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EA13-003

Analysis of Fuel Tank Leaks on Model Year 2003-08 Mercedes-Benz E-Class Vehicles

VEHICLE RESEARCH AND TEST CENTER
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16. Abstract

The initial objectives of the program were 1) to identify the leak sources in failed field sample fuel tank assemblies and components collected by ODI, 2) to collect additional failed assemblies and components, and 3) to quantify the volume of fuel leakage from each source individually and collectively. Additional objectives were added after reviewing the manufacturer's response to an extensive Information Request letter issued by ODI in July 2013. Subsequently, VRTC independently reviewed the manufacturer's analysis and conclusions.

The actual leak-rate analysis was performed by finding the average slope of the air-pressure decay trace over a 30-second interval beginning at the time when the pressure decay reached 1.23-psi. The majority of the fuel tank assemblies or individual components collected (18 of 24) leaked air at a rate below the 0.5-mm threshold, and may not immediately illuminate the malfunction indicator lamp (MIL), but could be noticeable to the vehicle owner as a gasoline smell, especially if liquid fuel were to exit through these small openings. Data collected from the testing is also shown grouped by component, as tanks, filters, and pumps. Only two tanks leaked above the 0.5-mm threshold that would have immediately illuminated the MIL. One tank leaked at a rate just slightly more than the new tank. The leak rate on the top plate of the fuel pumps was very low and similar to the normal leak rate of the new tank. While many of the right-side fuel-pump top-side plates had a small crack and yellow stain, no significant air leaks were found at any of these sites, including the heavily stained top plates. The leak rate of the filters was significantly different from the pumps. Fourteen of the 17 filters leaked at a rate that may not have immediately triggered a MIL for vapors, but could have still leaked liquid fuel since the opening location is below the full-fill fuel level of the tank. Three of the filters leaked at a rate that would have immediately triggered the MIL and one of those leaked at a rate over the 1.0-mm threshold (VOQ 10505868).

The ODI sent a detailed Engineering Analysis Information Request letter to Mercedes-Benz USA, LLC on 07/16/2013. The manufacturer responded with extensive information including testing to answer ODI's specific questions. A second objective was added to the test request to verify the information provided by the manufacturer. After reviewing the response from the manufacturer, as well as the material presented in the November, 2013 meeting, much of the information was verified and either matched VRTC assessments, or the differences were not substantial.

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List of Acronyms

AMG	subsidiary of Daimler AG, the parent company of Mercedes-Benz
CARB	California Air Resources Board
EA	Engineering Analysis
E-Class	Mercedes-Benz "W211" platform produced from calendar year 2002-09
EPA	Environmental Protection Agency
LLC	Limited Liability Corporation
MIL	Malfunction Indicator Lamp
MY	Model Year
NHTSA	National Highway Traffic Safety Administration
OBDII	On-Board Diagnostic System Version 2
ODI	Office of Defects Investigation
PE	Preliminary Analysis
USA	United States of America
VOQ	ODI's Vehicle Owner's Questionnaire form
VRTC	Vehicle Research and Test Center
WIS	Mercedes-Benz Workshop Information System

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1.0 INTRODUCTION

This test program was performed by the National Highway Traffic Safety Administration (NHTSA) at its Vehicle Research and Test Center (VRTC) at the request of the Office of Defects Investigation (ODI). ODI opened a Preliminary Evaluation (PE12-001) in January 2012 on model year (MY) 2003-06 Mercedes-Benz E55 AMG vehicles to investigate fuel leaks from the top area of the fuel tank assembly, including leaks that may be present in pressurized portions of the fuel delivery system. At that time, it was suspected that the leaks were associated with a U. S. Environmental Protection Agency (EPA) Emissions Recall Campaign #2008-020001. The investigation was upgraded to an Engineering Analysis (EA13-003) in March 2013 and expanded the vehicle scope of the investigation to include all E-Class vehicles in MY 2003-08. The investigation no longer focused solely on the E55 models or the previous emissions recall. Instead, the EPA recall issue was considered a potential, but not the primary fuel leak concern. Later that month, ODI submitted a test request[1] to VRTC requesting support for this investigation.

2.0 PROGRAM OBJECTIVE

The initial objectives of the program, as defined in ODI's March 18, 2013 test request, were 1) to identify the leak sources in failed field sample fuel tank assemblies and components collected by ODI, 2) to collect additional failed assemblies and components, and 3) to quantify the volume of fuel leakage from each source individually and collectively.

Additional objectives were added after reviewing the manufacturer's response to an extensive Information Request letter issued by ODI in July 2013. During a November 2013 meeting with ODI and VRTC, Mercedes-Benz (the manufacturer) presented[2] information and discussed the operation of the evaporative emissions control system noting its ability to detect the presence of

[1] The test request is available at www.safercar.gov in the EA13003 investigative file titled INME-EA13003-57672P.pdf

[2] The presentation was submitted under a request for confidentiality however, a summary is available to the public in the EA13003 investigative file at www.safercar.gov titled "EA13-003 Summary of Tests and Analysis.pdf".

leaks in non-pressurized portions of the fuel system[3]. They explained that when leaks in excess of regulated leak detection thresholds are detected, the system sets a diagnostic trouble code and illuminates the malfunction indication lamp (MIL) as a driver warning. The manufacturer further noted that 1) only a small portion of related ODI complaints (~5%) reported a MIL, 2) the majority of ODI complaints (88%) noted only fuel odor or smell (not the presence of liquid fuel leakage), and 3) a majority of ODI complaints (57%) associated the presence of the fuel odor with a refueling event.

Based on these observations, the manufacturer hypothesized that fuel leaks reported by ODI complainants involved small volume fuel leakage (possibly vaporous in nature) from unpressurized portions of the fuel system located at or near the top of the fuel tank. The manufacturer presented analysis and testing supporting its hypothesis. Finally the manufacturer concluded that a safety defect does not exist because only small volume fuel leaks that are either fully contained or evaporate away are occurring, and no potential vehicle source of ignition exists. NHTSA subsequently decided to independently review the manufacturer's analysis and conclusions.

3.0 COLLECTION OF FAILED COMPONENTS

The high-density polyethylene fuel tank is a sidesaddle design type with left and right connected compartments. There is a pass-through space on the underside of the tank, between the left and right compartments, for the exhaust and driveshaft to extend to the rear of the rear-wheel drive vehicle. Each side of the tank has a fuel-level sender unit. The right (passenger's-side) sender is combined with an electric fuel pump. The left (driver's-side) sender unit[4] includes a fuel filter, a tank-pressure sensor (for on-board diagnostic system version 2 (OBDII[5]) emissions checks upon startup), and a venturi-powered pickup to move fuel to the right-side saddle electric fuel pump.

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[3] The manufacturer reported that EPA required use of the onboard diagnostic system and mandated that it must detect evaporative control system leaks in excess of a defined and regulated amount. During this test, the tank is slightly purged of air (via applied engine vacuum) and then monitored for the occurrence of air leakage from the atmosphere into the fuel tank.

[4] The left-side sender and filter unit is a serviceable part to be replaced every 60,000 miles. Since it appears as a separate item on the service schedule, and costs ~$600, many owners do not replace the fuel filter.

[5] On-Board Diagnostics, or "OBD," is a computer-based system built into all 1996 and later light-duty vehicles and trucks, as required by the Clean Air Act Amendments of 1990. OBD systems are designed to monitor the

All observed leaks by NHTSA were found to be at the top of the tank from the pump, filter, or the fuel filling limiter valve located at the top center of the tank. The fuel filling limiter valve is a caged float located inside the fuel tank with an external elbow that is connected to the vent system, including the charcoal canister. During refueling, as the fuel level rises and the tank fills, the float raises and seals the air vent. Fuel then backs up in the filler neck, and the fuel-station nozzle shuts off.

Thirty-five field sample tanks, pumps, or filters were collected for inspection and testing and one new fuel tank was purchased for this test program. The ODI investigator provided 11 fuel components from dealership or repair center visits, and located several more components made available by vehicle owners that had filed Vehicle Owners Questionnaire (VOQ) complaints with NHTSA.

The VRTC fieldwork consisted of retrieving components from eight vehicle inspections (seven at dealerships and one inspection only at VRTC of an owner's car on his way to the dealership for a pre-scheduled appointment). At the dealerships, the fuel tank replacement steps were observed, specialized tools were documented for purchase, and use of the dealership's evaporative emissions device and leak-test smoke generator were observed. The diagnostic techniques of the fuel leaks were observed. More than one dealership had reported they had replaced a fuel filter (~$600), then had the vehicle comeback still leaking fuel. Then the unhappy customer was told it would cost another ~$2,500 to fix the leaking fuel tank due to a leaking fuel tank fitting at the integral fuel filling limiter valve. One dealership would no longer replace a leaking filter without also replacing the tank. Another dealership reported they would replace the leaking filter then fill the fuel tank and park the vehicle outside in the sun for the afternoon to check for secondary tank leaks. One manufacturer's area representative suggested using used-ring nuts to install the pump and filter on a used tank and using new-ring nuts on a new tank. At two dealerships, the technicians were observed to use a Mercedes-Benz brand plastic lubricant on the ring nuts. Later research in the Mercedes-Benz Workshop Information System indicated lubricant was not to be used on this vehicle. It appeared overall that the

performance of some of an engine's major components including those responsible for controlling emissions. http://www.epa.gov/obd/

dealerships did not have clear troubleshooting instructions on detecting and remedying fuel tank leaks, especially from the fuel filling limiter valve.

The fuel tanks, pumps, and filters collected during the analysis were marked with identifying information. The pumps and filters were stored in plastic bins. The collection of retrieved components is shown in Figure 1 below and listed in Tables 1 and 2 in Appendix 1.

Figure 1 – The Fuel Tank Components were Labeled, Inspected, and Photographed before Testing

4.0 INSPECTION RESULTS FROM THE COLLECTED FUEL COMPONENTS

The goal of the fieldwork was to collect all of the components that were diagnosed as leaking from each inspected vehicle. If one of the three main components, fuel tank, filter, and pump, were not collected, then it was assumed that it was not leaking. Therefore, most of the components collected had physical indications of leaks (stains).

Most of the fuel tanks collected had stains[6] indicating probable leak paths from around the fuel filter and fuel filling limiter valve, an example of which is shown in Figure 2. The fuel tank topside leaks were found to emanate from two main sources. The primary leak site was the left-side filter, which is located several inches below the full-fill line for the gasoline in the tank. This site could leak liquid gasoline when the fuel level was full or near full. The secondary leak

[6] Some tanks had been stored outside by repair centers and the weather may have removed evidence of the leak points.

site (and only leak found on the fuel tank itself) was a crack along the bottom of the horizontal vent tube of the fuel filling limiter valve located at the very top outside the fuel tank, as shown in Figure 3 from inside the tube. This site is above the normal-full line, but could pass vapors or leak liquid fuel while driving due to sloshing from lateral or longitudinal accelerations, or by overtopping when refilling the fuel tank.

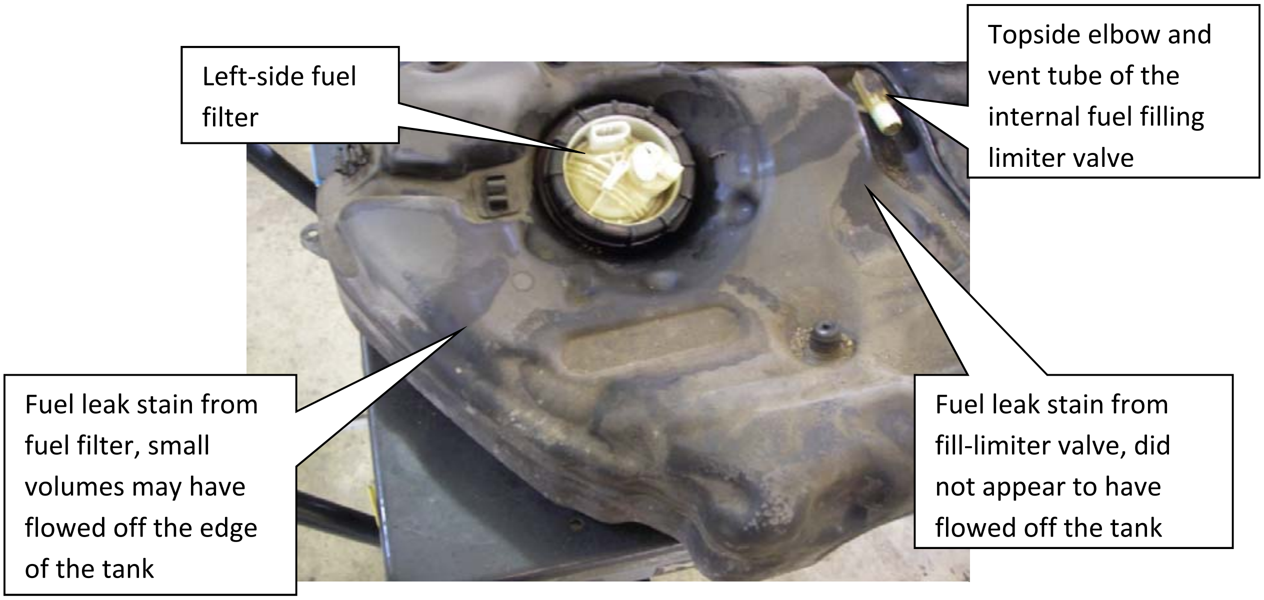

Figure 2 – Fuel Tank 05T with Fuel Leak Stains Around the Filter and the Fuel Filling Limiter Valve

On two of the six tanks, the stains indicated liquid fuel had leaked over the edge of the tank and onto the underbody aero-shield. Tank T05 leaked at the fuel filling limiter valve and at the filter.

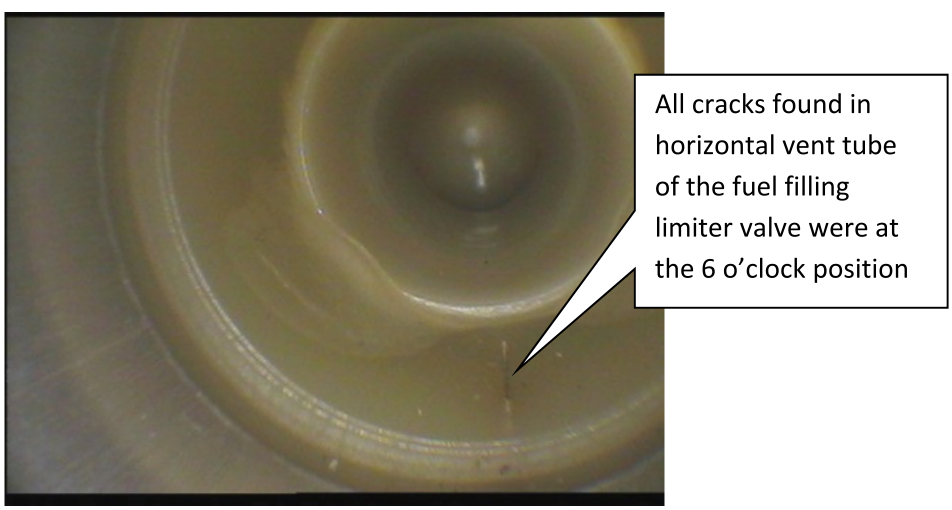

Figure 3 - A Borescope View of a Crack at the 6-O'Clock Position Inside the Horizontal Tube of the Fuel Filling Limiter Valve on Tank 15T

The witness stains on the tank indicated the fuel leaked over the edge at the left and right sides of the left saddle portion of the tank. Tank T12 leaked from the fuel filter and appeared to have spilled over the left side of the left saddle portion of the tank.

All of the top mounting plates of the left-side fuel filters had varying degrees of yellow stains indicating liquid or vapors of hydrocarbons had been leaking from the area of the OBDII tank pressure sensor along the seam for the top cap, as shown during a bubble test in Figure 4.

Most of the top plates of the right-side fuel pumps had a small crack and light yellow stain at the plastic receiver for the aluminum tubes that spring load the pump body into the bottom of the tank, as shown in Figure 5. Two of the fuel pump top plates had a more substantial stain that indicated the well area had probably contained liquid fuel, as shown in Figure 6.

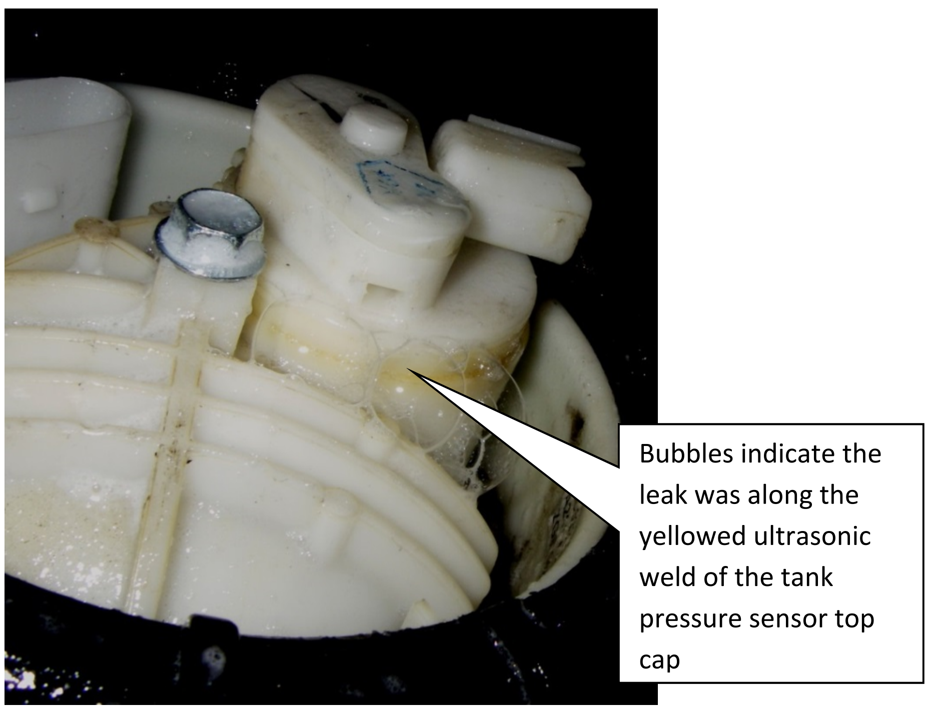

Figure 4 – While the Fuel Tank was Pressurized, Fuel Filter 11A was Sprayed with Soap to Verify the Leak along the Yellow Stain at the OBDII Pressure Sensor Seam

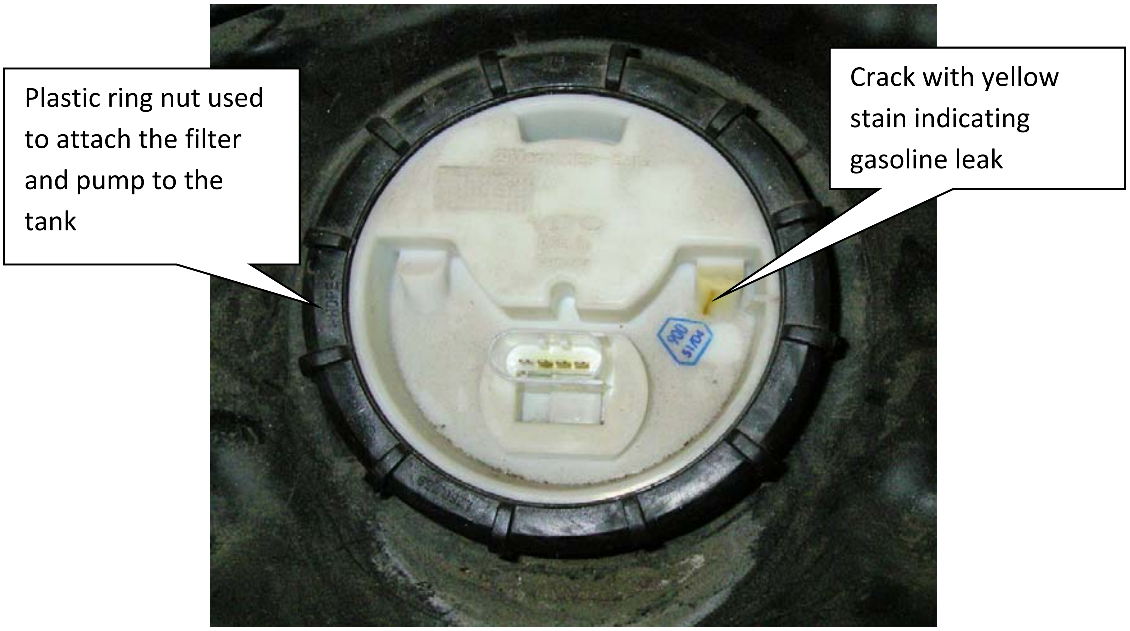

Figure 5 – The Top Side Plate of Fuel Pump 05B was Cracked at the Receiver for One of the Internal Aluminum Rods

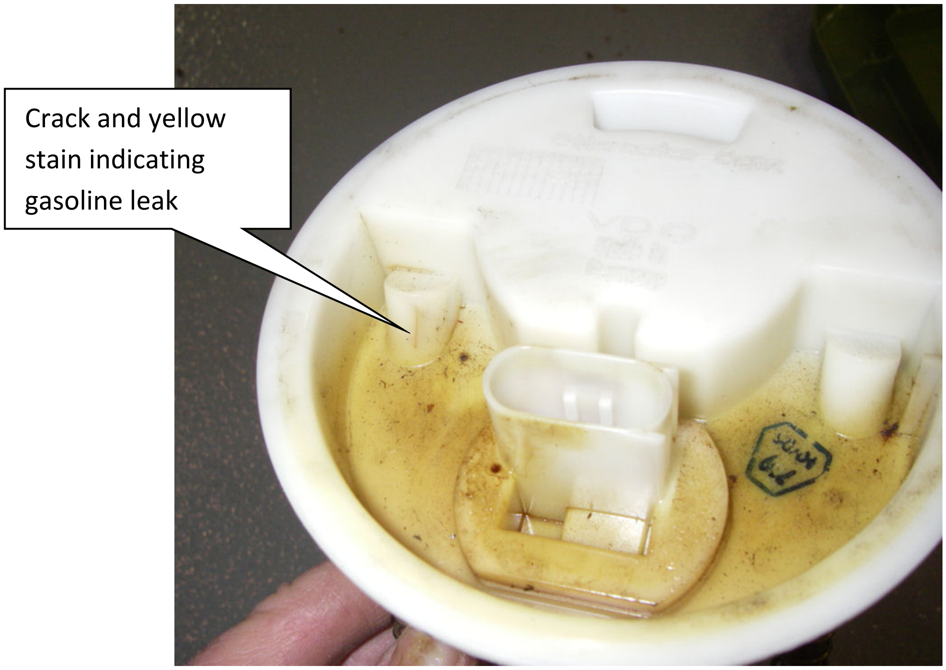

Figure 6 - The Top Side Plate of Fuel Pump 11B had a Small Crack and Significant Staining in Well Area Indicating a Previous Liquid Fuel Leak

5.0 COMPONENT TEST STAND AND PROCEDURE

Prior to the creation of the EPA and the passing of the Clean Air Act in 1970, fuel tanks could be vented to the atmosphere. Current fuel tanks are almost sealed but allowed to "leak" gaseous vapors at very low levels. The key leak rates used by the manufacturer for their testing were designed to meet or exceed the EPA requirements for illuminating the MIL. The key leak rates, those of the most significance for the purposes of this discussion, are the thresholds at which the vehicle's OBDII system recognizes a vacuum leak in the evaporative canister purge system when evaluated during a cold-engine start[7]. The engine intake provides a low 6 hPa (0.09 psi) vacuum to the fuel tank and the evaporative canister outlet port is closed. A leak rate equivalent to that produced through a hole 0.3 mm (0.01-inch) in diameter or less is considered a micro leak, which would set a diagnostic trouble code but not illuminate the MIL. A hole larger than 0.3 mm but not larger than 0.5 mm (0.02-inch) in diameter produces a minor leak and would illuminate the MIL, although maybe not immediately. A hole larger than 0.5 mm in diameter produces a major leak and would immediately cause a MIL illumination. The most common cause of this type of malfunction is leaving off the gas cap after refueling. These hole-size thresholds were used by the manufacturer to categorize the leak rates of the filter, pump, and fuel tank during this investigation, but at a different air pressure than the OBDII system.

At VRTC, each fuel pump or filter was fitted with a new green-colored multi-lipped seal and inserted into the topside ports of a new fuel tank that served as a bench test stand. Then the test tank was pressure tested to determine the air leak rate of each component. If a pump, filter, and tank were available from a single vehicle, then they were tested together to determine the overall leak rate. Then the pump and filter were tested on the new tank together, then one at a time, and finally the tank was tested alone to determine the individual and combined leak rates. If only either a fuel pump or filter were available from an individual vehicle, then the other tank top-side port was sealed with an aluminum plate (of the same thickness and diameter as the top-side plate of the filters and pumps) or with the top side plate of a pump that had been previously tested and found not to leak.

[7] These leak descriptions are more fully discussed in "*Development and Benchmarking of Leak Detection Methods for Automobile Evaporation Control Systems to Meet OBDII Emission Requirements*" 1998-02-23 Technical Paper 980043

As shown in Figure 7, the bench test stand was outfitted with a pressure transducer at the large diameter hose connected to the fuel filling limiter valve, and pressure was injected at the large diameter fuel refilling port through a shutoff valve. The two small-diameter vent lines, from the top of each sidesaddle compartment, were sealed off and not used for pressure monitoring or injection due to possible flow restrictions from their long length and small diameter. However, one of these vent lines was used during tests to determine the pressure drop over 30 seconds with an orifice of a known diameter causing a calibrated leak. Figure 8 shows the leak orifice devices selected for use in this program to produce the major, minor, and micro leaks described previously. Figure 9 shows the tablet computer used for data collection and real-time display of the pressure in the tank.

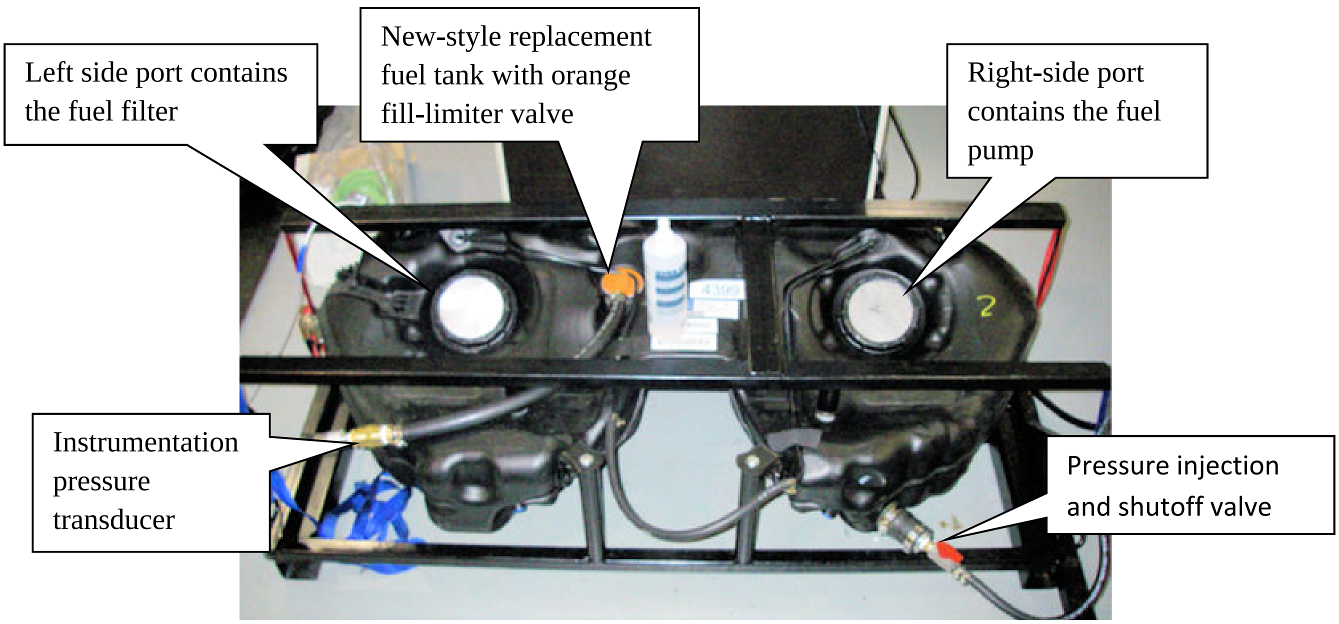

Figure 7 - The Bench Test for Evaluating the Fuel Pumps and Filters Consisted of a New Side-Saddle Fuel Tank, with Pressure Monitoring (center port) and Pressure Injection with a Red-Levered Shutoff Valve (right port)

The test procedure used on this project was to vent the tank to atmospheric pressure and re-zero the instrumentation. Using the shop air regulated to 2 psi, two in-line hand valves were then used to vent some air to the atmosphere to allow the pressure to be raised or lowered to set the initial injection air to 1.32 psi. Figure 10 contains a time history plot of all final test runs (used in the following plots) superimposed and aligned to the time that the shutoff valve was manually turned to seal the tank (at 240 sec).

Figure 8 - Leak Orifices included a 1.0-mm Drilled Hole in a Plastic Cap, a 0.5-mm Carburetor Main Jet, and a 0.3-mm Carburetor Air Jet

The data before 240 sec indicates the consistency of the manual pretest procedure. Data after 240 sec shows the resulting pressure decay for each test, which is dependent upon the amount of leakage in the component(s). These pressure decay traces include four threshold tests; three with the calibrated orifices discussed earlier, and one test with the new-style sealed fuel tank. These test results were used to grade (or evaluate) the leak rates of the collected components. More information on the development of the test procedure is shown in the Appendix 2.

Figure 9 - A Tablet PC was used for Instrumentation Setup, Data Collection, and Real-Time Display of the Tank Pressure

6.0 TEST RESULTS FROM THE COMPONENT TEST STAND

The actual leak-rate analysis was performed by finding the average slope of the air-pressure decay trace over a 30-second interval beginning at the time when the pressure decay reached 1.23-psi[8]. Test results[9] are shown in a bar graph in Figure 11. The left four bars show the leak rate of a new-style fuel tank and how the three horizontal threshold lines (0.3 mm, 0.5 mm, 1.0 mm) were determined from the test results of the calibrated leaks. The bars to the right represent the total leak rate of all of the components collected from each vehicle. The majority of the fuel tank assemblies or individual components collected (18 of 24) leaked air at a rate below the 0.5-mm threshold, and therefore may not immediately illuminate the MIL, but could be noticeable to the vehicle owner as a gasoline smell if liquid fuel were to exit through these small openings.

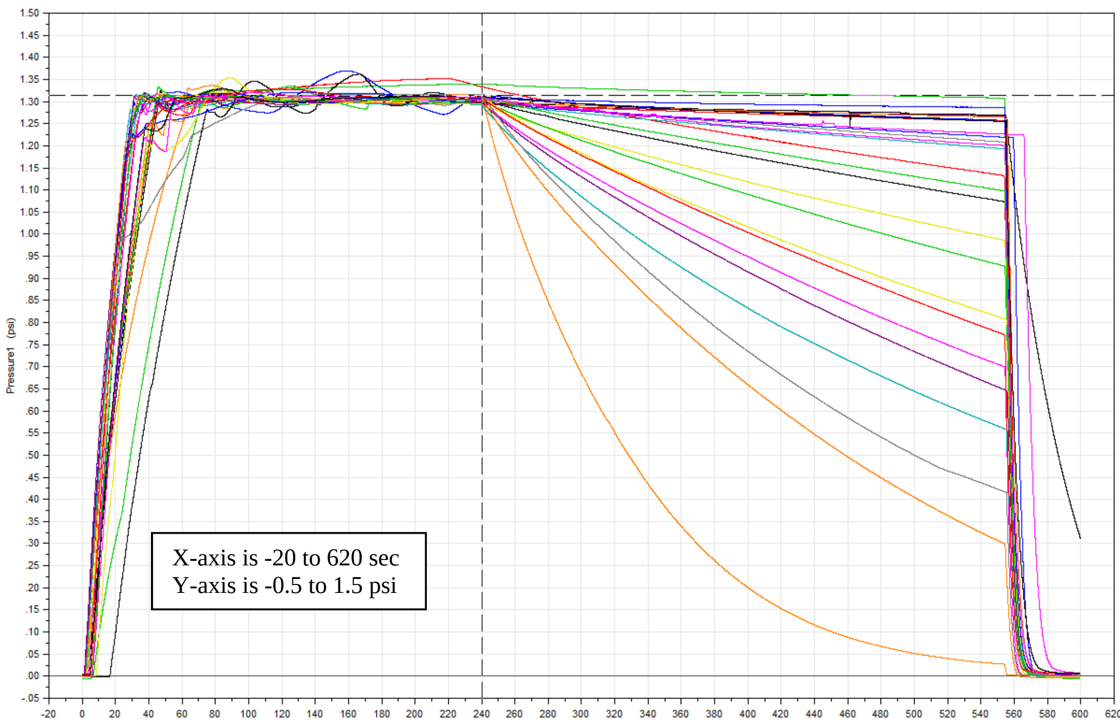

Figure 10 - A Composite Time History Plot of all Final Procedure Test Runs

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[8] A few test runs did not have 30 seconds of data after the crossing of the 1.23-psi point because the tank configurations had a low leak rate; therefore, the slope was calculated from the data available.

[9] In statements to ODI, the manufacturer claimed that after the fuel system components were removed from the gasoline environment and stored, that they would become "dried out". This would allow the plastic parts to shrink slightly and the measured leaks would be greater than if they were tested immediately after removal from the vehicle. This change in leak rate was not verified, but it should be noted that most of the collected items were tested months after removal from a gasoline environment.

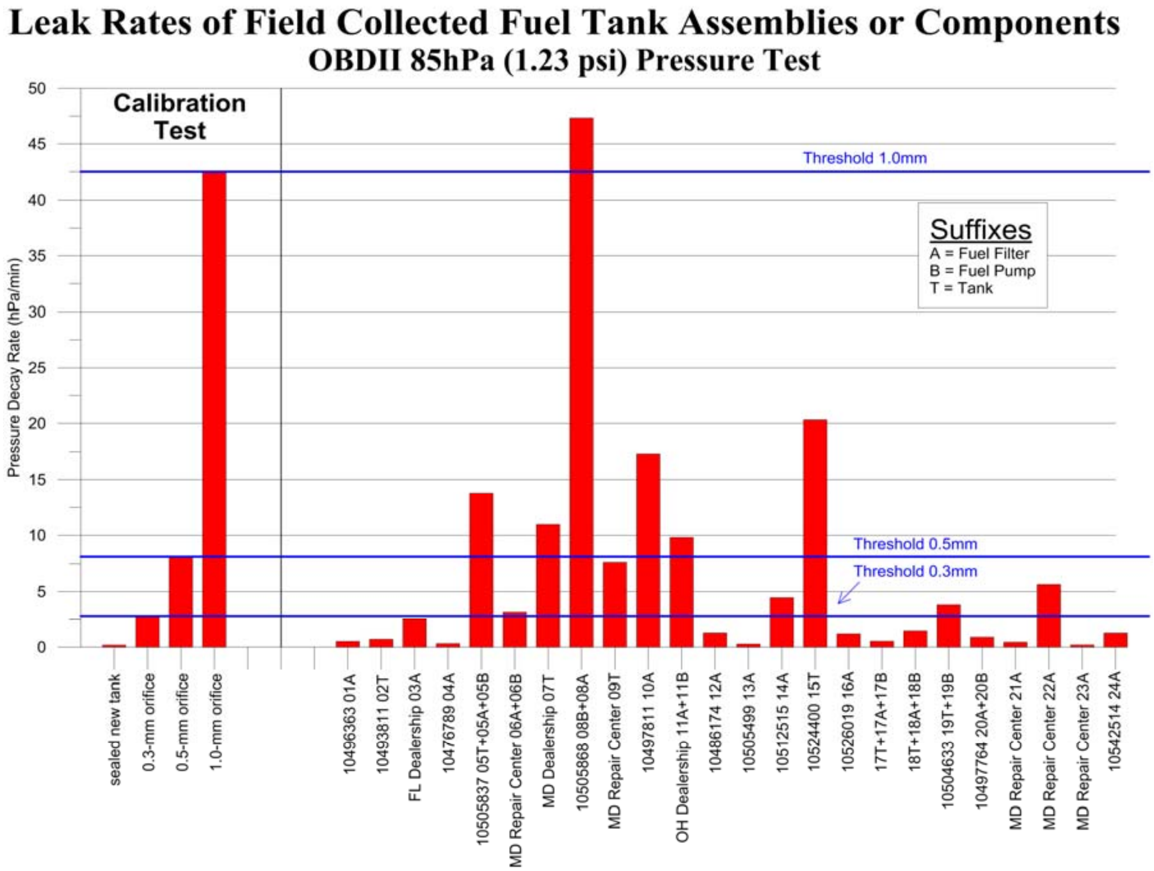

Figure 11 - The Total Leak Rate of All Components Combined into Fuel Tank Assemblies, When Possible, and the Leak Rates of Three Calibration Orifices and a New Tank

While these tanks are not required to be absolutely sealed, the OBDII thresholds are designed only for vapor leaks.

Data collected from the testing is also shown grouped by component, as tanks, filters, and pumps. The tank leak rates are shown in Figure 12. Only two tanks leaked above the 0.5-mm threshold that would have immediately illuminated the MIL. One tank (identified as tank 02T) leaked at a rate just slightly more than the new tank. The new tank may have been sealed better than the original 02T (with a white fuel filling limiter valve) since it was a newer design with an orange-colored fuel filling limiter valve, and was certified for all 50 states, including the California Air Resources Board (CARB) states. Previously the rest of the United States used an identical-appearing tank with a white fuel filling limiter valve; the CARB states had used a steel tank with six studs at each of the two topside ports, and the filter and pump were bolted to the tank. The manufacturer did not report the leak rate of any tanks from their component collections.

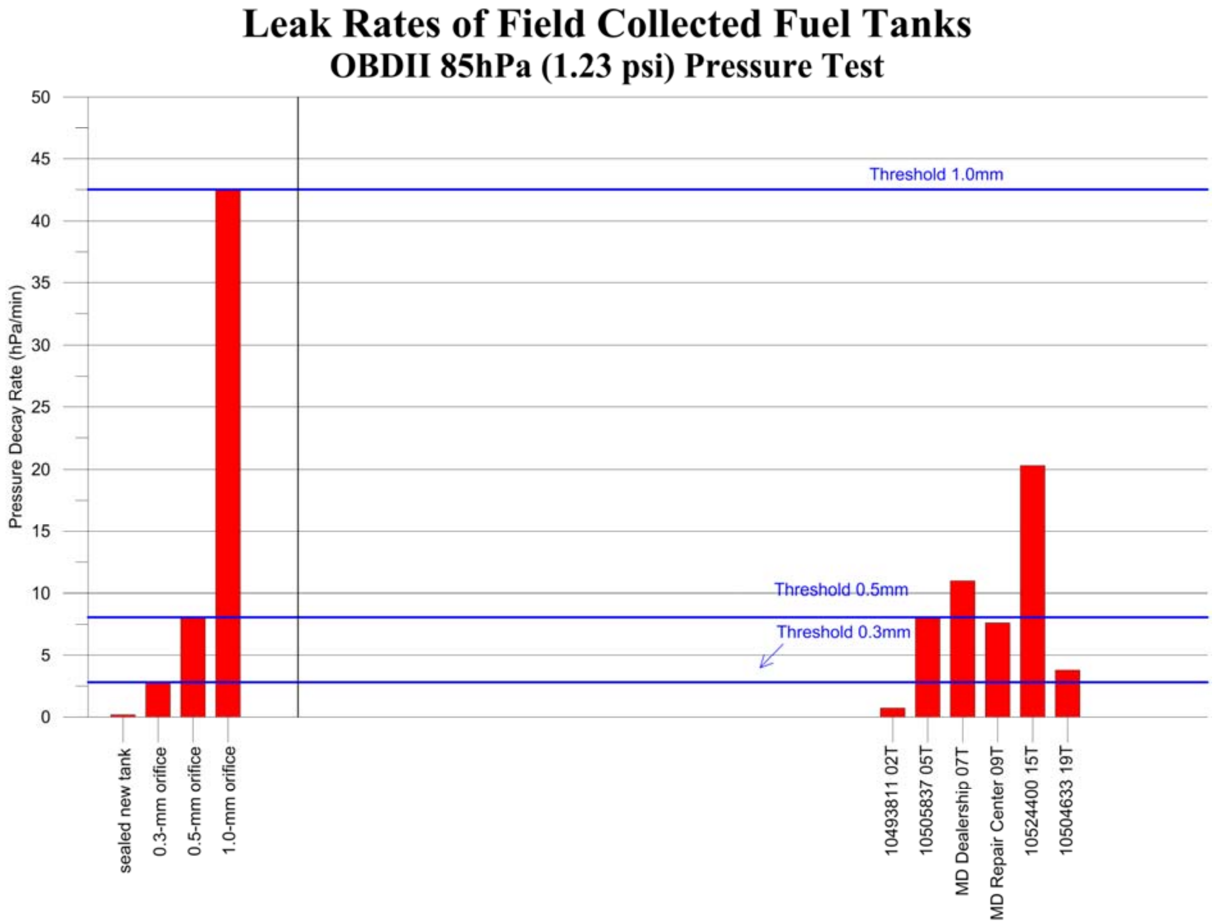

Figure 12 – The Leak Rates of the Fuel Tanks Showed Three Tanks were at or Above the Threshold for Immediate MIL Activation

The leak rate on the top plate of the fuel pumps was very low and similar to the normal leak rate of the new tank, as shown in Figure 13. However, since the pump top plate is below the full line of the fuel tank, two of these leaks appeared to have pooled liquid gasoline into the top-side well but not over the lip and onto the fuel tank. While many of the right-side fuel-pump top-side plates had a small crack and yellow stain, no significant air leaks were found at any of these sites, including the two more heavily stained top plates.

The leak rate of the filters was significantly different from the pumps, as shown in Figure 14. Fourteen of the 17 filters leaked at a rate that may not have immediately triggered a MIL, but could have still leaked liquid fuel since the opening location is below the full fuel level of the tank. Three of the filters leaked at a rate that would have immediately triggered the MIL and one of those leaked at a rate over the 1.0-mm threshold (VOQ 10505868).

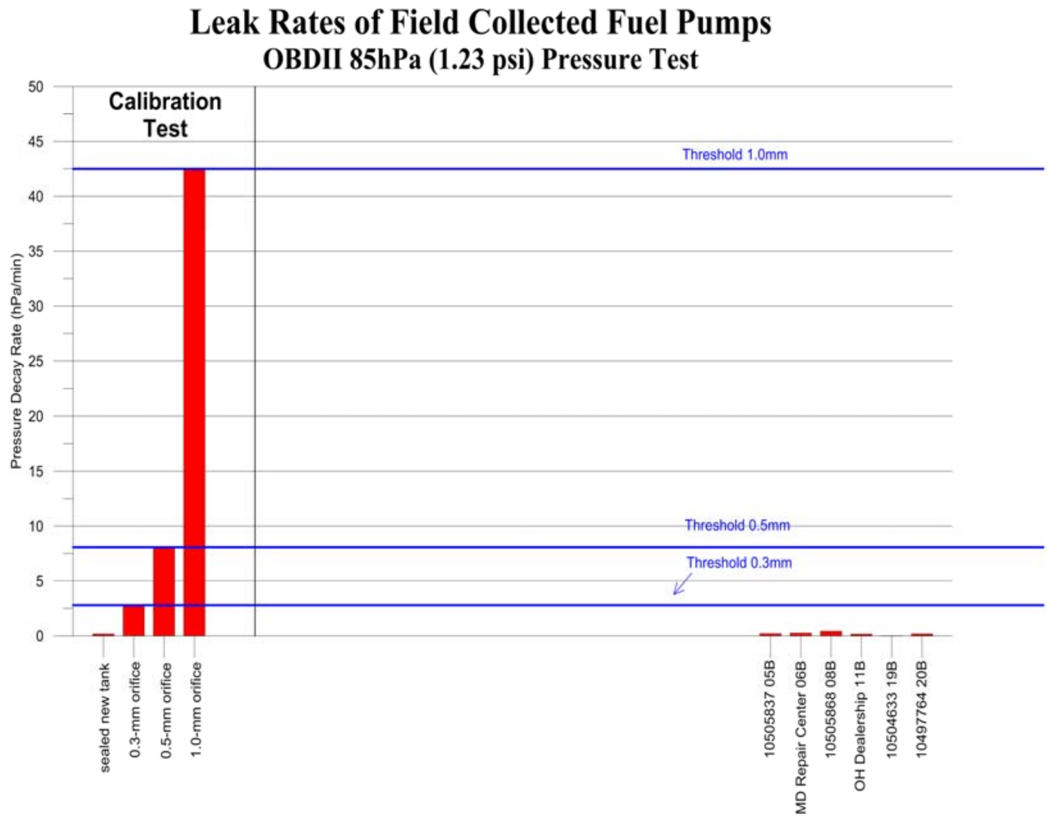

Figure 13 – The Leak Rates of all Fuel Pump Top Side Plates was Insignificant

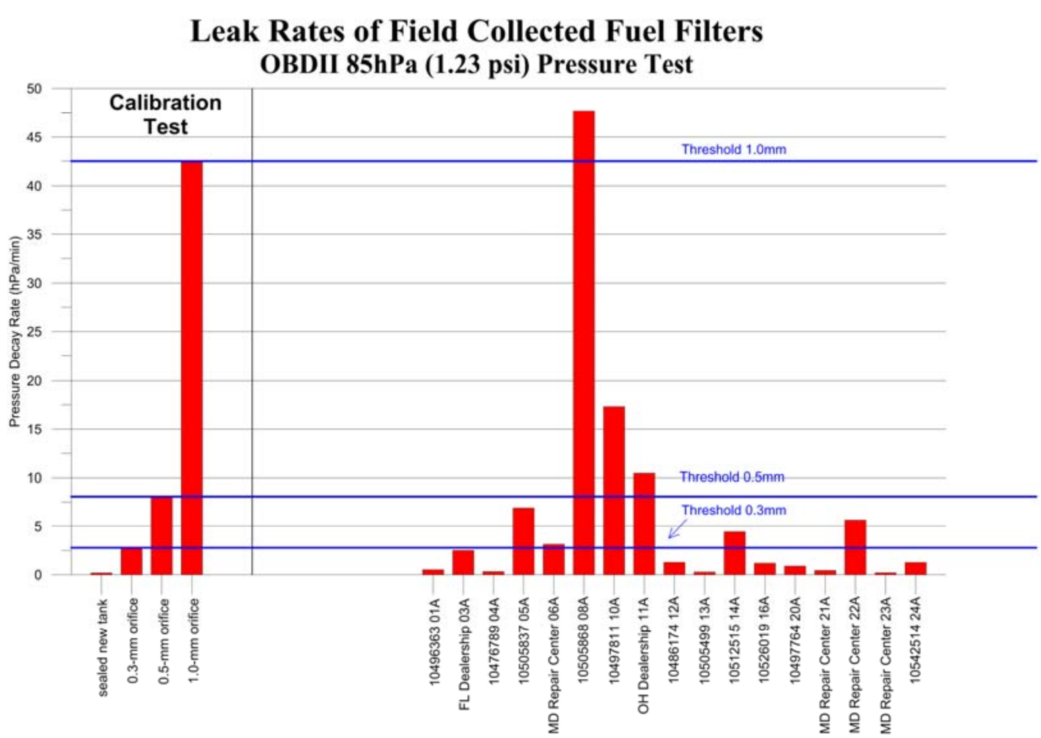

Figure 14 – The Leak Rates of the Fuel Filters Indicated that 14 of the 17 Filters May Not Have Immediately Illuminated the MIL

7.0 REVIEW OF INFORMATION REQUEST RESPONSE

The ODI sent a detailed EA Information Request[10] letter to Mercedes-Benz USA, LLC on 07/16/2013. The manufacturer responded with extensive information including testing to answer ODI's specific questions. The first half of the response[11] arrived on 10/31/13 and the second half of the response requested confidentiality and arrived on 11/07/13[12]. A second objective was added to the test request to verify the information provided by the manufacturer.

After reviewing the response from the manufacturer, as well as the material presented in the November, 2013 meeting, much of the information was verified and either matched VRTC assessments, or the differences were not substantial. The propounded root causes of the component failures suggested by the manufacturer, which in most cases attributed the failures to owners' overfilling the fuel tank (i.e., alleging possible owner abuse) and/or to technician service errors, were questioned by NHTSA (the filter, pump, fuel filling limiter valve plastic materials seemed ill suited for the expected modern gasoline with ethanol environment). However the differences in opinion were inconsequential as the leaks found by both the manufacturer and NHTSA were similar; small volume leak sources from the unpressurized portions of the fuel system which could seep through two of the three top side components as discussed and shown in Figures 3 through 6.

The volume of liquid that would need to be expelled from the top of the filter (at the seam on the built-in pressure sensor cap) such that it subsequently 1) flowed off the top of the tank onto the underlying aero shield, and then 2) flowed off the aero shield and onto the ground was evaluated by using water[13]. The total volume of liquid required for item 1 (off the tank onto the shield) was found to be 440 ml, and for item 2 (from the aero shield onto the ground) was found to be

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[10] INIM-EA13003-57338.pdf The Information Request letter from ODI to the manufacturer, other related attachments are available at http://www-odi.nhtsa.dot.gov/owners/SearchSafetyIssues after clicking on ***ID Number***, checking ***Investigations***, and typing "EA13003" in the search box

[11] INRL-EA13003-57960P.PDF The Information Request letter Part 1 with responses to Requests 1 to 14, dated 10/31/2013

[12] INRL-EA13003-58167P.pdf The Information Request letter Part 2 with responses to Requests 15 to 25

[13] The use of water was for safety considerations. This method of evaluation does not account for evaporative effects that could be a significant factor when gasoline is involved, especially if the leak rates are low and the ambient temperatures are high. Regarding this subject, the manufacturer-evaluated evaporative effects and provided analysis showing that, as the fuel pooled and produced a large surface area, evaporative effects would overcome the leak rates found from field returned parts, and that in its view this meant a fuel off the tank, or fuel to the ground condition could not result from these leak sources for a static vehicle.

550 ml. These results were similar to those found by the manufacturer. Evidence from multiple fuel tanks showed witness marks indicating various sized pools of gasoline had collected and evaporated multiple times. Two fuel tanks had marks that indicated the seeping fuel could fill the well surrounding the fuel filter ports and over flow the top of the tank, or alternatively slosh off during vehicle maneuvers involving longitudinal or lateral acceleration. Tank T05 evidenced leakage at the fuel filling limiter valve and at the filter. The witness stains on the tank indicated the fuel leaked over the edge at the left and right sides of the left saddle portion of the tank. Tank T12 leaked from the fuel filter and appeared to have spilled over the left side of the left saddle portion of the tank. The underbody heat in the areas of the possible spillover was verified to be below the autoignition point of gasoline, a finding the manufacturer also reported.

Liquid fuel entering the vehicle occupant compartment has been reported by a few complainants, however extensive testing by the manufacturer confirmed that fuel cannot enter the interior of the vehicle through the service access port covers if the covers are properly installed. NHTSA notes that the fuel tank assembly, including all of its components, is mounted outside of the vehicle/passenger compartment, and attached to the underside of the vehicle. The service access ports for the fuel filter and fuel pump located under the rear seat bench are covered by steel plates which are sealed and bolted to the vehicle floor. NHTSA also notes that the fuel filter or pump is intended to be serviced through the access ports and with the tank in-situ. Accordingly is it possible that service technicians can accidently spill fuel inside the vehicle when performing service to the filter or pump assemblies. NHTSA did not observe liquid fuel in the interior of the vehicles inspected during any fieldwork.

Generally speaking, the fieldwork and bench test data produced by the manufacturer matched the NHTSA/VRTC test data. The number of components the manufacturer tested, and the leak rate results reported, were almost identical to the results shown here.

APPENDIX 1

FUEL TANK COMPONENTS COLLECTED FOR STUDY

Table 1 - Fuel Tank Components Collected for Study - Part 1

Item No.	VRTC Test No.	VOQ No.	Model & Year	Mileage	Symptom	Parts	Cast Part Numbers	Pressure Sensor Numbers	Seal Notes	Comments	Pretest Observations of Component	Leak Rate (hPa/min)	Bubble Test Leak Position (o'clock)
01	01A	10496363	E350 2006	55,000	PARENTS CAR, GAS SOAKING SEAT CUSHION, INSULATION, & SOUND PAD	filter	VDO A2C53103733 2605ZGS002 A2114704094	DELCO 1222306951118	white full size	none	yellow stain at pressure sensor seam and entire top	0.52	press sensor 10-to-11
02	02T	10493811	E320 2005	44,000	GAS ODOR IN GARAGE	tank	Sticker: A2114703901 0428206104 08.10.04 Takt:F396 ML:362 W494 KKBDC W211 80L LEVII LFD-Nr.00080260F82 ink:18-20-25-31 circleK with crayon "9750" molded date 10/2004			possible witness pool stain under green gasket of breather tube at fuel filling limiter valve (FFLV)		0.71	FFLV 5-to-6
03	03A	none	E55 AMG 2004	98,000	na	filter	VDO 228.242/002/002 evidence of former sticker on top sidewall	A0015421118 2393	black full size	none	yellow stain at pressure sensor seam and most of top	2.53	press sensor 11-to-12
04	04A	10479849 10476789	E350 2006	47,426 40,804	HEAVY GAS SMELL INSIDE AND OUTSIDE VEHICLE	filter	VDO A2114704094 3005ZGS002 A2C53103733	DELCO 122306951778	white full size	repair #1 = filter, repair #2 = tank	yellow stain at pressure sensor top and seam	0.32	none
05	05T	10505837	E55 AMG 2005	88,000	FUEL LEAK AT OR NEAR THE TOP OF THE FUEL . . . GAS ODOR THAT PERMEATES THE CAR	tank	sticker:A2114704501 0435604871 21.12.04 Takt:S358 ML:362 W494 KKBDC W211 80L SWG LFD-NR 50054355180 ink:29-24-50-20 circleK with crayon "3" molded date 12/2004			witness marks of leak at mounting post, fuel filling limiter valve (FFLV), filter area		13.78	FFLV 5-to-6
06	05A					filter	still in tank	none	none	none	yellow all over (still in tank)		press sensor 5-to-6
07	05B					pump	still in tank	none	none	white , one aluminum tube receiver cracked and yellow (still in tank)			none
08	06A	none	C280 2007	NA	na	filter	VDO A2C53104194 A2094700494 42/06ZGS004	DELCO 12223096625815NG	green narrow half size	none	light yellow all over	3.16	press sensor 6
09	06B					pump	Siemens VDO A2C53033999 A2094700294	none	none	E55AMG-like cap without connector	both aluminum tube receivers cracked		none
10	07T	none	E350 NA	NA	leaks after left side unit repair	tank	sticker:A2114703901 0420307280 21.07.04 Takt:S068 ML:362 W494 KKBDC W211 80L LEVII LFD-Nr. 00667603F82 ink: 27-25-22-31 circleK with crayon "9820" molded date 07/2004			witness marks of leak at fuel filling limiter valve (FFLV) and filter area		10.97	FFLV 5-to-6
11	08A	10505868	E55 AMG 2003	94,764	STRONG ODOR OF GASOLINE IN THE INTERIOR	filter	VDO A2114705194 228.242/002/002	A0015421118 2138	green full size	none	yellow at pressure sensor seam and lightly all over	47.33	press sensor 6
12	08B					pump	VDO date grid: dots end 11-09	none	none	none	yellow on half of top one aluminum tube receiver cracked		none
13	09T	none	NA NA	NA	reported leak at fuel filling limiter valve	tank	sticker: A2114703901 23.10.03 Takt:T115 ML:461 KKBDC W211 80L LEVII LFD-Nr.00021982F82 ink: none circleK crayon "9840" molded date 10/2003			hole drilled in tank, appears free of witness marks of leak points, may have been stored outside		7.63	FFLV 5-to-6
14	10A	10497811	CLK 350 2006	59,000	GAS ODOR IN GARAGE	filter	VDO A2C53082729 A2094701394 2305ZGS002	DELCO 1222306951098	none	none	light yellow everywhere on external surfaces	17.31	press sensor 4-to-6
15	11A	none	E55 AMG 2005	47,997	fuel smell getting into car	filter	sticker: Siemens VDO A2C53307036 A211470519405 ZGS002 HD:12/07	A0015421118 2977	none	none	yellow at pressure sensor seam elbow broken off	9.81	press sensor 5-to-7
16	11B					pump	both pumps VDO 09/05 228235002002 A2114701794 ZGS.003	none	none	none	yellow at pressure sensor seam and in top side well		none
17	12A	10486174	E350 2007	30,000	FUEL PUMP LEAKING WHILE PARKED	filter	VDO A2C53103733 3106ZGS005 A2114704094	DELCO 1222306961731SNG	white full size	none	yellow at pressure sensor seam and half of top	1.27	press sensor 5
18	13A	10505499	E500 2004	200,125	STRONG SMELL OF GASOLINE ON DRIVER'S SIDE EXTERIOR WHEN FUEL FILLED	filter	VDO 228242002001 A2114701541	A0015421118 0824	white full size	none	entire top yellow crack at top	0.27	press sensor 6

note: A = filter, B = pump, FFLV = fuel filling limiter valve, RO = dealership repair order, T = tank, VOQ = Vehicle Owner's Questionnaire

Table 2- Fuel Tank Components Collected for Study - Part 2

Item No.	VRTC No.	VOQ No.	Model & Year	Mileage	Symptom	Parts	Cast Part Numbers	Pressure Sensor Numbers	Seal Notes	Comments	Pretest Observations of Component	Leak Rate (hPa/min)	Bubble Test (o'clock)
19	14A	10512515	E55 AMG 2003	112,646	UNIT LEAKING, STRONG ODORS IN CABIN, AND LEAKING ONTO GROUND	filter	VDO A2114705894 228.242/002/002	A0015421118 2538	none	10/05/12 third repair on fuel system per ROs	light yellow at pressure sensor	4.47	press sensor 8 and 4-to-6
20	15T	10524400	E320 2005	75,000	OVERWHELMING FUEL ODOR WHEN GAS TANK FILLED IN AND OUT SIDE OF CAR DISSIPATES AT 3/4	tank	sticker: A2114703901 042780563 04.10.04 Takt:T174 ML:461 KKBDC W211 80L LEVII LFD-Nr.00077744F82 ink:31-21 circleK with crayon "9650" molded date 09/2004			filter replaced previously (part not available), did not fix , witness pool marks at fuel filling limiter valve (FFLV) well		20.32	FFLV 6
21	16A	10526019	E350 2006	115,000	FUEL SMELL WHEN TANK >3/4 FULL AND PARKED ON SLIGHT INCLINE, AND LEFT A TRAIL OF FUEL TODAY	filter	VDO A2114704094 2405ZGS002 A2C53103733	DELCO 1222306951328 USA	white full size	none	yellow at pressure sensor seam and lightly on top	1.19	press sensor 6 and 12
22	17T	none	E350 2006	93,000	salvage yard tank, no fuel system repairs	tank	sticker: A2114706401 0526702838 24.09.05 Takt:blank ML:FTL Los.20050923050 KKBDC W211 80L LEVII LFD-Nr.50250728F82 ink:26-48 circleK with crayon "9760" molded date 09/2005			salvage yard unit	clean tank	0.53	none
23	17A					filter	still in tank	none	none		white (still in tank)		none
24	17B					pump	VDO	none	none		white (still in tank)		none
25	18T	none	E350 2007	>52,983	salvage yard tank, sender replaced 04/20/2007 and 03/16/2010 (CARFAX)	tank	sticker: A211470640 0682712051 23.11.06 Takt:blank ML:FTL Los.20061122224 KKBDC W211 80L LEVII SWG 80L 50539103F82 BECK ink: none circleK with crayon "7" molded date 11/2006			salvage yard unit	witness pool marks at filter area	1.45	none
26	18A					filter	still in tank	none	none		yellow all over (still in tank)		press sensor 5 and 11-to-2
27	18B					pump	still in tank	none	none		white one aluminum tube receiver cracked and yellow (still in tank)		none
28	19T	10504633	E320 2004	88,759	GAS SMELL AROUND VEHICLE AFTER FILLING, UNDER VEHICLE COULD SEE GAS IN TRAY, PULLED TRAY DOWN GAS DRIPPED OUT	tank	sticker: A2114703901 0403405952 03.02.04 Takt:T191 ML:461 W494 KKBD2 W211 80L LEVII LFD-Nr.00040339F82 ink: none circleK with crayon "9710" molded date 01/2004			left sender replaced by local shop, tank still leaks - grease on seals!	witness marks leak at mounting post, FFLV, filter area	3.82	FFLV 5-to-6
29	19B					pump	still in tank	none	none		white no cracks (still in tank)		none
30	20A	10497764	E500 2005	95,000	AFTER REFUELING STRONG SMELL OF FUEL VAPORS INSIDE CAR AND GARAGE	filter	O 228242002001 A2114701541 24/04ZGS003	A0015421118 1314	green full size	none	very yellow top	0.89	press sensor 4-to-6
31	20B					pump	VDO A2114701494 25/04ZGS004	NONE	white full size	none	yellow top and crack at one tube receiver		none
32	21A	repair center reported as VOQ vehicle	NA	NA	na	filter	VDOA2C53104194 0506ZGS002 A2094700494	1222306953435 DELCO	green narrow half size	none	yellow pressure sensor seam	0.44	press sensor 10-to-2
33	22A	repair center reported as VOQ vehicle	NA	NA	na	filter	VDO 228242002001 A2114701541 15/04ZGS003	A0015421118 1960	white full size	none	yellow pressure sensor seam and all of top	5.64	press sensor 4-to-7
34	23A	repair center reported as VOQ vehicle	NA	NA	na	filter	VDO 228242002001 A2214701541 47/04ZGS003	A0015421118 3174	none	none	light yellow at pressure sensor seam	0.20	press sensor 10-to-12
35	24A	10542514	E55 AMG 2003	NA	STRONG GAS SMELL, PUDDLE OF GAS IN BACK SEAT AT SENDING UNITS	filter	VDO A2114705194 228.242/002/002	A0015421118 0206	white full size	none	yellow at pressure sensor seam and all over top	1.27	press sensor 6-to-8
36	25T	none	NONE NONE	NONE	new	tank	sticker: A2114702502 4399 10808285F 09.12.08 KKBDC W211 80L LEVII (2K) SWG 31.01.2012.12 50974238F86 S0Nr. 5094238F86 Line: ML1 ink: none circleK with crayon "2" molded date 02/2012			new		0.18	None

note: A = filter, B = pump, FFLV = fuel filling limiter valve, RO = dealership repair order, T = tank, VOQ = Vehicle Owner's Questionnaire

APPENDIX 2

Development of the Bench Test Hardware and Procedure

Development of the Component Test Stand and Procedure

The bench test stand was outfitted with a pressure transducer at the large diameter hose connected to the fuel filling limiter valve, and pressure was injected at the large diameter fuel refilling port through a shutoff valve. The two small-diameter vent lines, from the top of each sidesaddle compartment, were sealed off and not used for pressure monitoring or injection due to possible flow restrictions from their long length and small diameter. However, one of these vent lines was used during tests to determine the pressure drop over 30 seconds with an orifice of a known diameter causing a calibrated leak.

The OBDII test is conducted with a fuel tank filled to near three-quarters of capacity with gasoline, which reduces the volume of air in the tank and includes slight pressurization from the gasoline "outgassing" or evaporating from the liquid state. The tests conducted by the manufacturer, for this investigation, ignored these effects. The goal of this evaluation was to quantify the leaking components and make a comparison to the manufacturer's test results, so these tests were conducted without consideration to the fuel volume in the tank or the outgassing of fuel. To parallel the manufacturer's tests, these bench tests were conducted using an air pressure of 1.23 psi (85 hPa), and the pressure drop was monitored as the field-collected components leaked the air.

An early practice test run on the new sealed fuel tank, filled from a pressure cylinder, found that the injected pressure in the tank immediately dropped a significant amount and then the rate of pressure drop slowed to a near constant rate. Calculating the slope of this curved trace would not result in the true decay rate. In an attempt to produce a linear rate of pressure loss, the fuel tank was pressurized by opening and closing the shutoff valve multiple times. However, the pressure still dropped off, as shown in the time-history plot in Figure 15 for a sealed tank and in Figure 16 for a tank with a calibrated leak orifice of 0.3-mm diameter.

Figure 15 - During a Procedure Development Test Run, the New Fuel Tank was Pressurized Three Times from a Pressure Cylinder, and the Pressure Decay Rate did not Stabilize until after 60 Seconds

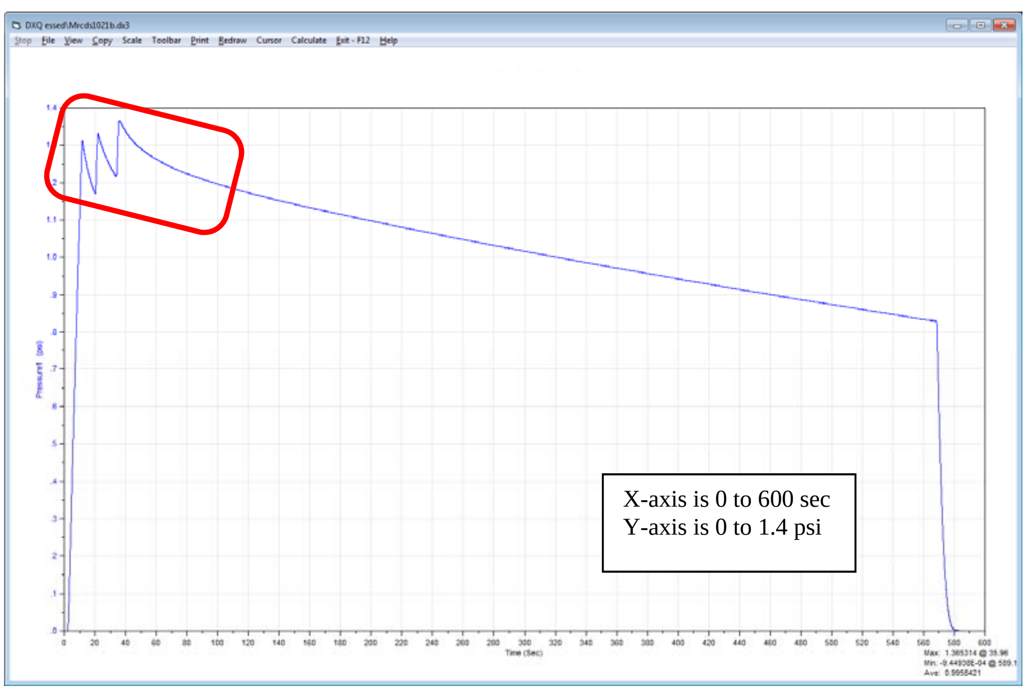

Figure 16 - Another Procedure Development Test Run with a 0.3-mm Diameter Calibrated Leak, the New Fuel Tank was Pressurized Three Times from a Pressure Cylinder, and the Pressure Decay Rate did not Stabilize until after 100 Seconds

In another attempt to create a smoother pressure rate of change (or slope), a Snap-On smoke-leak and evaporative-emissions tester (Model EELD500), shown in Figure 17, was attached to the bench-test tank to observe the procedure used by Snap-On to conduct their automated 5-minute pass/fail test at 0.5 psi (35 hPa). After a small overshoot, the fuel tank pressure was stabilized just under 0.50 psi, held for four minutes, and then the pressure decay was allowed to occur and was monitored to establish the leak rate, as shown in Figure 18.

Figure 17 - The Snap-On Smoke Leak and Evaporative Emissions Tester Model EELD500

It was theorized that the plastic tank slowly swelled with the increased pressure and the four-minute hold period allowed the tank pressure and volume to stabilize. The exact pressure injection procedure used by Mercedes-Benz was not known. Since the Snap-On tester resulted in a steady pressure of only 0.46 psi (32 hPa), which was lower than the 1.23 psi pressure used by the manufacturer, use of this device was not pursued further, however a similar method of filling the tank with air was used, as described next.

Based on the outcome of these practice runs, the test procedure was then established. The desired pressure was increased slightly from the 1.23 psi that the manufacturer used to ensure the slope was steady as the pressure dropped across the 1.23-psi point. Therefore, the final test procedure used on this project was to pressurize the tank to 1.32 psi and held for 240 seconds

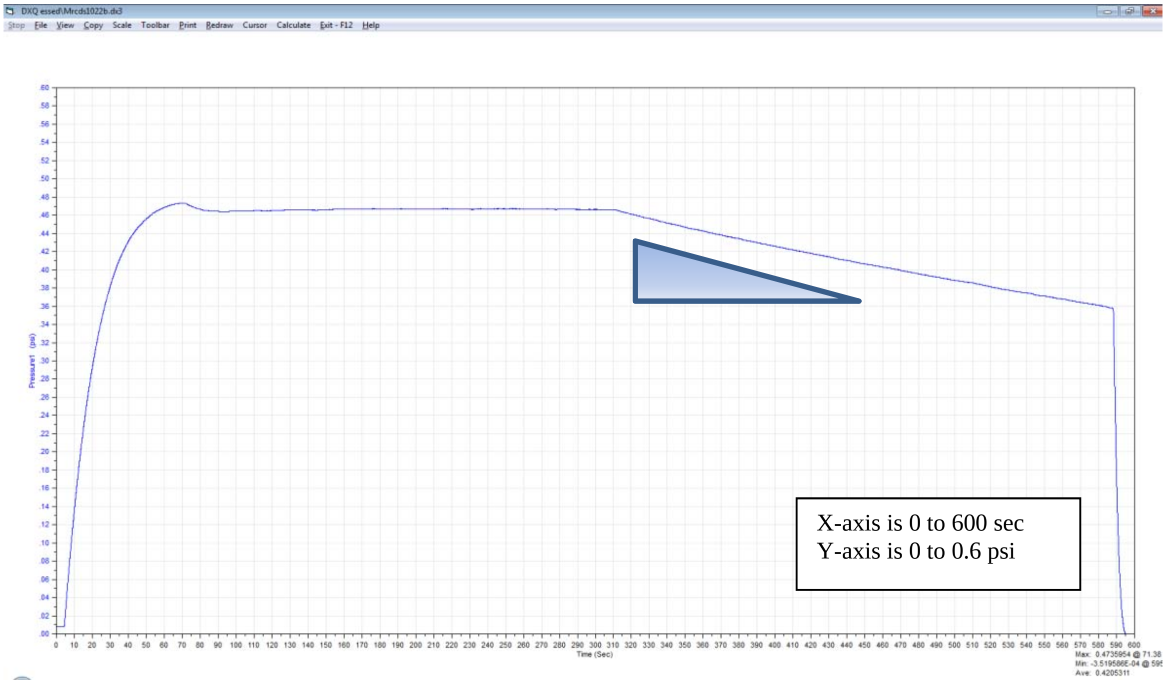

Figure 18 - In an Attempt to Develop a Better Procedure, the Snap-On Evaporative Emissions Tester was used to Charge the Fuel Tank and found to be Pressurizing the Tank for 240 Seconds and then Monitoring the Pressure Decay for 30 Seconds

with manual controls. Then the tank was sealed and the pressure decay was collected for another 60 seconds.

To accomplish this, the injection pressure was stepped down from the 120-psi shop air supply to 18 psi with a primary pressure regulator (Figure 19), and then the air passed through a 30-ft long hose to minimize temperature changes after the air expansion and pressure drop. A second regulator was used to reduce the pressure further to approximately 2 psi. In order to adjust the injection air as close to 1.32 psi as possible, two in-line hand-controlled valves were used to vent a portion of the injected air to the atmosphere, as shown in Figure 20. This allowed the injected pressure to be manually raised or lowered to hit the target pressure.

Figure 19 - The First Pressure Regulator was used to Drop the Shop Pressure to Approximately 18 psi

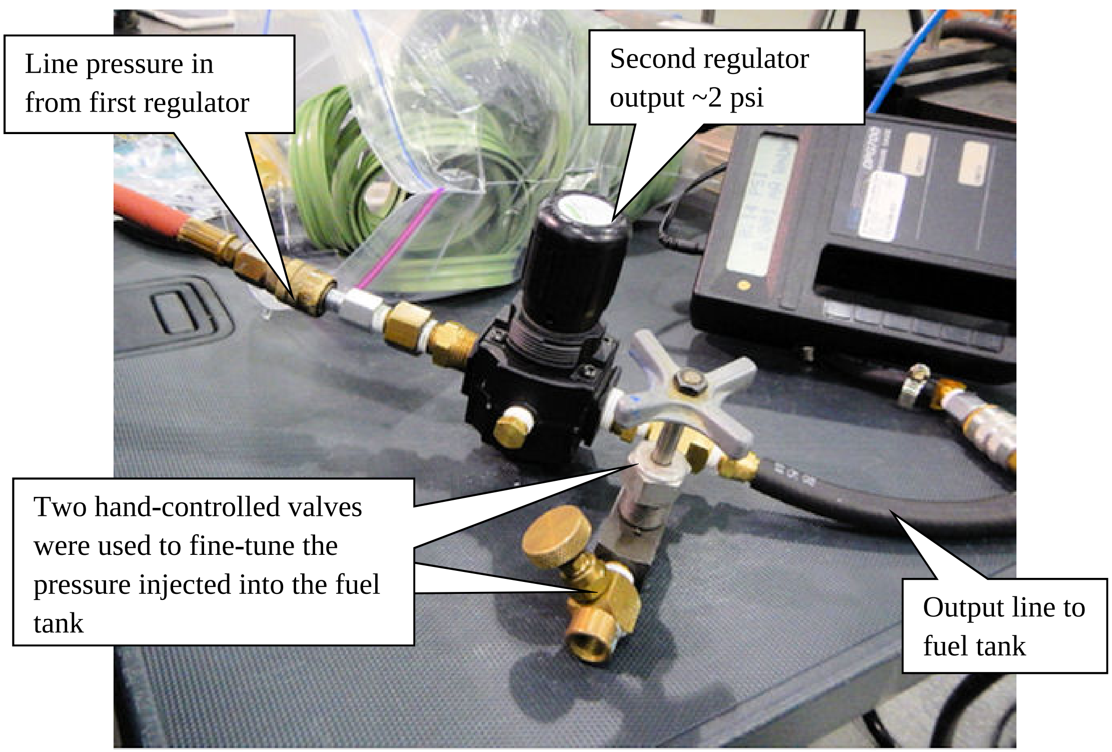

Figure 20 - A Second Pressure Regulator Dropped the Pressure to 2 psi and a Controlled Leak to Atmosphere was used to Manually Fine Tune the Injection Pressure to 1.32 psi for 240 Seconds