting Systems, LLC

Engineered Inerting Systems, LLC
545 Island Road, Suite 2B
Ramsey, NJ 07446
Phone: 201-995-1457 • Fax: 201-995-9504
Email: info@engineeredinerting.com
Web: www.engineeredinerting.com

Appendix J: Explosion Suppressant Matted Aluminum Mesh

eps

THE TECHNOLOGY TO STOP AN EXPLOSION

EXPLOSION PREVENTION SYSTEMS, LLC.

P.O. BOX SS-5804
NASSAU, THE BAHAMAS
TEL: (242) 363-2992
FAX: (242) 363-2840

1200 W. RISINGER ROAD
FORT WORTH, TEXAS 76134
TEL: (817) 293-3279
FAX: (817) 293-8014

eps

EXPLOSION ELIMINATING SYSTEMS

THE POINT IN QUESTION is how to effectively prevent a fuel tank from exploding when exposed to ignition, sparks, fire or impact without having the disadvantages of considerable loss of volume, too much weight or toxic chemical reactions.

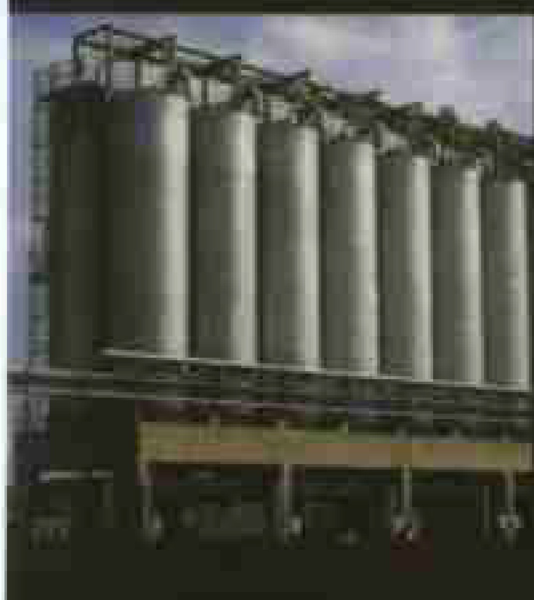
eps *IS THE ANSWER.* A finely meshed aluminum net which is fitted into the tank either in the form of a roll or in the form of spherical bodies protects the tank by using the principle of heat conductivity. This eliminates the dangers inherent in all kinds of tanks filled with combustible liquids.

eps **PROTECTS FUEL TANKS OF CARS, AIRCRAFTS, SHIPS - STORAGE TANKS OF PETROL STATIONS, INDUSTRIAL PLANTS AND REFINERIES - HOUSEHOLD GAS CYLINDERS FROM BACKFIRE GAS INGNITIONS - TANKS OF PETROL TRUCKS - MEDICAL GAS CONTAINERS - TANKS OF ALL KINDS OF MILITARY VEHICLES.**

eps

THE ADVANCED STEP:

A highly advanced compound of the aluminum alloy used and a permanent further development of the production process now guarantee unlimited durability, improved heat conductance, and a resultant higher efficiency as well as a reasonable price.



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eps

PREVENTS ALL KINDS OF TANKS FILLED WITH COMBUSTIBLE LIQUIDS OR GAS AIR MIXTURES FROM EXPLODING WHEN SUBJECTED TO INTERNAL OR EXTERNAL IGNITION SOURCES.

ALLOWS WELDING OF FILLED AND THUS HIGHLY EXPLOSIVE TANKS.

BRINGS EXISTING SOURCES OF FIRE UNDER CONTROL BY SLOWING DOWN COMBUSTION, AND THEREFORE FACILITATING FIRE EXTINGUISHING.

STABILIZES THE CONTENTS OF THE TANK AND REPLACES EXPENSIVE BAFFLE PLATES.

PREVENTS RUST, CORROSION AND ALGAE GROWTH.

IS EASILY INSTALLED EITHER AS NET ROLL DURING TANK MANUFACTURING OR SUBSEQUENTLY AS SPHERICAL BODIES.

RESISTS COMPACTION BECAUSE OF ITS STRUCTURE.

IS MAINTENANCE FREE.

TECHNICAL DATA:	**MATERIAL:**	
	CHEMICAL SUBSTANCE:	**INORGANIC, PASSIVE, DOES NOT REACT WITH COMBUSTIBLE LIQUIDS OR SOLVENTS**
	WEIGHT:	**NETWORK 0.035KG** **SPHERICAL BODIES 0.60 KG PER LITER OF VOLUME**
	LOSS OF VOLUME BY DISPLACEMENT OF FUEL:	**1.4 TO 1.7%**
	LOSS OF VOLUME BY ABSORBTION BY FUEL:	**0%**
	OPERATING TEMPERATURE:	**-100 TO +500° C**
	SMELTING TEMPERATURE:	**+650° C**

The following diagrams show the test results concerning maximum pressure in fuel tanks when ignited by sparks. The examinations were performed with both unprotected and with eps-protected tanks containing an appropriate saturated explosive mixture of n-hexane and air. The pressure in the unprotected tank rose to 4.01 bar while the container filled with eps Network only reached 0.54 bar.

UNPROTECTED

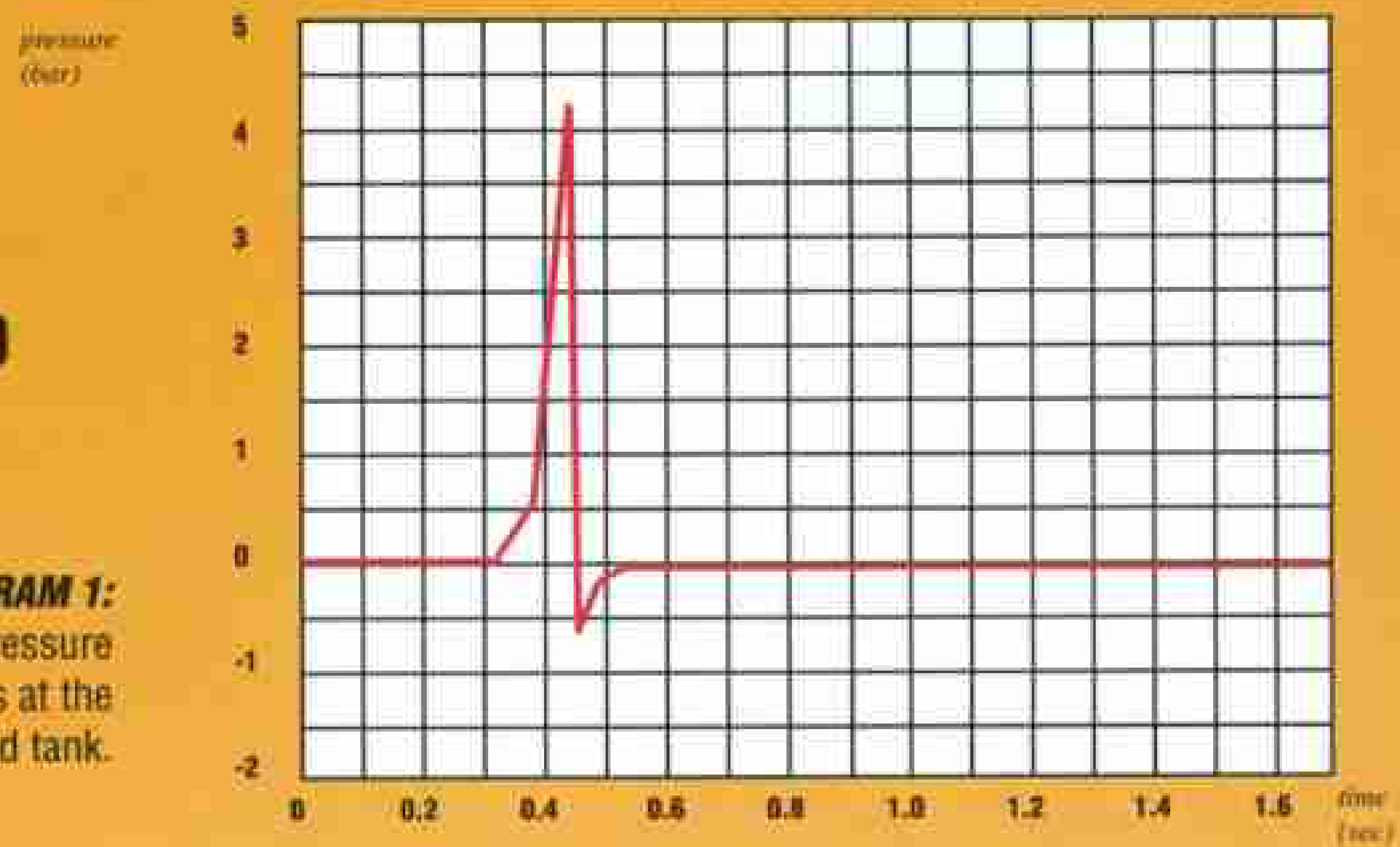


DIAGRAM 1: Time-pressure phases at the unprotected tank.

PROTECTED

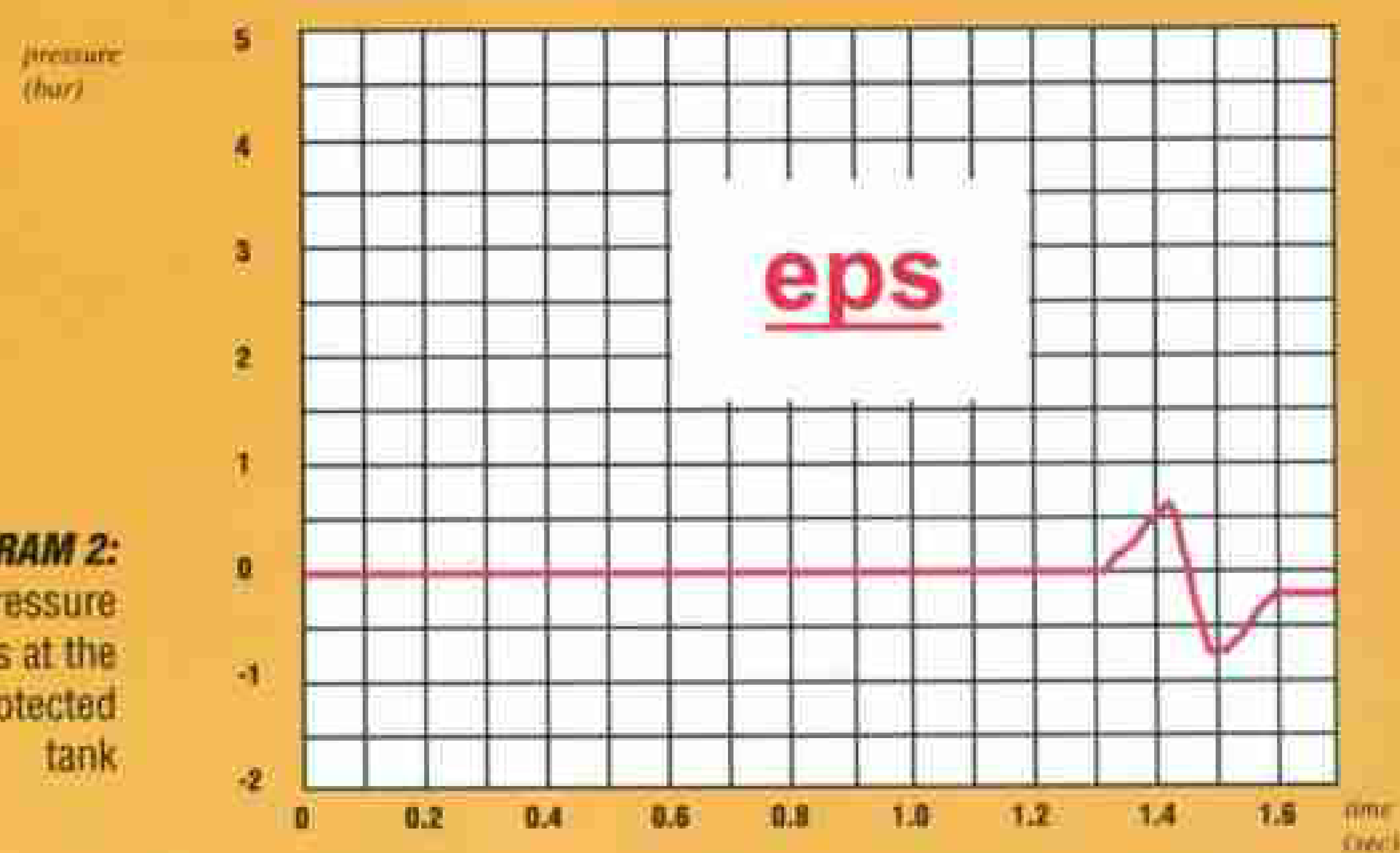


DIAGRAM 2: Time-pressure phases at the eps protected tank

Appendix K: Tank Bladder and Auto Racing Fuel Cells

What Are ATL Fuel Cells?

ATL Fuel Cells are sophisticated safety fuel tanks for race cars, stunt cars, race boats, rally cars, off-road vehicles, aircraft and military equipment. Over the past 30 years, ATL Fuel Cells have clearly demonstrated that they offer fire and explosion protection far in excess of any conventional gasoline or diesel tank.

The ATL Fuel Cell system is comprised of an impact resistant rubberized "bladder" filled with explosion suppressant foam baffling and outfitted with a leak-tight cap and fittings. Additional safety equipment frequently includes roll-over check valves and a metal container to deflect impacts and to serve as a flame shield.

Quality ATL Fuel Cells also feature aircraft type nut-ring flanges, fill-valve plates of steel and aluminum plus exclusive fuel-trap devices to prevent fuel starvation.

All of these refined ATL components, working in harmony, provide the serious racer and hobbyist alike with outstanding protection against fuel spillage, post-crash fire and explosion. It has been professionally estimated that the ATL-type fuel cell has prevented 95% to 98% of the fuel fires that otherwise would have erupted in high speed racing accidents.

What's In An ATL Fuel Cell?

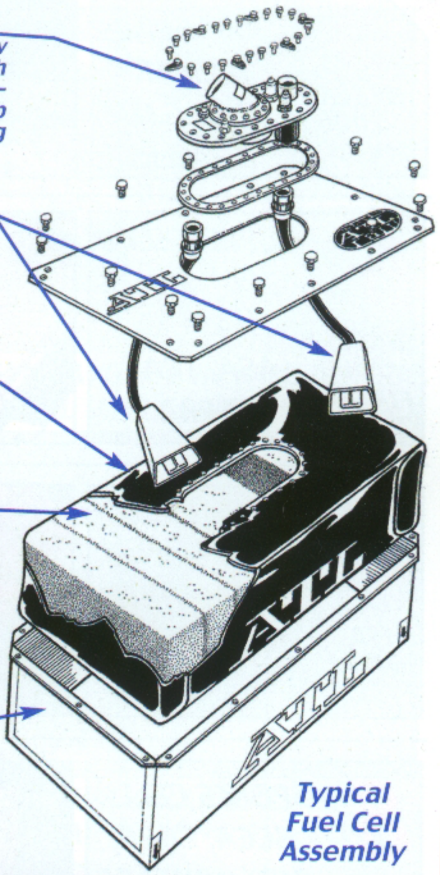
Check Valves
A check valve is a flow control device which closes during a "roll-over" accident to help prevent fuel escaping from the fill and vent.

"Duck-Foot" ™ Fuel Traps
The Duck-Foot collects and retains some fuel around the pickup filter, ensuring constant feed to the engine.

Safety Fuel Cell Bladder
The Heart of the fuel cell system; Ultra-Tough & impact resistant yet light and flexible.

Safety Foam
Nearly every ATL Fuel Cell comes complete with Safety Foam Baffling designed to reduce fuel slosh and help suppress explosion. ATL's safety foam takes up less than 2 percent of the cell's total volume.

Containers (Cans)
ATL's containers are made from powder-coated steel or aluminum. Carbon Fiber containers are also available as an option.



Typical Fuel Cell Assembly

ATL "SPORTS CELL" GOES THROUGH REAL-WORLD CRASH TEST

Before


During

After

130 MPH CRASH
NO EXPLOSION
NO LEAKAGE
NO FIRE
NO KIDDING!

Are There Different "Levels" Of Fuel Bladder Protection?

Yes, there are several distinct "levels" of fuel bladder crash resistance based primarily upon the far reaching standards established by the "Federation Internationale de L'Automobile" (FIA). FIA is the World Sanctioning Organization for Motor Racing, and among its many affiliate organizations are: NASCAR, SCCA, NHRA and USAC. The latter, United States Auto Club, has developed its own fuel bladder standards specifically for alcohol (methanol) fuels. Design specifications, test methods and the approval processes are quite involved, but to the right is a helpful summary, based on "NTS" (Nominal Tensile Strength), which offers a basic measure of fuel bladder toughness.

FIA SPEC FT-5 (GAS)
NTS = 2000 lb/in
F-1, Indy, F-3000, Prototypes

FIA SPEC FT-3.5 (GAS)
NTS = 1000 lb/in
NASCAR, ASA, TRAC, WRC

FIA SPEC FT-3
NTS = 450 lb/in
Soft or Hard Rubber Bladders Gas & Alky
SCCA, DIRT, CORR, USAR

USAC 1000 (ALKY)
NTS = 750 lb/in
SPRINTS, MIDGETS, MODIFIEDS

Appendix L: Self Sealing Tank System - BallistiCoat

Ballistic Treated Fuel Tanks — ATL's TC-103 & TC-108 Processes

For Over 25 years, ATL Has Been Converting Stock O.E.M. Gas Tanks Into Self-Sealing, Non-Exploding Safety Fuel Cells. ATL Proudly Provides These Ballistic Fuel Tanks For The Presidential Limousine Fleet, U.S. State Department Cars, Executive Town Cars, SUV's, Diplomats' Limousines, CIA Security Vehicles, Military Equipment And Off-Road 4x4's. Bullet Wounds Generally Seal 95 to 100%!

Toyota Landcruiser

Ford Expedition

Land Rover

Presidential Limo, U.S. Secret Service

ATL TC-103 "BallistiCoat" Features

- Helps Prevent Fuel Loss From Gun Fire
- Uses Existing O.E.M. Gas Tank or Diesel Tank
- Fully Baffled With Safety Foam
- Tank Remounts In Original Location

Approved By U.S. Secret Service !

- Suppresses Explosion & Fire
- Weighs Only 19 lb. (9 kg.) On Average
- Multi-Ply, Self-Sealing Rubber Envelope
- Reasonable Cost & Quick Delivery

ATL Can Supply TC-103 Ballistic Tanks Complete, Or On An Exchange Program, Using Your O.E.M. Tanks. The Full Conversion Process Takes About 2 Weeks. ATL's TC-108, "Foam-Only" Service, Is Also Available For Explosion Suppression Without Self-Sealing.

AM General Corporation (HUMMER)

TC-103 Process Cut-Away

Mercedes-Benz

Tested At Piccatinny Arsenal Against:
- **9mm Uzi**
- **7.62mm AK-47**
- **5.56mm M-16**

ARMED FORCES

HMMWV

BALLISTICOAT™

ATL'S #TC-103 PROCESS

CONVERTS O.E.M. GAS TANKS TO SELF-SEALING, NON-EXPLODING SAFETY FUEL CELLS

BULLET AND SHRAPNEL PROTECTION FOR DIPLOMATS' LIMOUSINES, EXECUTIVE TOWN CARS, SECURITY VEHICLES, SEARCH AND PURSUIT CARS, MILITARY EQUIPMENT, PATROL BOATS AND OFF-ROAD 4X4'S.

U.S. STATE DEPT.
APPROVED BY
U.S. SECRET SEVICE

TC-103
Self-Sealing
Tank

CADILLAC LIMOUSINE
(Photo courtesy of Moloney Coachbuilders)

CHEVY SUBURBAN
(Photo Courtesy of O'Gara Armoring Company)

HUMMER
H.M.M.W.V.

TC-103
Self-Sealing Tanks

MERCEDES-BENZ S-CLASS
(Photo Courtesy of O'Gara Armoring Company)

HELPS PREVENT FUEL LOSS, FIRE AND EXPLOSION FROM FUEL TANK PUNCTURES

DS #481
08/96

Typical TC-103 Process
BALLISTICOAT™

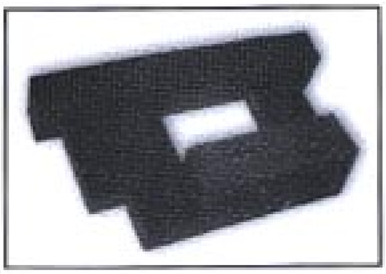
1.

Stock OEM Vehicle Fuel Tank (Metal or Plastic) is Cleaned and Inspected.

2.

A T L Access Flanges are Integrated for Safety-Foam Installation.

3.



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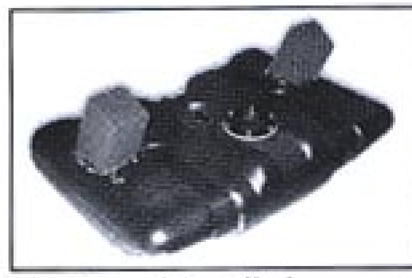
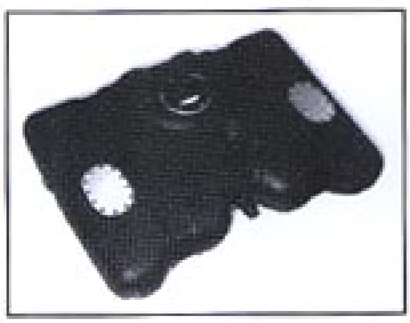
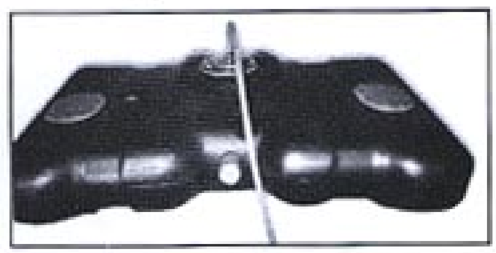


Safety Foam (such as Mil-B-83054) is Cut and Installed for Surge Mitigation and Explosion Suppression.

5.



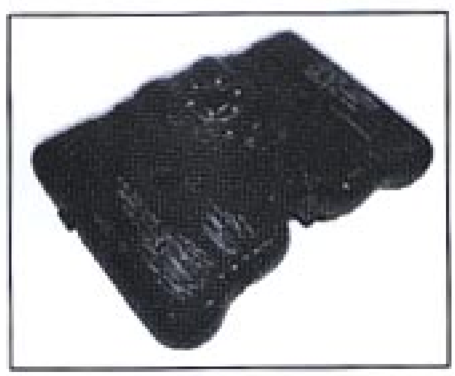
6.



Flange Covers are Installed and Static Pressure Test is Applied.

7.

8.



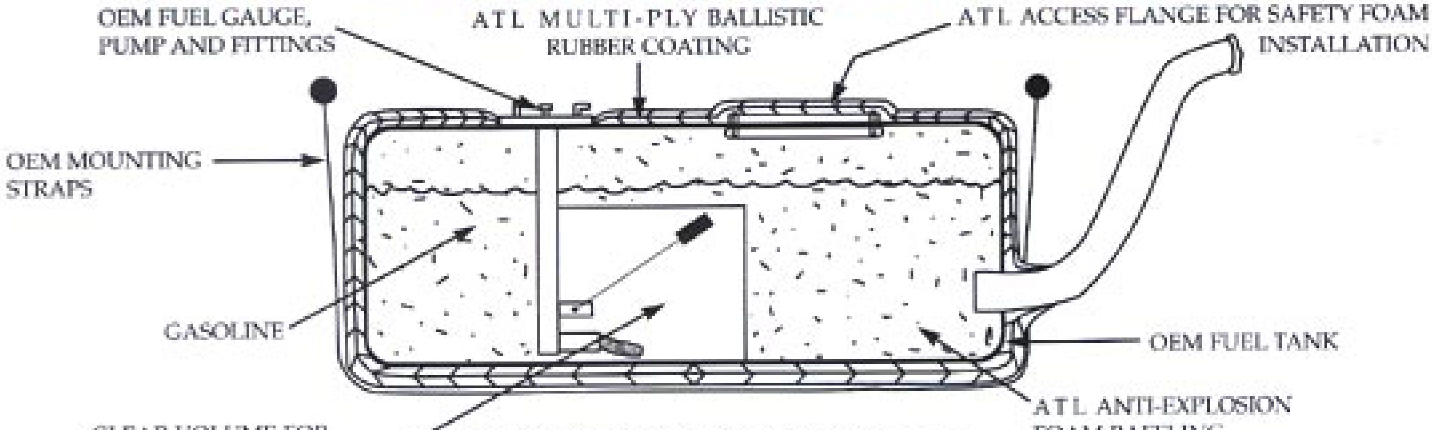
Layers of Proprietary Rubber Compounds are Vulcanized Over the External Tank Surface to Form a Self-Sealing "Ballistic" Encapsulant.

BALLISTICOAT IS A TOP QUALITY PRODUCT WITH AN UNBLEMISHED 20 YEAR RECORD. HOWEVER, DUE TO THE MANY SIGNIFICANT HAZARDS AND UNCERTAINTIES OF GUN-FIRE, ATL CAN OFFER NO GUARANTEE OR WARRANTY OF FITNESS UNDER ANY CONDITIONS.

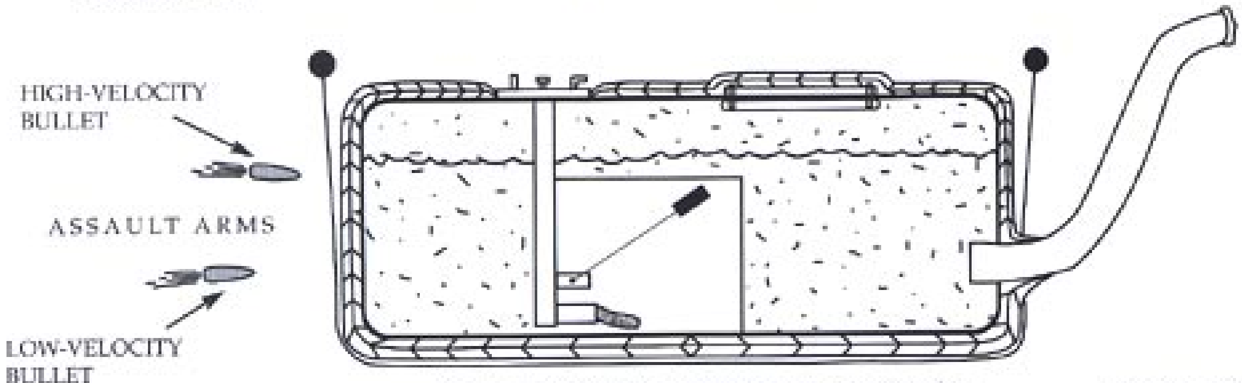
BALLISTICOAT BY ATL

- Re-uses OEM tank, straps and brackets
- Tank remounts in original location
- Weighs only 19 lb. (9 kg) on average
- Reasonable cost and quick delivery

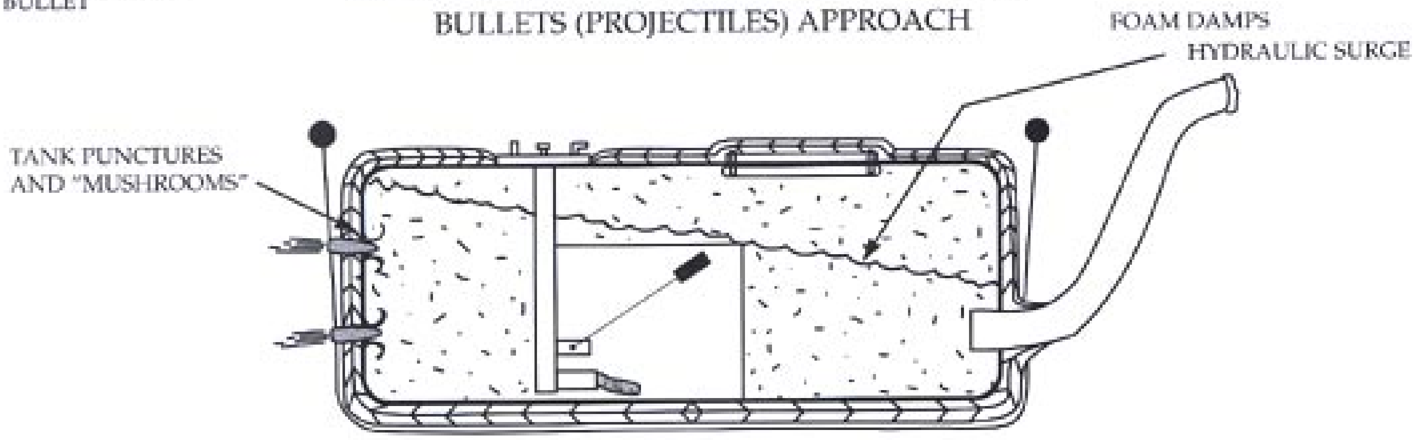
How BallistiCoat™ Works



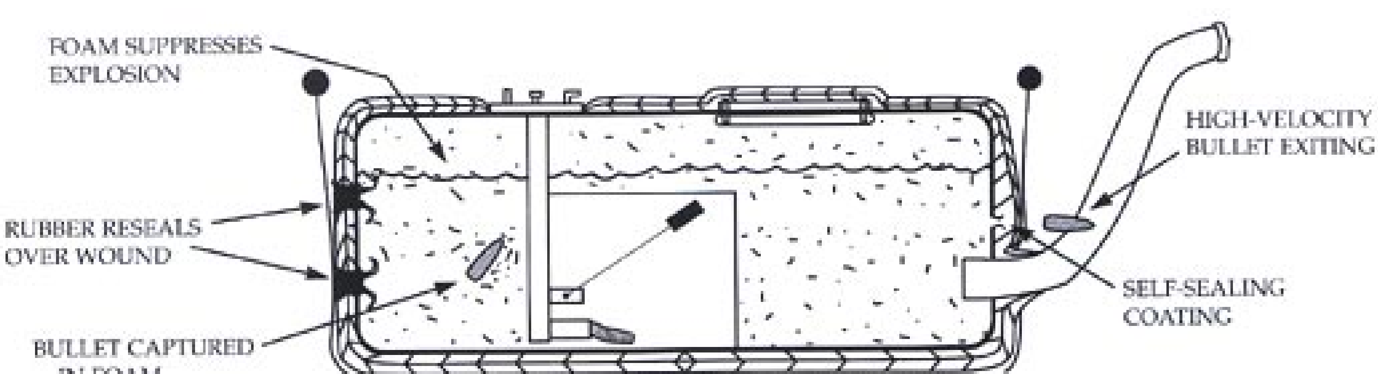
TC-103 FUEL TANK AS INSTALLED



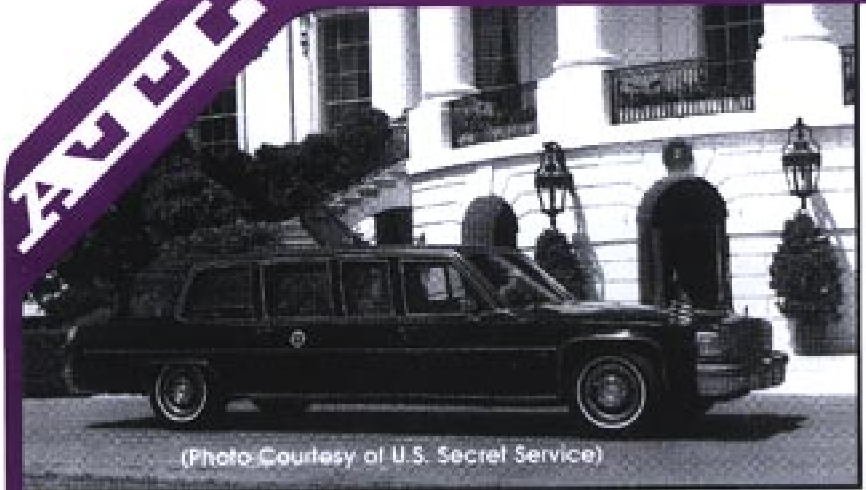
BULLETS (PROJECTILES) APPROACH



BULLETS ENTER TANK



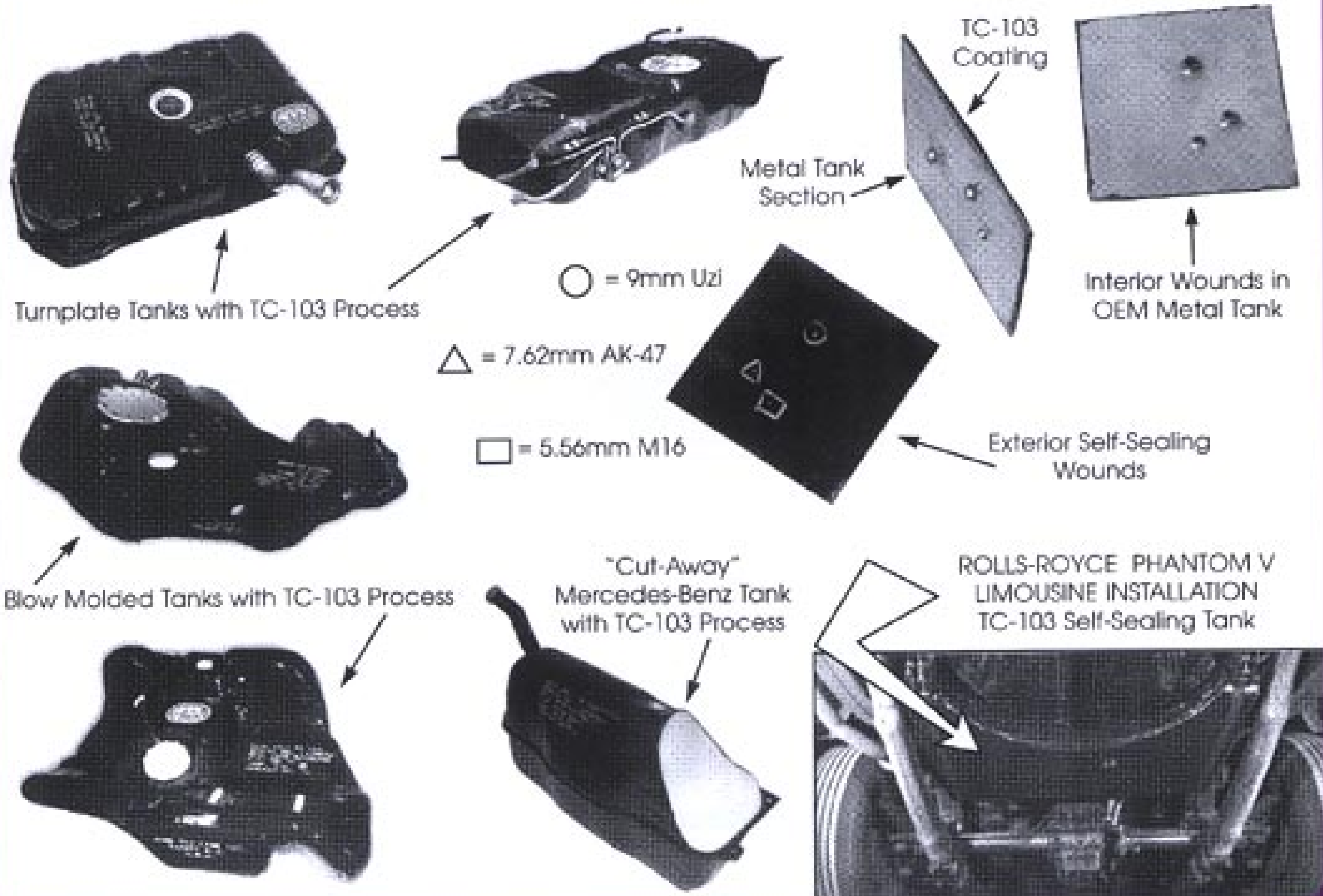
TYPICAL ENTRIES SEAL 95 TO 100%
CONTACT ATL TO DISCUSS ANY SPECIAL BALLISTIC CONDITIONS



ATL's BALLISTICOAT™

Used In All Presidential Ballistic Limousines Since 1975! Now Specified For Heads Of State & CEO's World Wide.

A T L can supply TC-103 ballistic tanks complete, or on an exchange program, using your OEM tanks. The conversion process takes about 2 weeks, and pricing is by quotation. A T L 's TC-108, "foam-only", service is also available for explosion suppression without self-sealing. These services are available from A T L U.S. in Ramsey, NJ U.S.A. and A T L U.K. in Milton Keynes, England.



ATL®

U.S.A. Order Line 800-526-5330

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Spear Road Industrial Park
Ramsey, NJ 07446-1251 U.S.A.
Tel: 201-825-1400
Fax: 201-825-1962

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40 Clarke Road, Mount Farm Industrial Estate
Milton Keynes MK1 1LG England
Tel: 01908-270590
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