Monitoring and Laboratory Division
Vapor Recovery and Fuel Transfer Branch
Vapor Recovery Regulatory Development Section

Project Number: VR-11-11

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OVERPRESSURE STUDY

Technical Support Document

Evaluation of Assist Vapor Recovery Nozzle ORVR Vehicle Recognition Performance Under Controlled Fueling Conditions

December 6, 2017

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EXECUTIVE SUMMARY

Throughout the summer of 2015, California Air Resources Board (CARB) staff performed a series of motor vehicle fuelings at a retail gasoline dispensing facility (GDF) equipped with the Assist Phase II Enhanced Vapor Recovery System (Assist System) with the Healy model 900 vapor recovery nozzle to determine the reason for the inconsistent recognition[1] of the on-board refueling vapor recovery (ORVR) system on certain makes and models of vehicles. This evaluation was prompted by an Assist System ORVR recognition survey which was conducted by CARB staff several months prior (January 2015) which involved observation of over 1,500 ORVR vehicle fueling events at six GDFs located in San Diego. The ORVR recognition survey suggested that customer behavior (handling of the nozzle) may play a significant role in the performance of the assist nozzle relative to ORVR vehicle recognition. The ability of the assist nozzle to properly recognize ORVR equipped vehicles is crucial because improper recognition results in excess air ingestion which can lead to overpressure conditions within the headspace of the underground storage tanks.

The motor vehicles used in this evaluation were selected due to characteristics documented in the ORVR recognition survey[2] and were obtained through retail rental car agencies (Enterprise) and the "State Garage" operated by the State of California, Department of General Services. Each vehicle refueling event was conducted in a manner to minimize the variability which exists at a typical GDF. To the extent possible, orientation of the nozzle, position of vehicle, nozzle age, nozzle condition, vapor to liquid ratio setting, fuel dispensing rate, and volume of gasoline dispensed, were kept identical for each event. To ensure consistency and repeatability, fueling events were performed numerous times (back to back) on the same vehicle under the same conditions.

Initially, testing was limited to the 2014 Toyota Prius. However, as the evaluation progressed, testing was expanded to include several other makes and models of ORVR equipped vehicles and a limited number of non-ORVR vehicles. From May 2015 to September 2015, a total of 161 fueling events were conducted on 18 different makes and models of vehicles, totaling of 670 gallons of fuel dispensed. During the refueling process for some vehicles, a hand held vacuum gauge was installed within the vapor collection boot of the nozzle to determine leak integrity of the nozzle and vehicle fill-pipe interface.

CARB staff determined that the variation in assist nozzle ORVR recognition performance for certain vehicles was indeed related to customer behavior. If the nozzle is placed into the vehicle fill-pipe in a deliberate, intentional manner, a "secure latch" will be achieved along with a tight seal at the nozzle and vehicle fill pipe interface. However, if the nozzle is not placed deeply into the vehicle fill-pipe a "loose latch" can occur resulting in a poor seal at the interface. A "loose latch" causes the nozzle to improperly recognize an ORVR

[1] ORVR vehicle recognition means that the vapor to liquid ratio of the fueling event is less than or equal to 0.5. An improperly recognized ORVR vehicle fueling event means that the vapor to liquid ratio is greater than 0.5 and is of concern due to excess air ingestion.
[2] "Healy Model 900 Assist Vapor Recovery ORVR Vehicle Recognition Study" report available upon request.

vehicle, meaning that the vapor to liquid ratio will average around 1.0 which normally occurs with non-ORVR vehicles. Due to the high population of ORVR vehicles (~80% statewide) improper recognitions results in excess air ingestion as the nozzle does not restrict airflow to the headspace of the underground storage tanks. Additionally, CARB staff determined that the occurrence of “loose latch” on certain vehicles is due in part to the design/shape of the assist nozzle spout “latch ring” and the mating surface within the vehicle fill pipe called the “locking lip.”CARB staff eventually shared these findings with Franklin Fueling Systems (FFS), the manufacturer of the Healy model 900 nozzle. In response, FFS has redesigned the spout “latch ring” in an effort to improve the ORVR vehicle recognition rate[3].

The result of this study highlights the importance of compatibility between the vapor recovery nozzle and vehicle fill pipe. This has prompted the establishment of a Society of Automotive Engineers Fuels System Committee to update the vehicle fill pipe and nozzle dimensional requirements to ensure compatibility at the interface.

[3] CARB certified the redesigned spout on August 23, 2017.

I. BACKGROUND

In January 2015, CARB staff and California Air Pollution Control Officer's Association (CAPCOA) staff conducted a Healy Model 900 Assist Vapor Recovery Nozzle On-Board Refueling Vapor Recovery (ORVR) Vehicle Recognition Survey at six retail gasoline dispensing facilities (GDF) located in the San Diego. For the remainder of this document, this study will be referred to as the "ORVR recognition survey[4]." Approximately 1,500 ORVR equipped vehicle fueling events were observed followed by retrieval of vapor to liquid ratio values obtained for each fueling event by the GDF's In-Station Diagnostic (ISD) system. ORVR vehicle fueling events which yielded a vapor to liquid ratio of less than or equal to 0.5 were considered properly recognized. ORVR vehicle fueling events which yielded a vapor to liquid ratio of greater than 0.5 were considered improperly recognized or mis-identified.

The ORVR recognition survey resulted in several key findings which are summarized as follows:

- The ORVR vehicle mis-identification rate of the assist nozzle, which is the percentage of ORVR vehicle fueling transactions yielding a vapor to liquid ratio of greater than or equal to 0.5, has increased from approximately 17% in 2007 to approximately 30% in 2015.

- The average ORVR vehicle vapor to liquid ratio of the assist nozzle has increased by approximately 38% when compared to a prior study conducted in 2007.

- In many cases, the ORVR vehicle mis-identification rate was found to be dependent on customer behavior as the exact same make and model and model year of vehicle yielded different results because different members of the public performed the fueling.

- Certain newer ORVR vehicle fill pipe designs (capless) utilize drain ports, outer ring, and injection molded components which when joined, may contain gaps which create an open path the atmosphere. These openings exist within the vehicle fill pipe and nozzle interface and cause the assist nozzle to collect excess air ingestion during vehicle refueling.

Among the many findings resulting from the ORVR recognition survey, CARB staff generated a list called the "top ten vehicles of interest". As the name implies, this list consists of the top ten makes and models of ORVR equipped vehicles which displayed the highest ORVR mis-identification rates throughout the recognition survey. The list was created in order to better understand and identify the fill pipe design characteristics

[4] Results of the ORVR Recognition Study are discussed in a CARB Technical Support Document titled Evaluation of Healy Model 900 Assist Vapor Recovery Nozzle with Enhanced On-Board Refueling Vapor Recovery (ORVR) Vehicle Recognition Feature During the Winter of 2015/2016.

which are problematic for the assist nozzle. To qualify for the list, a minimum of 15 records (meaning fueling observations) for each make and model along with a minimum ORVR mis-identification rate of 20% were required. The “top ten vehicles for interest” list is provided in Table I-1 below.

During the ORVR recognition survey, a total of 45 Toyota Prius refueling events were observed followed by retrieval of vapor to liquid ratio data captured by the ISD system. Upon review and analysis of the ISD data, the 2013 model-year Toyota Prius was the main contributor to the overall Prius’ ORVR misidentification rate of 47%. As previously mentioned, the ORVR mis-identification rate is determined by calculating the percentage of fueling events with a vapor to liquid ratio greater than 0.5. Under optimum operating conditions, the assist nozzle is designed to reduce the vapor to liquid ratio on ORVR vehicles to less than or equal to 0.5. Since all Toyota Prius vehicles in the recognition survey were manufactured after 2001 and were require to have ORVR, CARB staff expected to observe a V/L of less than 0.5 on all fueling events.

In addition to having a high ORVR mis-identification rate, the rate varied considerably by model year. For example, of the fourteen 2013 Toyota Prius observed during the recognition survey, eight events had a vapor to liquid ratio of less than 0.5 (as expected) but six had a vapor to liquid greater than 0.5 which yielded a mis-identification rate of 43%. For the 2012 model year, of the six vehicles observed, four had vapor to liquid ratios greater than 0.5, or a mis-identification rate of 67%. For the remaining model years, the data is likely skewed due to the small sample size. Table I-2 provides the ORVR recognition survey results specific to the Toyota Prius.

Table I-1: Top Ten Vehicles of Interest Resulting from ORVR Recognition Survey

Make	Model	Number of Fueling Observations	Number of Vehicles with V/L Ratio >0.5	Mis–ID Rate[5]
Ford	F150[6]	18	12	66.7%
Ford	Focus[7]	27	16	59.3%
Toyota	Prius	45	21	46.7%
Honda	CRV	17	7	41.2%
Toyota	Highlander	15	6	40.0%
Honda	Accord	37	13	35.1%
Toyota	Scion	18	5	27.8%
Hyundai	Elantra	15	4	26.7%
Toyota	Camry	39	10	25.6%
Honda	Civic	37	9	24.3%

[5] Defined as the percentage of fueling events with a vapor to liquid ratio of greater than to 0.5

[6] Ford F150 were not included in this evaluation due to the introduction of capless fill pipes designs (beginning in 2008) which incorporate an open drain path within the fill pipe interface, this open drain path was responsible for poor nozzle performance

[7] Ford Focus were not included in this evaluation due to the introduction of capless fill pipe designs (beginning in 2008) which incorporate an open drain path within the fill pipe interface, this open drain path was responsible for poor nozzle performance

Table I-2: ORVR Vehicle Survey Results Specific to Toyota Prius[8]

Vehicle Year	Number of Vehicles in Data Set	Vehicles with V/L Ratio < 0.5
2002	1	100%
2003	0	-
2004	2	50%
2005	3	67%
2006	1	100%
2007	3	0%
2008	3	33%
2009	0	-
2010	3	33%
2011	3	33%
2012	6	67%
2013	14	43%
2014	5	60%
2015	1	100%
Total	**45**	**47%**

[8] There are five body styles (design variants) of Toyota Prius including: “V” 5-door hatchback, “IV” 5-door hatchback, “III” 5-door hatchback, “III SE” 5-door hatchback, “II” 5 door hatchback

II. OBJECTIVE

The objective of this evaluation was to determine the reason for wide variation in assist nozzle ORVR recognition performance with certain makes and models of vehicles. Once the common characteristic or "smoking gun" is identified, appropriate mitigation measures can be pursued to improve ORVR recognition performance which in turn, will reduce the volume of excess air ingestion and help mitigate the occurrence of overpressure conditions.

A major challenge in achieving this objective is the fact that numerous factors can influence the ability of the assist nozzle to properly recognize an ORVR equipped vehicle. These factors include the following:

1. <u>Nozzle Vapor To Liquid Ratio Setting</u>: The assist nozzle vapor to liquid ratio must be properly set between 0.95 and 1.15 as required in Exhibit 2 of the Assist System Executive Order, otherwise, ORVR recognition results will be biased high or low. To eliminate this potential bias, CARB staff conducted compliance testing to ensure the vapor to liquid ratio of the nozzle was set between 0.95 -1.15.
2. <u>Condition of the Nozzle Vapor Boot</u>: The nozzle vapor boot must be properly aligned with body of the nozzle and spout. The vapor boot must be free of nicks, tears, deformities, excessive wear, or missing material at the sealing surface. To eliminate this potential bias, CARB staff verified proper condition of boot via visual inspection.
3. <u>Condition of the Nozzle Spout Latch Ring</u>. The nozzle latch ring must fully round and free of excess wear and deformation. To eliminate this potential bias, CARB staff verified proper condition of spout latch ring via visual inspection.
4. <u>Condition of the Nozzle ORVR Recognition Diaphragm</u>: The ORVR recognition diaphragm within the nozzle body must be fully operational and fully capable of restricting the vapor return volume when refueling ORVR equipped vehicle. To eliminate this potential bias, CARB staff conducted refueling events on ORVR equipped vehicle and retrieved vapor to liquid ratio data from the ISD system to ensure proper recognition.
5. <u>Leak Integrity of Dispenser Vapor Return Plumbing</u>. Due to the high level of vacuum achieved by the assist system vacuum pump, the dispenser vapor return piping must be free of leaks, otherwise excess air ingestion may result. To eliminate this potential bias, CARB staff conducted dispenser integrity testing as specified in the Assist System Installation, Operation, and Maintenance Manual.
6. <u>Fuel Dispensing Rate</u>: Low flow rates, less than five gallons per minute, compromise the ability of the assist nozzle to recognize ORVR equipped vehicles. Flow rates should be maintained between six and ten gallons per minute.
7. <u>Volume of Fuel Dispensed</u>: For the ISD system to accurately capture a fueling transaction, a minimum of 3.5 gallons of fuel must be dispensed. Smaller volumes are not sufficient for the ISD system to provide an accurate reading. To eliminate this potential bias, CARB staff dispensed a minimum of four gallons per fueling transaction.
8. <u>Vehicle Orientation Relative to Dispenser</u>: For optimal nozzle performance, the vehicle fill pipe access zone should be positioned direct adjacent to the nozzle.

Fueling from the opposite of vehicle was avoided because the nozzle is often placed upside down in the fill pipe.

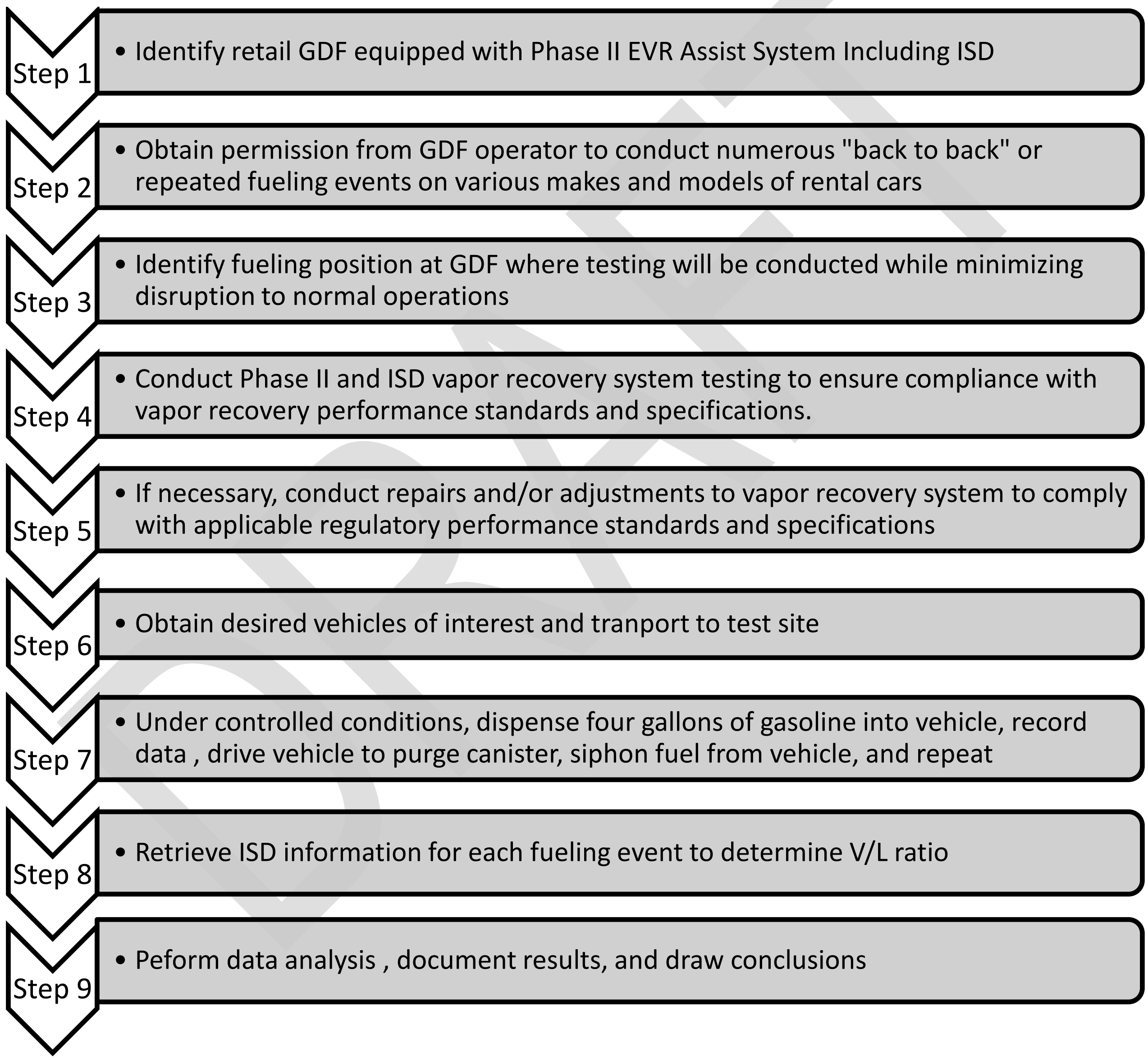
9. Nozzle Orientation Relative to Vehicle: The nozzle must be placed in the vehicle at the six o clock position (right side up) to optimize the ability to seal. Fueling with the nozzle in the twelve o clock position (upside down) should be avoided. Fueling with the nozzle upside down may also defeat the primary shut off mechanism resulting in spillage of liquid gasoline.
10. Customer Handling of the Nozzle: customer handling of the nozzle can vary considerably, for this evaluation, CARB staff will handle the nozzle and to the extent possible, use the hands free “hold open latch” feature for the majority of fueling events.
11. Condition of the Vehicle Fill Pipe: Vehicles with excessively worn fill pipe features such as the locking lip or missing/deformed sections of the face seal of the fill pipe should be avoided. To eliminate this potential bias, CARB staff will inspect the condition of the vehicle fill pipe and make note of any issues. CARB staff will also procure newer rental cars, with presumable less wear and tear.

In order to conduct this evaluation in a scientifically valid, repeatable manner, the above factors had to be controlled, meaning that they must remain constant for each fueling event, to the maximum extent possible. This was achieved by establishing a test site at a retail GDF located in Sacramento and optimizing a single fueling position at which the vehicles were to be refueled on a repeated basis. This also meant that CARB staff, rather than members of the public, would conduct all vehicle fueling events to ensure consistency.

III. METHODOLOGY

Prior to conducting testing, CARB staff developed a multi-step methodology for this evaluation. The manner in which the nozzle is handled during fueling events would be the “manipulated variable” while all other vapor recovery system components were considered “controlled variables” and were not to be altered with the exception of bringing them into compliance with regulatory performance standards and specifications. As depicted in Figure III-1, the methodology consists of nine steps.

Figure III-1: Multi Step Methodology Developed for Controlled Fueling Evaluation



The following paragraphs describe in further detail many of the key components which comprise the methodology of this evaluation.

A. Test Site Selection

In the winter of 2009, in support of the overpressure study, CARB staff made arrangements/received permission from six retail GDF operators located in the Sacrament region to continuously monitor underground storage tank pressure and vehicle fueling event information captured by the ISD system. Each site was equipped with specialized monitoring system to quantify vent line and fugitive emissions which result when overpressure conditions are present. One of the six "study sites" was a retail GDF located approximately 12 miles from CARB headquarters in Sacramento. This particular location was deemed an ideal candidate for this evaluation because of its proximity to rental car facilities and its physical layout. Due to its large lot size, there was plenty of room for CARB equipment and temporary storage of rental cars. Permission to proceed from the GDF operator was granted in April 2015. Table III-1 provides further details including operating characteristics.

Table III-1: Description of Test Site Selected for Controlled Fueling Events

GDF Location	Sacramento, CA
Monthly Gasoline Throughput	~150,000 gallons
Number of Fueling Points	8 (single hose, multi-product fueling points)
Number of UST	2 Unleaded Regular 1 Unleaded Premium
Vapor Recovery System	Phase I: OPW EVR Phase II: Assist EVR
ISD System	Veeder-Root Software Version 1.02
Secondary Containment	Non-VPH
Turbine Configuration	Variable Speed, FE Petro
Hours of Operation	24 hours/ 7 days per week
Pressure Vacuum Vent Valve	Franklin Fueling Systems "PV Zero"
ISD Data Acquisition System	Inform Software Version 4.1

B. Vapor Recovery System Performance Testing

In order to ensure that the vapor recovery system and the assist nozzle at the test site were operating properly, CARB staff conducted the following compliance tests on the desired fueling position prior to the vehicle fueling events. This was considered a key component of the evaluation because as described in the objective section, an improperly operating assist nozzle will bias the results of this evaluation. At the test site, fueling point eight (FP8) was selected due to its location and low impact on the traffic flow. Fueling point eight **passed all applicable tests on May 11, 2015** prior to actually conducting fueling events on the vehicles of interest. Fueling point seven (FP7) on the opposite side was taken out of service to avoid simultaneous fueling events which yields the ISD vapor to liquid ratio data invalid.

Table III-2: Description of Vapor Recovery System Performance (VRS) Testing Conducted at Test Site Selected for Controlled Fueling Evaluation

Test Procedure	Description	Reference
VR-202 Exhibit 5	Vapor to Liquid Ratio and Fuel Dispensing Flow Rate	http://www.arb.ca.gov/vapor/eos/eo-vr202/vr202t_ex05.pdf
VR-202 Exhibit 9	Veeder-Root ISD Vapor Flow meter Operability Test Procedure	http://www.arb.ca.gov/vapor/eos/eo-vr202/vr202t_ex09.pdf
VR-202 IOM 8	Dispenser Integrity	http://www.arb.ca.gov/vapor/eos/eo-vr202/vr202t_iom08.pdf
VR-202 IOM 2	Visual inspection of nozzle spout, vapor enhancing guard (boot)	http://www.arb.ca.gov/vapor/eos/eo-vr202/vr202t_iom01.pdf

C. Vehicle Fueling Events

For each fueling event, three CARB staff members were involved. One staff member drove the vehicle, a second staff member handled the nozzle and fueled the vehicle, and a third staff member videotaped the fueling event, and documented pertinent information on a field data form. Items such as the nozzle orientation, hold open latch usage, existing tank level of vehicle, (half full or empty), fuel flow rate, duration of fueling event, total gallons dispensed, and time at which fueling occurred were recorded.

Appendix I of this document provides an example of the field data form that was utilized to record information. Approximately four gallons of gasoline was dispensed for each fueling event. Most vehicles evaluated were equipped with at least a ten gallon capacity fuel tank. This allowed CARB staff to conduct at least two, four gallon fueling events back to back. After fueling was performed and the vehicle fuel tank was full, a CARB staff member drove the vehicle on a predetermined nine mile route that included a mixture of freeway and surface street driving. This was done to purge the on board carbon canister that is part of the ORVR emissions control system.

D. Motor Vehicle Fuel Siphoning System

Upon completion of the nine mile driving circuit to purge the ORVR carbon canister, the vehicle was returned to the test site with a full tank of gas, minus whatever fuel was consumed during the nine mile driving circuit. Next, gasoline was removed from the vehicle fuel tank to make room for additional fueling events. This was accomplished by mechanically syphoning the gasoline from the motor vehicle tank into a larger capacity portable fuel storage tank supplied by CARB staff. When the portable tank reached full capacity (approximately 65 gallons) the gasoline was transferred back to the underground storage tank of the test site. The fuel siphoning system consists of several components which are depicted in Figure III-2. It should be noted that prior to deploying resources into the field, the concept of siphoning gasoline from a vehicle in the field presented a challenge for CARB staff. Fortunately, CARB staff was able to develop a safe and efficient method of transferring fuel from the vehicle to the portable tank using purpose built equipment including a pneumatically operated diaphragm pump, and special semi rigid, small diameter tubing lines that could be inserted into the vehicle fill pipe.

It should also be noted that rather than paying for the gasoline dispensed for each fueling event, the GDF operator authorized each fueling as a “pump test” (typically done to accommodate county weights and measures or to accommodate vapor recovery testing) in which the gasoline will be returned to the underground storage tank after the test is completed. Images of vehicles being test, the fueling position, the vapor recovery nozzle, and the motor vehicle fuel siphoning system are provided in figure III-3

Figure III-2: Motor Vehicle Fuel Syphoning System

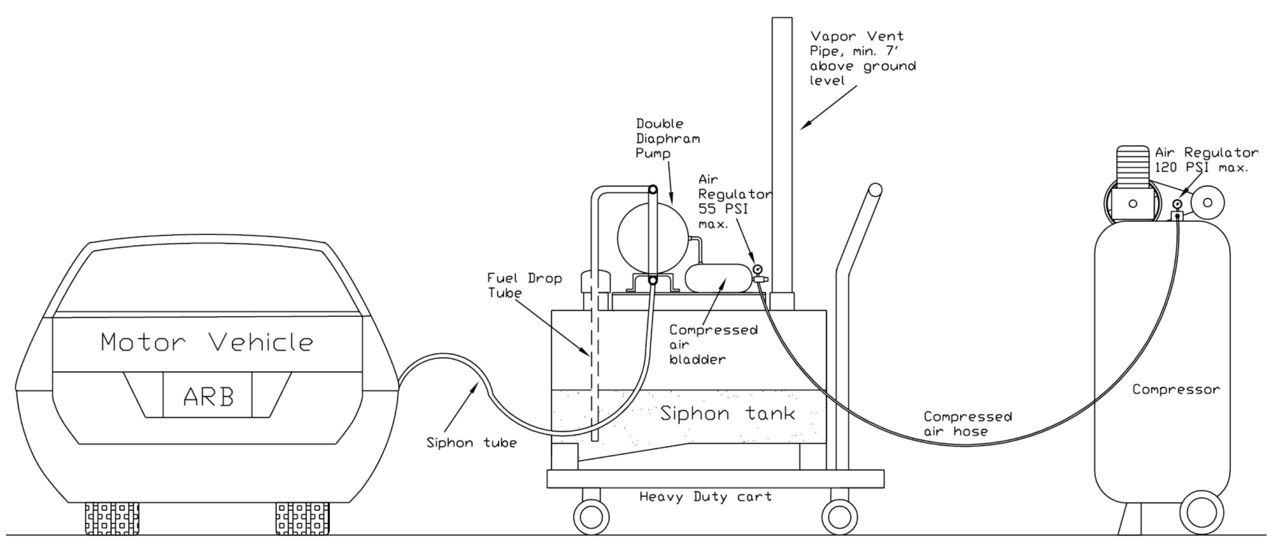
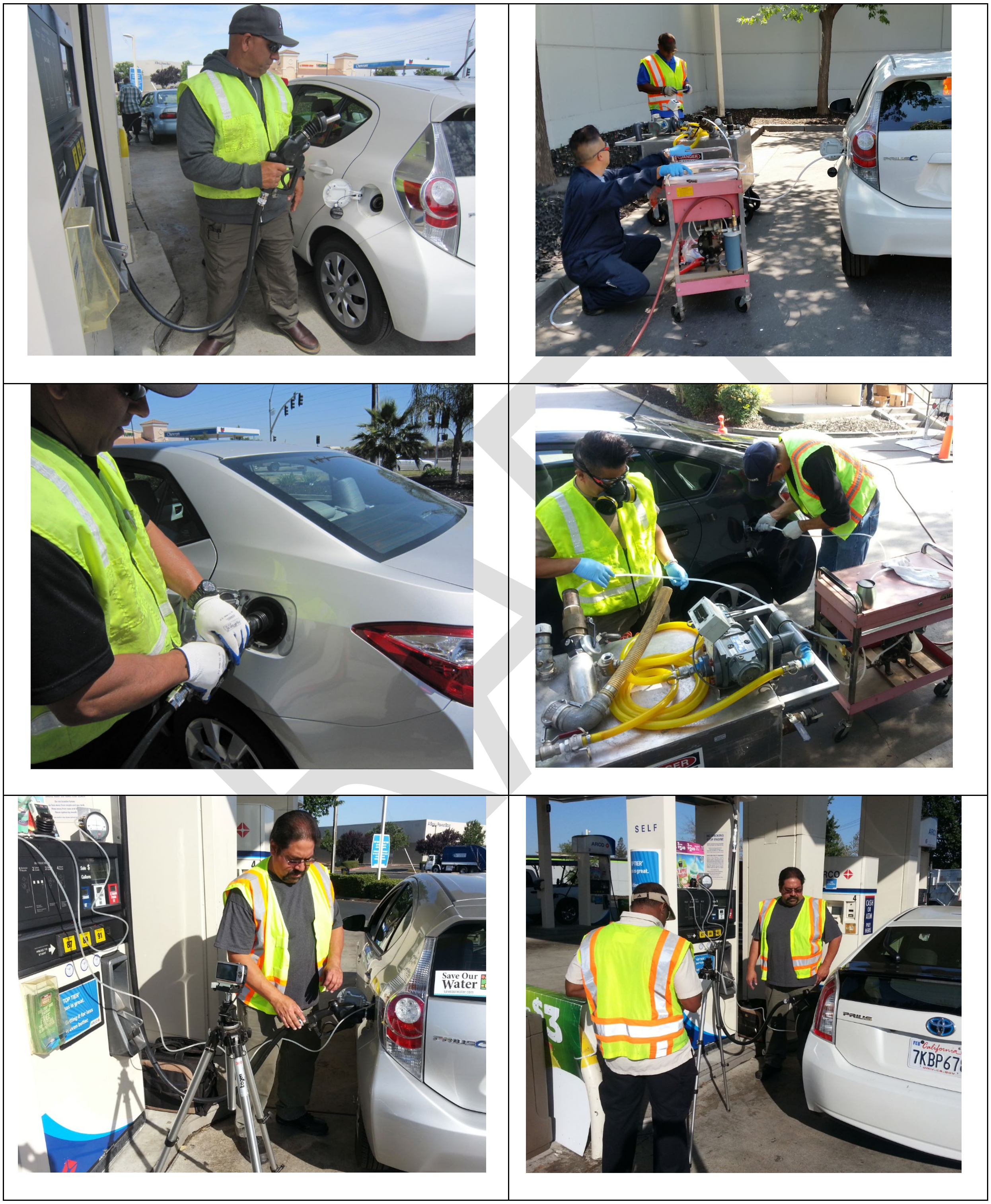


Figure III-3: Images of Test Site and Motor Vehicle Fuel Syphoning System



E. Use of Hand Held Vacuum Guage

Beginning with the series fueling events occurring on July 22, 2015, CARB staff connected a hand held pressure measurement gauge to the nozzle vapor boot to measure the vacuum level achieved at the vehicle fill pipe interface. The use of the vacuum gauge was suggested as a way to directly measure real time nozzle performance rather than relying on retrieval of vapor to liquid ratio data recorded by the ISD system which is only available several minutes after the fueling event has ended. In order for the assist nozzle to properly recognize an ORVR equipped vehicle, a good seal must be established at the vehicle fill pipe interface. When a good seal is present on an ORVR vehicle, the assist system will draw a slight vacuum of approximately 1.0 to 1.5 inches water column gauge at the boot. Conversely, if a good seal is not achieved at the nozzle and fill pipe interface, there will be no vacuum present and the gauge will read zero. A reading of zero gauge vacuum when fueling an ORVR vehicle indicates that the nozzle is ingesting fresh air.

In terms of equipment, CARB staff inserted a stainless steel barbed fitting through the boot (not the calibrated pair of holes in the boot as this will affect the V/L of the vehicle) and attached a flexible line to the vacuum gauge. Staff ensured that the insertion of the barbed fitting was well sealed and did not create a leak path.

Figure III-4: Measurement of Vacuum at Nozzle and Vehicle Fill Pipe Interface

As shown in the image above (Figure III-4) a flexible line and stainless steel barbed fitting was connected to a mechanical (Dwyer Magnehelic) pressure gauge, as well as a battery operated digital manometer (Love Model HM28). These were used to measure the vacuum at the nozzle/vehicle fill-pipe interface. The digital manometer was set to record the "MIN/MAX" value as well. The vehicle fueling events were then performed according to the methodology previously described.

F. Retrieval of Vapor to Liquid Ratios from the ISD System

After the controlled fueling events where completed on each testing date, CARB staff downloaded individual fueling transaction data from the test site's ISD system. For each fueling event, the ISD system records the duration of the fueling event in seconds, the vapor to liquid ratio (labeled as "A/L" in the figure below), the volume of vapor collected in gallons, the liquid volume dispensed, and the fueling position. Information from the ISD system is then compared with the information recorded on the field data sheet. Figure III-5 below provides an example of the information available from the ISD system. Appendix III (raw data) provides the full set of ISD fueling transaction data downloaded for this evaluation.

Figure III-5: Example of ISD Fueling Transaction Report

I&1804
MAY 28, 2015 11:47 AM
AFM BUSY EVENTS: FLOWMETER 4

INDEX	START DATE-TIME	DUR	A/L	VAPOR	FUEL	#EV	FLAGS	FPS	HOSES
0970	15-05-28 08:27:07	892	0.98	78.4	80.4	2	0032	07&08	06&07
0971	15-05-28 08:45:13	188	0.66	16.3	24.6	2	0032	07&08	06&07
0972	15-05-28 08:57:07	46	0.22	0.9	4.0	1	003E	08	07
0973	15-05-28 09:00:36	77	0.22	1.6	7.2	1	003E	08	07
0974	15-05-28 09:10:02	37	0.25	1.0	4.0	1	003E	08	07
0975	15-05-28 09:12:49	64	1.09	4.5	4.1	1	002E	08	07
0976	15-05-28 09:19:24	60	1.00	6.1	6.1	1	002E	08	07
0977	15-05-28 09:36:29	276	0.28	9.3	33.2	2	0032	07&08	06&07
0978	15-05-28 09:42:56	82	0.46	0.7	1.5	1	0037	08	07
0979	15-05-28 09:44:47	45	0.48	1.5	3.1	1	003E	07	06
0980	15-05-28 09:47:18	62	1.01	3.1	3.1	1	002E	08	07
0981	15-05-28 09:52:40	34	0.98	4.0	4.1	1	002E	08	07
0982	15-05-28 09:55:36	43	1.00	4.2	4.2	1	002E	08	07
0983	15-05-28 09:58:51	74	0.99	5.8	5.9	1	002E	08	07
0984	15-05-28 10:03:15	61	0.63	2.6	4.0	1	002E	08	07
0985	15-05-28 10:06:30	55	1.15	4.6	4.0	1	002E	08	07
0986	15-05-28 10:13:45	127	0.25	2.7	10.7	1	003E	08	07
0987	15-05-28 10:16:42	137	0.18	3.3	18.1	1	003E	07	06
0988	15-05-28 10:19:32	146	0.22	3.1	13.9	1	003E	08	07
0989	15-05-28 10:25:05	138	0.20	2.3	11.5	1	003E	07	06
0990	15-05-28 10:28:41	335	0.43	11.3	26.2	2	0032	07&08	06&07
0991	15-05-28 10:38:19	60	0.43	1.9	4.3	1	003E	08	07
0992	15-05-28 10:42:11	45	0.36	1.5	4.1	1	003E	08	07
0993	15-05-28 10:46:17	43	0.49	2.1	4.2	1	003E	08	07
0994	15-05-28 10:51:06	55	1.13	4.6	4.0	1	002E	08	07
0995	15-05-28 10:54:01	35	1.17	4.7	4.1	1	002E	08	07
0996	15-05-28 11:09:24	99	1.14	10.6	9.3	1	002E	08	07
0997	15-05-28 11:21:57	120	0.37	4.5	12.2	1	003E	07	06
0998	15-05-28 11:26:20	150	0.28	5.2	18.4	2	0032	07&08	06&07
0999	15-05-28 11:34:18	46	0.23	0.9	4.1	1	003E	08	07
1000	15-05-28 11:37:32	38	1.14	3.6	3.2	1	002E	08	07

IV. RESULTS

Between May 2015 and September 2015, a total of 161 controlled fueling events were conducted on 18 different makes and models of vehicles, totaling of 670 gallons of fuel dispensed. The majority of ORVR vehicles used in this evaluation were obtained through Sacramento area rental car agencies (Enterprise) and the State of California, Department of General Services “State Garage.” Other vehicles, including conventional or non-ORVR vehicles were obtained through CARB’s vehicle fleet or CARB staff’s personal vehicles. To the extent possible, orientation of nozzle, position of vehicle, the nozzle at which the vehicle was refueled, CARB staff member handling the nozzle, fuel dispensing rate, and volume dispensed were kept identical for each event. To ensure consistency and repeatability of results, fueling events were repeated several times (usually four times) for the majority of ORVR equipped vehicles under the same conditions.

Initially, CARB staff’s focus was on the 2014 model year Toyota Prius. However, as the evaluation progressed, testing was expanded to include several other makes and models of vehicles. During the refueling process for some of the vehicles, a hand held vacuum gauge was inserted into the boot of the nozzle to determine leak integrity and fill-pipe interface.

In order to convey the results of this evaluation in a clear and concise manner, this section of the report is organized by “test sequence”. The term test sequence is used to identify a series of distinct dates (some test sequences consisted of two days in a row) when CARB staff evaluated certain makes and models of ORVR equipped vehicles. As listed in the chronology provide below (Table IV-1), a total of eight test sequences were conducted for this evaluation. The chronology also provides a description of each vehicle tested including make, model, model year and number of controlled fueling events. Appendix IV: provides the full data set comparing vehicle information and ISD fueling transaction data for this evaluation.

Table IV-1: Chronology of Events: Controlled Fueling Evaluation

Test Sequence	Date	Vehicle Tested Year/Make/Model	Fueling Events
1	5/13/15-5/14/15	2014 Toyota Prius C	18
		Number of Events Per Test Sequence	**18**
2	5/27/15-5/28/15	2015 Toyota 4 Runner	5
		2015 Toyota Corolla	5
		2014 Hyundai Elantra	4
		2014 Toyota Prius Hatchback	2
		2005 Honda Accord	3
		2007 Toyota Camry Hybrid	2
		1995 VW Golf	1
		2014 Toyota Prius Hatchback	8
		2001 Toyota Tacoma	3
		Number of Events Per Test Sequence	**33**
3	6/9/15	2014 Toyota Prius C	8
		2014 Toyota Camry Hybrid	2
		Number of Events Per Test Sequence	**10**
4	7/22/15	2015 Hyundai Elantra	5
		2015 Toyota Prius Hatchback	8
		2001 Toyota Tacoma	3
		2008 Toyota Rav4	1
		2015 Honda Civic	1
		1998 Ford Ranger	2
		Number of Events Per Test Sequence	**20**
5	7/29/15	2014 Toyota Prius C	8
		2015 Toyota Prius H	8
		2007 Chevy Impala	2
		1998 GMC 3500 Truck	3
		Number of Events Per Test Sequence	**21**
6	8/18/15	2015 Nissan Altima	10
		2012 Honda Civic	8
		Number of Events Per Test Sequence	**18**
7	8/20/15	2014 Ford Focus	3
		2015 Nissan Versa	8
		2015 Toyota Corolla	9
		Number of Events Per Test Sequence	**20**
8	9/28/15	2015 Nissan Altima	5
		2013 Dodge Ram Truck	2
		2012 Honda Civic	4
		2015 Mercedes C300	2
		2015 Toyota Corolla	3
		2014 Toyota Prius C	4
		Number of Events Per Test Sequence	**21**

A. Test Sequence 1 through 3

As indicated in Table II-1, the Toyota Prius was identified as a vehicle of interest due to its relatively high mis-identification rate of ~47%. Table IV-1 summarizes the results of the first three test sequences of fueling events performed on various model year Toyota Prius and other vehicles that became readily available through the rental car agencies. Under controlled fueling conditions, the Toyota Prius (both the C model and hatchback) had a mis-identification rate of about 80%, with an average vapor to liquid (V/L) value of 0.9. This was worse performance when compared to the results of the gathered from the prior ORVR recognition survey (Table II-1). Upon analysis of the data, CARB staff was puzzled by the higher than anticipated mis-identification rate, lack of repeatability, and variation in performance for each vehicle make.

In addition to the Toyota Prius, CARB staff was also able to obtain access to other Toyota models including Camry, 4 Runner, and Corolla. A Honda Accord and a Hyundai Elantra were also evaluated during this time frame. Due to difference in fill pipe design, the assist nozzle performed optimally on the Altima and Elantra. Results are summarized below.

Table IV-2: Results of Test Sequence 1-3 for ORVR Vehicles

Make	Model	V/L from ISD	Mis-ID Rate	Fueling Events
Toyota	Prius C	1.04	88.5%	26
Toyota	Camry Hybrid	0.29	0.0%	4
Toyota	Prius Hatchback	0.81	70.0%	10
Toyota	4 Runner	0.41	20.0%	5
Toyota	Corolla	1.14	100.0%	5
Hyundai	Elantra	0.25	0.0%	4
Honda	Accord	0.43	0.0%	3

Upon review of the data collected during test sequence 1-3, and after careful deliberation as to why such poor ORVR recognition was documented under controlled fueling events, a suggestion was made to use a vacuum gauge at the fill pipe and nozzle interface for future testing. A description of this device is provided in the methodology section of this report.

B. Test Sequence 4

Test sequence four resulted in what CARB staff considers to be a breakthrough finding. Test sequence four was slightly different than the prior three sequences for two important reasons. First, CARB staff installed a vacuum gauge at the nozzle vapor boot which provided a real time indication of ORVR recognition. Second, the decision was made to use a new CARB staff member to handle the nozzle for most of the test sequence. Upon refueling the Toyota Prius by this new staff member, a vacuum of approximately 1.5 Inches water column gauge was observed at the nozzle vehicle fill pipe interface for the first four fueling events. However, on the fifth fueling event on the same vehicle, a third CARB staff member handled the nozzle which resulted a vacuum reading of zero inches water column gauge. This result prompted CARB staff to try different insertion depths of the assist nozzle within the vehicle fill pipe. Additional fueling events were then completed in two ways: (1) deliberately and intentionally inserting the nozzle as deeply as possible into the vehicle fill-pipe, and (2) lightly inserting the nozzle into the vehicle fill-pipe. During this second method, CARB staff observed the nozzle slightly slip back away from vehicle, creating a loose interface between the boot and mating surface of the fill pipe. Under this scenario, the vacuum gauge displayed a vacuum reading of zero. Table IV-3 below summarizes the results of test sequence 4.

Table IV-3: Results of Test Sequence 4 for ORVR Vehicles

Make	Model	Average Vacuum* At Nozzle Boot		V/L ISD	Mis-ID Rate
Toyota	Prius Hatchback	Run 1	1.30	0.48	0
		Run 2	1.20	0.37	0
		Run 3	1.70	0.24	0
		Run 4	1.70	0.25	0
		Run 5	0.00	1.09	100
		Run 6	1.70	0.17	0
Honda	Civic	1.70		0.46	0%
Hyundai	Elantra	1.82		0.25	0%

*Inches Water Column Gauge

After reviewing the vacuum readings, the vapor to liquid values from ISD, and the observations documented test sequence 4, CARB staff decided to incorporate two different ways of fueling for future testing. For the purpose of documentation, these two different methods of fueling were labeled as “secure latch” and “loose latch”. More discussion on loose latch and secure latch are provided in the discussion section of this document.

C. Test Sequence 5 through 8

Test sequence five through eight, were completed on four different days. Unlike test sequence 1 through 4, fueling events were conducted in a manner to intentionally achieve both a secure latch and loose latch. Table IV-4 summarizes the results. The Toyota vehicles with a secure latch fueling resulted in a vacuum greater one inch water column gauge, a vapor to liquid value of less than 0.5, and a mis-identification rate of zero percent. However the opposite results were observed for the loose latch fueling. The vacuum at the nozzle boot and fuel fill-pipe interface read zero inches of water column gauge. The ISD recorded an average V/L value of one, and a mis-identification rate of 90%.

Unlike the Toyota vehicles, the Honda vehicles and Nissan vehicles performed better. The Honda vehicles with a secure latch fueling resulted in a vacuum averaging 0.9 inches of water column gauge, vapor to liquid value of less than 0.5, and a mis-identification rate of 0%. With a loose latch fueling results almost resembled the secure latch fueling. The Nissan vehicles with a secure latch fueling resulted in a vacuum greater 1.20 inches of water column gauge, vapor to liquid ratio value of less than 0.5, and a mis-identification rate of 0%. With a loose latch fueling results were different. The Nissan Versa, when fueled with a loose latch, resulted in a vacuum of 0.48 inches of water column gauge, a vapor to liquid ratio value greater than 0.5, and a mis-identification rate of 75%.

Table IV-4: Results of Test Sequence 5-8 for ORVR Vehicles

Make	Model	Average Vacuum* at Nozzle Boot		V/L ISD		Mis-ID Rate	
		Secure	Loose	Secure	Loose	Secure	Loose
Toyota	Prius C	1.47	0.30	0.26	0.95	0%	80%
Toyota	Prius Hatchback	1.38	0.00	0.44	1.14	0%	100%
Toyota	Corolla	1.74	0.30	0.25	0.91	0%	80%
Honda	Civic	1.42	0.95	0.46	0.48	0%	25%
Honda	Civic Hybrid	0.80	0.90	0.26	0.27	0%	0%
Nissan	Altima	1.24	0.85	0.38	0.55	0%	25%
Nissan	Versa	1.45	0.48	0.38	0.89	0%	75%

* Inches Water Column Gauge

As indicated in the above table, fueling events with a secure latch and a loose latch result in vastly different values for the interface vacuum, vapor to liquid ratio, and the mis-identification rate. Results also vary by vehicle make and model. This is likely due to the design of the vehicle fill pipe “locking lip” which is further described in the discussion section of this document.

When the nozzle is securely latched within the fill-pipe, a vacuum of approximately 1.5 inches water column gauge was documented, and a V/L less than 0.5 was recorded by ISD. When the nozzle is loosely latched in the fill-pipe, then the gauge read ambient pressure and ISD recorded a V/L greater than 0.5.

V. DISCUSSION

Throughout this evaluation, 161 controlled vehicle fueling events were performed on eight different test sequences (10 days) between May 13, 2015 and September 28, 2015. For reference, Appendix II contains details of each fueling event. The following paragraphs summarize CARB staff findings resulting from this evaluation.

A. Test Sequence 1-3

Fueling events in sequence 1 through 3 did not provide any new information; rather it replicated or reinforced the results observed during the prior ORVR recognition survey, completed in San Diego in January 2015. Under controlled fueling conditions at the Sacramento test site, the vast majority of fueling events resulted in a vapor to liquid value of greater than 0.5 for the Toyota Prius, resulting in a high mis-identification rate. After internal discussion to understand the poor nozzle performance, CARB staff was advised to incorporate a vacuum gauge at the nozzle boot and fuel fill-pipe interface to determine whether or not there was a tight seal between the nozzle boot and fill pipe.

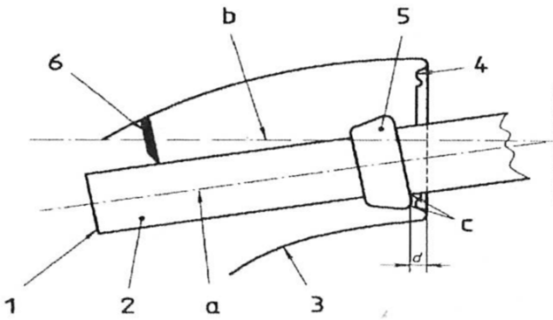
B. Test Sequence 4-8

While fueling a Toyota Prius Hatchback on July 22, 2015 (Test Sequence 4) CARB staff discovered that the nozzle will operate in two positions within the vehicle fill pipe. If the nozzle is placed into the fill-pipe in a deliberate, aggressive manner, it will latch in a location deeper within the fill-pipe. When this occurs, a tight seal will form at the nozzle and vehicle fill pipe interface. This is referred to as a “secure latch.” However, if the nozzle is not forced deeply into the fill-pipe, it will still latch, but in a higher location where the nozzle will not form a tight seal at the fill pipe face. This is referred to as “loose latch”. This result was observed in real time, during the fueling event, by using the hand held vacuum gauges connected at the nozzle boot. CARB staff determined that the reason for the loose latch was due to two key components: the nozzle latch ring not being fully engaged upon the fill pipe locking lip.

C. Secure Latch vs Loose Latch

Throughout this evaluation, CARB staff studied different fill pipe designs and their ability to latch with the assist nozzle. The data indicates that assist nozzle ORVR vehicle recognition (determined by measuring V/L ratio, level of vacuum generated at the fill pipe interface) can vary depending on whether the nozzle is securely or loosely latched within the ORVR vehicle fill pipe. Figure V-1 shows a cross-sectional view of a nozzle spout inside the vehicle fill pipe under secure latched conditions. Note the position of the item labeled 5 (nozzle latch ring) relative to the item labeled C (vehicle fill pipe locking lip).

Figure V-1: Cross Sectional View of Nozzle Spout and Vehicle Fill Pipe



Item	Description
5	Nozzle Latch Ring
C	Fill Pipe Locking Lip

As depicted in Figure V-1, the nozzle spout has a “latch ring” which needs to securely engage upon the “locking lip” of the vehicle fill pipe during fueling in order to ensure a secure latch. One finding from this evaluation is that different vehicle makes and models were able to be fueled with a loose latch. Figure V-2 provides images of a secure and loose latch fueling into an ORVR vehicle fill pipe. In the image of the secure latch, the compression of the bellows can be seen in the nozzle boot.

Figure V-2: Example of Secure Latch and Loose Latch

	
Nozzle Secure Latch	Nozzle Loose Latch

Note, Figure V-2 provides an example of an obvious loose latch during the fueling of an ORVR vehicle. In a majority of instances, the loose latch condition cannot be visually seen but can be determined by the V/L measurement or presence or lack of vacuum achieved at the vapor boot of the nozzle.

D. V/L Data based on “Secure” and “Loose” Latch

The fueling of ORVR vehicles with a loose latch consistently exhibited higher vapor to liquid ratios. This results in excess air ingestion at the fill pipe/nozzle interface and a high mis-identification rate.

VI. CONCLUSION

Based upon the results of this evaluation, CARB staff has concluded that the reason for variation in assist nozzle performance relative to ORVR recognition is the tendency of the nozzle to form a “loose latch” when inserted into certain vehicle fill-pipes. The presence of a “loose latch” is due to the design of the nozzle latch ring coupled with the design of the vehicle fill pipe locking lip. If the assist nozzle is deliberately and intentionally inserted into the fill pipe, a secure latch will occur. However, if the assist nozzle is lightly inserted, a loose latch can occur.

When the nozzle is “securely latched” within the fill-pipe, a vacuum of approximately 1 to 1.5 inches water column gauge was observed and a vapor to liquid ratio of less than 0.5 was recorded by ISD. When the nozzle is “loosely latched” in the fill-pipe, then the vacuum gauge read ambient pressure and ISD recorded a vapor to liquid ratio greater than 0.5.

There are two key recommendations resulting from this evaluation. First, CARB staff suggests that Franklin Fueling Services, the manufacturer of the assist nozzle, consider design enhancements that would enable the nozzle to more readily securely latch to the vehicle fill-pipe. Secondly, CARB staff will work with the automotive manufactures to amend vehicle fill pipe and nozzle dimensional specifications to ensure that the locking lip of the fill pipe would prove a secure latch.

VII. APPENDICES

Appendix I: Field Data Forms (Sample)

Appendix II: Field Data Forms (Raw data)

Appendix III: ISD Data (Raw Data)

Appendix IV: Results Data Set

Appendices will be provided upon request