

# A Survey and Analysis of Liquid Gasoline Released to the Environment During Vehicle Refueling at Service Stations

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# **A Survey and Analysis of Liquid Gasoline Released to the Environment During Vehicle Refueling at Service Stations**

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**June 1989**

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## ABSTRACT

Methods have been devised and demonstrated to characterize liquid gasoline releases to the environment during vehicle refueling at service stations. These methods have been employed in a limited study of the release characteristics of contemporary refueling equipment at well-maintained Stage II facilities in the District of Columbia, and at comparable conventional facilities in the Baltimore metropolitan area. Within the limitations of the study, results show that 33 percent and 37 percent of all refueling events at Stage II and conventional facilities, respectively, are completed without liquid release. When release occurs, it most commonly consists of a very small amount ( $\leq 0.1$  grams) which almost entirely can be described as drips. Larger releases ( $> 0.1$  grams), when they occur, are more frequent at Stage II facilities. Moreover, when release is expressed in terms of the amount of fuel dispensed, the resultant emission factor is significantly larger at Stage II facilities. The statistical significance of this conclusion depends upon the larger average amount of fuel dispensed per refueling event at conventional facilities. This, in turn, is due at least partially to the characteristics of the dispensing equipment which results in the practice of topping-off at conventional facilities. In any case, topping-off has a statistically significant impact on increasing the volume of fuel released from both Stage II and conventional dispensing systems.

A SURVEY AND ANALYSIS OF LIQUID GASOLINE RELEASED TO  
THE ENVIRONMENT DURING VEHICLE REFUELING AT SERVICE STATIONS

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EXECUTIVE SUMMARY

The capture of displaced hydrocarbon vapors at the point of vehicle refueling (so-called Stage II control) has been practiced for many years as an ozone abatement strategy in urban areas of California and the District of Columbia. More recently, Stage II requirements have appeared in other ozone nonattainment areas, including the City of St. Louis, Missouri, and the states of New York and New Jersey. State and local interest in Stage II requirements has been increasing rapidly, creating a need for the complete assessment of the overall efficacy of Stage II as a hydrocarbon emission control measure.

A complete assessment requires the characterization of all fuel released at the dispenser, and cannot be based only on measurements of the captured vapor. Accordingly, the objectives of this study are to 1) learn how to measure liquid release, and 2) study the release characteristics of Stage II versus conventional equipment over the range of gasoline throughput characteristic of contemporary marketing facilities. Both objectives have been reached; however, the liquid release factors reported apply to 1) well-maintained equipment, functioning as intended by the respective manufacturers, and 2) operations characteristic of the geographic areas of the study. No attempt has been made in this study to perform a compliance assessment, and the investigators caution that other release factors may be applicable to equipment less well maintained, and/or subject to other demographic variables. At the same time, the methods developed here are considered universally applicable, and constitute a salient accomplishment. They should be considered if more extensive studies are undertaken.

ES-1

The methodology developed in this study, and detailed in the following report, is believed to be unique in that it recognizes releases both before and after (as well as during) the dispensing operation. Although releases before and, more particularly, after the refueling event are frequent occurrences, they also are generally so small as to be inconsequential. An exception would be their aggregate impact on emissions. For example, among 1278 refueling observations at Stage II outlets and 1357 at conventional outlets, 66 percent and 78 percent respectively, involved either no releases of fuel or releases of less than 0.1 grams. These releases almost entirely can be described as drips. But in their aggregate, they represent just 0.59 percent and 0.95 percent, respectively, of the total liquid fuel observed to be released during refueling in the course of this study. Releases greater than 0.1 grams typically include both drips and spills, so it is convenient to think about these events in terms of a somewhat arbitrary division. A release of 0.1 grams results in a wetted area on the apron of the dispenser island equivalent to a circle about two inches in diameter.

Data that quantified and described liquid releases were collected at 20 well-maintained retail facilities in Washington, D.C., that had Stage II vapor recovery controls, and 20 conventional facilities in the Baltimore metropolitan area, matched in pairs according to volume throughput. These were selected from larger groups nominated by American Petroleum Institute (API) member companies as representative of facilities maintained in good operating condition. Fifteen of the 20 Stage II-equipped facilities had coaxial dispenser hoses with nozzles and recovery boots of current design.

In terms of whether there was a release of liquid fuel, the results of the refueling observations may be summarized as follows:

PERCENTAGE DISTRIBUTION OF TOTAL REFUELING OBSERVATIONS

| <u>Type of Release</u>              | <u>Type of Facility</u> |                 |
|-------------------------------------|-------------------------|-----------------|
|                                     | <u>Conventional</u>     | <u>Stage II</u> |
| None                                | 37                      | 33              |
| Drips ( $\leq 0.1$ gram)            | 41                      | 33              |
| Drips and/or Spills ( $> 0.1$ gram) | 22                      | 34              |

Directionally, the principal difference in these results is that there is a substantially higher frequency of occurrence of releases greater than 0.1 grams per refueling event for the Stage II facilities. Indeed, when comparing both refueling observation populations, the frequency of drips/spills is significantly greater at the 0.10 probability level. When considered in terms of gallons dispensed, the resulting release or emissions factors become statistically different at the 0.02 probability level. These are given in the following table:

AVERAGE LIQUID EMISSIONS FACTOR  
(grams released per gallon dispensed)

| <u>Type of Facility</u> | <u>Emissions Factor</u> |
|-------------------------|-------------------------|
| Stage II                | 0.23                    |
| Conventional            | 0.14                    |

Topping-off the tank at the end of refueling is not a recommended practice, and in any case, is specifically admonished against in the instructions at the dispensers at Stage II facilities. Nevertheless, topping-off was observed in 20.2 percent of the conventional refueling observations, and at 14.8 percent of the Stage II refuelings. The practice increases the amount of fuel dispensed during a given refueling event, and is certainly one factor (though not necessarily the only one) which accounts for the higher average amount of fuel dispensed per refueling at the

conventional facilities in this study. The higher average amount dispensed, for whatever reason, is also critical to the finding of statistical significance in the difference between the release or emission factors recorded in the previous table.

Although determination of the effects of topping off was not a primary objective of this study, the observations indicate that the practice has a statistically significant impact on releases at both Stage II and conventional facilities. Averages appear in the following table:

AVERAGE LIQUID FUEL RELEASE  
(grams per refueling event)

| <u>Type of Facility</u> | <u>Top-Off</u> | <u>No Top-Off</u> |
|-------------------------|----------------|-------------------|
| Stage II                | 3.6            | 1.4               |
| Conventional            | 2.4            | 0.9               |

Other factors characterizing the refueling process within type of facility (i.e., Stage II or conventional) also were evaluated, including, for example, placement of the filler tube on the vehicle (side or rear), nozzle orientation during refueling (upside down vs. right side up), whether the customer drove off without having filled the tank, and whether the customer latched the nozzle during refueling. All these factors individually were found to have a statistically significant difference in the amount of liquid fuel released during refueling when comparing the opposing possibilities within each, except for whether the nozzle was latched during refueling. When comparing the amount of fuel dripped/spilled between Stage II and conventional facilities, the only refueling characteristics found to be statistically significant included placement of the filler (side and rear), whether the nozzle was latched during refueling, and whether the customer drove away

without filling the tank. In each case, the average amount of fuel dripped/spilled was greater at Stage II facilities compared to conventional facilities except for vehicles with rear fill.

In conclusion, methods have been devised and demonstrated to characterize all types of liquid release to the environment during vehicle refueling at vehicle refueling facilities. These methods have been employed in a limited study of the release characteristics of contemporary refueling equipment at well-maintained Stage II facilities in the District of Columbia, and at comparable conventional facilities in the Baltimore metropolitan area. Within the limitations of the study, results show that 33 percent and 37 percent of all refueling events at Stage II and conventional facilities, respectively, to be completed without liquid release. When release occurs, it most commonly consists of a very small amount ( $\leq 0.1$  grams) which almost entirely can be described as drips. Larger releases ( $> 0.1$  grams), when they occur, are more frequent at Stage II facilities. Moreover, when release is expressed in terms of the amount of fuel dispensed, the resultant emission factor is significantly larger at Stage II facilities. The statistical significance of this conclusion depends upon the larger average amount of fuel dispensed per refueling event at conventional facilities. This, in turn, is due at least partially to the characteristics of the dispensing equipment which results in the practice of topping-off at conventional facilities. In any case, topping-off has a statistically significant impact on increasing the volume released from both Stage II and conventional dispensing systems.

## 1.0 INTRODUCTION

### 1.1 Objective

The primary objectives of this project were to: 1) learn how to measure liquid fuel released to the environment at the point of vehicle refueling; and 2) study the automotive refueling operation, comparing the characteristics of liquid fuel releases from Stage II with conventional equipment over the range of gasoline throughput characteristic of contemporary marketing facilities. The study focused on service stations with dispensing equipment in good working condition. The secondary objectives of this project were to identify various factors which may affect the frequency and/or amount of liquid fuel emitted to the environment at the point of refueling. To accomplish these objectives, it was necessary that vehicle refueling observations be made from both Stage II and conventional service stations to allow direct comparisons while minimizing the effect of extraneous variables.

This study did not attempt to measure or estimate the vapor recovery efficiency of Stage II systems relative to conventional service stations.

### 1.2 Background

The Environmental Protection Agency (EPA) has identified refueling emissions as contributors to ambient hydrocarbons and the resulting air pollution to which they contribute. Two technologies have been identified to control refueling emissions: Stage II control systems at service stations and carbon canisters onboard the vehicle. The EPA has proposed regulations requiring onboard carbon canisters.

Stage II vapor recovery systems are designed so that the gasoline vapors displaced from a vehicle's tank during the refueling process are captured and returned to the underground gasoline service station supply tank. Presently, Stage II systems are in place at service stations in St. Louis, Missouri, Washington D.C., and all the major urban areas of California.

The differences between Stage II and conventional service station refueling systems are found in three areas: the dispensing nozzle, the dispensing hose, and the piping from the storage tank to the pumps. The Stage II nozzle is surrounded by a rubber "boot," which forms an interface with the vehicle's fill pipe. The purpose of the nozzle boot is to prevent the refueling vapors that are displaced from the vehicle's tank from escaping into the atmosphere. These fuel vapors are directed to the underground fuel storage tank through the use of hoses (either parallel or coaxial with the dispensing hose) from the dispensing nozzle and piping between the dispenser and underground storage tank, which are part of the Stage II vapor recovery system.

One of the issues that has arisen is the difficulty in using Stage II equipment and/or technical problems with Stage II system design, which can affect the amount of liquid fuel released during refueling at Stage II service stations compared with conventional service stations. Only a few studies have attempted to address some of the performance concerns with Stage II systems (1,2,3)<sup>1</sup>. These studies were conducted soon after Stage II systems were required in California service stations, and were directed at evaluating user problems with Stage II equipment. A recent study by Lundberg Reports, which focused on ease of use of Stage II systems in

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<sup>1</sup>Numbers in parentheses denote references listed in Section 4.

California, observed that 23 percent of the gasoline service stations, customers spilled fuel when refueling (4). However, this study did not measure the amount of fuel spilled and did not include comparable conventional service stations. As a result, it is now appropriate to study the relative frequency of fuel spillage and amount for Stage II relative to conventional fuel dispensing systems typically in use during the 1988/1989 timeframe.

This study differs from those conducted previously in the following ways:

- o It includes all the liquid fuel releases before, during and after the refueling event, regardless of amount. Previous studies tended to ignore releases before and after refueling and concentrated only on the larger releases, which for descriptive purposes are best classified as spills. By observing and recording all liquid fuel releases, this study includes releases which can be most accurately classified as drips. These drips came from not only full-size drops, but from droplets as well. In most cases, the customer is not even aware that he has dripped fuel and it is only through careful observer training that these releases can be consistently observed and accurately quantified
- o It compares the difference in the frequency and amount of liquid fuel released between Stage II service stations and comparable conventional service stations. Some of the previous studies focused on the frequency and not the amount of liquid fuel released
- o Earlier studies focused on the performance and ease of use of Stage II vapor recovery equipment and its effect on liquid fuel releases. This study does not focus on these characteristics
- o Most of the previous studies were conducted in California, while this study was conducted in the Baltimore-Washington D.C. metropolitan area
- o Service station users in Washington D.C. have a long experience with using Stage II equipment. When many of the earlier studies took place, Stage II systems were just being implemented and people doing vehicle refueling did not have as much experience with them
- o The number of refueling observations and service stations

visited was limited in most of the previous studies compared to the number of observations and service stations used in developing the data for this study

- o Earlier studies often included a mix of observations from both balance and aspirator-assisted Stage II vapor recovery systems. The technology of vapor recovery systems has evolved so that now the vast majority of Stage II systems are balance types. All the Stage II service stations from which observations were made during this study had balance systems
- o In previous studies, there was wide variation in the types of Stage II equipment. Through the process of evolution, the variation in equipment has become much narrower
- o The Stage II equipment in Washington D.C. is representative of the latest Stage II designs in that the majority of stations have coaxial dispensing hoses, which make the Stage II systems easier to use.

## 2.0 METHODOLOGY

### 2.1 Overview of Data Collection Methodology

Preparation for data collection followed two parallel paths as presented in Figure 2-1. The upper path illustrates the steps taken to select the service stations from which data would be collected. During these activities, the API served as an intermediary between EA Mueller and the member companies. The lower path illustrates the activities which were performed in preparation of data collection. These activities were performed in parallel themselves with feedback between development of the data collection forms and training of the data collection team members. Each of the activities presented as part of Figure 2-1 will be explained in detail in the following sections.

### 2.2 Selection of Service Stations

The Baltimore-Washington D.C. metropolitan area was chosen to conduct the test project for the following reasons:

- o All service stations in Washington D.C. have required Stage II refueling vapor recovery systems since July 1, 1977, ensuring that the population of typical gasoline service station customers should have considerable experience using the systems
- o The existence of conventional service stations in the surrounding area provided a population of service stations with similar demographics (location, profile of customers, etc.), from which a direct comparison of fuel spillage could be made.

Candidate service stations were nominated by representatives from API-member companies. While the entire service station selection process was directed by EA Mueller, the population of potential candidates was coordinated by the API, with the cooperation of member companies. Each individual company submitted

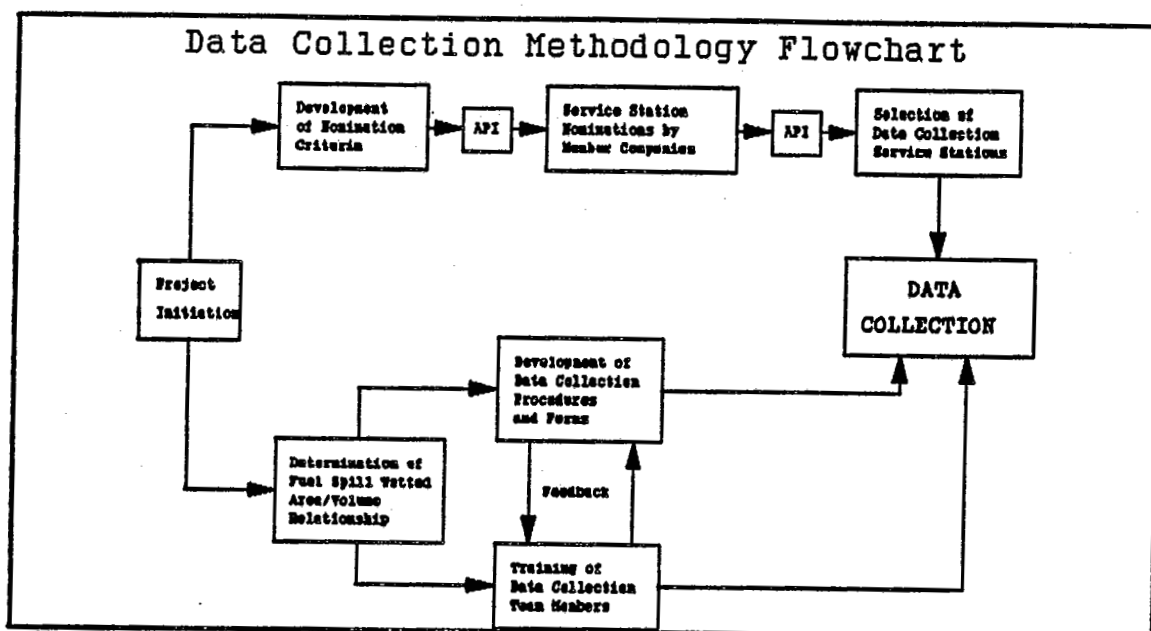


Figure 2-1. Flow Chart of Data Collection Activities

its own nominations without knowledge of other nominations. The individual service station nominations were delivered to EA Mueller through the API. The identity of the nominated service stations was kept confidential and known only to EA Mueller. During the data collection process, the service stations were identified by number only to minimize the chance that station identities would be revealed inadvertently.

The process of nominating appropriate service stations was initiated by defining a set of guidelines and constraints to be used by the participating companies. These guidelines and constraints as presented to the API member companies are listed in Table 2-1.

Table 2-1. SERVICE STATION NOMINATION GUIDELINES

- o Service Station Location: The Stage II service stations must be located in Washington D.C. Service stations without Stage II may be located in Baltimore City, Baltimore County, Arlington, Virginia, Alexandria, Virginia, or in the corridor between Baltimore and Washington D.C. However, to ensure a

good match with the Stage II service stations in Washington D.C., stations in Baltimore City are preferred, or stations with characteristics similar to those in Washington, D.C. If your company does not have any stations in Washington, D.C., make all your nominations from the areas specified for conventional service stations

- o Dispensing Equipment: The dispensing equipment should be in good working condition, e.g., no torn boots on Stage II nozzles, no leaking nozzles, no dispensers with abnormally high flow rates, etc.
- o Refueling Area: The area where the vehicles are refueled must be level and made of concrete and not asphalt
- o Certification: All Stage II systems must have a permit to operate by the appropriate local jurisdiction certifying that the system was installed properly
- o Payment Procedure: All stations should employ a "post-fill" payment procedure to minimize the number of controlled partial fills which rarely result in drips/spills at the end of refueling. (Note: This condition had to be revised during the study as will be explained in the following.)

Additionally, potential service stations were grouped into three profiles which related to average monthly dispensed fuel volume. Table 2-2 summarizes the service station nominations requested of each API-member company.

Table 2-2. SUMMARY OF REQUESTED SERVICE STATION NOMINATIONS

| <u>Station Profile</u> | <u>Monthly Volume (gallons)</u> | <u>Number of Stations Requested</u> |
|------------------------|---------------------------------|-------------------------------------|
| No. 1                  | >150,001                        | 6                                   |
| No. 2                  | 75,001-150,000                  | 4                                   |
| No. 3                  | <75,000                         | 4                                   |

Equal proportions between the number of Stage II and conventional stations and between busy morning and busy afternoon stations, if possible, were also requested.

Blank service station nominating forms were provided to the participating companies. [An example form (for stations with average monthly volumes over 150,000 gallons) is shown in Figure 2-2.] Forty service stations were selected for data collection from the returned nomination forms.

The populations of nominated service stations were sorted to identify pairs of like Stage II and conventional stations. The stations were first sorted into Stage II and conventional groups. These subsets were then sorted into numbered groups by generic profile. The last sorting step rearranged the listing of service stations in each group according to the number of hose outlets (i.e., the number of total dispensing hoses).

A matched pair of stations was then selected if there existed a Stage II and conventional station with the same profile numbers and equal or approximately equal number of hose outlets. The final set of selected stations consisted of ten profile No. 1 station pairs, nine profile No. 2 station pairs, and one profile No. 3 station pair. Although station brand was not a selection criterion, the resulting pairs included representation from all the five companies which submitted nominations.

All the service stations selected for data collection had dispensing equipment that was in good operating condition. Fifteen of the 20 Stage II stations in the study had coaxial dispensing hoses. Overhead connection of the dispensing hoses was the predominant configuration of the dispensing systems at both Stage II and conventional stations from which data was collected. The payment procedure predominant in both the Stage II and conventional service stations from which data was collected was found to be "prepay" instead of "postpay," as requested in the guidelines for nominating service stations. Stations with full service were included in both types of service station for data collection.

## SERVICE STATION PROFILE No. 1\* DATA COLLECTION FORM

Type: ☐ Conventional  
☐ Stage II

Time of Day When Most Busy: ☐ A.M.  
☐ P.M.

Total Number of Self Serve Unleaded Fuel Dispensers:

Total Number of Full Service Unleaded Fuel Dispensers:

Option to dial-in dollar amount of purchase  
before pumping: ☐ Yes  
☐ No

Station Manager Name:

Station Phone Number: (  )  -

Street Address of Station:

\*/ Average monthly volume over 150,000 gallons per month;  
Nominate 3 Stage II and 3 Conventional stations if possible,  
but 6 total.

Figure 2-2. Service Station Profile No. 1\* Data Collection Form

### 2.3 Determination of Fuel Wetted Area/Volume Relationship

The method selected to obtain data on fuel drips/spills from actual "real-world" refuelings with least disruption to the service station customer was to measure the wetted area left by the fuel. With this method, it is necessary to relate fuel wetted area to the volume of fuel dripped/spilled. Because of the importance of this wetted area/volume relationship, the characteristics of fuel drips/spills were studied extensively to design an effective data collection methodology (see Appendix A). This resulted in a decision to collect fuel wetted area/volume data from all 40 service stations from which drip/spill observations were taken (separate from the refueling observations). The reasons for this decision are summarized below:

- o Refueling pad surface condition was identified though pre-data-collection experimentation as one of the most significant factors affecting the fuel wetted area/volume relationship
- o Differences in fuel properties, although not found to be statistically significant to the fuel wetted area/volume relationship in sample tests, would be taken into account
- o Calibrations of fuel wetted area/volume relationships for each service station and/or for each fuel type were not justified or deemed necessary, given the amount of time and data required to develop accurate calibrations for each service station. Also, the experimentation with varying fuel properties indicated that the effect due to different fuel types would be small to insignificant
- o The accuracy of the observation techniques, which includes the observer estimation error discussed in Section 2.7, did not warrant the improvement in dripped/spilled fuel volume estimate accuracy which might be obtained by separate calibrations of fuel wetted area/volume relationships at each station.

When the data collection was completed, the results from the calibration tests were compiled and a regression analysis was performed. A good straight line least squares fit was found using

the natural log of the fuel drip/spill area and the natural log of the fuel drip/spill volume. The regression equation follows:

$$\ln \text{ volume} = 2.722 + 0.813 * \ln \text{ area},$$

where volume is in ml and area is in inches squared

The correlation coefficient for this straight line fit is 0.97. This linear relationship, along with an assumed gasoline density of 6.0 pounds per gallon, allowed a direct conversion from fuel drip/spill wetted area to drip/spill amount in grams.

A more detailed explanation of the entire process used to determine the fuel wetted area/volume relationship is presented in Appendix A. An example of the wetted area left by the fuel predicted by this equation is presented in Section 3 as Figure 3-1.

#### 2.4 Training of Data Collection Team Members

The five members of the data collection team were trained during a series of meetings and field training sessions. An initial project overview/objective meeting and two practice days at selected service stations (one Stage II and one conventional) were conducted. Each part of the data collection and calibration process was demonstrated and practiced by all of the team members. The practice days confirmed that it would not be possible to measure the wetted fuel drip/spill area directly for the following reasons:

- o Most of the small fuel drips/spills evaporated before the refueling process was completed. It was not possible to measure the small drips or spills directly with some type of measuring device without affecting the refueling process
- o Most of refueling drips/spills are small in diameter with dimensions which were easy to estimate with reasonable accuracy

- o Most large refueling drips/spills last long enough to allow direct measurement after the vehicle has left the refueling pad.

As a consequence of these findings, a decision was made to estimate the small drips or spills visually and to measure the large drips/spills directly, with a tape measure. It was also determined during the practice days that observing the refueling process from a distance did not significantly affect the refueling habits of typical service station customers, even though they often were aware of data collection team members presence.

Fuel wetted area estimation tests were conducted by initiating controlled releases of gasoline, having the team members estimate the wetted spot dimensions, and then measuring the actual wetted spot size. The purpose of this test was to refine the data collectors' ability to estimate fuel wetted area dimensions.

After the two field work training days, a second group meeting was held. At this meeting, the data collection process and forms were reviewed and updated based upon the experience gained from the practice days. The station schedule was presented and assignment of team members to specific service stations was made. The composition of the teams was varied over the duration of data collection, so that all of the team members were exposed to all types of both Stage II and conventional service stations. Team composition was changed at least every two days, and typically every day to prevent bias from developing due to working with the same team member over long periods.

## 2.5 Development of the Data Collection Procedures and Forms

Three objectives were sought in developing data collection procedures and forms: 1) maintain a uniform approach among the

team members in conducting the data collection procedures; 2) ensure consistency in the interest of reducing the number of errors; and 3) collect the data in an organized and efficient manner.

The forms used to guide the data collection procedure (presented in full as Appendix B) are summarized as follows:

- o Equipment Check List: A list of equipment required for the data collection process ensured that all the equipment necessary to conduct data collection was brought to each station
- o Station Set Up: Four brief guidelines to follow before beginning any data collection or calibration. Included is a recommendation for identifying the data collection team members to the station owner/manager and explaining the objective of the project.
- o Station Calibration:
  1. Directions on how to use the vapor return line backpressure testing equipment to measure the flow restriction in the vapor return line from the dispenser to the underground tank at Stage II stations.
  2. How to fill out the Station Equipment Check Form.
  3. How to complete the Station Calibration Data Form.
- o Data Collection: Instructions on how to complete the Refueling Observation Data Form (See Appendix B)
- o Response Statement: A statement used to respond to customers' inquiries related to observation of the data collection process, if asked (See Appendix B).

Group meetings among the team members were held before and after data collection training to review, discuss, and answer any questions pertaining to the procedure. A copy of the procedure (shown in Appendix B) was given to each team member.

A Station Calibration Form, Figure 2-3, was completed for each service station for which observations were taken. This form was used to collect fuel wetted area/volume calibration data (item No. 9) as described in Section 2.3.

A Station Equipment Check Form was also completed for each data collection service station. This form, as seen in Figure 2-4, is a record of the data from a visual check of the fuel dispensing equipment so that any obvious problems could be noted (it was also used to record Stage II dispensing outlet nozzle backpressure values).

The third form used in the data collection process was the Refueling Observation Data Form, Figure 2-5. One of these forms was completed for every observation. The most important data on this form are the descriptions of the sizes of drips or spills (item No. 10). The other information recorded on this form describes each refueling operation in great detail.

## 2.6 Data Collection

Data were collected from 20 Stage II and 20 conventional service stations during the period of October 3 through October 19, 1988. Other than having to reschedule a few planned visits to service stations, no obstacles to data collection were encountered at any of the service stations visited. Data collection was not possible during rainy weather because fuel wetted areas were not visible on wet concrete.

The team members were assigned to collect data from the service stations in teams of two. The team members were scheduled so that each rotated between type of service station (Stage II and conventional) and among the other data collection team members.

## STATION CALIBRATION DATA FORM

1. Station ID \_\_\_\_\_

2. Observer \_\_\_\_\_

3. Date \_\_\_\_\_

4. Preset Capabilities (Y/N)? \_\_\_\_\_

5. Time \_\_\_\_\_

6. Weather:

a. Sunny ☐ or Cloudy ☐

b. Windy ☐

c. Raining ☐

7. Surface Material \_\_\_\_\_

8. Flow Rate:

|               | Amount (Gal) | Time (Sec) |
|---------------|--------------|------------|
| a. Pump _____ |              |            |
| b. Pump _____ |              |            |
| c. Pump _____ |              |            |

9. Spot Size Calibration:

a. Location \_\_\_\_\_

b. Volume (ML)                      Spot Size (inches)

1 \_\_\_\_\_

2 \_\_\_\_\_

3 \_\_\_\_\_

4 \_\_\_\_\_

5 \_\_\_\_\_

10 \_\_\_\_\_

25 \_\_\_\_\_

50 \_\_\_\_\_

10. Air Temperature Readings:

| <u>Time</u> | <u>Temperature</u> |
|-------------|--------------------|
| _____       | _____              |
| _____       | _____              |
| _____       | _____              |
| _____       | _____              |

Figure 2-3. Station Calibration Form

| STATION ID             | DATE | OBSERVER |
|------------------------|------|----------|
| PUMP 6                 |      |          |
| BACOPRESSURE TEST      |      |          |
| VALUE                  |      |          |
| TOP OF BOOT SPLIT      |      |          |
| CRACKED OR PUNCTURED   |      |          |
| BOTTOM OF BOOT SPLIT   |      |          |
| CRACKED OR PUNCTURED   |      |          |
| BOOT LOOSE             |      |          |
| SEAL/BASKET MISSING    |      |          |
| OR LOOSE               |      |          |
| SHUT OFF HOLE          |      |          |
| NOT ON BOTTOM          |      |          |
| NOZZLE LOOSE           |      |          |
| ROSE TO PUMP           |      |          |
| DAMAGED                |      |          |
| OVERHEAD HOSES         |      |          |
| LATCH CAPABILITY       |      |          |
| PARALLEL               |      |          |
| SLOPE (DEGREES)        |      |          |
| PERPENDICULAR          |      |          |
| SLOPE (DEGREES)        |      |          |
| UNCONTROLLED STATIONS  |      |          |
| NO SHIELD/SPLASH GUARD |      |          |
| OTHER:                 |      |          |
| OTHER:                 |      |          |

\* only as required + stage 2 stations only

Figure 2-4. Station Equipment Check Form

1. Station ID \_\_\_\_\_

2. Observer \_\_\_\_\_

3. Date \_\_\_\_\_

4. Weather:

a. Sunny ☐ or Cloudy ☐

b. Windy ☐

c. Raining ☐

5. Stage II ☐ Conventional ☐

6. Time \_\_\_\_\_

7. Pump # \_\_\_\_\_

8. a. Self Serve ☐ or Full Serve ☐

b. PREPAY ☐ or POSTPAY ☐

9. Vehicle:

a. Passenger Car ☐ or Pickup ☐ Van ☐

b. Make \_\_\_\_\_

c. Model \_\_\_\_\_

d. Rear Fill ☐ or Side Fill ☐

e. If side fill, dispenser on: \_\_\_\_\_ or Opposite side ☐

10. Spill Description: (Check all that apply)

|                     | BEFORE | DURING | AFTER |
|---------------------|--------|--------|-------|
| Overflow            | XXXXXX | _____  | XXXXX |
| Spitback            | XXXXXX | _____  | XXXXX |
| Dripped from nozzle | _____  | _____  | _____ |
| Other               | _____  | _____  | _____ |

REMARKS:

11. Refueling Procedures: (CHECK ALL THAT APPLY)

No Wait ☐ Some Wait ☐ 10 Second/10 sec Wait ☐

Upside down/Sideways ☐

Topping off ☐ # of clicks \_\_\_\_\_

Latched ☐

Other ☐

REMARKS:

12. Miscellaneous Information:

Aggressive Behavior ☐

Difficulty with Equipment ☐

REMARKS:

13. Sales:

Same side ☐ or Opposite side ☐

Total Fuel Dispensed \_\_\_\_\_

\$ Amount \_\_\_\_\_ Driveway ☐

Figure 2-5. Refueling Observation Data Form

There were five data collection team members, four of whom did most of the data collection while the fifth member served as an alternate when necessary. Each team member experienced each type of station and worked with all the other team members.

As explained in Section 2.2, the service stations were placed in three different sizes. The schedule of data collection varied the size of the service stations within each type of service station (Stage II and conventional).

## 2.7 Determination of Observer Estimation Error

Even though the team members were trained to estimate fuel spill or drip dimensions as accurately as possible, and the data collection period was short (two and one-half weeks), EA Mueller felt it was desirable to measure the estimation accuracy of the team as a whole after the data collection process was completed. In a manner similar to the fuel wetted area training tests described in Section 2.5, different dripped/spilled fuel spot sizes were created for the data collectors to estimate. The difference from the earlier fuel wetted area estimation testing was that during this test the team members were not told the volume dripped/spilled or the correct fuel wetted area sizes after the drip/spill.

Twenty-four fuel drips/spills of volumes typical of those observed during the project were created by an individual who was not a member of the data collection team. Observers estimated fuel wetted area and the data were reduced to correlate the estimated areas with the actual volume of fuel dripped/spilled. The five team members as a whole underestimated the wetted areas by an average of 17 percent. The standard deviation of the wetted area estimation errors was also 17 percent.

A few points about the observer estimation error should be noted. First, it is assumed that the observers began the data collection period with very accurate estimation capabilities, and that this learned capability declined over time. Secondly, during the actual data collection process, the larger drips/spills (which are most difficult to estimate accurately) remained visible after the customer left the service station. This allowed the team members to measure accurately the area of large drips/spills using a tape measure in most of these cases. Thus, it is believed that the estimation error of 17 percent represents a worse case scenario and is more applicable to the smaller drip/spill sizes.

## 2.8 Data Analysis Procedures

Four different statistical analysis methods were used to evaluate the data collected; descriptive statistics, frequency plots, chi-squared tests, and T-tests. The application of these methods are summarized below:

- o Descriptive statistics include variables such as number of occurrences, mean, and standard deviation, among others
- o Frequency plots were drawn when evaluating the differences in drips and spills between the two types of service stations
- o Chi-squared tests were performed to identify differences in the frequency of drips and/or spills between Stage II and conventional service stations
- o T-tests were used to test the difference in the average amounts of drips and/or spills between Stage II and conventional stations.

### 3.0 RESULTS

#### 3.1 Introduction

This section presents a summary of the data collected and the analyses performed. Refueling observations were made at 20 Stage II facilities in Washington D.C. and 20 comparable conventional facilities in Baltimore. Statistical analyses were performed on both the frequency of drip/spill occurrences and the average drip/spill amount for Stage II facilities compared to conventional facilities. Further statistical analyses were performed on refueling characteristics to identify customer habits which may contribute to drip/spill frequency and amount.

#### 3.2 Summary of Data Populations

Table 3-1 summarizes the populations of refueling observations taken from both the Stage II and conventional stations. As Table 3-1 illustrates, the Stage II and conventional refueling observation populations are similar in size, a result of the experimental design which called for spending equal times for data collection at both types of stations. However, it also suggests that the frequency of usage of both types of stations was similar overall for the groups of stations chosen to be observed.

Table 3-1. SUMMARY OF REFUELING OBSERVATION POPULATIONS

|              | <u>Number of<br/>Observations</u> | <u>Number of<br/>Drips/Spills</u> | <u>Percentage of<br/>Observations</u> |
|--------------|-----------------------------------|-----------------------------------|---------------------------------------|
| Stage II     | 1278                              | 848                               | 66.4                                  |
| Conventional | <u>1357</u>                       | <u>857</u>                        | 63.2                                  |
| Total        | 2635                              | 1705                              | 64.7                                  |

Table 3-2 lists the percentages of the refueling observations by the type of release of fuel observed. Table 3-2 suggests that the principal difference in the observations from both types of

stations is seen to be a substantially higher frequency of occurrences of fuel releases greater than 0.1 grams per refueling event at the Stage II stations. The differences between the fuel releases at the Stage II and conventional stations will be compared in detail later in this section.

TABLE 3-2. PERCENTAGE DISTRIBUTION OF TOTAL REFUELING OBSERVATIONS

| <u>Type of Release</u>              | <u>Type of Facility</u> |                     |
|-------------------------------------|-------------------------|---------------------|
|                                     | <u>Stage II</u>         | <u>Conventional</u> |
| None                                | 33                      | 37                  |
| Drips ( $\leq 0.1$ gram)            | 33                      | 41                  |
| Drips and/or Spills ( $> 0.1$ gram) | 34                      | 22                  |

All liquid fuel releases before, during, and after the flow of fuel during vehicle refueling were observed. The majority of these releases were very small, as illustrated in Figure 3-1. (The

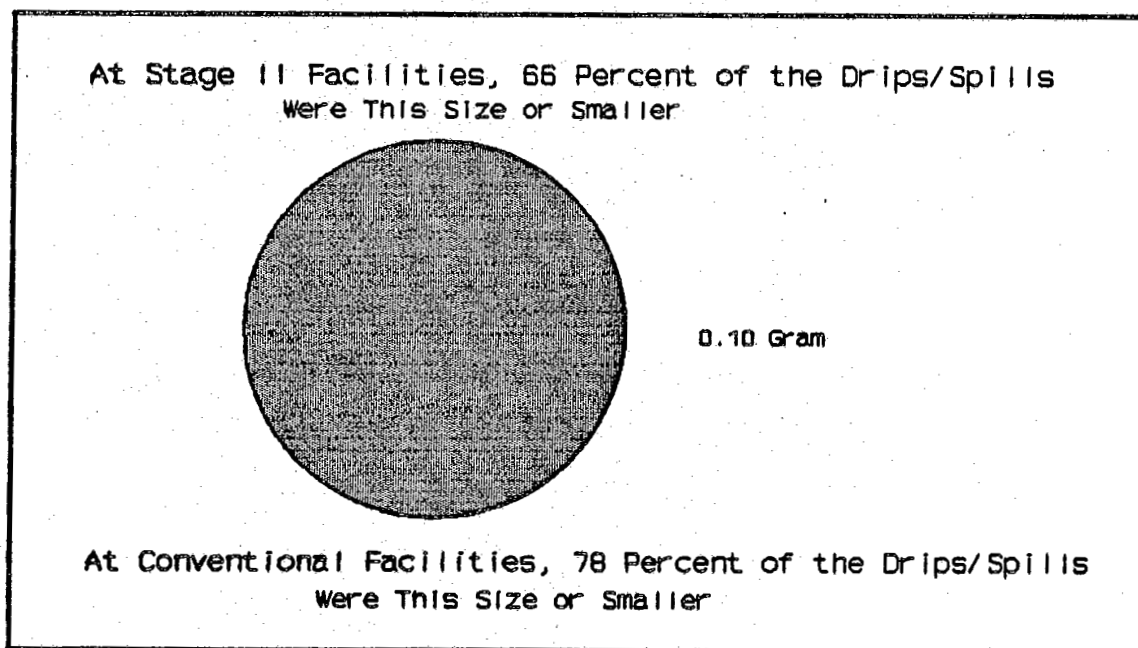


Figure 3-1. Drip Area Representation

area of the spot in Figure 3-1 is predicted based on the linear regression developed between fuel volume and wetted area presented in Appendix A. The observers in the field estimated fuel wetted area by the diameter of the spot left on the refueling apron, which was translated into volume by the linear regression.) These very small releases were caused exclusively by drips of fuel. Before refueling, the drips were primarily from fuel which was present in the nozzle from the previous refueling. As the customer lowered the nozzle to the vehicle filler, fuel, if present in the nozzle, would drip out onto the refueling apron. Drips of fuel released during refueling were typically carried along with the fuel vapor expelled from the filler tube for refuelings at conventional stations and from an incomplete interface between the nozzle boot and the filler at Stage II stations. Drips of fuel released after refueling were typically due to fuel which was clinging to both the inside and outside of the nozzle, similar to when a straw is withdrawn from a glass of water. The number of drops of fuel released after refueling was often a function of the care with which the customer removed the nozzle from the filler and replaced it in the dispenser. This concern by the customer could be nullified by the next customer if he/she allowed the nozzle to point downward before insertion in the filler, causing the fuel inside the nozzle spout to drip out (a "before refueling" release).

It can be said with near absolute certainty that all the fuel releases equal to or smaller than 0.1 gram were drips. Even releases totaling more than 0.1 gram were often a collection of drips. (It should be noted that the data presented is the total fuel released for a given type of release. Only the total amount of fuel released is reported and was used in the analyses, even though it may have been caused by multiple drips of fuel.) The instances in which liquid fuel actually splashed to the ground were very rare. This is illustrated by Figures 3-2, 3-3, and 3-4. Figure 3-2 presents the cumulative percentage of refueling observations for both Stage II and conventional stations as a

function of the amount of fuel dripped/spilled per refueling observation (including zero drips/spills). This illustrates that a larger percentage of the drips/spills at conventional stations were small compared to the drips/spills at Stage II stations. Figure 3-3 presents the cumulative percentage of fuel releases for both Stage II and conventional stations as a function of the amount of fuel dripped/spilled per refueling observation. This illustrates that of the total fuel releases observed, a larger percentage of the releases at Stage II stations came from larger releases dripped/spilled instead of smaller ones, compared to conventional stations. The differences between the Stage II and conventional station fuel releases are further illustrated in Figure 3-4, which compares the percentage of total refuelings in terms of grams per drip/spill. Figure 3-4 clearly shows that the percentage of fuel releases at small fuel drip/spill amounts for conventional stations was higher compared to Stage II stations.

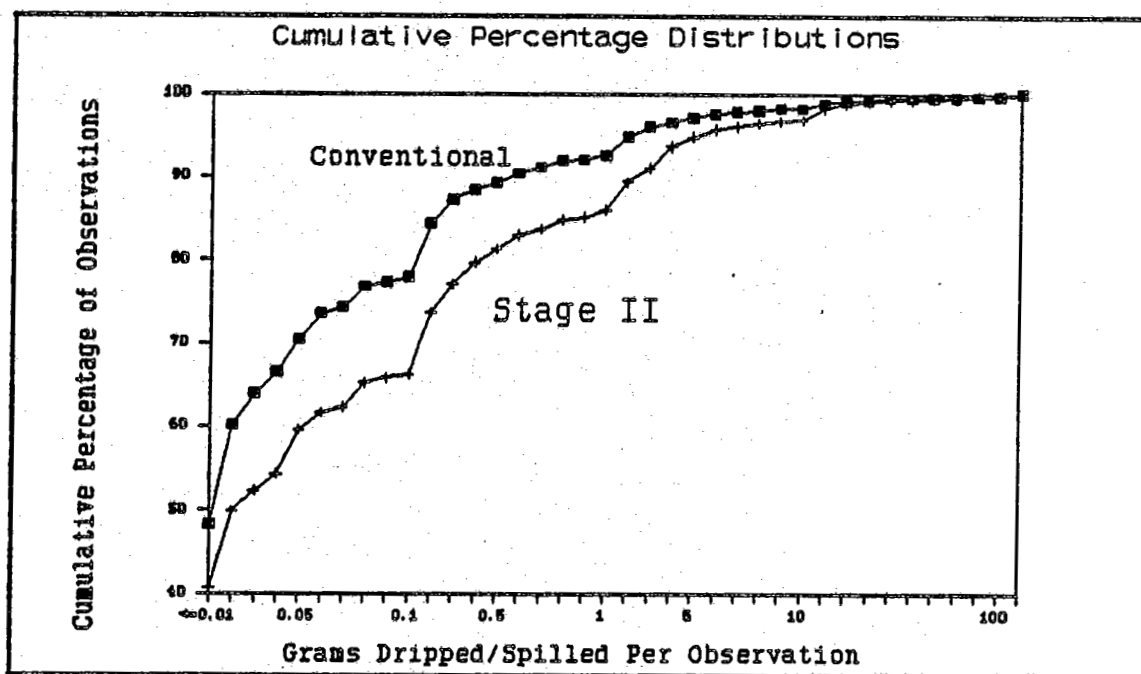


Figure 3-2. Cumulative Percentage Observations by Amount of Fuel Released

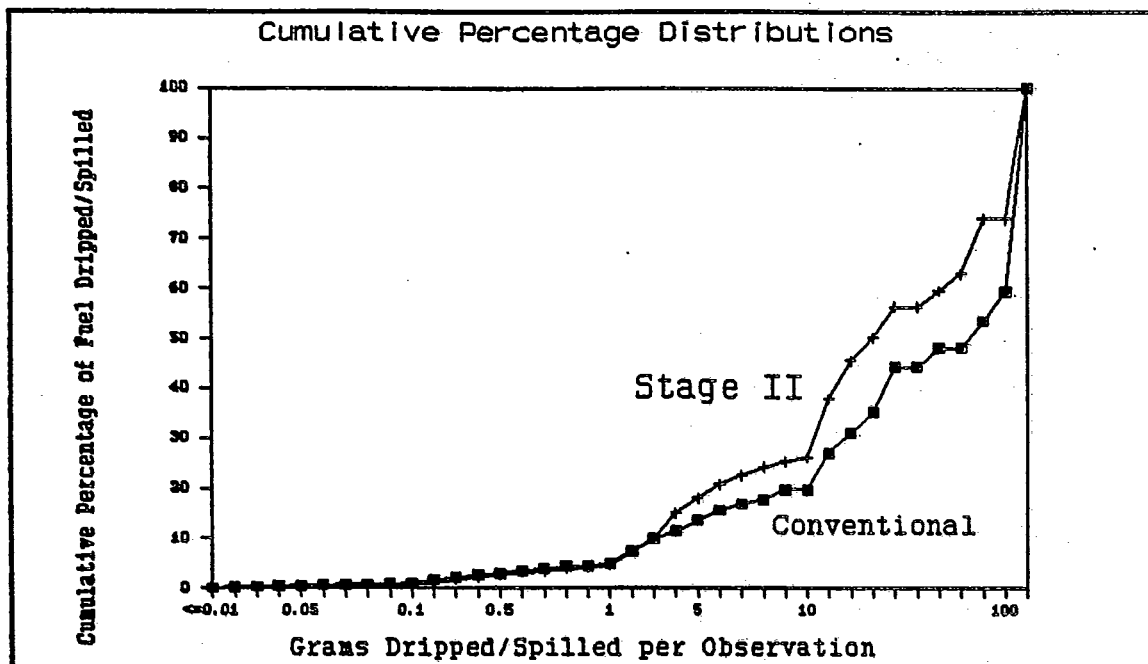


Figure 3-3. Cumulative Percentage Fuel Releases by Amount Released

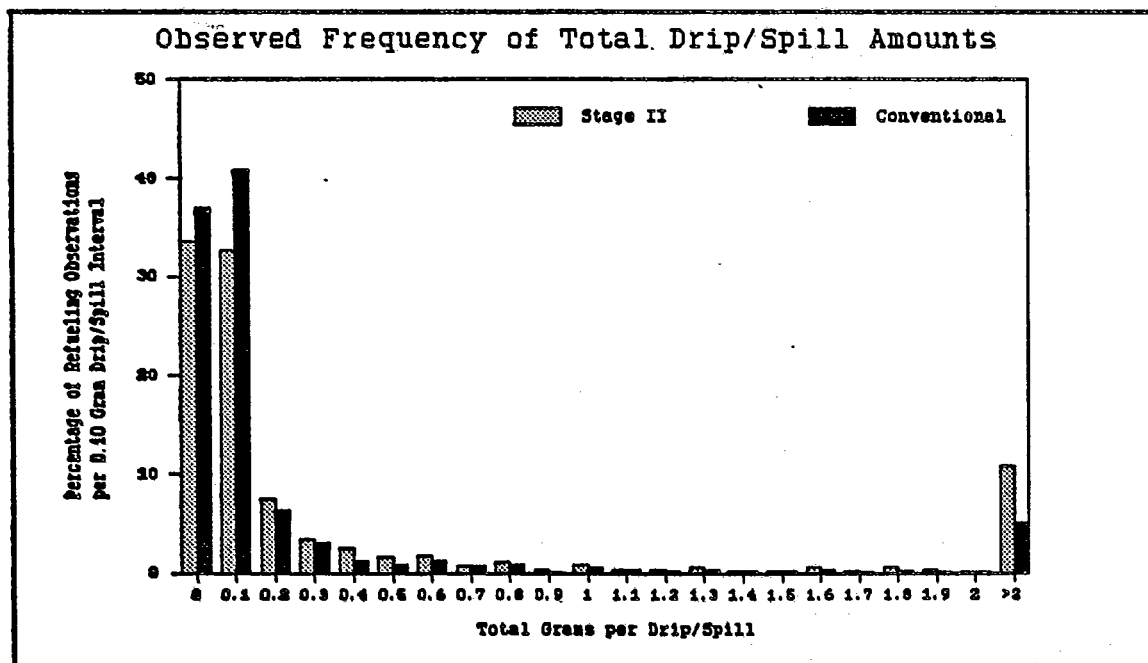


Figure 3-4. Distribution of Refuelings as a Function of Amount of Fuel Released

Conversely, the percentage of fuel releases at fuel release amounts greater than two grams was lower for conventional stations compared to Stage II stations.

The frequency plots for the amount of fuel dispensed at the Stage II and conventional stations are shown in Figures 3-5 and 3-6. Both plots have bi-modal distributions around five and 10 gallons dispensed. This corresponds to the frequently observed even dollar purchases of \$5.00 and \$10.00, as the typical price of gasoline during the time of data collection was near \$1 per gallon. The average amount of fuel dispensed from the Stage II stations was 7.8 gallons and the average amount from the conventional stations was 8.6 gallons. These differences were found to be strongly statistically significant (T-value of 4.84) at a very small probability level (P-value of less than 0.0001). The total amount of fuel dispensed at Stage II stations for the observed refuelings was 9,852 gallons, while 11,604 gallons were dispensed at conventional stations for the refuelings observed.

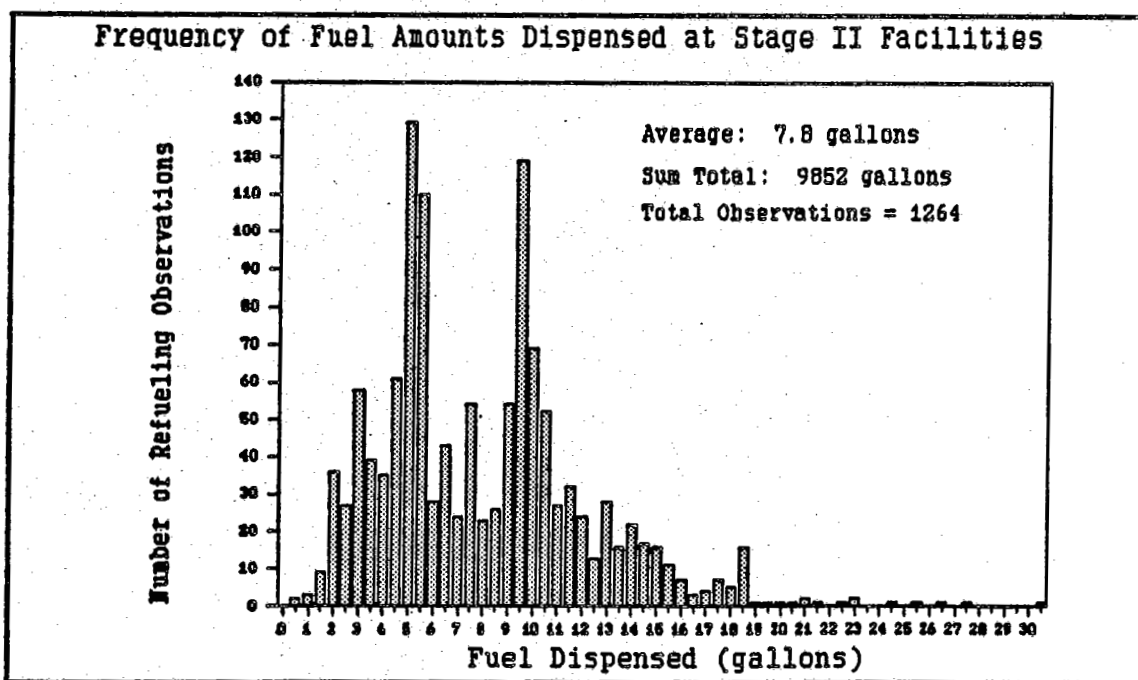


Figure 3-5. Stage II Fuel Dispensed Distribution

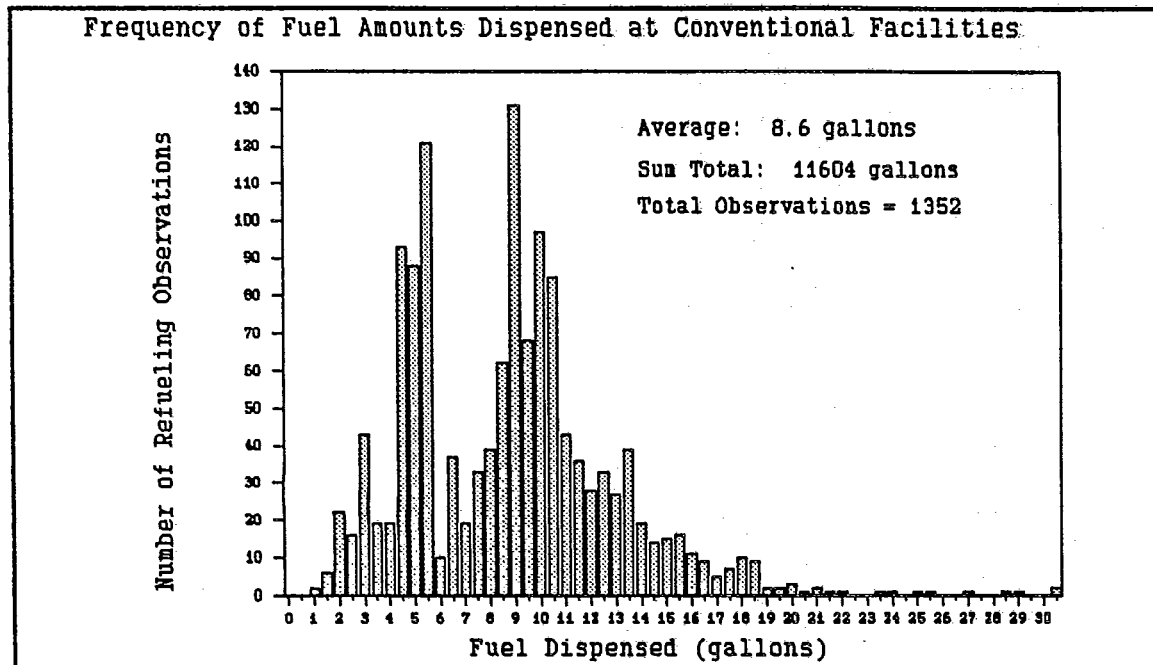


Figure 3-6. Conventional Fuel Dispensed Distribution

### 3.2.1. Statistical Analysis of Total Data Populations

The frequency of all the drips/spills together at both Stage II and conventional facilities was compared using the Chi-square test and the following null hypothesis:

There is not a significant difference between the frequency of fuel drips/spills during refuelings at Stage II and conventional service stations.

The above hypothesis is rejected. As Table 3-3 shows, there is a significant difference in the frequency of spills between Stage II and conventional facilities such that the probability of drips/spills is greater at Stage II stations compared to conventional stations.

Table 3-3. DRIP/SPILL FREQUENCY CHI-SQUARE TEST RESULTS

| Type of<br>Drip/spill           | Number of Drips/spills |              | Chi-Square | Probability<br>of Chance* |
|---------------------------------|------------------------|--------------|------------|---------------------------|
|                                 | Stage II               | Conventional |            |                           |
| All<br>Drips/spills<br>Together | 848                    | 857          | 3.37       | 0.06                      |

\* Probabilities of less than 0.10 are considered significant

The amount of fuel dripped/spilled was calculated in three ways: 1) in grams per refueling, 2) grams per gallon fuel dispensed, and 3) grams per observation in which drips/spills occurred. The analysis of the total drip/spill amounts between Stage II and conventional stations was conducted using the T-test and the following null hypothesis:

There is not a significant difference between the average drip/spill amounts for refuelings made at Stage II and conventional service stations.

Table 3-4 summarizes the results obtained. (Appendix E contains additional data about these T-test results.)

Table 3-4. AVERAGE DRIP/SPILL AMOUNT T-TEST RESULTS FOR THE TOTAL POPULATIONS OF STAGE II AND CONVENTIONAL STATIONS

| Type of<br>Drip/spill                        | Difference<br>Stage II-Conventional | t-Statistic | Probability<br>of t* |
|----------------------------------------------|-------------------------------------|-------------|----------------------|
| All Observations<br>(gm/refueling)           | 1.74-1.20 = 0.54                    | 1.33        | 0.18                 |
| All Observations<br>(gm/gallon<br>dispensed) | 0.23-0.14 = 0.09                    | 2.36        | 0.02                 |
| All Drips/spills<br>(gm/drip/spill)          | 2.61-1.90 = 0.71                    | 1.14        | 0.25                 |

\* Probabilities of less than 0.10 are considered significant

Of these three drip/spill groupings, only the difference in the average amount of gasoline dripped/spilled per gallon of fuel dispensed was statistically significant between refuelings observed at the Stage II service stations compared to the observations at the conventional stations. This result is believed to be dependent on the statistically significant difference in the average amount of gasoline dispensed between the Stage II and conventional station refuelings observed. Since more gasoline on average was dispensed per refueling at the conventional service stations (8.6 gallons) than at the Stage II service stations (7.8 gallons), the average amount of gasoline dripped/spilled per gallon of gasoline dispensed would be lower for the conventional stations compared to the Stage II stations. However, to the extent that refueling behavior at the stations surveyed in this study is typical of differences in refueling characteristics between Stage II and conventional facilities observed elsewhere in the country, these results reflect real differences between Stage II and conventional facilities.

The reasons for difference in the amount of fuel released between Stage II and conventional stations was explored by examining refueling characteristics within type of facility. The refueling characteristics explored included topping-off the fuel tank placement of the refueling filler (side or rear), orientation of the nozzle during refueling during refueling (right side up or up side down), whether the customer drove away after refueling without filling the tank completely and whether the customer latched the nozzle when refueling.

Topping-off the tank at the end of refueling is not a recommended practice. There are warnings against it in the instructions at the dispensers at Stage II facilities. Nevertheless, topping-off was observed in 20.2 percent of the conventional refueling observations, and 14.8 percent of the Stage

II refuelings. The practice increases the amount of fuel dispensed during a given refueling event. Figures 3-7 and 3-8 illustrate the cumulative percentage of fuel dripped/spilled for top-off and non-top-off refueling observations at Stage II and conventional stations, respectively. Both show that the refuelings in which the customer did not top-off were higher in percentage at the smaller dripped/spilled amounts. Each of the refueling characteristics was tested in terms of grams of fuel dripped/spilled using the T-test and the following null hypothesis:

There is not a significant difference between the average drip/spill amount for the alternative possibilities of a given refueling characteristic.

Table 3-5 lists the results of the T-tests in grams per refueling event. All the refueling characteristics were statistically significant except for latching the nozzle and

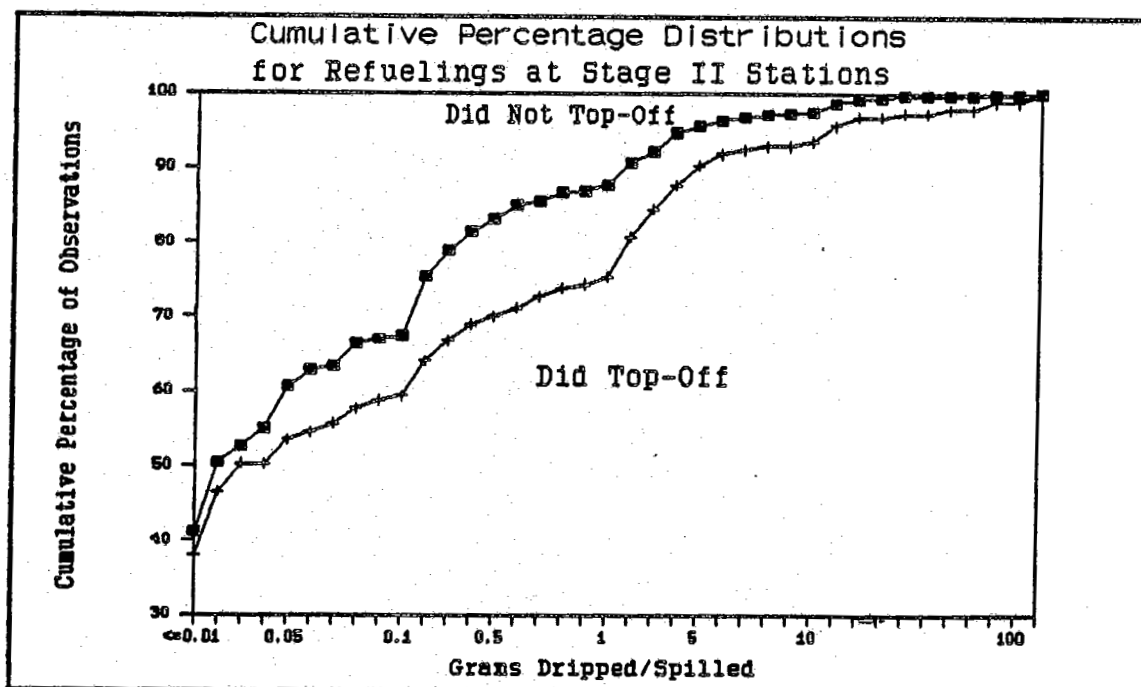


Figure 3-7. Stage II Cumulative Percentage of Fuel Dripped/Spilled For Top-Off and Non-Top-Off

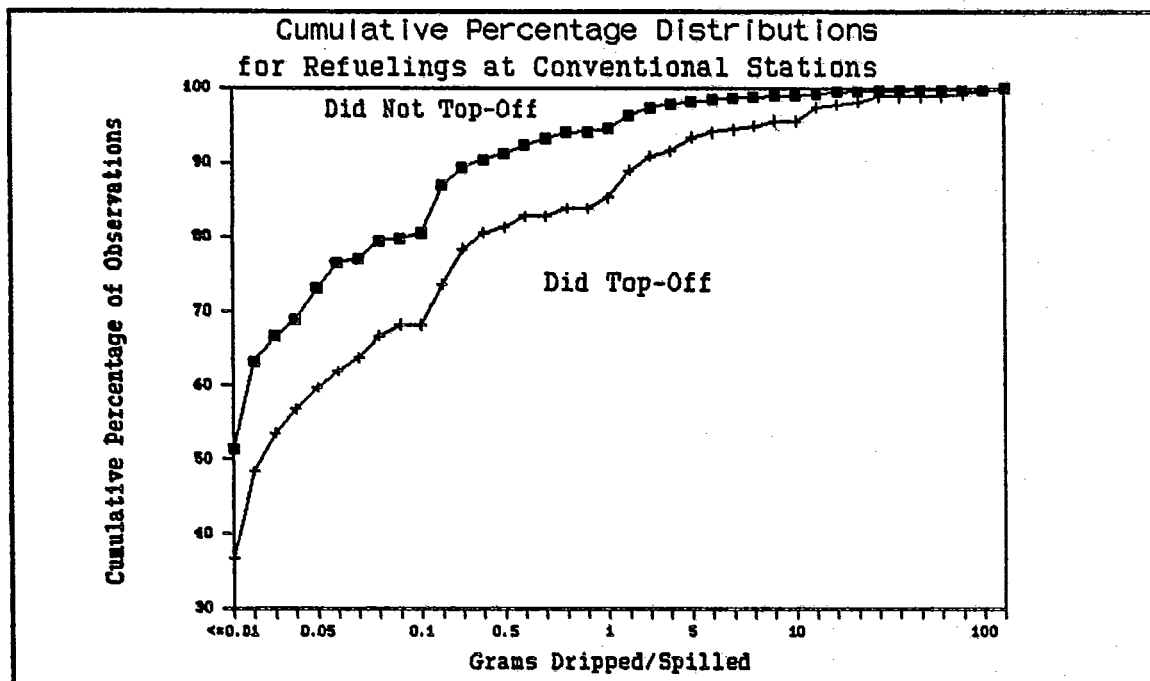


Figure 3-8. Conventional Cumulative Percentage of Fuel Dripped/Spilled For Top-Off and Non-Top-Off

placement of the filler at Stage II facilities. (Nozzle orientation at Stage II stations was extremely close to being statistically significant and will be considered to be.) It is believed that each of these characteristics contributes to the difference in grams released per gallon fuel dispensed at both Stage II and conventional facilities. Of these characteristics, topping-off and nozzle orientation appear to be the most important in terms of average fuel released and statistical significance of the differences.

Table 3-5. AVERAGE RELEASE IN GRAMS PER REFUELING EVENT FOR DIFFERENT REFUELING CHARACTERISTICS

| <u>Type of Facility</u> | <u>Top-Off</u> |           | <u>t-statistic</u> | <u>Probability of t*</u> |
|-------------------------|----------------|-----------|--------------------|--------------------------|
|                         | <u>Yes</u>     | <u>No</u> |                    |                          |
| Stage II                | 3.6            | 1.4       | 3.29               | 0.0010                   |
| Conventional            | 2.4            | 0.9       | 2.20               | 0.0282                   |