American Petroleum Institute

STEP Strategies for Today's Environmental Partnership

A Study to Characterize Air Concentrations of Methyl Tertiary Butyl Ether (MTBE) at Service Stations in the Northeast

Health and Environmental Sciences Department
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A Study to Characterize Air Concentrations of Methyl Tertiary Butyl Ether (MTBE) at Service Stations in the Northeast

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PREFACE

Preliminary findings from a presentation on MTBE made by Ted Johnson to the U. S Environmental Protection Agency (EPA) are included as an attachment to this report. The presentation was made at the EPA Conference, **MTBE and Other Oxygenates: A Research Update**, July 26-28, 1993 in Falls Church, VA. The attachment contains additional information -- a presentation summary and copies of projection transparencies for inclusion in the conference proceedings. It has been included solely for the convenience of the reader.

ABSTRACT

The compound methyl tertiary butyl ether (MTBE) is routinely added to gasoline during the winter driving season to reduce carbon monoxide (CO) emissions from motor vehicles in CO nonattainment areas. In 1992, the U.S. Environmental Protection Agency (EPA) began receiving anecdotal complaints of headaches, nausea, and other symptoms following alleged wintertime exposures to MTBE in fuels. EPA solicited estimates of typical air concentrations of MTBE that motorists and attendants might experience during refueling at service stations that dispense gasoline containing MTBE. In response, the American Petroleum Institute (API) funded breathing zone, pump island and station perimeter measurements of ambient MTBE concentrations at 10 service stations in the New York metropolitan area in April 1993. Air samples were also analyzed for BTEX (benzene, toluene, ethylbenzene, xylene), THC (total hydrocarbons), CO and formaldehyde. Field personnel monitored meteorological parameters, gasoline composition (oxygenate content, Reid vapor pressure, BTEX), and gasoline sales and deliveries during each sampling period. Personnel also noted the time each vehicle was refueled and conducted regular counts of traffic on nearby roadways. The principal findings of the study are summarized below:

1. Mean and maximum four-hour average MTBE concentrations generally decrease from breathing zone to pump island to perimeter, suggesting that refueling activities are the principal source of MTBE measured at service stations, and MTBE concentrations are generally lower at stations with Stage II vapor controls.

2. Median four-hour average MTBE concentrations for all stations are below 2 ppm at breathing zone and pump island locations and below 0.02 ppm at the station perimeters.

3. Maximum four-hour average MTBE concentrations are below 2.6 ppm at breathing zone and pump island locations and below 0.2 ppm at station perimeters.

4. Because the canisters also sampled nonrefueling periods, breathing zone measurements may underestimate actual breathing zone concentrations during fuel dispensing by station-specific factors ranging from 1 to 3. Most factors fall between 1.0 and 1.4.

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EXECUTIVE SUMMARY

In 1992, the U.S. Environmental Protection Agency (EPA) began receiving anecdotal complaints of headaches, nausea, and other symptoms following alleged wintertime exposures to methyl tertiary butyl ether (MTBE) in fuels. In early 1993, EPA began a series of clinical research studies to investigate the validity of these claims. To properly design these studies, EPA solicited estimates of typical air concentrations of MTBE that motorists and attendants may experience during refueling at service stations that dispense gasoline containing MTBE. EPA also expressed interest in determining typical MTBE concentrations at the property boundaries of these service stations.

In response to these needs, the American Petroleum Institute (API) funded a field study in which IT Air Quality Services (ITAQS) measured ambient MTBE concentrations at ten service stations in the New York metropolitan area. The stations included:

1. Two full-service stations with Stage II vapor recovery on a commuting route near East Brunswick, New Jersey;

2. Three self-service stations with Stage II vapor recovery in Westchester County, New York; and

3. Five self-service stations without Stage II vapor recovery in Fairfield County, Connecticut.

The selection of full-service stations in New Jersey was unavoidable, as self-service stations are not permitted in that state.

Each station was sampled on a separate day between April 7, 1993 and April 23, 1993. The monitoring activities at each station were conducted during two four-hour periods, nominally 9 a.m. to 12 a.m. and 2 p.m. to 6 p.m. Four-hour canister and impinger samples were collected at four perimeter locations (north, east, south, and west) and one pump location at each station, in customer breathing zones at the New

York and Connecticut stations, and in attendant breathing zones at the New Jersey stations. In addition, four-hour charcoal tube samples were collected in the breathing zones of all stations. These samples were analyzed to determine air concentrations of MTBE, BTEX (benzene, toluene, ethyl benzene, xylene), total hydrocarbon (THC) concentration, and formaldehyde.

Continuous carbon monoxide measurements were made in the pump area of each station using a Metrosonics® pm-7700 monitor. Organic vapor analyzers (OVA) were used to continuously monitor THC concentrations in the pump areas and breathing zones. These measurements were made as a means of identifying individual refueling events which could not be distinguished in the four-hour samples collected by the canister samplers.

Field personnel monitored meteorological parameters, gasoline composition (oxygenate content, Reid vapor pressure, BTEX), and gasoline sales as well as deliveries during each sampling period. Personnel also noted the time each vehicle was refueled and conducted regular counts of traffic on nearby roadways. Gasoline pumping activities were continuously recorded by a stationary video camera.

Statistical analyses of the data obtained from the field monitoring activities support the following general findings.

1. Mean and maximum four-hour average MTBE concentrations generally decrease from breathing zone to pump island to perimeter, suggesting that refueling activities are the principal source of MTBE measured at service stations.

2. MTBE concentrations are generally lower at stations with Stage II vapor controls.

3. Median four-hour MTBE concentrations for all stations are below 2 ppm at breathing zone and pump island locations and below 0.02 ppm at the station perimeters.

4. Maximum four-hour MTBE concentrations for all stations are below 2.6 ppm at breathing zone and pump island locations and below 0.2 ppm at station perimeters.

5. For all stations, because the canisters also sampled nonrefueling periods, breathing zone measurements of MTBE concentration may underestimate actual breathing zone concentrations during fuel dispensing by station-specific factors ranging from 1 to 3. Most factors fall between 1.0 and 1.4.

A series of special statistical analyses were performed to identify patterns in the individual component data and to compare sampling methodologies. An analysis of concentration ratios (the ratio of MTBE to a second component) found that ratios were generally larger for pump and breathing zone canister samples than for perimeter canister samples. This pattern suggests that refueling operations were the principal source of MTBE at each station, whereas other sources (e.g., local traffic) contributed significantly to the levels of BTEX and THC.

The results of stepwise regression analyses performed on the four-hour canister data indicate that MTBE concentration can be predicted well (R^2 = 0.886) as a linear function of simultaneously-measured concentrations of benzene, toluene, ethyl benzene, and THC. Of these four predictors, benzene provides the best single means of predicting MTBE concentration. Benzene also provides the best prediction of toluene and THC concentration. Toluene is the best predictor of ethyl benzene concentration.

Other stepwise regression analyses were performed on the four-hour canister measurements to identify factors that potentially affect component concentration values. The analyses suggest that following conditions are associated with an increase in MTBE concentration:

- Measurements are made at pump island or breathing zone locations rather than perimeter locations;

- Measurements are made at a Connecticut station (i.e., a station with no Stage II vapor recovery) rather than a New York or New Jersey station;
- Low wind speed;
- High traffic on nearby roads.

Analysts also attempted to identify possible conditions that could explain fourteen high MTBE values. Seven of the 14 values were found to be associated with the combination of two unusual conditions: (1) average wind speed less than 3 mph and (2) number of serviced vehicles exceeded 115. Four of the high values were associated with spills or overflows, two were associated with cumulative street traffic exceeding 10,000 vehicles, and three were associated with average gasoline dispensing rates exceeding 325 gallons/hour. Active use of garage bays may have contributed to two of the high values. Other potential events that may be relevant include a gasoline delivery and a vehicle running during refueling.

Although the field study was conducted primarily to obtain representative air concentrations of MTBE at service stations, the collected data also provide a means for comparing canisters and charcoal tubes. These sampling methodologies are routinely used in chemical exposure studies. The data base contains 20 cases in which canister and charcoal tube samples were collected at the same location for the same time period. An analysis of the 14 cases in which MTBE concentrations exceeded the limit of detection for both sampling methodologies found that the ratio of canister MTBE to tube MTBE ranged from 0.52 to 9.74. Fifty percent of the canister-to-tube ratios were between 0.62 and 1.17; the median ratio was 1.00.

Ten pairs of duplicate samples were collected using canister samplers, and ten pairs were collected using impinger samples. The median percent difference in concentration between the duplicate measurements was 21.8 percent for MTBE, 12.2 percent for benzene, 19.4 percent for toluene, 30.5 percent for ethyl benzene, 11.8 percent for xylene, and 19.0 percent for formaldehyde. Note that duplicate pairs

containing values below the detection limit were not considered in calculating these values.

During the ITAQS service station study, an independent research team headed by Dr. Paul Lioy of the Environmental and Occupational Health Sciences Institute (EOHSI) collected air samples in the passenger compartments of automobiles during typical home-to-work commutes (manuscript in preparation). Selected automobiles in the Lioy study were refueled at stations included in the service station study. Breathing zone MTBE concentrations measured by the EOHSI team during these refueling events were comparable to breathing zone measurements made by the ITAQS team.

Section 1
INTRODUCTION

The compound methyl tertiary butyl ether (MTBE) is routinely added to gasoline during the winter driving season to reduce carbon monoxide (CO) emissions from motor vehicles. In 1992, the U. S. Environmental Protection Agency (EPA) began receiving anecdotal complaints about headaches, nausea, and other symptoms following alleged exposure to MTBE. In early 1993, EPA began planning a series of clinical research studies to investigate the validity of these claims. To properly design these studies, EPA solicited data which could be used to estimate the MTBE exposures of motorists during refueling at service stations that dispense gasoline containing MTBE. EPA also expressed interest in determining typical "fenceline" concentrations of MTBE at service stations. In response to these needs, the American Petroleum Institute (API) supported two related studies in the New York Metro area: a service station study conducted by IT Air Quality Services (ITAQS) and a commuter study conducted by the Environmental and Occupational Health Sciences Institute (EOHSI). In addition to MTBE, both studies measured air concentrations of the four BTEX compounds (benzene, toluene, ethyl benzene, and xylene), formaldehyde, and carbon monoxide (CO).

During the service station study, ITAQS collected air samples at stations located in East Brunswick, NJ (two stations); Mamaroneck, NY (two stations); Port Chester, NY (one station); Greenwich, CT (four stations); and Stamford, CT (one station). The samples represented four general locations: the breathing zone of customers, the breathing zone of attendants, the general vicinity of the pumps, and the property boundary. Field personnel also monitored meteorological parameters, gasoline composition, gasoline sales as well as deliveries during each sampling period. Gasoline pumping activities were recorded by a stationary video camera.

In the commuter study, an EOHSI research team directed by Dr. Paul Lioy collected air samples in the passenger compartments of automobiles during typical home-to-work commutes. These automobiles were fueled with gasoline containing MTBE and were driven through areas in which MTBE use was mandatory. Selected automobiles in the commuter study were refueled at stations included in the service station study. The refueling operations were timed to coincide with the collection of air samples at the stations. Further information concerning the commuter study can be obtained from the Lioy research team.

This report provides a description of the service station study and summarizes the results of statistical analyses performed on data collected during the study. Section 2 of the report briefly discusses the procedures used in selecting service stations for the study, lists the sampling dates and times associated with each station, and presents the general characteristics of each station. Section 3 provides a detailed description of the monitoring activities performed at each station. Section 4 provides summary statistics for the data collected during the field portion of the study. The results of a series of special statistical analyses are presented in Section 5. Section 6 provides a summary of the major findings of the study. Section 7 provides references for the sampling and analytical techniques employed in the study. Appendix A contains a schematic of each station showing sampling locations. Appendix B contains a record of the notable events that occurred during the study.

Section 2
SELECTION OF SERVICE STATIONS AND MONITORING PERIODS

In March of 1993, API issued a request to member petroleum companies for the names and locations of potential service station participants for the study. The resulting list of stations was combined with a list of service stations identified by the EOHSI research team as being located along roadways selected for the commuting study. After completing an evaluation of all candidate stations, API identified ten stations that were suitably located and willing to participate in the study. The stations fall into three general categories:

1. Two full-service stations with Stage II vapor recovery on a commuting route near East Brunswick, New Jersey;

2. Three self-service stations with Stage II vapor recovery in Westchester County, New York;

3. Five self-service stations without Stage II vapor recovery in Fairfield County, Connecticut.

The stations differ with respect to geographic location, service type (full versus self), and the use of vapor recovery. Note that the selection of full-service stations for New Jersey was mandatory, as self-service stations are not permitted in this state. Both New Jersey stations were located on a commuting route used by the Lioy group. The remaining eight stations were located in a 20-mile-long commuting corridor between Mamaroneck, NY, and Stamford, CT. Table 2-1 provides a general description of each station. The names and street addresses of the stations have been omitted to comply with confidentiality agreements.

Each station was monitored on a separate calendar day between April 7, 1993 and April 23, 1993. The monitoring activities at each station were conducted during two four-hour periods, nominally 8 a.m. to 12 a.m. and 2 p.m. to 6 p.m. Table 2-1 lists the sampling date for each station and the actual start/stop times for each four-hour sampling period.

Table 2-1. Service station characteristics.

Station Identification Code	Nearest City	Date Sampled	Four-hour Sampling Periods		Service Type[a]	Number of Service Bays	Stage II Vapor Recovery?	Major Adjoining Roadways
			Morning	Afternoon				
1NJ	East Brunswick, NJ	4/7/93	10:00-14:00	16:30-20:30	Full	2	Yes	West - 6 lanes
2NJ	East Brunswick, NJ	4/8/93	8:30-12:30	15:00-19:00	Full	3	Yes	West - 6 lanes
3C	Greenwich, CT	4/12/93	8:00-12:00	14:17-18:17	Full and self	4	No	East - 4 lanes, South - 2 lanes
4NY	Mamaroneck, NY	4/13/93	8:00-12:00	14:25-18:31	Full and self	0	Yes	West - 4 lanes, South - 2 lanes
5C	Stamford, CT	4/15/93	7:47-12:48	14:17-18:16	Full and self	3	No	West - 2 lanes, South - 2 lanes
6C	Greenwich, CT	4/16/93	7:51-11:53	14:04-18:00	Self	0	No	East - 2 lanes, West - 2 lanes
7C	Greenwich, CT	4/19/93	7:37-11:37	14:33-18:36	Full and self	3	No	West - 4 lanes, North - 2 lanes
8C	Greenwich, CT	4/20/93	7:47-11:50	13:59-18:03	Full and self	5	No	East - 4 lanes, North - 2 lanes
9NY	Mamaroneck, NY	4/22/93	[b]	14:00-18:02	Full and self	3	Yes	South - 4 lanes, West - 2 lanes
10NY	Port Chester, NY	4/23/93	7:40-11:56	14:00-17:52	Self	0	Yes	South - 4 lanes, East - 2 lanes

[a]Applies to service in area where pumps and customers were monitored.
[b]Split sampling period: 7:30-8:00 and 8:43-10:47.

Section 3
MONITORING ACTIVITIES

Table 3-1 provides an overview of the field monitoring activities. Four-hour canister and impinger samples were obtained at four perimeter locations (north, east, south, and west) and one pump island location at each station. Four-hour canister and impinger samples were also obtained for customer breathing zones at the New York and Connecticut stations and for attendant breathing zones at the New Jersey stations. Four-hour charcoal tube samples were obtained for customer breathing zones at the New York and Connecticut stations. Attendant breathing zones were sampled at the New Jersey stations because customers are not permitted to refuel motor vehicles in New Jersey.

To assist the EOHSI commuting study, field personnel collected special one-hour canister and charcoal tube samples at both of the New Jersey stations and at Station 10NY in New York for comparison to EOHSI adsorbent tube values. The samples were collected at the west perimeter location of each New Jersey station. The sampling periods were 13:00 to 14:00 for Station 1NJ and 8:27 to 9:30 for Station 2NJ. Two sets of special samples were also obtained near the pumps at Station 10NY in New York. The sampling periods were 16:05 to 17:05 and 17:13 to 18:15.

In addition, eight-hour charcoal tube samplers were attached to attendants at Connecticut stations 3C and 8C. The sampling periods were 6:58 to 15:00 (8 h, 2 min) for Station 3C and 7:07 to 14:29 (7 h, 22 min) for Station 8C. Field personnel were not able to monitor the Station 8C attendant for a full eight-hour period, as his work shift ended at 14:30.

Table 3-2 lists the number of individual air samples collected using canisters, impingers, and charcoal tubes. The listings are organized by station and location within station.

Table 3-1. Summary of principal monitoring activities.

Property perimeter (all stations)

- Canisters (4-hour samples): MTBE, BTEX, and THC
- Impingers (4-hour samples): formaldehyde

Vicinity of pumps (all stations)

- Canisters (4-hour samples): MTBE, BTEX, and THC
- Impinger samplers (4-hour samples): formaldehyde
- Metrosonics® pm-7700 (continuous): carbon monoxide
- Organic vapor analyzer (continuous): THC

Breathing zone (attendant: NJ stations, customer: NY and CT stations)

- Canisters (4-hour samples): MTBE, BTEX, and THC
- Impinger samplers (4-hour samples): formaldehyde
- Organic vapor analyzer (continuous): THC
- Charcoal tube (4-hour samples): MTBE and BTEX

Attendant breathing zone (two Connecticut stations)

- Charcoal tube (8-hour sample): MTBE and BTEX

One-hour samples (see Table 3-2)

Meteorological station (all stations)

- Wind speed - 15 minute intervals
- Wind direction - 15 minute intervals
- Temperature - 30 minute intervals
- Relative humidity - 30 minute intervals

Gasoline samples (all stations)

Table 3-2. Number of individual air samples collected using canisters, impingers, and charcoal tubes.

Sampler type	Sampling period	Location	New Jersey		New York			Connecticut					Total
			1	2	4	9	10	3	5	6	7	8	
Canister	4h	Perimeter	9	9	9	9	9	9	9	9	9	9	90
		Pumps	2	2	2	2	2	2	2	2	2	2	20
		Customer	0	0	2	2	2	2	2	2	2	2	16
		Attendant	2	2	0	0	0	0	0	0	0	0	4
		Subtotal	13	13	13	13	13	13	13	13	13	13	130
Canister	1h	West Perimeter	1	1	0	0	0	0	0	0	0	0	2
		Pumps	0	0	0	0	2	0	0	0	0	0	2
		Subtotal	1	1	0	0	2	0	0	0	0	0	4
Impinger	4h	Perimeter	9	9	8	5	9	9	9	9	9	9	85
		Pumps	2	2	2	1	2	2	2	2	2	2	19
		Customer	0	0	2	1	2	2	2	2	2	2	15
		Attendant	2	2	0	0	0	0	0	0	0	0	4
		Subtotal	13	13	12	7	13	13	13	13	13	13	123
Charcoal tube	4h	Attendant	2	2	0	0	0	0	0	0	0	0	4
		Customer	0	0	2	2	2	1	2	2	2	2	15
		Subtotal	2	2	2	2	2	1	2	2	2	2	19
Charcoal tube	1h	West Perimeter	1	1	0	0	0	0	0	0	0	0	2
		Pumps	0	0	0	0	2	0	0	0	0	0	2
		Subtotal	1	1	0	0	2	0	0	0	0	0	4
Charcoal tube	8h	Attendant	0	0	0	0	0	1	0	0	0	1	2
		Total	30	30	27	22	32	28	28	28	28	29	282

Continuous carbon monoxide measurements were made in the pump island area of each station using a Metrosonics® pm-7700 monitor. Organic vapor analyzers employing flame ionization detectors were used to continuously monitor THC concentrations in the pump areas and breathing zones. Data obtained from these monitors are useful in identifying individual refueling events which cannot be distinguished in the four-hour samples collected by canister and charcoal tube samplers.

The approximate heights of the sample intake ports at each sampling location are listed in Table 3-3. Generalized station schematics, including sampling locations, are provided in Appendix A.

Section 7 provides references for the sampling methods used during the field monitoring activities. References are also provided for the procedures used in analyzing the collected samples. Table 3-4 provides a summary of this material.

Table 3-3. Approximate heights of sampling points.

Sample location	Approximate height of sample intake port above the ground (feet)
North	4.25
East	4.25
South	4.25
West	4.25
Pump	5.00
Breathing zone	4.75

Table 3-4. Sampling methods and analytical techniques.

Canister (MTBE, BTEX, and THC)		
	Sampling method	Six-liter SUMMA (tm) polished stainless steel canister
	Analytical method	Gas chromatography (GC/MS) – Method TO14[1]
Charcoal tube (MTBE and BTEX)		
	Sampling method	Two charcoal tubes in series (front 400 mg, back 200 mg) – NIOSH Method 1615
	Analytical method	Gas chromatography (FID) – NIOSH Method 1615[2]
Impinger (formaldehyde)		
	Sampling method	Midget impinger containing 10 ml of DNPH reagent
	Analytical method	High performance liquid chromatography – Method TO5[3]
Carbon monoxide monitor		
	Sampling method	Metrosonics® pm-7700 continuous analyzer[4]
	Calibration	Carbon monoxide gas cylinder (20 ppm, ± 5%) traceable to National Institute of Standards & Technology
Organic vapor analyzer (continuous THC)		
	Sampling method	Foxboro® Model 108 organic vapor analyzer
	Calibration	U.S.E.P.A. Method 21 (40 CFR 60, Appendix A)[5]
Gasoline samples		
	Sampling method	One gallon metal can
	Analytical Method 1	Gas chromatography – ASTM 4815 (MTBE and BTEX)[6]
	Analytical Method 2	High resolution capillary gas chromatography (MTBE only)[7]

[1-7] See References, Section 7-1.

Section 4
DESCRIPTIVE STATISTICS

Table 3-1 in Section 3 lists the principal monitoring activities performed during the field portion of this study. These activities can be grouped into the following general categories according to measurement methodology:

- Canister samples;
- Impinger samples;
- Charcoal tube samples;
- Continuous carbon monoxide measurements;
- Continuous THC measurements;
- Meteorological station measurements;
- Analysis of liquid gasoline samples.

This section provides descriptive statistics for the data provided by each methodology.

CANISTER SAMPLES

Two sets of canister samples were collected during the field study. The first set consisted of 130 samples collected over nominal four-hour periods; the second set included four, one-hour samples for comparison to EOHSI absorbent tubes.

The four-hour samples were collected at four locations (north, east, south, and west) on the perimeter of each station, at one location on a pump island, and in a location referred to as the "breathing zone." In monitoring the breathing zone, the technician placed the sample collection probe near the face of each customer or attendant during each refueling operation. During other time periods, the probe was placed on the top of the organic vapor analyzer at a height of approximately four feet. The organic vapor analyzer was typically located on the pump island. These are the combined measurements that constitute the breathing zone sample values in the tables that follow.

Two of the one-hour samples were collected at the west perimeter locations associated with the New Jersey stations (NJ1 and NJ2); the remaining two samples

were collected at the pump location of NY10. These canister samples were collocated with one-hour absorbent tube samples placed by the EOHSI research team. The one-hour canister samples provided a means for evaluating the accuracy of the concentrations obtained from the one-hour tube samples.

The canister samples were analyzed for six component species: total hydrocarbons (THC), MTBE, benzene, toluene, ethyl benzene, and xylene. Tables 4-1 through 4-6, respectively, list the concentrations for each of the six species according to station, time period, and monitoring location (e.g., north perimeter). The actual sampling period associated with each measurement is listed under "time period." Note that the morning sample for Station 9NY was collected during two time intervals: 7:30 to 8:00 and 8:43 to 10:47.

Tables 4-7 through 4-12 provide descriptive statistics for the four-hour canister data according to component species, station grouping (all stations, New Jersey stations, New York stations, or Connecticut stations), and monitoring location. The descriptive statistics include total number of concentration values, number of concentration values below the level of detection, minimum, maximum, median, geometric mean (GM), and geometric standard deviation (GSD). In calculating these statistics, each value below the detection limit was assigned a value equal to the detection limit. (Note that a majority of the ethyl benzene values were below the detection limit.) Whenever the collection of collocated samples produced two concentration values for a particular location, the average of the two values was used in calculating the descriptive statistics.

Arithmetic means have been purposely omitted from the tables of descriptive statistics. Because the data distributions are often highly skewed, the arithmetic mean may provide a misleading representation of the central tendency in the data. In such cases, the median and GM statistics will provide a better indication of "average" concentration.

Table 4-1. Concentrations of total hydrocarbon (THC) obtained from four-hour canister samples.

Station	Sample type	TTime period	Total hydrocarbon concentration, ppm as hexane					
			Perimeter monitors				Pump island sampler	Breathing zone sampler[a]
			North	East	South	West		
1NJ	Morning 4h	10:00-14:00	0.540	(0.005)[b]	(0.005)	0.170	0.730	0.390
	Afternoon 4h	16:30-20:30	2.200	0.150	0.160	0.130	2.300	1.300
2NJ	Morning 4h	8:30-12:30	0.400	0.260	0.180	0.440	5.500	13.000
	Afternoon 4h	15:00-19:00	0.680	0.150	(0.005)	0.200	2.100	4.300
3C	Morning 4h	8:00-12:00	(0.005)	0.140	0.800	(0.005)	(0.005)	1.300
	Afternoon 4h	14:17-18:17	(0.005)	(0.005)	0.700	(0.005)	0.940	7.600
4NY	Morning 4h	8:00-12:00	(0.005)	0.091	0.120	(0.005)	0.100	0.430
	Afternoon 4h	14:25-18:31	(0.005)	0.170	(0.005)	(0.005)	0.095	0.380
5C	Morning 4h	7:47-12:48	0.140	0.170	0.037	0.200	0.500	5.300
	Afternoon 4h	14:17-18:16	0.074	0.088	0.039	0.230	0.900	7.900
6C	Morning 4h	7:51-11:53	0.170	3.300	0.480	27.000	5.900	1.100
	Afternoon 4h	14:04-18:00	0.790	3.200	0.270	11.000	1.100	6.400
7C	Morning 4h	7:37-11:37	0.450	0.120	3.800	0.890	2.900	7.600
	Afternoon 4h	14:33-18:36	0.210	0.160	1.900	0.400	1.500	3.800
8C	Morning 4h	7:37-11:50	0.380	0.360	0.520	0.270	0.540	7.800
	Afternoon 4h	13:59-18:03	0.210	0.067	0.190	0.280	0.220	4.100
9NY	Morning 4h	7:30-8:00 8:43-10:47	0.210	0.260	0.110	M[c]	0.810	1.300
	Afternoon 4h	14:00-18:02	0.350	0.120	1.100	0.120	0.490	1.700
10NY	Morning 4h	7:40-11:56	0.400	0.180	0.190	0.310	0.240	1.000
	Afternoon 4h	14:00-17:52	0.510	M	0.110	0.280	M	2.200

[a]Breathing zone sampler values are a station-specific composite of pump island and breathing zone concentrations (see discussion at pages 4-1 and 6-3).
[b]Numbers in parentheses are detection limits
[c]M = Missing (sample not available for analysis).

Table 4-2. Concentrations of methyl tertiary butyl ether (MTBE) obtained from four-hour canister samples.

Station	Sample type	Time period	MTBE concentration, ppm					
			Perimeter monitors				Pump island sampler	Breathing zone sampler[a]
			North	East	South	West		
1NJ	Morning 4h	10:00-14:00	0.002	0.001	0.002	0.012	0.120	0.084
	Afternoon 4h	16:30-20:30	0.001	(0.0011)[b]	0.002	0.009	0.220	0.520
2NJ	Morning 4h	8:30-12:30	0.016	0.021	0.015	0.036	1.600	0.200
	Afternoon 4h	15:00-19:00	0.003	0.004	0.002	0.025	0.660	0.290
3C	Morning 4h	8:00-12:00	0.008	0.008	0.019	(0.0011)	(0.0005)	0.196
	Afternoon 4h	14:17-18:17	0.013	0.008	0.027	(0.0012)	0.300	1.500
4NY	Morning 4h	8:00-12:00	0.002	0.003	0.014	0.002	0.014	0.100
	Afternoon 4h	14:25-18:31	0.002	0.007	0.010	0.007	0.019	0.077
5C	Morning 4h	7:47-12:48	0.009	0.016	0.003	0.028	0.160	1.200
	Afternoon 4h	14:17-18:16	0.010	0.007	0.002	0.044	0.330	2.100
6C	Morning 4h	7:51-11:53	0.017	0.005	0.120	0.120	1.500	0.170
	Afternoon 4h	14:04-18:00	0.016	0.005	0.025	0.060	0.180	2.200
7C	Morning 4h	7:37-11:37	0.059	0.010	0.032	0.140	0.230	1.500
	Afternoon 4h	14:33-18:36	0.068	0.011	0.004	0.043	0.083	1.600
8C	Morning 4h	7:37-11:50	0.033	0.012	0.004	0.071	0.034	2.600
	Afternoon 4h	13:59-18:03	0.029	0.030	0.002	0.038	0.009	0.460
9NY	Morning 4h	7:30-8:00 8:43-10:47	0.029	0.022	0.006	0.008	0.068	0.250
	Afternoon 4h	14:00-18:02	0.006	0.004	0.019	0.003	0.080	0.300
10NY	Morning 4h	7:40-11:56	0.081	0.014	0.008	0.002	0.027	0.160
	Afternoon 4h	14:00-17:52	0.083	0.004	0.014	0.004	0.080	0.780

[a]Breathing zone sampler values are a station-specific composite of pump island and breathing zone concentrations (see discussion at pages 4-1 and 6-3).
[b]Numbers in parentheses are detection limits.

Table 4-3. Concentrations of benzene obtained from four-hour canister samples.

Station	Sample type	Time period	Benzene concentration, ppm					
			Perimeter monitors				Pump island sampler	Breathing zone sampler[a]
			North	East	South	West		
1NJ	Morning 4h	10:00-14:00	0.001	0.001	0.001	0.001	0.010	0.005
	Afternoon 4h	16:30-20:30	<0.001[b]	(0.0005)[c]	(0.0004)	0.002	0.022	0.032
2NJ	Morning 4h	8:30-12:30	0.003	0.002	0.002	0.003	0.079	0.014
	Afternoon 4h	15:00-19:00	0.001	0.001	0.001	0.004	0.049	0.029
3C	Morning 4h	8:00-12:00	0.001	0.001	0.002	(0.0004)	0.017	0.014
	Afternoon 4h	14:17-18:17	0.001	0.001	0.002	(0.0005)	0.018	0.082
4NY	Morning 4h	8:00-12:00	0.001	0.001	0.001	0.001	0.002	0.003
	Afternoon 4h	14:25-18:31	0.001	0.001	0.001	0.001	0.002	0.003
5C	Morning 4h	7:47-12:48	0.001	0.001	0.001	0.002	0.008	0.039
	Afternoon 4h	14:17-18:16	0.001	0.001	0.001	0.002	0.012	0.085
6C	Morning 4h	7:51-11:53	0.001	0.001	0.004	0.005	0.054	0.012
	Afternoon 4h	14:04-18:00	0.001	0.001	0.003	0.003	0.011	0.050
7C	Morning 4h	7:37-11:37	0.006	(0.0004)	0.004	0.008	0.040	0.110
	Afternoon 4h	14:33-18:36	0.003	0.001	0.001	0.003	0.005	0.059
8C	Morning 4h	7:37-11:50	0.004	0.002	0.001	0.005	0.002	0.072
	Afternoon 4h	13:59-18:03	0.002	0.001	0.001	0.004	0.001	0.018
9NY	Morning 4h	7:30-8:00 8:43-10:47	0.002	0.002	0.002	0.002	0.005	0.010
	Afternoon 4h	14:00-18:02	0.001	0.001	0.003	0.001	0.006	0.009
10NY	Morning 4h	7:40-11:56	0.003	0.002	0.001	ND	0.001	0.005
	Afternoon 4h	14:00-17:52	0.005	0.001	0.002	0.001	0.004	0.017

[a]Breathing zone sampler values are a station-specific composite of pump island and breathing zone concentrations (see discussion at pages 4-1 and 6-3).
[b]The value is less than the specified value, but above the detected limit.
[c]Numbers in parentheses are detection limits.

Table 4-4. Concentrations of toluene obtained from four-hour canister samples.

Station	Sample type	Time period	Toluene concentration, ppm					
			Perimeter monitors				Pump island sampler	Breathing zone sampler[a]
			North	East	South	West		
1NJ	Morning 4h	10:00-14:00	0.002	0.001	0.001	0.004	0.039	0.011
	Afternoon 4h	16:30-20:30	0.001	0.001	0.001	0.004	0.071	0.061
2NJ	Morning 4h	8:30-12:30	0.005	0.004	0.004	0.005	0.070	0.019
	Afternoon 4h	15:00-19:00	0.001	0.002	0.002	0.007	0.055	0.046
3C	Morning 4h	8:00-12:00	0.001	0.002	0.003	(0.0004)[b]	0.016	0.010
	Afternoon 4h	14:17-18:17	0.003	0.003	0.004	0.001	0.029	0.065
4NY	Morning 4h	8:00-12:00	0.002	0.002	0.002	0.001	0.004	0.005
	Afternoon 4h	14:25-18:31	0.002	0.003	0.002	0.002	0.004	0.005
5C	Morning 4h	7:47-12:48	0.002	0.004	0.002	0.003	0.016	0.046
	Afternoon 4h	14:17-18:16	0.002	0.002	0.001	0.007	0.020	0.099
6C	Morning 4h	7:51-11:53	0.004	0.003	0.007	0.017	0.074	0.037
	Afternoon 4h	14:04-18:00	0.003	0.002	0.008	0.009	0.035	0.130
7C	Morning 4h	7:37-11:37	0.011	0.006	0.009	0.015	0.076	0.120
	Afternoon 4h	14:33-18:36	0.006	0.003	0.004	0.025	0.011	0.070
8C	Morning 4h	7:37-11:50	0.007	0.004	0.004	0.010	0.005	0.088
	Afternoon 4h	13:59-18:03	0.071	0.002	0.002	0.008	0.003	0.024
9NY	Morning 4h	7:30-8:00 8:43-10:47	0.007	0.005	0.006	0.003	0.014	0.020
	Afternoon 4h	14:00-18:02	0.003	0.003	0.005	0.002	0.012	0.013
10NY	Morning 4h	7:40-11:56	0.010	0.003	0.002	0.001	0.003	0.008
	Afternoon 4h	14:00-17:52	0.012	0.001	0.004	0.002	0.007	0.038

[a]Breathing zone sampler values are a station-specific composite of pump island and breathing zone concentrations (see discussion at pages 4-1 and 6-3).
[b]Numbers in parentheses are detection limits.

Table 4-5. Concentrations of ethyl benzene obtained from four-hour canister samples.

Station	Sample type	Time period	Ethyl benzene concentration, ppm					
			Perimeter monitors				Pump island sampler	Breathing zone sampler[a]
			North	East	South	West		
1NJ	Morning 4h Afternoon 4h	10:00-14:00 16:30-20:30	(0.0003)[b] (0.0003)	(0.0004) (0.0005)	(0.0004) (0.0004)	(0.0005) 0.001	0.007 0.017	0.002 0.008
2NJ	Morning 4h Afternoon 4h	8:30-12:30 15:00-19:00	0.001 (0.0005)	0.001 (0.0005)	(0.0006) (0.0004)	0.001 0.001	0.006 0.008	(0.0047) 0.009
3C	Morning 4h Afternoon 4h	8:00-12:00 14:17-18:17	(0.0004) (0.0004)	(0.0004) (0.0004)	(0.0004) <0.001[c]	(0.0004) (0.0005)	(0.0038) (0.0036)	(0.0052) (0.0036)
4NY	Morning 4h Afternoon 4h	8:00-12:00 14:25-18:31	(0.0003) (0.0004)	(0.0004) 0.001	<0.001[c] (0.0004)	(0.0004) (0.0005)	0.001 0.001	0.001 0.001
5C	Morning 4h Afternoon 4h	7:47-12:48 14:17-18:16	(0.0004) (0.0004)	0.001 (0.0003)	(0.0004) (0.0004)	(0.0004) 0.001	(0.0004) (0.0040)	(0.0038) 0.006
6C	Morning 4h Afternoon 4h	7:51-11:53 14:04-18:00	0.001 (0.0006)	<0.001[c] (0.0003)	0.001 0.001	(0.0042) 0.001	0.007 (0.0055)	0.004 0.013
7C	Morning 4h Afternoon 4h	7:37-11:37 14:33-18:36	0.002 0.001	0.001 (0.0005)	0.001 (0.0005)	0.002 0.002	0.011 0.002	0.012 0.005
8C	Morning 4h Afternoon 4h	7:37-11:50 13:59-18:03	0.001 0.004	0.001 (0.0005)	(0.0005) (0.0005)	0.002 0.002	0.001 (0.0005)	0.007 (0.0043)
9NY	Morning 4h Afternoon 4h	7:30-8:00 8:43-10:47 14:00-18:02	0.002 (0.0004)	0.001 (00003)	0.002 0.001	(0.0006) (0.0004)	0.002 0.002	0.003 (0.0029)
10NY	Morning 4h Afternoon 4h	7:40-11:56 14:00-17:52	0.002 0.002	(0.0008) (0.0005)	(0.0004) 0.001	(0.0006) (0.0005)	(0.0004) 0.001	0.001 0.003

[a]Breathing zone sampler values are a station-specific composite of pump island and breathing zone concentrations (see discussion at pages 4-1 and 6-3).
[b]Numbers in parentheses are detection limits.
[c]The value is less than the specified value, but above the detection limit.

Table 4-6. Concentrations of xylene obtained from four-hour canister samples.

Station	Sample type	Time period	Xylene concentration, ppm					
			Perimeter monitors				Pump island sampler	Breathing zone sampler[a]
			North	East	South	West		
1NJ	Morning 4h	10:00-14:00	0.001	0.001	0.001	0.002	0.032	0.008
	Afternoon 4h	16:30-20:30	<0.001[b]	(0.0005)[c]	(0.0004)	0.003	0.066	0.037
2NJ	Morning 4h	8:30-12:30	0.004	0.002	0.003	0.003	0.027	0.008
	Afternoon 4h	15:00-19:00	0.001	0.001	0.001	0.004	0.036	0.040
3C	Morning 4h	8:00-12:00	<0.001	0.001	0.001	(0.0004)	0.280	(0.0052)
	Afternoon 4h	14:17-18:17	0.001	0.001	0.002	(0.0005)	0.009	(0.0036)
4NY	Morning 4h	8:00-12:00	0.001	0.001	0.002	0.001	0.003	0.003
	Afternoon 4h	14:25-18:31	0.001	0.006	0.001	0.002	0.004	0.004
5C	Morning 4h	7:47-12:48	0.001	0.002	0.001	0.001	0.006	0.008
	Afternoon 4h	14:17-18:16	0.001	0.001	0.001	0.003	0.006	0.021
6C	Morning 4h	7:51-11:53	0.002	0.002	0.003	0.008	0.028	0.016
	Afternoon 4h	14:04-18:00	0.001	0.001	0.004	0.005	0.011	0.047
7C	Morning 4h	7:37-11:37	0.008	0.005	0.006	0.010	0.046	0.049
	Afternoon 4h	14:33-18:36	0.003	0.002	0.002	0.007	0.007	0.014
8C	Morning 4h	7:37-11:50	0.006	0.003	0.002	0.008	0.003	0.024
	Afternoon 4h	13:59-18:03	0.007	0.001	0.001	0.011	0.002	0.006
9NY	Morning 4h	7:30-8:00 8:43-10:47	0.006	0.004	0.008	0.003	0.010	0.012
	Afternoon 4h	14:00-18:02	0.002	0.003	0.004	0.002	0.011	0.004
10NY	Morning 4h	7:40-11:56	0.010	0.002	0.002	0.001	0.002	0.004
	Afternoon 4h	14:00-17:52	0.010	0.001	0.004	0.001	0.005	0.014

[a]Breathing zone sampler values are a station-specific composite of pump island and breathing zone concentrations (see discussion at pages 4-1 and 6-3).
[b]The value is less than the specified value, but above the detection limit.
[c]Numbers in parentheses are detection limits.

Table 4-7. Descriptive statistics for concentrations of THC obtained from four-hour canister samples.

State	Station type	Location	Number of values		THC concentration, ppm as hexane				
			All	ND[a]	Minimum	Maximum	Median	GM[b]	GSD[c]
New Jersey	Stage II full-serve	Perimeter	16	3	0.100	2.200	0.220	0.262	2.29
		Pumps	4	0	0.730	5.500	2.200	2.099	2.29
		BZ[d]	4	0	0.390	13.000	2.800	2.307	4.54
New York	Stage II self-serve	Perimeter	24	9	0.077	1.245	0.145	0.196	2.12
		Pumps	6	1	0.095	1.000	0.365	0.311	2.79
		BZ	6	0	0.380	2.200	1.150	0.962	2.06
Connecticut	Non-Stage II self-serve	Perimeter	40	8	0.039	11.000	0.250	0.320	3.51
		Pumps	10	3	0.220	5.900	0.970	1.058	2.51
		BZ	10	0	1.100	7.900	5.850	4.395	2.09

[a]Number of values below detection limit. ND values replaced by 1.0 x detection limit.
[b]Geometric mean (ppm).
[c]Geometric standard deviation (dimensionless).
[d]Breathing zone sampler values are a station-specific composite of pump island and breathing zone concentrations (see discussion at pages 4-1 and 6-3).

Table 4-8. Descriptive statistics for concentrations of MTBE obtained from four-hour canister samples.

State	Station type	Location	Number of values		MTBE concentration, ppm				
			All	ND[a]	Minimum	Maximum	Median	GM[b]	GSD[c]
New Jersey	Stage II full-serve	Perimeter	16	1	0.001	0.036	0.003	0.005	3.48
		Pumps	4	0	0.120	1.600	0.440	0.409	3.16
		BZ[d]	4	0	0.084	0.520	0.245	0.224	2.15
New York	Stage II self-serve	Perimeter	24	0	0.002	0.083	0.007	0.008	3.03
		Pumps	6	0	0.014	0.080	0.048	0.038	2.18
		BZ	6	0	0.077	0.780	0.205	0.204	2.31
Connecticut	Non-Stage II self-serve	Perimeter	40	2	0.001	0.140	0.014	0.014	3.61
		Pumps	10	1	0.009	1.500	0.170	0.109	5.05
		BZ	10	0	0.170	2.600	1.500	0.978	2.73

[a]Number of values below detection limit. ND values replaced by 1.0 x detection limit.
[b]Geometric mean (ppm).
[c]Geometric standard deviation (dimensionless).
[d]Breathing zone sampler values are a station-specific composite of pump island and breathing zone concentrations (see discussion at pages 4-1 and 6-3).

Table 4-9. Descriptive statistics for concentrations of benzene obtained from four-hour canister samples.

State	Station type	Location	Number of values		Benzene concentration, ppm				
			All	ND[a]	Minimum	Maximum	Median	GM[b]	GSD[c]
New Jersey	Stage II full-serve	Perimeter	16	2	<0.001	0.004	0.001	0.001	2.36
		Pumps	4	0	0.010	0.079	0.036	0.030	2.52
		BZ[d]	4	0	0.005	0.032	0.022	0.016	2.42
New York	Stage II self-serve	Perimeter	24	1	0.001	0.005	0.001	0.001	1.82
		Pumps	6	0	0.001	0.006	0.003	0.002	1.93
		BZ	6	0	0.003	0.017	0.007	0.006	2.04
Connecticut	Non-Stage II self-serve	Perimeter	40	3	<0.001	0.008	0.001	0.002	2.21
		Pumps	10	0	0.001	0.054	0.012	0.010	3.34
		BZ	10	0	0.012	0.110	0.055	0.042	2.23

[a]Number of values below detection limit. ND values replaced by 1.0 x detection limit.
[b]Geometric mean (ppm).
[c]Geometric standard deviation (dimensionless).
[d]Breathing zone sampler values are a station-specific composite of pump island and breathing zone concentrations (see discussion at pages 4-1 and 6-3).

Table 4-10. Descriptive statistics for concentrations of toluene obtained from four-hour canister samples.

State	Station type	Location	Number of values		Toluene concentration, ppm				
			All	ND[a]	Minimum	Maximum	Median	GM[b]	GSD[c]
New Jersey	Stage II full-serve	Perimeter	16	0	0.001	0.007	0.002	0.002	2.20
		Pumps	4	0	0.039	0.071	0.063	0.057	1.32
		BZ[d]	4	0	0.011	0.061	0.033	0.028	2.20
New York	Stage II self-serve	Perimeter	24	0	0.001	0.012	0.002	0.003	1.92
		Pumps	6	0	0.003	0.014	0.006	0.006	1.98
		BZ	6	0	0.005	0.038	0.010	0.011	2.27
Connecticut	Non-Stage II self-serve	Perimeter	40	1	<0.001	0.050	0.004	0.004	2.57
		Pumps	10	0	0.003	0.076	0.018	0.018	2.93
		BZ	10	0	0.010	0.130	0.068	0.055	2.25

[a]Number of values below detection limit. ND values replaced by 1.0 x detection limit.
[b]Geometric mean (ppm).
[c]Geometric standard deviation (dimensionless).
[d]Breathing zone sampler values are a station-specific composite of pump island and breathing zone concentrations (see discussion at pages 4-1 and 6-3).

Table 4-11. Descriptive statistics for concentrations of ethyl benzene obtained from four-hour canister samples.

State	Station type	Location	Number of values		Ethyl benzene concentration, ppm				
			All	ND[a]	Minimum	Maximum	Median	GM[b]	GSD[c]
New Jersey	Stage II full-serve	Perimeter	16	12	<0.001	0.001	0.001	0.001	1.37
		Pumps	4	0	0.006	0.017	0.007	0.009	1.60
		BZ[d]	4	1	0.002	0.009	0.006	0.005	2.11
New York	Stage II self-serve	Perimeter	24	12	<0.001	0.002	0.001	0.001	1.73
		Pumps	6	1	<0.001	0.002	0.001	0.001	2.08
		BZ	6	1	0.001	0.003	0.002	0.001	2.17
Connecticut	non-Stage II self-serve	Perimeter	40	19	<0.001	0.004	0.001	0.001	2.00
		Pumps	10	6	<0.001	0.011	0.004	0.002	3.16
		BZ	10	4	0.004	0.013	0.005	0.006	1.57

[a]Number of values below detection limit. ND values replaced by 1.0 x detection limit.
[b]Geometric mean (ppm).
[c]Geometric standard deviation (dimensionless).
[d]Breathing zone sampler values are a station-specific composite of pump island and breathing zone concentrations (see discussion at pages 4-1 and 6-3).

Table 4-12. Descriptive statistics for concentrations of xylene obtained from four-hour canister samples.

State	Station type	Location	Number of values		Xylene concentration, ppm				
			All	ND[a]	Minimum	Maximum	Median	GM[b]	GSD[c]
New Jersey	Stage II full-serve	Perimeter	16	2	<0.001	0.004	0.001	0.001	2.52
		Pumps	4	0	0.027	0.066	0.034	0.038	1.48
		BZ[d]	4	0	0.008	0.040	0.023	0.018	2.46
New York	Stage II self-serve	Perimeter	24	0	0.001	0.010	0.002	0.002	2.38
		Pumps	6	0	0.002	0.011	0.004	0.005	2.01
		BZ	6	0	0.003	0.014	0.004	0.005	1.96
Connecticut	non-Stage II self-serve	Perimeter	40	2	<0.001	0.011	0.002	0.002	2.66
		Pumps	10	0	0.002	0.281	0.008	0.012	4.24
		BZ	10	2	0.004	0.049	0.015	0.014	2.47

[a]Number of values below detection limit. ND values replaced by 1.0 x detection limit.
[b]Geometric mean (ppm).
[c]Geometric standard deviation (dimensionless).
[d]Breathing zone sampler values are a station-specific composite of pump island and breathing zone concentrations (see discussion at pages 4-1 and 6-3).

The medians listed in Tables 4-7 through 4-12 exhibit a common pattern in that median concentrations are always larger for pump and breathing zone samples than for perimeter samples. Breathing zone medians for the New York and Connecticut stations are generally larger than the corresponding pump medians. The pattern is reversed for the New Jersey stations.

The descriptive statistics for MTBE (Table 4-8) suggest that MTBE concentrations are generally lower at stations with Stage II vapor controls than at stations without controls. Regardless of location, the measured four-hour MTBE concentrations are relatively low when compared to the proposed 40 ppm threshold limit value (TLV) for eight-hour occupational exposures currently under consideration by the American Conference of Governmental Industrial Hygienists (ACGIH). The median four-hour MTBE concentrations are below 2.00 ppm for breathing zone and pump island locations and below 0.02 ppm for the station perimeters.

Table 4-13 lists the concentration measurements for MTBE, benzene, toluene, ethyl benzene, and xylene obtained from the special one-hour canister samples. The samples were collected at the west perimeter locations of the two New Jersey stations and at the pump location at Station 10NY. The maximum toluene concentration was measured at Station 2NJ. The maximum concentration values for the other components occurred during the afternoon sampling period (17:13 - 18:15) at Station 10NY. With the single exception of the ethyl benzene concentration measured at Station 1NJ, all of the one-hour values exceeded the limit of detection.

IMPINGER SAMPLES (FORMALDEHYDE)

Impinger samples were collected at the same times and locations as the four-hour canister samples. Table 4-14 lists the formaldehyde concentrations determined from analyses of these samples. Table 4-15 presents descriptive statistics for these data by station grouping and monitor location. These statistics were calculated using the same procedures applied to the canister data.

Table 4-13. Concentration measurements obtained from one-hour canister samples.

Station	Time period	Sample location	Component concentration, ppm				
			MTBE	Benzene	Toluene	Ethyl benzene	Xylene
1NJ	13:00-14:00	West perimeter	0.008	0.001	0.003	(0.0006)[a]	0.002
2NJ	8:27-9:30	West perimeter	0.021	0.003	0.005	0.001	0.003
10NY	16:05-17:05	Pumps	0.057	0.003	0.001	0.008	0.006
	17:13-18:15	Pumps	0.098	0.005	0.002	0.011	0.008

[a]Numbers in parentheses are detection limits.

Table 4-14. Concentrations of formaldehyde obtained from four-hour impinger samples.

Station	Sample type	Time period	Formaldehyde concentration, ppm					
			Perimeter monitors				Pump island sampler	Breathing zone sampler[a]
			North	East	South	West		
1NJ	Morning 4h	10:00-14:00	0.018	0.012	(0.0106)[b]	(0.0104)	(0.0123)	(0.0125)
	Afternoon 4h	16:30-20:30	0.018	0.015	0.011	0.013	0.015	0.019
2NJ	Morning 4h	8:30-12:30	(0.0091)	0.016	0.014	0.014	0.017	0.018
	Afternoon 4h	15:00-19:00	0.033	0.012	0.019	0.012	0.014	0.017
3C	Morning 4h	8:00-12:00	(0.0095)	0.012	0.018	0.016	(0.0090)	(0.0096)
	Afternoon 4h	14:17-18:17	0.018	0.011	0.016	0.016	0.010	0.011
4NY	Morning 4h	8:00-12:00	0.010	(0.0087)	0.014	0.011	0.011	0.016
	Afternoon 4h	14:25-18:31	0.014	0.016	M[c]	0.001	0.008	0.013
5C	Morning 4h	7:47-12:48	(0.0090)	(0.0118)	(0.0087)	(0.0085)	(0.0088)	(0.0089)
	Afternoon 4h	14:17-18:16	(0.0089)	(0.0163)	(0.0090)	(0.0087)	(0.0079)	(0.0080)
6C	Morning 4h	7:51-11:53	0.011	0.009	(0.0092)	0.011	0.016	0.011
	Afternoon 4h	14:04-18:00	0.022	0.015	0.010	0.011	0.015	0.015
7C	Morning 4h	7:37-11:37	0.014	0.012	0.018	0.019	0.035	0.015
	Afternoon 4h	14:33-18:36	0.010	0.009	0.014	0.012	0.011	0.013
8C	Morning 4h	7:37-11:50	0.010	0.012	0.012	0.014	ND	0.012
	Afternoon 4h	13:59-18:03	0.012	0.014	0.011	0.012	0.009	0.013
9NY	Morning 4h	7:30-8:00 8:43-10:47	M	M	M	M	M	M
	Afternoon 4h	14:00-18:02	(0.0088)	(0.0117)	(0.0086)	(0.0086)	(0.0085)	(0.0119)
10NY	Morning 4h	7:40-11:56	(0.0089)	(0.0101)	(0.0090)	(0.0091)	(0.0107)	(0.0086)
	Afternoon 4h	14:00-17:52	(0.0119)	(0.0124)	(0.0098)	(0.0094)	(0.0130)	(0.0103)

[a]Breathing zone sampler values are a station-specific composite of pump island and breathing zone concentrations (see discussion at pages 4-1 and 6-3).
[b]Numbers in parentheses are detection limits.
[c]M = Missing (sample not available for analysis).

Table 4-15. Descriptive statistics for concentrations of formaldehyde obtained from four-hour samples.

State	Station type	Location	Number of values		Formaldehyde concentration, ppm				
			All	ND[a]	Minimum	Maximum	Median	GM[b]	GSD[c]
New Jersey	Stage II full-serve	Perimeter	16	3	0.009	0.033	0.014	0.014	1.36
		Pumps	4	1	0.012	0.017	0.015	0.014	1.13
		BZ[d]	4	1	0.013	0.019	0.017	0.016	1.20
New York	Stage II self-serve	Perimeter	20	13	0.009	0.016	0.010	0.011	1.23
		Pumps	5	3	0.008	0.013	0.011	0.010	1.21
		BZ	5	3	0.009	0.016	0.012	0.012	1.27
Connecticut	Non-Stage II self-serve	Perimeter	40	10	0.009	0.019	0.012	0.012	1.28
		Pumps	10	4	0.008	0.035	0.010	0.012	1.57
		BZ	10	3	0.008	0.015	0.011	0.011	1.24

[a]Number of values below detection limit. ND values replaced by 1.0 x detection limit.
[b]Geometric mean (ppm).
[c]Geometric standard deviation (dimensionless).
[d]Breathing zone sampler values are a station-specific composite of pump island and breathing zone concentrations (see discussion at pages 4-1 and 6-3).

The individual four-hour formaldehyde concentration values listed in Table 4-14 range from the limit of detection (0.0085 - 0.0163 ppm) to 0.035 ppm. The largest median concentration listed in Table 4-15 (0.017 ppm) is associated with the breathing zone locations of the New Jersey stations. There is no general pattern evident in the formaldehyde data, possibly because a large fraction (36 percent) of the formaldehyde values were below the detection limit.

CHARCOAL TUBE SAMPLES

Three sets of charcoal tube samples were collected during the field study. The first set consisted of 19 four-hour samples collected in the breathing zones of attendants at the New Jersey stations and customers at the New York and Connecticut stations. The second set consisted of four special one-hour samples collected at the same times and locations as the one-hour canister samples; i.e., two samples at the west perimeter locations associated with the New Jersey stations (1NJ and 2NJ) and two samples at the pump location of 10NY. These samples were collected at the same times and locations as the corresponding canister samples as a means of comparing measurements made by the canister and charcoal tube collection methods.

The third set of samples were collected by placing charcoal tubes on attendants at two of the Connecticut stations (CT3 and CT8). These samples were collected to determine typical occupational exposures of attendants at stations without Stage II vapor controls. The principal duty of each attendant was to provide full service gasoline pumping to consumers. Time spent inside service bays was kept to a minimum.

The charcoal tube samples were analyzed for five compounds species: MTBE, benzene, toluene, ethyl benzene, and xylene. Table 4-16 lists the concentrations for each according to station, time period, and monitoring location.

Table 4-16. Concentration measurements obtained from charcoal tube samples.

Station	Sample type	Time period	Sample location[a]	Component concentration, ppm				
				MTBE	Benzene	Toluene	Ethyl benzene	Xylene
1NJ	Morning 4h	10:00-14:00	Attendant	ND[b]	ND	ND	ND	ND
	Afternoon 4h	16:30-20:30	Attendant	0.260	ND	ND	ND	ND
	Afternoon 1h	13:00-14:00	West perimeter	ND	ND	ND	ND	ND
2NJ	Morning 4h	8:30-12:30	Attendant	0.558	ND	ND	ND	ND
	Afternoon 4h	15:00-19:00	Attendant	0.423	ND	0.028	ND	ND
	Morning 1h	8:27-9:30	West perimeter	ND	ND	ND	ND	ND
3C	Morning 4h	8:00-12:00	Customer	M[c]	M	M	M	M
	Afternoon 4h	14:17-18:17	Customer	1.660	0.070	0.065	ND	ND
	Attendant 8h[d]	6:58-15:00	Attendant	0.554	0.027	0.033	ND	0.017
4NY	Morning 4h	8:00-12:00	Customer	0.119	ND	ND	ND	ND
	Afternoon 4h	14:25-18:31	Customer	0.090	ND	ND	ND	ND
5C	Morning 4h	7:47-12:48	Customer	1.060	ND	0.048	ND	ND
	Afternoon 4h	14:17-18:16	Customer	2.395	0.047	0.079	ND	ND
6C	Morning 4h	7:51-11:53	Customer	1.656	0.043	0.078	ND	0.021
	Afternoon 4h	14:04-18:00	Customer	1.142	ND	0.076	ND	0.026
7C	Morning 4h	7:37-11:37	Customer	1.818	0.062	0.065	ND	ND
	Afternoon 4h	14:33-18:36	Customer	0.981	ND	ND	ND	ND
8C	Morning 4h	7:37-11:50	Customer	1.710	0.037	0.038	ND	ND
	Afternoon 4h	13:59-18:03	Customer	0.515	ND	ND	ND	ND
	Attendant 8h[d]	7:07-14:29	Attendant	1.191	0.055	0.068	ND	0.022
9NY	Morning 4h	7:30-8:00 8:43-10:47	Customer	ND	ND	ND	ND	ND
	Afternoon 4h	14:00-18:02	Customer	0.169	ND	ND	ND	ND
10NY	Morning 4h	7:40-11:56	Customer	0.138	ND	ND	ND	ND
	Afternoon 4h	14:00-17:52	Customer	0.482	ND	ND	ND	ND
	Afternoon 1h	16:05-17:05	Pumps	ND	ND	ND	ND	ND
	Afternoon 1h	17:13-18:15	Pumps	ND	ND	ND	ND	ND

[a]Attendant and customer locations are breathing zones. Breathing zone sampler values are a station-specific composite of pump island and breathing zone concentrations (see discussion at pages 4-1 and 6-3).
[b]ND = Below detection limit.
[c]M = Missing (sample not collected).
[d]Sampler continuously located in attendant's breathing zone.

Sixty-seven percent of the concentration measurements listed in Table 4-16 are below the limit of detection. One or more MTBE concentrations above 1 ppm were reported for each of the five Connecticut stations (3C, 5C, 6C, 7C, and 8C); the maximum reported value was 2.395 ppm (the afternoon four-hour sample for Station 5C).

CONTINUOUS CARBON MONOXIDE MEASUREMENTS

A Metrosonics® model pm-7700 monitor was used to continuously measure carbon monoxide at the pump islands of seven of the ten stations. The monitor probe was positioned to sample the same air being sampled by the canister at the pump island. The resulting carbon monoxide data were reported as one-minute averages. Table 4-17 presents descriptive statistics for the one-minute values included in each of the four-hour sampling periods. The arithmetic mean statistic is comparable to a component concentration determined from a four-hour canister sample. The median and geometric mean statistics are provided as supplementary indications of the central tendency of the one-minute CO data.

The arithmetic means in Table 4-17 range from 1.15 ppm (Station 10NY, morning) to 5.44 ppm (Station 2NJ, afternoon). In addition to the maximum mean value, the one-minute values reported by Station 2NJ for the afternoon period exhibited the highest degree of variability (arithmetic standard deviation = 11.99 ppm) and included the largest reported one-minute value (144 ppm).

CONTINUOUS THC MEASUREMENTS

An organic vapor analyzer (OVA) was operated continuously at the pump island sampling location of each station. The OVA probe was positioned to sample the same air being sampled by the canister at the pump island. The resulting THC measurements were recorded continuously on a strip chart with a linear time scale and a logarithmic concentration scale.

Table 4-17. Descriptive statistics for one-minute carbon monoxide concentrations measured by continuous monitors located near fuel pumps.

Station[a]	Sample type	Time period	Number of reported one-minute values	Carbon monoxide concentration, ppm						
				Minimum	Median	Maximum	Arithmetic		Geometric	
							Mean[b]	Std. dev.	Mean	Std. dev.[c]
1NJ	Morning 4h	10:00-14:00	214	2.0	2.0	5.0	2.39	0.62	2.32	1.25
	Afternoon 4h	16:30-20:30	229	2.0	3.0	20.0	3.49	1.85	3.24	1.42
2NJ	Morning 4h	8:30-12:30	211	2.0	3.0	10.0	3.05	0.83	2.97	1.25
	Afternoon 4h	15:00-19:00	235	2.0	3.0	144.0	5.44	11.99	3.79	1.75
5C	Morning 4h	7:47-12:48	243	1.0	2.0	15.0	2.57	1.66	2.34	1.44
	Afternoon 4h	14:17-18:16	237	0.0	2.0	23.0	2.62	2.39	2.30	1.50
7C	Morning 4h	7:37-11:37	234	3.0	4.0	28.0	4.87	2.26	4.61	1.34
	Afternoon 4h	14:33-18:36	235	3.0	4.0	35.0	4.46	2.71	4.20	1.33
8C	Morning 4h	7:37-11:50	238	3.0	4.0	15.0	4.20	1.18	4.09	1.24
	Afternoon 4h	13:59-18:03	239	2.0	4.0	14.0	3.84	1.17	3.72	1.27
9NY	Morning 4h	7:30-8:00 8:43-10:47	148	2.0	3.0	7.0	3.06	1.05	2.90	1.38
	Afternoon 4h	14:00-18:02	234	1.0	2.0	7.0	2.06	0.84	1.91	1.46
10NY	Morning 4h	7:40-11:56	243	0.0	1.0	6.0	1.15	0.48	1.10	1.30
	Afternoon 4h	14:00-17:52	225	1.0	2.0	40.0	3.02	2.91	2.64	1.53

[a]Carbon monoxide monitors were not operated at Stations 3C, 4NY, and 6C.
[b]Corresponds to nominal four-hour average.
[c]Dimensionless.

The horizontal time scale of each strip chart was marked by a vertical index line at regular intervals of approximately 30 seconds, the actual interval varying slightly from chart to chart. Analysts developed a data base from each strip chart which listed the following parameters for each time index mark:

- Time
- THC concentration
- Event status (event or nonevent)
- Fuel log status (refueling or nonrefueling)
- Commuter status
- Equipment status
- Miscellaneous codes.

The time value was determined by assuming that the time index marks were equally spaced in time between the reported start and end times for the strip chart. The THC concentration was read directly from the chart at the time index mark.

To determine event status, analysts reviewed the THC trace on each strip chart and identified periods during which the THC concentration exhibited a positive spike or was noticeably higher than the average or "background" level. These periods were identified as "events." Each time index mark that occurred during an event was labeled as event status = event. The remaining time index marks were labeled as event status = nonevent.

The fuel log status was determined by reviewing technician records listing the times that vehicles were refueled at the pump island being monitored by the OVA. If the time index mark occurred during a refueling period, the fuel log status was characterized as "refueling." Otherwise the fuel log status was characterized as "nonrefueling."

The commuter status was determined by reviewing technician records listing the times that the designated "commuter" vehicles refueled at the monitored pump island. These commuter vehicles were operated by members of the EOHSI research team who collected in-vehicle air samples while driving over specified commuter routes. If

a time index mark occurred during the refueling period of a commuter vehicle, the commuter status was characterized as "commuter refueling." Otherwise, the commuter status was characterized as "commuter nonrefueling."

It is probable that some determinations of fuel log status and commuter status are in error. Because the refueling times listed in the technician logs were reported in terms of minutes rather than seconds, the start and end times reported for each refueling period may be uncertain by as much as one minute. In a similar manner, the start and stop times assigned to each strip chart may also be off by as much as one minute. Consequently, the times assigned to the time index marks on each strip chart may be shifted by several minutes with respect to the times entered in the fuel log. As most refueling periods were less than three minutes in duration, it is likely that many strip chart values which actually occurred during vehicle refueling periods were assigned to nonrefueling periods (and vice versa). Because of these uncertainties, this report omits statistics relating THC to fuel log status.

Table 4-18 presents descriptive statistics for the THC concentration values at the time index marks according to station, sampling period, and category (all, nonevent/event, and commuter). Because the distribution of values is highly skewed, the median statistic is preferable to the mean as an indicator of central tendency. Ranges for the medians by category are listed below.

All:	1.7 ppm - 19.0 ppm
Nonevent:	1.4 ppm - 15.0 ppm
Event:	2.0 ppm - 34.0 ppm
Commuter:	2.1 ppm - 30.0 ppm

The maximum median value for the "all" category (19.0 ppm) occurs during the morning sampling period at Station 3C. The morning sampling period of Station 2NJ has the highest median (34.0 ppm) for the "event" category. The two largest individual THC readings (3000 ppm and 3100 ppm) were reported for the morning

Table 4-18. Descriptive statistics for instantaneous THC concentrations taken at nominal 30-second intervals from strip charts.

Station	Sample type	Time period	Category	n	THC concentrations, ppm						
					Mean	S.D.	Min	Percentiles			Max
								25	50	75	
1NJ	Morning 4h	10:00-14:00	All	432	2.26	1.41	1.7	2.0	2.0	2.1	24.0
			Nonevent	393	2.09	0.25	1.7	2.0	2.0	2.1	3.6
			Event	39	3.96	4.31	2.0	2.1	2.4	3.2	24.0
	Afternoon 4h	16:30-20:30	All	509	14.14	24.60	6.0	9.0	10.0	11.0	340.0
			Nonevent	378	9.65	0.78	6.0	9.0	10.0	10.0	14.0
			Event	131	27.08	46.22	8.5	11.0	14.0	20.0	340.0
2NJ	Morning 4h	8:30-12:30	All	439	43.95	148.34	6.0	8.0	13.0	23.0	1900.0
			Nonevent	262	10.25	4.05	6.0	7.0	9.0	13.0	23.0
			Event	177	93.84	224.83	7.0	17.0	34.0	70.0	1900.0
	Afternoon 4h	15:00-19:00	All	596	13.91	35.54	2.2	3.1	4.5	9.0	380.0
			Nonevent	264	4.60	18.28	2.2	2.8	3.1	4.0	300.0
			Event	332	21.31	43.37	2.4	5.0	8.0	19.0	380.0
3C	Morning 4h	8:00-12:00	All	528	24.19	42.38	5.0	9.0	19.0	23.0	600.0
			Nonevent	323	14.23	6.47	5.0	8.0	15.0	20.0	30.0
			Event	205	39.88	64.58	6.0	18.0	25.0	38.0	600.0
	Afternoon 4h	14:17-18:17	All	500	13.51	23.08	1.9	4.1	5.9	12.0	200.0
			Nonevent	263	4.71	1.76	1.9	3.8	4.1	5.1	21.0
			Event	237	23.29	30.68	3.6	8.0	13.0	24.0	200.0

(continued)

Table 4-18 (Continued)

Station	Sample type	Time period	Category	n	THC concentrations, ppm						
					Mean	S.D.	Min	Percentiles 25	50	75	Max
4NY	Morning 4h	8:00-12:00	All	499	2.00	0.36	1.7	1.8	1.9	2.0	7.5
			Nonevent	428	1.93	0.14	1.7	1.8	1.9	2.0	2.5
			Event	71	2.45	0.75	1.8	2.1	2.2	2.6	7.5
			Commuter	8	2.23	0.46	1.8	1.9	2.1	2.5	3.2
	Afternoon 4h	14:25-18:31	All	515	6.30	10.75	3.4	4.2	4.9	5.4	210.0
			Nonevent	401	4.77	0.94	3.4	4.1	4.7	5.1	13.0
			Event	114	11.70	22.02	3.8	5.0	6.0	9.3	210.0
5C	Morning 4h	7:47-12:48	All	395	32.84	197.36	1.2	2.0	3.1	8.0	3100.0
			Nonevent	125	2.07	0.64	1.2	1.6	1.9	2.4	4.8
			Event	270	47.09	237.50	1.4	3.0	5.0	15.5	3100.0
			Commuter	3	4.57	0.51	4.0	-	4.7	-	5.0
	Afternoon 4h	14:17-18:16	All	387	31.14	173.49	1.9	3.4	5.4	13.0	3000.0
			Nonevent	106	2.79	0.43	1.9	2.4	2.9	3.1	3.4
			Event	281	41.84	202.67	3.5	5.0	8.0	16.0	3000.0
6C	Morning 4h	7:51-11:53	All	464	9.51	43.45	1.0	1.3	1.7	2.9	510.0
			Nonevent	264	1.61	2.29	1.0	1.2	1.4	1.7	38.0
			Event	200	19.95	64.76	1.0	1.9	3.5	7.1	510.0
			Commuter	5	12.90	4.88	6.0	-	16.0	-	17.0
	Afternoon 4h	14:04-18:00	All	434	15.66	91.17	1.0	1.5	1.9	3.1	1200.0
			Nonevent	263	1.92	1.31	1.1	1.4	1.7	2.0	19.0
			Event	171	36.79	142.92	1.0	2.1	3.9	9.5	1200.0

(continued)

Table 4-18 (Continued)

Station	Sample type	Time period	Category	n	THC concentrations, ppm						
					Mean	S.D.	Min	Percentiles			Max
								25	50	75	
7C	Morning 4h	7:37-11:37	All	393	15.53	57.22	1.8	2.5	3.5	6.2	700.0
			Nonevent	140	2.33	0.40	1.8	2.0	2.2	2.7	3.3
			Event	253	22.83	70.31	2.0	3.7	4.8	11.0	700.0
			Commuter	5	89.26	147.64	1.8	-	30.0	-	350.0
	Afternoon 4h	14:33-18:36	All	367	26.51	72.47	1.0	1.8	4.5	17.0	700.0
			Nonevent	227	6.56	8.85	1.0	1.7	2.0	7.0	40.0
			Event	140	58.87	109.54	1.7	6.5	12.0	60.0	700.0
8C	Morning 4h	7:37-11:50	All	337	12.59	41.85	1.1	1.8	2.4	4.9	500.0
			Nonevent	237	2.25	0.79	1.1	1.7	2.0	2.6	5.5
			Event	97	38.18	72.11	1.2	7.0	19.0	30.0	500.0
	Afternoon 4h	13:59-18:03	All	445	9.21	48.59	1.2	1.7	2.2	3.1	700.0
			Nonevent	291	2.03	0.72	1.2	1.6	1.9	2.2	9.0
			Event	154	22.78	81.03	1.4	2.6	3.5	6.0	700.0
9NY	Morning 4h	7:30-8:00 8:43-10:47	All	226	3.59	10.02	1.0	1.3	1.6	2.0	100.0
			Nonevent	183	1.55	0.39	1.0	1.2	1.5	1.8	3.6
			Event	43	12.28	21.03	1.3	2.0	3.0	12.0	100.0
	Afternoon 4h	14:00-18:02	All	382	6.72	23.41	1.0	1.8	2.0	3.2	300.0
			Nonevent	294	2.24	0.95	1.0	1.8	2.0	2.5	6.8
			Event	88	21.67	45.85	1.3	3.1	6.0	18.8	300.0
10NY	Morning 4h	7:40-11:56	All	357	2.05	1.41	1.0	1.5	1.9	2.1	19.0
			Nonevent	336	1.87	0.46	1.0	1.5	1.9	2.0	3.5
			Event	21	5.01	4.68	2.2	2.7	3.1	5.5	19.0
	Afternoon 4h	14:00-17:52	All	349	5.22	5.13	1.0	1.5	5.1	6.1	40.0
			Nonevent	273	3.85	2.36	1.0	1.4	5.0	5.9	9.9
			Event	76	10.13	8.41	1.4	5.2	7.7	12.0	40.0

and afternoon periods, respectively, of Station 5C. Individual THC readings above 1000 ppm were also reported for Stations 2NJ (morning) and 6C (afternoon).

Although the average THC concentration during refueling periods cannot be accurately determined from the strip chart readings because of the inherent imprecision in the time records, an upper bound for this quantity can be estimated from the average of the THC concentrations associated with "events." The event THC values should include most of the periods during which vehicles were being refueled upwind from the OVA monitor, both at the pump island being monitored and at nearby pump islands. The average THC concentration calculated for the events is likely to be higher than the average THC concentration recorded at the monitored pump island during actual refueling periods, as the latter average includes some periods when the refueling vehicle was downwind of the OVA.

Each four-hour canister MTBE measurement represents a weighted average of MTBE concentrations that occurred during refueling and nonrefueling periods. The ratio of the mean THC concentration for events to the mean THC concentration for the four-hour period should provide a rough upper-bound estimate of the ratio of the mean MTBE concentration during refueling periods to the mean MTBE concentration for the four-hour period. In Table 4-18, the ratio of (a) mean THC for event OVA readings to (b) mean THC for all OVA readings ranges from 1.00 to 3.00 for the four-hour sampling periods. Consequently, typical values for the ratio of (a) mean MTBE during vehicle refueling to (b) four-hour MTBE concentrations are anticipated to fall within this same range.

METEOROLOGICAL STATION MEASUREMENTS

The meteorological parameters measured at each station included wind speed, wind direction, temperature, and relative humidity. Technicians also reported general meteorological conditions (precipitation, cloud cover, haze, gusty winds, etc.) at regular intervals. Table 4-19 lists the values of selected meteorological parameters

Table 4-19. Values of selected meteorological parameters for specified sampling periods.

Station	Sample type	Time period	Mean wind speed, mph			Mean temperature, °F	Mean relative humidity percent	Precipitation?
			Any direction	North vector	East vector			
1NJ	Morning 4h	10:00-14:00	6.818	5.551	1.821	59.77		No
	Afternoon 4h	16:30-20:30	3.627	-0.6124	2.840	55.23	40	No
	Afternoon 1h	13:00-14:00	5.226	3.895	3.213	61.20		No
2NJ	Morning 4h	8:30-12:30	2.486	0.431	2.983	59.69	51	No
	Afternoon 4h	15:00-19:00	4.147	-0.681	3.905	65.40	38	No
	Morning 1h	8:27-9:30	0.710			50.75	59	No
3C	Morning 4h	8:00-12:00	3.655	3.376	-0.529	52.93	52	No
	Afternoon 4h	14:17-18:17	2.858	2.641	-0.632	49.44	78	No
	Attendant 8h	6:58-15:00	3.677	3.397	-0.586	53.06	55	No
4NY	Morning 4h	8:00-12:00	5.629	5.200	0.102	49.44	64	No
	Afternoon 4h	14:25-18:31	5.077	4.691	1.617	58.75	56	No
5C	Morning 4h	7:47-12:48	3.089	2.854	1.182	50.62	85	No
	Afternoon 4h	14:17-18:16	3.836	0.978	3.544	50.56	95	Yes
6C	Morning 4h	7:51-11:53	2.769	-1.940	1.579	59.31	86	No
	Afternoon 4h	14:04-18:00	2.946	-1.467	1.858	61.31	81	No
7C	Morning 4h	7:37-11:37	3.694	-2.276	0.130	62.06	55	No
	Afternoon 4h	14:33-18:36	3.800	-3.000	-0.346	69.00	44	No
8C	Morning 4h	7:37-11:50	2.627	-2.242	0.675	61.37	64	No
	Afternoon 4h	13:59-18:03	3.778	-3.400	1.229	66.88	57	No
	Attendant 8h	7:07-14:29	2.586	-2.135	0.752	61.89	63	No
9NY	Morning 4h	7:30-8:00 8:43-10:47	3.305	-3.053	-0.435	53.18	100	Yes
	Afternoon 4h	14:00-18:02	4.012	2.592	-1.201	51.65	91	Yes
10NY	Morning 4h	7:40-11:56	6.551	1.103	-6.052	45.29	72	Yes
	Afternoon 4h	14:00-17:52	4.616	0.392	-3.841	52.50	66	No
	Afternoon 1h	16:05-17:05	5.397	3.757	-3.295	52.75	70	No
	Afternoon 1h	17:13-18:15	3.407	0.652	-3.148	53.50	71	No

for each one-hour, four-hour, or eight-hour sampling period for which concentration data were obtained.

Table 4-19 presents three distinct wind speed parameters. The variable "mean wind speed - any direction" is the mean of the individual wind speed values reported for the sampling period without regard to wind direction. This parameter provides an indication of the general dispersion conditions. The parameter "mean wind speed - north vector" is based on wind speed and direction. It is the mean length of the wind vector in the northerly direction. (Note: wind direction refers to the direction from which the wind blows.) Similarly, the parameter "mean wind speed - east vector" is the mean length of the wind vector in the easterly direction. These wind vectors can be used to determine whether a particular emission source (e.g., an adjoining roadway) tended to be upwind of a particular monitor during a specified sampling period.

Most of the four-hour sampling periods listed in Table 4-19 have mean wind speeds (any direction) below 5 mph. The four-hour periods with mean wind speeds above 5 mph are associated with Stations 1NJ (morning), 4NY (morning and afternoon), and 10 NY (morning). Very low mean wind speeds are associated with Stations 2NJ (morning, 2.486 mph) and 8C (morning, 2.627 mph). Precipitation occurred during four of the four-hour sampling periods: 5C - afternoon, 9NY - morning, 9NY - afternoon, and 10NY - morning.

TRAFFIC-RELATED PARAMETERS

Field personnel recorded the number of vehicles which were serviced at each station (all pumps) as one-hour totals. They also estimated the traffic volume on nearby roadways during each one-hour period. These data were processed to determine (1) the number of vehicles serviced during each multi-hour sampling period and (2) the cumulative traffic on nearby roadways during each sampling period. Table 4-20 presents the results organized by station and sampling period.

Table 4-20. Values of selected traffic-related parameters for specified sampling periods.

Station	Sample type	Time period	Total number of vehicles serviced in station[a]			Cumulative street traffic, vehicles
			Self	Full	Total	
1NJ	Morning 4h	10:00-14:00	0	31	31	13,920
	Afternoon 4h	16:30-20:30	0	38	38	12,120
	Afternoon 1h	13:00-14:00	0	8	8	1,740
2NJ	Morning 4h	8:30-12:30	0	161	161	17,100
	Afternoon 4h	15:00-19:00	0	149	149	19,260
	Morning 1h	8:27-9:30	0	29	29	4,800
3C	Morning 4h	8:00-12:00	33	44	77	6,150
	Afternoon 4h	14:17-18:17	65	32	97	5,880
	Attendant 8h	6:58-15:00	40	48	88	7,770
4NY	Morning 4h	8:00-12:00	86	40	126	8,220
	Afternoon 4h	14:25-18:31	114	41	155	7,050
5C	Morning 4h	7:47-12:48	63	13	76	3,840
	Afternoon 4h	14:17-18:16	74	15	89	4,710
6C	Morning 4h	7:51-11:53	127	[b]	127	5,700
	Afternoon 4h	14:04-18:00	132	[b]	132	5,760
7C	Morning 4h	7:37-11:37	95	16	111	5,220
	Afternoon 4h	14:33-18:36	94	16	110	7,080
8C	Morning 4h	7:47-11:50	69	66	135	6,510
	Afternoon 4h	13:59-18:03	60	61	121	6,660
	Attendant 8h	7:07-14:29	75	72	147	7,290
9NY	Morning 4h	7:30-8:00	19	12	31	3,300
		8:43-10:47				
	Afternoon 4h	14:00-18:02	45	17	62	7,110
10NY	Morning 4h	7:40-11:56	101	[b]	101	6,120
	Afternoon 4h	14:00-17:52	118	[b]	118	8,940
	Afternoon 1h	16:05-17:05	31	[b]	31	2,280
	Afternoon 1h	17:13-18:15	35	[b]	35	2,280

[a]Greater than number of vehicles in BZ samples.
[b]Station had no full-service islands.

To facilitate the regression analyses discussed later in this report, the values were divided by the sample duration to determine an average hourly value during each sampling period (not shown in Table 4-20).

The number of vehicles serviced during each four-hour sampling period exceeded 120 vehicles for the following stations: 2NJ, 4NY, 6C, and 8C. Field personnel estimated that the cumulative street traffic exceeded 12,000 vehicles during each four-hour sampling period at Stations 1NJ and 2NJ.

ANALYSIS OF LIQUID FUEL GASOLINE SAMPLES

Field personnel collected a sample of each gasoline grade dispensed at each station. Samples were collected at the pumps by filling a one gallon metal can using a sampling apparatus provided by API. The samples were subsequently analyzed by Sun Oil using two tests: the ASTM 4815 oxygenate method (calibration span = 15 percent volume) and "the infra-red (MTBE filter) method" using a Hewlett Packard Model 5890 Series II gas chromatograph.

Table 4-21 presents selected results of these analyses by station and gasoline grade. The table lists values for percent composition by volume for benzene, toluene, xylene, and MTBE as determined by the ASTM 4815 method. The table also lists MTBE values determined by the infra-red method. The MTBE values determined by the two methods show close agreement when compared by sample, with the infra-red method generally producing the higher of the two values. The range of values associated with each compound is listed below.

Benzene (ASTM 4815): 0.3 percent to 2.8 percent
Toluene (ASTM 4815): 2.1 percent to 10.9 percent
Xylene (ASTM 4815): 1.4 percent to 11.0 percent
MTBE (ASTM 4815): 13.4 percent to 15.7 percent
MTBE (Infra-red method): 14.5 percent to 15.7 percent

Table 4-21. Results of analyses of gasoline samples collected at dispensing pumps.

Station	Sample collection time	Gasoline octane number	Percent composition by volume					RVP, psi	T90, °F
			Benzene[a]	Toluene[a]	Xylene[a]	MTBE-1[a]	MTBE-2[b]		
1NJ	17:40	87	2.8	4.8	4.5	15.1	15.2	9.0	326
		89	1.3	5.5	7.5	14.9	15.2	10.9	337
		93	0.9	6.9	11.0	15.2	ND	8.6	342
2NJ	M[c]	87	2.4	5.1	5.4	14.9	15.3	8.2	325
		89	1.5	4.3	4.8	14.4	15.1	8.7	343
		93	0.6	3.5	1.4	14.9	15.1	9.0	349
3C	M	87	2.8	5.2	5.0	14.7	15.4	9.7	327
		89	2.1	5.7	6.9	14.5	15.5	10.2	332
		93	0.9	6.6	10.7	15.4	15.7	11.3	339
4NY	16:42	87	0.4	2.1	3.0	15.0	15.5	8.5	295
		89	0.5	3.4	4.8	14.5	15.3	9.6	342
		93	0.3	5.1	5.0	14.6	15.3	9.0	342
5C	14:45-14:55	87	0.9	4.8	5.0	14.2	15.5	11.8	340
		89	0.9	6.3	6.0	14.7	15.4	11.8	340
		92	1.0	11.0	7.5	15.7	14.8	12.0	326
6C	15:15-15:20	87	0.9	5.0	5.0	14.5	15.2	11.7	341
		89	0.9	6.3	5.9	14.8	14.9	11.8	334
		92	1.0	10.9	7.4	15.3	15.2	12.1	328
7C	M	87	0.9	4.8	5.0	15.2	15.2	11.8	342
		89	0.9	6.2	6.0	14.7	15.1	11.7	335
		93	2.4	10.2	6.7	13.5	14.8	8.4	312
8C	M	87	0.9	5.1	4.8	14.3	14.8	11.3	343
		89	2.3	10.2	6.7	13.4	14.8	8.5	312
		93	0.9	6.3	6.0	15.3	15.2	11.8	342
9NY	M	87	0.5	3.1	4.5	14.4	14.9	9.2	340
		89	0.6	3.5	4.9	14.7	15.0	8.8	353
		93	0.9	8.5	6.8	14.1	14.9	8.2	339
10NY	M	87	0.5	2.9	4.4	13.9	14.5	8.3	346
		89	0.6	3.5	4.8	14.6	15.0	8.7	351
		93	0.8	6.3	6.4	13.6	14.5	8.4	338

[a]ASTM 4815 method.
[b]Infra-red method.
[c]M = Missing (time not recorded).

Table 4-21 also lists values for Reid Vapor Pressure (RVP) and T90. RVP is the vapor pressure of a liquid determined at 100°F and expressed in pounds per square inch. T90 is the temperature in degrees Fahrenheit (F) at which 90 percent of a gasoline mixture will enter the vapor phase. RVP and T90 provide indications of gasoline volatility. RVP values range from 7.3 psi to 11.8 psi, with the Connecticut stations tending to have larger values than the New Jersey and New York stations. The T90 values range from 295 to 353 degrees F.

VOLUME OF GASOLINE DISPENSED

Field personnel requested station records listing the total volume of gasoline dispensed at all pumps during the sampling activities at each station. In most cases, the available data spanned time periods that did not exactly coincide with the specified sampling periods. Analysts matched the data as closely as possible to develop the estimates presented in Table 4-22.

Note that each entry in Table 4-22 lists two time periods: the specified sampling period and the most similar time period for which gasoline records are available. The value listed under "volume of gasoline dispensed" is the volume dispensed during the latter time period. The value listed under "average dispensing rate" is the average hourly volume dispensed during this period. For example, the morning sampling period for 2NJ was 8:30 to 12:30. Gasoline records were available for the 3.5 hour period from 9:00 to 12:30. The total volume of gasoline dispensed between 9:00 and 12:30 was 3275 gallons. Consequently, gasoline was dispensed at an average rate of 935 gallons/hr (i.e., 3275 gallons divided by 3.5 hours) between 9:00 and 12:30.

The hourly average dispensing rate for the morning period at 2NJ (935 gallons/hr) is the maximum rate listed in Table 4-22. All other rates are less than 400 gallons/hr. Stations with dispensing rates less than 250 gallons/hr include 5C, 6C (morning only), 7C, 9NY, and 10NY.

Table 4-22. Estimated average gasoline dispensing rates based on station records.

Station	Sample type	Monitoring time period	Time period with applicable gasoline data	Volume of gasoline dispensed, gallons	Average dispensing rate, gallons/hour
1NJ	Morning 4h	10:00-14:00	M[a]	M	-
	Afternoon 4h	16:30-20:30	M	M	-
	Special 1h	13:00-14:00	M	M	-
2NJ	Morning 4h	8:30-12:30	9:00-12:30	3,275	936
	Afternoon 4h	15:00-19:00	15:00-19:00	1,500	375
	Morning 1h	8:27-9:30	(only 4 h data available)		-
3C	Morning 4h	8:00-12:00	8:45-12:00	1,213	373
	Afternoon 4h	14:17-8:17	14:25-18:00	1,086	303
	Attendant 8h	6:58-15:00	8:45-15:00	1,425	228
4NY	Morning 4h	8:00-12:00	8:30-12:00	1,171	335
	Afternoon 4h	14:25-18:31	14:30-18:30	1,500	375
5C	Morning 4h	7:47-12:48	7:45-11:45	634	158
	Afternoon 4h	14:17-18:16	14:15-18:15	863	216
6C	Morning 4h	7:51-11:53	5:22-12:01	1,380	208
	Afternoon 4h	14:04-18:00	14:03-17:36	1,355	382
7C	Morning 4h	7:37-11:37	5:17-13:20	1,813	225
	Afternoon 4h	14:33-18:36	13:20-18:28	1,349	263
8C	Morning 4h	7:37-11:50	7:45-11:45	1,505	376
	Afternoon 4h	13:59-18:03	14:00-18:00	1,212	303
	Attendant 8h	7:07-14:29	7:45-11:45 and 14:00-18:00	2,717	340
9NY	Morning 4h	7:30-8:00	7:30-11:30	590	148
		8:43-10:47			148
	Afternoon 4h	14:00-18:02	14:00-18:00	598	150
10NY	Morning 4h	7:40-11:56	7:45-11:45	480	120
	Afternoon 4h	14:00-17:52	14:00-18:00	637	159
	Afternoon 1h	16:05-17:05	No applicable data	M	-
	Afternoon 1h	17:13-18:15	No applicable data	M	-

[a]M = Missing (data not available).

NOTABLE EVENTS

Appendix D presents a listing of the notable events reported by field personnel. Table 4-23 provides an abbreviated summary of the Appendix D material in which the time of each event is categorized by station, sampling period, and event type (e.g., gasoline delivery).

Table 4-23. Notable events occurring during sampling periods.

Station	Sample type	Time period	Gasoline delivery	Gasoline spill/ overflow	Vehicle running during refueling	Painting	Rain	Sampling equipment adjustment	Sampling equipment repair	Other
1NJ	Morning 4h Afternoon 4h Afternoon 1h	10:00-14:00 16:30-20:30 13:00-14:00	9:45					13:55 THC 13:55 THC	11:45 form.	
2NJ	Morning 4h Afternoon 4h Morning 1h	8:30-12:30 15:00-19:00 8:27-9:30		18:00, 18:15	18:58					15:00- 19:00[a]
3C	Morning 4h Afternoon 4h Attendant 8h	8:00-12:00 14:17-18:17 6:58-15:00					15:50-16:30	10:35-10:48 THC 11:17 THC	8:25 CO 10:10 CO off	17:20[b]
4NY	Morning 4h Afternoon 4h	8:00-12:00 14:25-18:31		9:00-9:04 9:25-9:26 11:00-11:04		14:33-			CO off	
5C	Morning 4h Afternoon 4h	7:47-12:48 14:17-18:16		8:37, 9:39		12:10-14:17 15:09	15:00		8:05 form. 9:35-9:45	
6C	Morning 4h Afternoon 4h	7:51-11:53 14:04-18:00		9:13					CO off 14:54 form.	
7C	Morning 4h Afternoon 4h	7:37-11:37 14:33-18:36							8:48 form. 17:27- 17:32 THC	17:40[c] 18:20- 18:25[d] see sig. event log

(continued)

Table 4-23 (Continued)

Station	Sample type	Time period	Gasoline delivery	Gasoline spill/ overflow	Vehicle running during refueling	Painting	Rain	Sampling equipment adjustment	Sampling equipment repair	Other
8C	Morning 4h Afternoon 4h Attendant 4h	7:37-11:50 13:59-18:03 7:07-14:29				14:15-14:35			10:22-10:30 THC	6:30[e]
9NY	Morning 4h Afternoon 4h	7:30-8:00 8:43-10:47 14:00-18:02					8:00-8:43	14:07-14:32 THC		f
10NY	Morning 4h Afternoon 4h Afternoon 1h Afternoon 1h	7:40-11:56 14:00-17:52 16:05-17:05 17:13-18:15	11:45				Yes		9:17-9:34 THC 16:48 THC	

[a]Van was left running. North site data may be high.
[b]OVA readings are high when the garage bay doors are open.
[c]Hose to gas pump #5 broke.
[d]Attendant disposed of used motor oil near the south site.
[e]A city work truck sprayed the trees near the service station were located.
[f]This station is a remediation site. Monitoring wells were located around the underground gasoline tanks to check for possible tank leaks.

(continued)

Section 5
SPECIAL STATISTICAL ANALYSES

This section presents the results of a series of special statistical analyses performed on the data obtained from the service station study. An overview of the significance of these results is presented in Section 6.

POLLUTANT RATIOS BASED ON CANISTER DATA

Tables 5-1 through 5-5 present descriptive statistics for ratio values calculated as

RATIO = (MTBE concentration)/(SECOND concentration).

The MTBE concentration is the value obtained from a canister sample for a particular four-hour sampling period. The SECOND concentration is THC or one of the BTEX compounds (benzene, toluene, ethyl benzene, or xylene) measured at the same location during the same time period. Each table presents results for one SECOND component based on four-hour canister data only. In calculating values of RATIO, analysts replaced pollutant concentrations below the detection limit with values equal to the detection limit.

The median values of RATIO for all locations (based on 120 samples) are listed below by pollutant.

RATIO	Median value
MTBE/benzene	10.99
MTBE/toluene	4.37
MTBE/ethyl benzene	24.33
MTBE/xylene	6.85
MTBE/THC	0.08

The location-specific median values of RATIO are generally larger for pump and breathing zone samples than for perimeter samples. For example, the median

values for the MTBE-to-benzene ratios are 7.80 for perimeter locations, 14.95 for pump locations, and 25.28 for breathing zone locations. This general pattern suggests that refueling operations are the principal source of MTBE at each station, whereas other sources (e.g., local traffic) contribute significantly to the levels of BTEX and THC.

Table 5-1. Descriptive statistics for MTBE-to-benzene ratios based on four-hour canister samples.

Sample description			Ratio				
Stations	Locations	n	Mean	S.D.	Minimum	Median	Maximum
NJ	Perimeter	16	5.65	2.50	2.20	5.70	10.6
	Pumps	4	14.06	4.38	10.00	12.99	20.3
	BZ[a]	4	14.60	3.40	10.00	15.27	17.9
NY	Perimeter	24	7.80	5.62	2.50	5.68	23.8
	Pumps	6	16.06	5.28	9.33	14.83	22.5
	BZ	6	32.78	7.15	25.00	31.13	45.9
CT	Perimeter	40	10.96	6.49	2.40	10.69	30.0
	Pumps	10	15.49	8.74	0.56	16.52	27.8
	BZ	10	24.84	10.19	13.64	25.13	44.0

[a]Breathing zone sampler values are a station-specific composite of pump island and breathing zone concentrations (see discussion at pages 4-1 and 6-3).

Table 5-2. Descriptive statistics for MTBE-to-toluene ratios based on four-hour canister samples.

Sample description			Ratio				
Stations	Locations	n	Mean	S.D.	Minimum	Median	Maximum
NJ	Perimeter	16	2.79	1.64	0.94	2.57	7.1
	Pumps	4	10.26	9.39	3.08	7.55	22.9
	BZ[a]	4	8.25	1.77	6.30	8.08	10.5
NY	Perimeter	24	3.32	2.01	0.79	2.91	8.1
	Pumps	6	6.95	3.15	3.78	5.76	11.3
	BZ	6	18.88	3.95	12.50	20.47	23.0
CT	Perimeter	40	4.54	3.22	0.43	4.18	17.4
	Pumps	10	8.35	6.15	0.59	6.98	20.3
	BZ	10	19.62	7.07	4.59	20.71	29.5

[a]Breathing zone sampler values are a station-specific composite of pump island and breathing zone concentrations (see discussion at pages 4-1 and 6-3).

Table 5-3. Descriptive statistics for MTBE-to-ethyl benzene ratios based on four-hour canister samples.

Sample description			Ratio				
Stations	Locations	n	Mean	S.D.	Minimum	Median	Maximum
NJ	Perimeter	16	15.61	15.42	2.20	6.80	51.4
	Pumps	4	94.94	118.80	12.94	50.07	266.7
	BZ[a]	4	47.78	13.71	33.33	45.98	65.8
NY	Perimeter	24	16.61	12.41	3.20	13.93	46.1
	Pumps	6	42.27	21.88	23.33	31.45	72.7
	BZ	6	156.95	68.85	92.59	138.33	269.0
CT	Perimeter	40	28.09	24.70	2.40	22.56	133.3
	Pumps	10	94.31	122.28	2.50	47.19	400.0
	BZ	10	222.01	141.26	37.69	242.51	416.7

[a]Breathing zone sampler values are a station-specific composite of pump island and breathing zone concentrations (see discussion at pages 4-1 and 6-3).

Table 5-4. Descriptive statistics for MTBE-to-xylene ratios based on four-hour canister samples.

Sample description			Ratio				
Stations	Locations	n	Mean	S.D.	Minimum	Median	Maximum
NJ	Perimeter	16	5.05	2.31	2.20	4.69	10.6
	Pumps	4	21.12	26.22	3.33	11.05	59.0
	BZ[a]	4	14.02	7.28	7.25	12.36	24.1
NY	Perimeter	24	4.26	2.51	0.73	4.00	9.2
	Pumps	6	8.80	4.64	4.38	6.84	15.1
	BZ	6	42.29	23.52	20.16	36.77	81.1
CT	Perimeter	40	9.42	7.67	2.00	6.85	36.4
	Pumps	10	22.00	20.13	0.03	14.38	55.9
	BZ	10	109.12	116.38	10.63	88.98	416.7

[a]Breathing zone sampler values are a station-specific composite of pump island and breathing zone concentrations (see discussion at pages 4-1 and 6-3).

Table 5-5. Descriptive statistics for MTBE-to-THC ratios based on four-hour canister samples.

Sample description			Ratio				
Stations	Locations	n	Mean	S.D.	Minimum	Median	Maximum
NJ	Perimeter	16	0.04	0.04	4.55×10^{-4}	0.02	0.11
	Pumps	4	0.22	0.10	0.10	0.23	0.31
	BZ[a]	4	0.17	0.17	0.02	0.14	0.40
NY	Perimeter	24	0.06	0.05	5.16×10^{-3}	0.04	0.20
	Pumps	6	0.13	0.05	0.08	0.13	0.20
	BZ	6	0.22	0.07	0.16	0.20	0.35
CT	Perimeter	40	0.08	0.07	1.55×10^{-3}	0.07	0.26
	Pumps	10	0.16	0.13	0.01	0.11	0.33
	BZ	10	0.24	0.10	0.11	0.21	0.42

[a]Breathing zone sampler values are a station-specific composite of pump island and breathing zone concentrations (see discussion at pages 4-1 and 6-3).

REGRESSION ANALYSES OF CANISTER DATA TO DEVELOP PREDICTIVE RELATIONSHIPS

A series of stepwise regression analyses were performed on the four-hour canister data with the goal of determining which factors significantly affected the measured concentrations of MTBE, benzene, toluene, ethyl benzene, xylene, and THC. Each analysis was initiated by selecting a dependent variable (indicating pollutant concentration) and a candidate set of predictive parameters (possible causal factors) from the list of parameters in Table 5-6. These parameters included both continuous variables (e.g., temperature) and binary "dummy" variables (e.g., PUMP = 1 for pump locations, PUMP = 0 for other locations).

The result of each stepwise regression analysis is a regression equation and an associated coefficient of determination (R^2). The regression equation contains only those predictive parameters that make a significant contribution to explaining the variation in the dependent variable. The general form of each regression equation is

$$Y = a_0 + (a_1)(X_1) + (a_2)(X_2) + \ldots + (a_i)(X_i) + \ldots + (a_m)(X_m) \qquad \text{(Equation 5-1)}$$

where Y is the dependent variable (pollutant concentration expressed in ppb), m is the number of variables selected for the regression equation, X_i is the i-th variable selected for the regression equation, and a_i is the coefficient associated with variable X_i. The a_0 term is a constant which corresponds to the Y intercept of the regression equation.

Table 5-6. Regression parameters.

Category	Acronym	Explanation
Component concentrations	MTBE1DL	MTBE concentration, ppb[a]
	BENZ1DL	Benzene concentration, ppb[a]
	TOLU1DL	Toluene concentration, ppb[a]
	ETBE1DL	Ethyl benzene concentration, ppb[a]
	XYLE1DL	Xylene concentration, ppb[a]
	THC1DL	THC concentration, ppb[a]
Sampling location	PERIM	1 = perimeter sample, 0 = other
	PUMP	1 = pump sample, 0 = other
	BRZONE	1 = breathing zone sample, 0 = other
State	NJSTAT	1 = New Jersey station, 0 = other
	NYSTAT	1 = New York station, 0 = other
	CTSTAT	1 = Connecticut station, 0 = other
Meteorological parameters	WSPEED	Mean wind speed (mph) regardless of direction
	INVWSP	Inverse of WSPEED
	NWVEC	Mean wind speed in the northerly direction
	EWVEC	Mean wind speed in the easterly direction
	TEMP	Mean temperature, degrees Fahrenheit
	RELHUM	Mean relative humidity, percent
	PREC	1 = precipitation occurred, 0 = no precipitation
Duration and time of day	DURHR	Duration of sampling period (hours)
	AM4H	1 = morning 4-hour period, 0 = other
	PM4H	1 = afternoon 4-hour period, 0 = other
Traffic and gasoline dispensing	SELFHR	Average vehicles/hour at self-service pumps
	FULLHR	Average vehicles/hour at full-service pumps
	TOTHR	Average vehicles/hour at all pumps
	TRAFHR	Average vehicles/hour on nearby roadways
	GALLONHR	Average gasoline dispensing rate, gallons/hour

[a]Values below the detection limit replaced with detection limit.

Table 5-7 provides the results of five stepwise regression analyses of MTBE data. The entries for each analysis include data subset (perimeter, pump island, or breathing zone), the set of candidate parameters considered by the regression analysis, the set of parameters selected for the regression equation, the coefficients of the regression equation, the level of significance (p value) associated with each selected parameter, and the R^2 value. Note that parameters with small p values are more powerful predictors than those with large p values.

The first four analyses presented in Table 5-7 were performed on a set of 14 candidate parameters ("Group A") selected from Table 5-6. Each of the remaining parameters listed in Table 5-6 was omitted from Group A because preliminary analyses of the data indicated that (1) inclusion of the parameter would cause colinearity, (2) the parameter was not significantly correlated with concentration, and/or (3) there were a large number of missing values associated with the parameter.

When all samples with complete data are considered (n = 114), a regression equation containing the parameters PUMP, BRZONE, and INVWSP explains approximately 44 percent of the variation in the MTBE concentration (as indicated by the R^2 value of 0.4392). These variables are related to sample location (PUMP and BRZONE) and wind speed (INVSPD).

The regression analysis of MTBE data from the perimeter samples yields a regression equation containing INVWSP and SELFHR that explains 15 percent of the variation in MTBE concentration (n = 76). The variables relate to wind speed (INVWSP) and number of motor vehicles served at self-service pumps (SELFHR).

Table 5-7. Results of stepwise linear regression analyses in which four-hour MTBE concentration is the dependent variable.

Data subset	Candidate parameters	n	Regression equation			
			Parameter	Coefficient	p	R^2
All samples	Group A[a]	114	Constant PUMP BRZONE INVWSP	-398.38 273.71 831.57 1496.36	0.0104 0.0048 0.0000 0.0050	0.4392
Perimeter samples	Group A	76	Constant INVWSP SELFHR	-24.91 106.31 0.97	0.1119 0.0283 0.0021	0.1495
Pump samples	Group A	19	Constant INVWSP TRAFHR	-1127.86 3649.71 0.21	0.0082 0.0081 0.0184	0.5100
Breathing zone samples	Group A	19	Constant CTSTAT	297.44 1055.16	0.1791 0.0022	0.4334
All samples	BENZ1DL TOLU1DL ETBE1DL XYLE1DL THC1DL	120	Constant BENZ1DL TOLU1DL ETBE1DL THC1DL	-17.46 9.73 16.08 -78.41 0.02	0.3548 0.0000 0.0000 0.0000 0.0108	0.8860

[a]Group A: PUMP, BRZONE, NYSTAT, CTSTAT, WSPEED, INVWSP, TEMP, RELHUM, PREC, AM4H, SELFHR, FULLHR, TOTAL, TRAFHR.

The regression equation obtained from the regression analysis of pump data (n = 19) contains two variables, one related to wind speed (INVSPD) and one to traffic on nearby road ways (TRAFHR). The regression equation explains 51 percent of the variation in MTBE concentration.

The regression equation for breathing zone contains only one variable (CTSTAT). This variable indicates whether or not the station is located in Connecticut; it explains 43 percent of the variability in MTBE concentration (n = 19). Note that the Connecticut stations were the only stations in the study which did not have Stage II vapor recovery systems.

The BTEX and THC parameters were purposely omitted from the above regression analyses to permit the identification of other significant predictive parameters. In the fifth and last analysis presented in Table 5-7, the set of candidate parameters includes only the BTEX and THC parameters. The resulting regression equation contains four of the five candidate parameters (BENZ1DL, TOLU1DL, ETBE1DL, and THC1DL) and explains 89 percent of the variation in MTBE concentration. Of the four compounds, benzene concentration is the best single predictor of MTBE concentration. Benzene explains over 82 percent of the variation in MTBE when considered as the sole predictive parameter.

Tables 5-8 through 5-12 present stepwise regression results for benzene, toluene, ethyl benzene, xylene, and THC, respectively. Each table follows the same format used in Table 5-7.

The Group A parameters selected for the benzene regression equations include PUMP, BRZONE, and INVWSP when all samples are considered, TEMP and AM4H for perimeter samples, INVWSP and TRAFHR for pump samples, and CTSTAT for breathing zone samples (Table 5-8). When the candidate parameters include MTBE1DL, THC1DL and the remaining BTEX compounds, the resulting regression equation includes MTBE1DL, TOLU1DL, and THC1DL (R^2 value = 0.8805).

Table 5-8. Results of stepwise linear regression analyses in which four-hour benzene concentration is the dependent variable.

Data subset	Candidate parameters	n	Regression equation			
			Parameter	Coefficient	p	R^2
All samples	Group A[a]	114	Constant PUMP BRZONE INVWSP	5.13 15.88 33.07 -10.51	0.0108 0.0001 0.0000 0.0008	0.4527
Perimeter samples	Group A	76	Constant TEMP AM4H	-3.15 0.08 0.97	0.0322 0.0018 0.0034	0.1780
Pump samples	Group A	19	Constant INVWSP TRAFHR	-49.19 151.82 0.13	0.0070 0.0094 0.0018	0.5955
Breathing zone samples	Group A	19	Constant CTSTAT	13.52 40.58	0.1301 0.0030	0.4137
All samples	MTBE1DL TOLU1DL ETBE1DL XYLE1DL THC1DL	120	Constant MTBE1DL TOLU1DL THC1DL	-0.53 0.19 0.35 0.00	0.5008 0.0000 0.0000 0.0343	0.8805

[a]Group A: PUMP, BRZONE, NYSTAT, CTSTAT, WSPEED, INVWSP, TEMP, RELHUM, PREC, AM4H, SELFHR, FULLHR, TOTAL, TRAFHR.

Table 5-9. Results of stepwise linear regression analyses in which four-hour toluene concentration is the dependent variable.

Data subset	Candidate parameters	n	Regression equation			
			Parameter	Coefficient	p	R^2
All samples	Group A[a]	114	Constant PUMP BRZONE NYSTAT	-9.50 22.63 42.57 -14.39	0.0002 0.0000 0.0000 0.0002	0.4786
Perimeter samples	Group A	76	Constant TEMP TRAFHR	-16.55 0.43 -0.00	0.0087 0.0003 0.0340	0.1775
Pump samples	Group A	19	Constant NYSTAT CTSTAT	65.33 -58.10 -36.85	0.0000 0.0009 0.0137	0.5083
Breathing zone samples	Group A	19	Constant CTSTAT	23.82 45.05	0.0417 0.0077	0.3493
All samples	MTBE1DL BENZ1DL ETBE1DL XYLE1DL THC1DL	120	Constant MTBE1DL BENZ1DL ETBE1DL	0.20 0.02 0.27 4.37	0.7659 0.0000 0.0003 0.0000	0.9480

[a]Group A: PUMP, BRZONE, NYSTAT, CTSTAT, WSPEED, INVWSP, TEMP, RELHUM, PREC, AM4H, SELFHR, FULLHR, TOTAL, TRAFHR.

Table 5-10. Results of stepwise linear regression analyses in which four-hour ethyl benzene concentration is the dependent variable.

Data subset	Candidate parameters	n	Regression equation			
			Parameter	Coefficient	p	R^2
All samples	Group A[a]	114	Constant PUMP BRZONE NYSTAT	1.30 3.25 4.29 -1.58	0.0000 0.0000 0.0000 0.0005	0.4490
Perimeter samples	Group A	76	Constant TEMP TRAFHR	-1.05 0.04 -0.00	0.1001 0.0013 0.0217	0.1513
Pump samples	Group A	19	Constant NYSTAT CTSTAT FULLHR	18.89 -16.22 -13.14 -0.29	0.0000 0.0000 0.0001 0.0018	0.7377
Breathing zone samples	Group A	19	Constant NYSTAT	6.62 -4.86	0.0000 0.0017	0.4485
All samples	MTBE1DL BENZ1DL TOLU1DL XYLE1DL THC1DL	120	Constant MTBE1DL TOLU1DL XYLE1DL	0.25 -0.00 0.15 0.01	0.0346 0.0000 0.0000 0.0134	0.8626

[a]Group A: PUMP, BRZONE, NYSTAT, CTSTAT, WSPEED, INVWSP, TEMP, RELHUM, PREC, AM4H, SELFHR, FULLHR, TOTAL, TRAFHR.

Table 5-11. Results of stepwise linear regression analyses in which four-hour xylene concentration is the dependent variable.

Data subset	Candidate parameters	n	Regression equation			
			Parameter	Coefficient	p	R^2
All samples	Group A[a]	114	Constant PUMP BRZONE	2.90 26.73 13.89	0.3384 0.0001 0.0420	0.1352
Perimeter samples	Group A	76	Constant TEMP PREC AM4H SELFHR	-11.31 0.21 2.17 1.64 0.07	0.0005 0.0001 0.0072 0.0052 0.0158	0.2625
Pump samples	Group A	19	Constant	29.63	0.0562	0.0000
Breathing zone samples	Group A	19	Constant NYSTAT	21.44 -14.72	0.0000 0.0494	0.2084
All samples	MTBE1DL BENZ1DL TOLU1DL ETBE1DL THC1DL	120	Constant ETBE1DL	0.86 4.26	0.7555 0.0000	0.2014

[a]Group A: PUMP, BRZONE, NYSTAT, CTSTAT, WSPEED, INVWSP, TEMP, RELHUM, PREC, AM4H, SELFHR, FULLHR, TOTAL, TRAFHR.

Table 5-12. Results of stepwise linear regression analyses in which four-hour THC concentration is the dependent variable.

Data subset	Candidate parameters	n	Regression equation			
			Parameter	Coefficient	p	R^2
All samples	Group A[a]	114	Constant BRZONE INVWSP TOTALHR	-2945.92 3341.61 9397.75 42.99	0.0008 0.0000 0.0005 0.0393	0.4001
Perimeter samples	Group A	76	Constant WSPEED SELFHR	1123.60 -339.25 46.76	0.0671 0.0318 0.0033	0.1357
Pump samples	Group A	19	Constant INVWSP TRAFHR	-3348.01 12969.30 0.63	0.0299 0.0114 0.0509	0.4503
Breathing zone samples	Group A	19	Constant INVWSP	-5160.51 33297.20	0.0719 0.0024	0.4261
All samples	MTBE1DL BENZ1DL TOLU1DL ETBE1DL XYLE1DL	120	Constant BENZ1DL	528.33 80.32	0.0019 0.0000	0.4844

[a]Group A: PUMP, BRZONE, NYSTAT, CTSTAT, WSPEED, INVWSP, TEMP, RELHUM, PREC, AM4H, SELFHR, FULLHR, TOTAL, TRAFHR.

The results for toluene are presented in Table 5-9. The selected Group A parameters include PUMP, BRZONE, and NYSTAT for all samples, TEMP and TRAFHR for perimeter samples, NYSTAT and CTSTAT for pump samples, and CTSTAT for breathing zone samples. The results of the fifth analysis presented in the table show that a regression equation containing MTBE1DL, BENZ1DL, and ETBE1DL can explain 95 percent of the variation in toluene concentration.

Table 5-10 presents regression results for xylene. The selected Group A parameters are PUMP and BRZONE for all samples; TEMP, PREC, AM4H, and SELFHR for perimeter samples; and NYSTAT for breathing zone samples. The regression analysis of pump samples did not identify any significant predictive parameters and thus has an R^2 value equal to zero. The fifth regression analysis in Table 5-10 indicates that 20 percent of the variation in xylene can be explained by ETBE1DL. Note that all R^2 values in Table 5-10 are below 0.27. The low values are likely the result of a large number of xylene concentrations below the detection limit.

Regression results for ethyl benzene are presented in Table 5-11. From Group A, the regression equation includes PUMP, BRZONE, and NYSTAT for all samples; TEMP and TRAFHR for perimeter samples; NYSTAT, CTSTAT, and FULLHR for pump samples; and NYSTAT for breathing zone samples. Three pollutant parameters (MTBE1DL, TOLU1DL, and XYLE1DL) are included in the final regression equation in the table. The resulting R^2 value is 0.8626.

Table 5-12 contains the regression results for THC as determined by the four-hour canister samples. The selected Group A parameters are BRZONE, INVWSP, and TOTALHR for all samples, WSPEED and SELFHR for perimeter samples, INVSPD and TRAFHR for pump samples, and INVWSP for breathing samples. The R^2 values of these analyses vary from 0.1357 to 0.4503. Only one component parameter (BENZ1DL) is included in the final regression equation in the table. The associated R^2 value is 0.4844.

EVALUATION OF MAXIMUM MTBE CONCENTRATION VALUES OBTAINED FROM CANISTERS

Table 5-13 lists the maximum MTBE concentrations obtained from four-hour canister samplers located at perimeter, pump, and breathing zone locations. The six highest perimeter values range from 0.140 ppm to 0.071 ppm. The four highest pump island values range from 1.600 ppm to 0.330 ppm. The range of the four highest breathing zone values is 2.600 ppm to 1.500 ppm. The table also indicates various reported conditions which may have contributed to these values. The conditions include:

- Occurrence of a gasoline spill or overflow;
- Poor dispersion as indicated by a wind speed below 3 mph;
- Heavy traffic on nearby roadways as indicated by a cumulative traffic count exceeding 10,000 vehicles for the nominal four-hour period;
- A relatively high emission rate as indicated by an average gasoline dispensing rate exceeding 325 gallons/hour over the four-hour period;
- Heavy station traffic as indicated by the number of serviced vehicles exceeding 115.

Analysts selected the numerical values for these criteria (3 mph, 10,000 vehicles, etc.) by examining the distribution of the values reported for all four-hour sampling periods. The far right-hand column in Table 5-13 lists miscellaneous factors which may have contributed to the high concentration values.

Seven of the 14 high concentration values in Table 5-13 are associated with the combination of two conditions: (1) average wind speed less than 3 mph and (2) number of serviced vehicles exceeded 115. Four of the values were

Table 5-13. Possible explanations of maximum MTBE concentrations obtained from four-hour canister samples.

Location	MTBE concentration, ppm	Station	Time period	Spill or overflow?	Average wind speed less than 3 mph?	Cumulative street traffic exceeded 10,000 vehicles?	Average gasoline dispensing rate exceeded 325 gal/hr?	Number of serviced vehicles exceeded 115?	Other?
Perimeter samplers	0.140	7C	Morning	No	No	No	No	No	[a]
	0.120	6C	Morning	Yes	Yes	No	No	Yes	
	0.120	6C	Morning	Yes	Yes	No	No	Yes	
	0.083	10NY	Afternoon	No	No	No	No	Yes	
	0.081	10NY	Morning	No	No	No	No	No	Gasoline delivery
	0.071	8C	Morning	No	Yes	No	No	Yes	
Pump samplers	1.600	2NJ	Morning	No	Yes	Yes	Yes	Yes	
	1.500	6C	Morning	Yes	Yes	No	No	Yes	
	0.660	2NJ	Afternoon	Yes	No	Yes	Yes	Yes	Vehicle running during refueling
	0.330	5C	Afternoon	No	No	No	No	No	Painting[b]
Breathing zone samplers[c]	2.600	8C	Morning	No	Yes	No	No	Yes	
	2.200	6C	Afternoon	No	Yes	No	Yes	Yes	
	2.100	5C	Afternoon	No	No	No	No	No	Painting[b]
	1.500	3C	Afternoon	No	Yes	No	No	No	Open garage doors registered on OVA

[a] All three garage bays were open and busy. There was an open container of cleaning solvent (unknown composition) in the garage bay farthest from the station office.
[b] Possible solvent use associated with painting and clean-up activities.
[c] Breathing zone sampler values are a station-specific composite of pump island and breathing zone concentrations (see discussion at pages 4-1 and 6-3).

associated with spills or overflows, two were associated with cumulative street traffic exceeding 10,000 vehicles, and three were associated with average dispensing rates exceeding 325 gallons/hour. Active use of the garage bays may have contributed to two of the high values (perimeter - 0.140 ppm and breathing zone - 2.600 ppm). Other potential explanations include a gasoline delivery and a vehicle running during refueling.

In summary, analysts have identified at least one plausible explanation for each of the concentration values in Table 5-13. The combination of low wind speed and heavy station traffic is associated with half of the listed high values. The reader should note that the factors listed in Table 5-13 provide potential rather than proven explanations for the high values. Other unreported factors may be associated with these high values.

COMPARISON OF CANISTER AND CHARCOAL TUBE DATA

Table 5-14 lists 20 cases in which canister and charcoal tube samples were collected at the same location for the same time period. The table presents concentration values for MTBE, benzene, and toluene obtained from these samples. As most of the charcoal tube measurements for ethyl benzene and xylene were below the detection limit, these components have been excluded from the table. THC does not appear in the table because the charcoal tube samples were not analyzed for THC.

Table 5-15 presents descriptive statistics for the tube-to-canister ratios of the component concentrations obtained from the collocated samples. The median (50th percentile) value listed for each component provides an indication of the average tube-to-canister ratio. The median ratios for MTBE, benzene, and toluene are 1.00, 0.56, and 0.80, respectively. Note that the median values are based on relatively small sample sizes and that there is a wide range of ratios associated with each of the three components.

Table 5-14. Component concentration measurements obtained from collocated canister and charcoal tube samples.

Station	Sample type	Time period	Sample location	Component concentration, ppm					
				MTBE		Benzene		Toluene	
				Canister	Tube	Canister	Tube	Canister	Tube
1NJ	Special 1h	13:00-14:00	West perimeter	0.008	(0.1227)[a]	0.001	(0.1108)	0.003	(0.0939)
2NJ	Special 1h	8:27-9:30	West perimeter	0.021	(0.1235)	0.003	(0.1115)	0.005	(0.0945)
3C	Morning 4h	8:00-12:00	Breathing zone	0.196	M[b]	0.014	M	0.010	M
	Afternoon 4h	14:17-18:17	Breathing zone	1.500	1.660	0.082	0.070	0.065	0.065
4NY	Morning 4h	8:00-12:00	Breathing zone	0.100	0.119	0.003	(0.0299)	0.005	(0.0254)
	Afternoon 4h	14:25-18:31	Breathing zone	0.077	0.090	0.003	(0.0312)	0.005	(0.0265)
5C	Morning 4h	7:47-12:48	Breathing zone	1.200	1.060	0.039	(0.0281)	0.046	0.048
	Afternoon 4h	14:17-18:16	Breathing zone	2.100	2.395	0.085	0.047	0.099	0.079
6C	Morning 4h	7:51-11:53	Breathing zone	0.170	1.656	0.012	0.043	0.037	0.078
	Afternoon 4h	14:04-18:00	Breathing zone	2.200	1.142	0.050	(0.0277)	0.130	0.076
7C	Morning 4h	7:37-11:37	Breathing zone	1.500	1.818	0.110	0.062	0.120	0.065
	Afternoon 4h	14:33-18:36	Breathing zone	1.600	0.981	0.059	0.0310)	0.070	(0.0263)
8C	Morning 4h	7:37-11:50	Breathing zone	2.600	1.710	0.072	0.037	0.088	0.038
	Afternoon 4h	13:59-18:03	Breathing zone	0.460	0.515	0.018	(0.0294)	0.024	(0.0249)
9NY	Morning 4h	7:30-8:00 8:43-10:47	Breathing zone	0.250	(0.0507)	0.010	(0.0457)	0.020	(0.0388)
	Afternoon 4h	14:00-18:02	Breathing zone	0.300	0.169	0.009	0.0283)	0.013	(0.0240)
10NY	Morning 4h	7:40-11:56	Breathing zone	0.160	0.138	0.005	(0.0270)	0.008	(0.0229)
	Afternoon 4h	14:00-17:52	Breathing zone	0.780	0.482	0.017	(0.0302)	0.038	(0.0256)
	Special 1h	16:05-17:05	Pumps	0.057	(0.1296)	0.003	(0.1170)	0.001	(0.0992)
	Special 1h	17:13-18:15	Pumps	0.098	(0.1254)	0.005	(0.1132)	0.002	(0.0960)

[a]Numbers in parentheses are detection limits.
[b]M = Missing (sample not collected).

Table 5-15. Descriptive statistics for ratios of component concentrations obtained from canister and charcoal tube samplers.

Pollutant	Number of data pairs (n)	Ratio of tube to canister concentrations				
		Minimum	Percentiles			Maximum
			25th	50th	75th	
MTBE	14	0.52	0.62	1.00	1.17	9.74
Benzene	5	0.51	0.53	0.56	2.22	3.58
Toluene	7	0.43	0.54	0.80	1.04	2.11

REPLICATE SAMPLES

One replicate pair of canister samples and one replicate pair of impinger (formaldehyde) samples were collected at each station. Table 5-16 lists the values of the component concentrations obtained from these samples by station. All concentration values are associated with nominal four-hour samples, and all were obtained from perimeter monitoring locations.

Analysts calculated a "percent difference" statistic for each replicate pair using the equation

$$\text{percent difference} = (100 \text{ percent})[ABS(A - B)]/(0.5)(A + B)$$

where A and B are the replicate concentrations, ABS(A - B) is the absolute value of the difference between A and B, and (0.5)(A + B) is the average value of A and B. Table 5-17 presents descriptive statistics for this quantity by component. Note that replicate pairs with value(s) below the detection limit were not considered in calculating these statistics.

The median values provide a good indication of the average percent difference value. The medians are 21.8 percent for MTBE, 12.2. percent for benzene, 19.4

Table 5-16. Component concentration measurements obtained from duplicate four-hour canister and impinger samples.

Station	Time period	Perim-eter location	Component concentration, ppm											
			MTBE		Benzene		Toluene		Ethyl benzene		Xylene		Formaldehyde	
			A	B	A	B	A	B	A	B	A	B	A	B
1NJ	Afternoon	West	0.009	0.007	0.002	0.001	0.004	0.002	0.001	(0.0006)[a]	0.003	0.001	(0.0131)	(0.0111)
2NJ	Afternoon	West	0.025	0.029	0.004	0.004	0.007	0.006	0.001	0.001	0.004	0.004	0.012	0.016
3C	Morning	East	0.008	0.008	0.001	0.001	0.002	0.001	(0.0004)	(0.0004)	0.001	0.001	0.012	0.012
4NY	Afternoon	South	0.010	0.009	0.001	0.001	0.002	0.002	(0.0004)	(0.0005)	0.001	0.001	M[b]	0.016
5C	Afternoon	West	0.044	0.058	0.002	0.003	0.007	0.011	0.001	0.001	0.003	0.005	0.009	0.011
6C	Afternoon	North	0.016	0.013	0.001	0.001	0.003	0.003	(0.0006)	(0.0005)	0.001	0.001	0.022	0.015
7C	Afternoon	North	0.068	0.054	0.003	0.003	0.006	0.008	0.001	0.001	0.003	0.004	0.010	0.010
8C	Afternoon	North	0.029	0.014	0.002	0.002	0.071	0.028	0.004	0.001	0.007	0.003	0.012	0.014
9NY	Afternoon	North	0.006	0.005	0.001	0.001	0.003	0.003	(0.0004)	(0.0004)	0.002	0.002	(0.0088)	(0.0092)
10NY	Morning	East	0.014	0.021	0.002	0.001	0.003	0.003	(0.0005)	(0.0003)	0.002	0.002	(0.0124)	(0.0112)

[a]Numbers in parentheses are detection limits.
[b]M is missing value

Table 5-17. Descriptive statistics for percent difference between duplicate samples.

Component	Number of replicate pairs (n)[a]	Percent difference in duplicate concentrations[b]						
		Mean	Standard deviation	Minimum	Percentiles			Maximum
					25th	50th	75th	
MTBE	10	24.4	18.9	7.4	9.1	21.8	30.6	70.0
Benzene	10	14.7	13.6	0	1.8	12.2	29.1	38.5
Toluene	10	27.8	27.6	0	3.3	19.4	46.4	86.9
Ethyl benzene	4	41.3	37.8	11.8	-	30.5	-	92.3
Xylene	10	26.7	32.0	0	3.2	11.8	53.2	88.4
Formaldehyde	6	18.1	13.8	0	3.9	19.0	29.2	38.5

[a]Omits duplicate pairs containing value(s) below the detection limit.
[b]Percent difference = (100) | A-B | / [(0.5)(A+B)]
A: duplicate A concentration
B: duplicate B concentration.

percent for toluene, 30.5 percent for ethyl benzene, 11.8 percent for xylene, and 19.0 percent for formaldehyde. Note that the relatively high median for ethyl benzene (30.5 percent) is based on only four duplicate pairs.

Section 6
SUMMARY AND DISCUSSION

In 1992, the U.S. Environmental Protection Agency (EPA) began receiving anecdotal complaints of headaches, nausea, and other symptoms following alleged wintertime exposures to MTBE in fuels. In early 1993, EPA began a series of clinical research studies to investigate the validity of these claims. To properly design these studies, EPA solicited estimates of typical air concentrations of MTBE that motorists and attendants may experience during refueling at service stations that dispense gasoline containing MTBE. EPA also expressed interest in determining typical MTBE concentrations at the property boundaries of these service stations.

In response to these needs, API funded a field study in which ITAQS measured ambient MTBE concentrations at 10 service stations in the New York metropolitan area. The stations included

1. Two full-service stations with Stage II vapor recovery on a commuting route near East Brunswick, New Jersey;

2. Three self-service stations with Stage II vapor recovery in Westchester County, New York; and

3. Five self-service stations without Stage II vapor recovery in Fairfield County, Connecticut.

The selection of full-service stations in New Jersey was unavoidable, as self-service stations are not permitted in that state.

Each station was sampled on a separate day between April 7, 1993 and April 23, 1993. The monitoring activities at each station were conducted during two four-hour periods, nominally 9 a.m. to 12 a.m. and 2 p.m. to 6 p.m. Four-hour canister and impinger samples were collected at four perimeter locations (north, east, south, and west) and one pump location at each station, in customer breathing zones at the New

York and Connecticut stations, and in attendant breathing zones at the New Jersey stations. In addition, four-hour charcoal tube samples were collected in the breathing zones of all stations. These samples were analyzed to determine air concentrations of MTBE, BTEX (benzene, toluene, ethyl benzene, xylene), total hydrocarbon (THC) concentration, and formaldehyde.

Continuous carbon monoxide measurements were made in the pump area of each station using a Metrosonics® pm-7700 monitor. Organic vapor analyzers (OVA) were used to continuously monitor THC concentrations in the pump areas and breathing zones. These measurements were made as a means of identifying individual refueling events which could not be distinguished in the four-hour samples collected by the canister samplers.

Field personnel monitored meteorological parameters, gasoline composition (oxygenate content, Reid vapor pressure, BTEX), and gasoline sales and deliveries during each sampling period. Personnel also noted the time each vehicle was refueled and conducted regular counts of traffic on nearby roadways. Gasoline pumping activities were continuously recorded by a stationary video camera.

Statistical analyses of the data obtained from the field monitoring activities support the following general findings.

1. Mean and maximum four-hour average MTBE concentrations generally decrease from breathing zone to pump island to perimeter, suggesting that refueling activities are the principal source of MTBE measured at service stations.

2. MTBE concentrations are generally lower at stations with Stage II vapor controls.

3. Median four-hour MTBE concentrations for all stations are below 2 ppm at breathing zone and pump island locations and below 0.02 ppm at the station perimeters.

4. Maximum four-hour MTBE concentrations for all stations are below 2.6 ppm at breathing zone and pump island locations and below 0.2 ppm at station perimeters.

5. For all stations, because the canisters also sampled nonrefueling periods, breathing zone measurements of MTBE concentration may underestimate actual breathing zone concentrations during fuel dispensing by station-specific factors ranging from 1 to 3. Most factors fall between 1.0 and 1.4.

A series of special statistical analyses were performed to identify patterns in the individual component data and to compare sampling methodologies. An analysis of concentration ratios (the ratio of MTBE to a second component) found that ratios were generally larger for pump and breathing zone canister samples than for perimeter canister samples. This pattern suggests that refueling operations were the principal source of MTBE at each station, whereas other sources (e.g., local traffic) contributed significantly to the levels of BTEX and THC.

The results of stepwise regression analyses performed on the four-hour canister data indicate that MTBE concentration can be predicted well (R^2 = 0.886) as a linear function of simultaneously-measured concentrations of benzene, toluene, ethyl benzene, and THC. Of these four predictors, benzene provides the best single means of predicting MTBE concentration. Benzene also provides the best prediction of toluene and THC concentration. Toluene is the best predictor of ethyl benzene concentration. Other stepwise regression analyses were performed on the four-hour canister measurements to identify factors which potentially affect component concentration values. The analyses suggest that following conditions are associated with an increase in MTBE concentration:

- Measurements are made at pump island or breathing zone locations rather than perimeter locations;

- Measurements are made at a Connecticut station (i.e., a station with no Stage II vapor recovery) rather than a New York or New Jersey station;

- Low wind speed;
- High traffic on nearby roads.

Analysts also attempted to identify possible conditions that could explain fourteen high MTBE values. Seven of the 14 values were found to be associated with the combination of two unusual conditions: (1) average wind speed less than 3 mph and (2) number of serviced vehicles exceeded 115. Four of the high values were associated with spills or overflows, two were associated with cumulative street traffic exceeding 10,000 vehicles, and three were associated with average gasoline dispensing rates exceeding 325 gallons/hour. Active use of garage bays may have contributed to two of the high values. Other potential events that may be relevant include a gasoline delivery, a vehicle running during refueling.

Although the field study was conducted primarily to obtain representative air concentrations of MTBE at service stations, the collected data also provide a means for comparing canisters and charcoal tubes. These sampling methodologies are routinely used in chemical exposure studies. The data base contains 20 cases in which canister and charcoal tube samples were collected at the same location for the same time period. An analysis of the 14 cases in which MTBE concentrations exceeded the limit of detection for both sampling methodologies found that the ratio of canister MTBE to tube MTBE ranged from 0.52 to 9.74. Fifty percent of the canister-to-tube ratios were between 0.62 and 1.17; the median ratio was 1.00.

Ten pairs of duplicate samples were collected using canister samplers, and ten pairs were collected using impinger samples. The median percent difference in concentration between the duplicate measurements was 21.8 percent for MTBE, 12.2 percent for benzene, 19.4 percent for toluene, 30.5 percent for ethyl benzene, 11.8 percent for xylene, and 19.0 percent for formaldehyde. Note that duplicate pairs containing values below the detection limit were not considered in calculating these values.

During the ITAQS service station study, an EOHSI research team headed by Dr. Paul Lioy collected air samples in the passenger compartments of automobiles during typical home-to-work commutes (manuscript in preparation). Selected automobiles in the Lioy study were refueled at stations included in the service station study. Breathing zone MTBE concentrations measured by the EOHSI team during these refueling events were comparable to breathing zone measurements made by the ITAQS team.

Section 7

REFERENCES

1. *Compendium of Methods for Determination of Toxic Organic Compounds in Ambient Air*, 1988, pp. TO14-1 to TO14-5.

2. *NIOSH Manual of Analytical Methods, Third Edition*, Volume 1, 1988, pp. 1615-1 to 1615-3.

3. *Compendium of Methods for Determination of Toxic Organic Compounds in Ambient Air*, 1988, pp. TO5-1 to TO5-3.

4. Metrosonics pm-7700 Probe #7701 Continuous CO Analyzer Operations Manual, Orr Safety, 351 South Lombard Road, Addison, Illinois 60101.

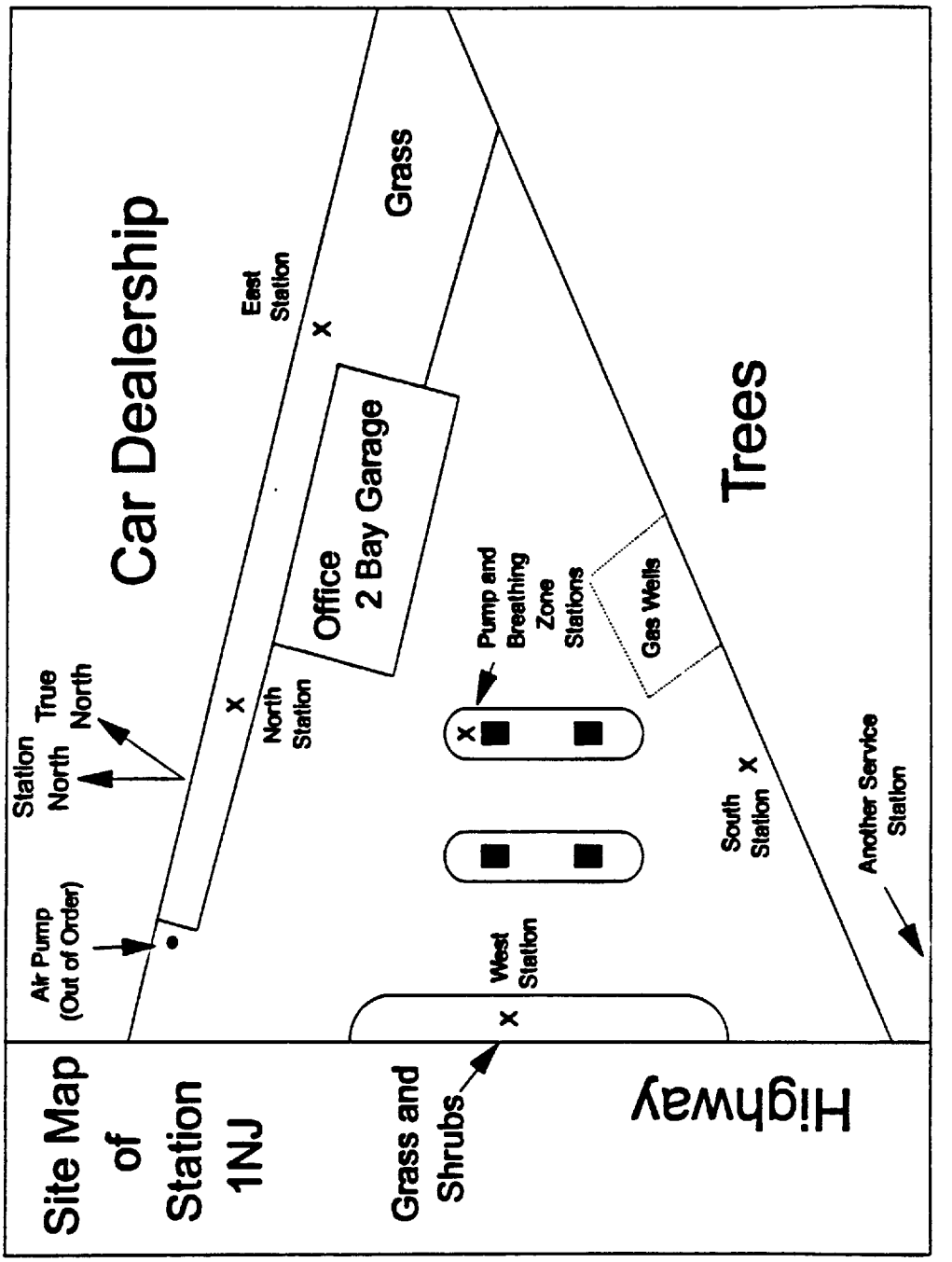
5. U.S. E.P.A. Method 21 (40 CFR 60 Appendix A).

6. *1994 ASTM Annual Book of ASTM Standards*, Section 5 - Petroleum Products, Lubricants, and Fossil Fuels, Volume 05.03, pp. 136 to 142.

7. Detailed Hydrocarbon Analysis by High Resolution Gas Chromatography, Neil G. Johansen, Consultant, 102 Pine Tree Lane, Boulder, Colorado 80304.

APPENDIX A

GENERALIZED STATION SCHEMATICS



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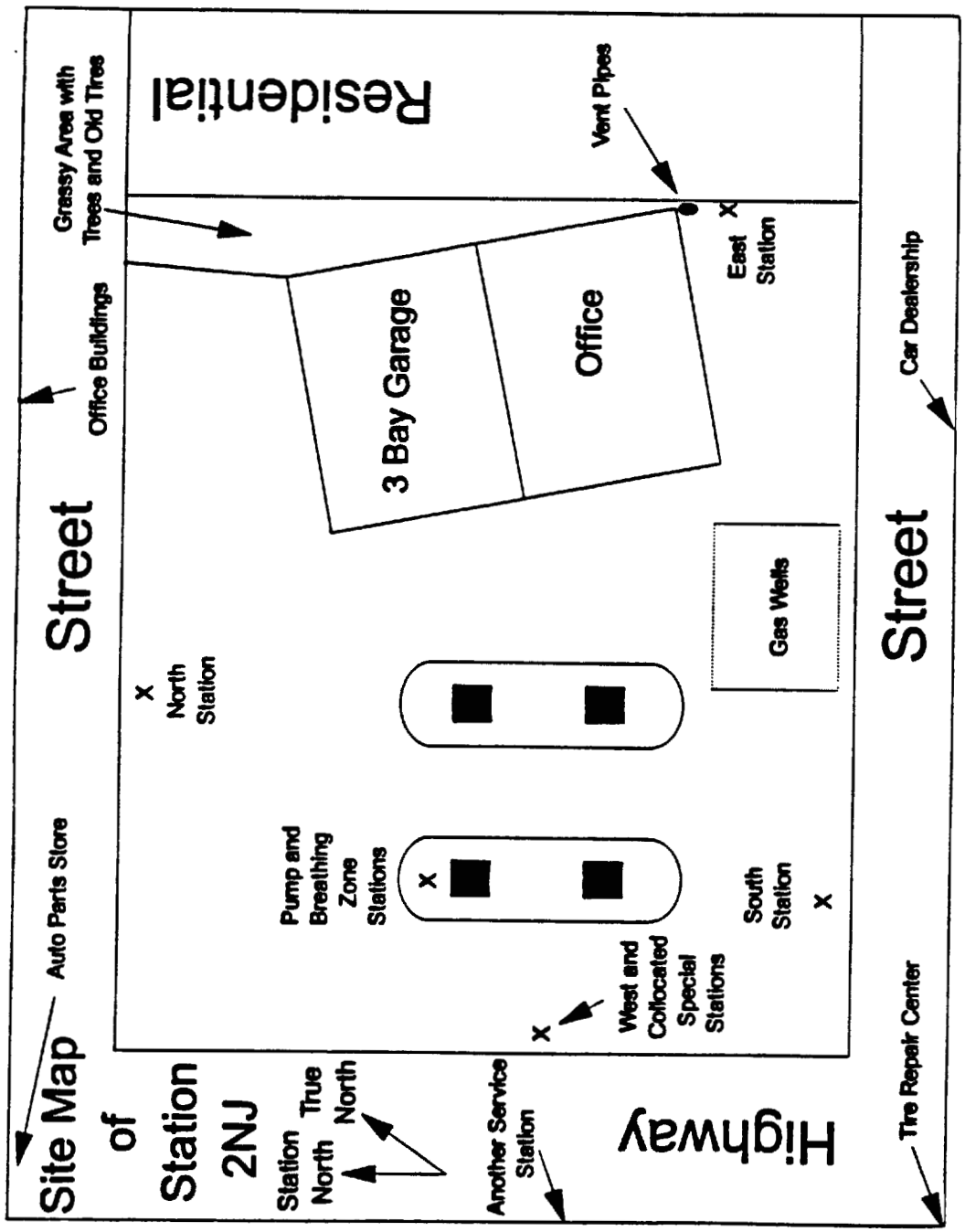
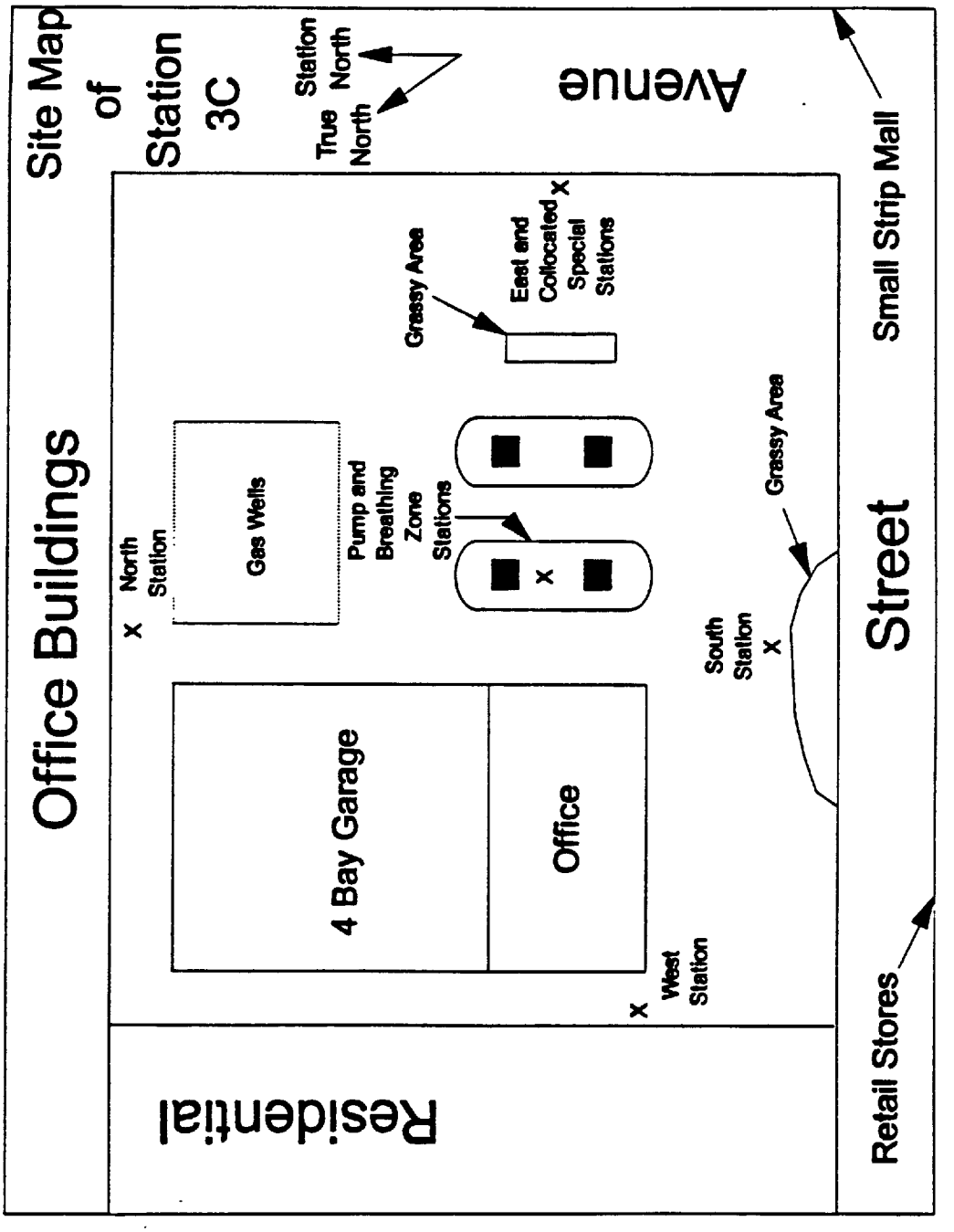
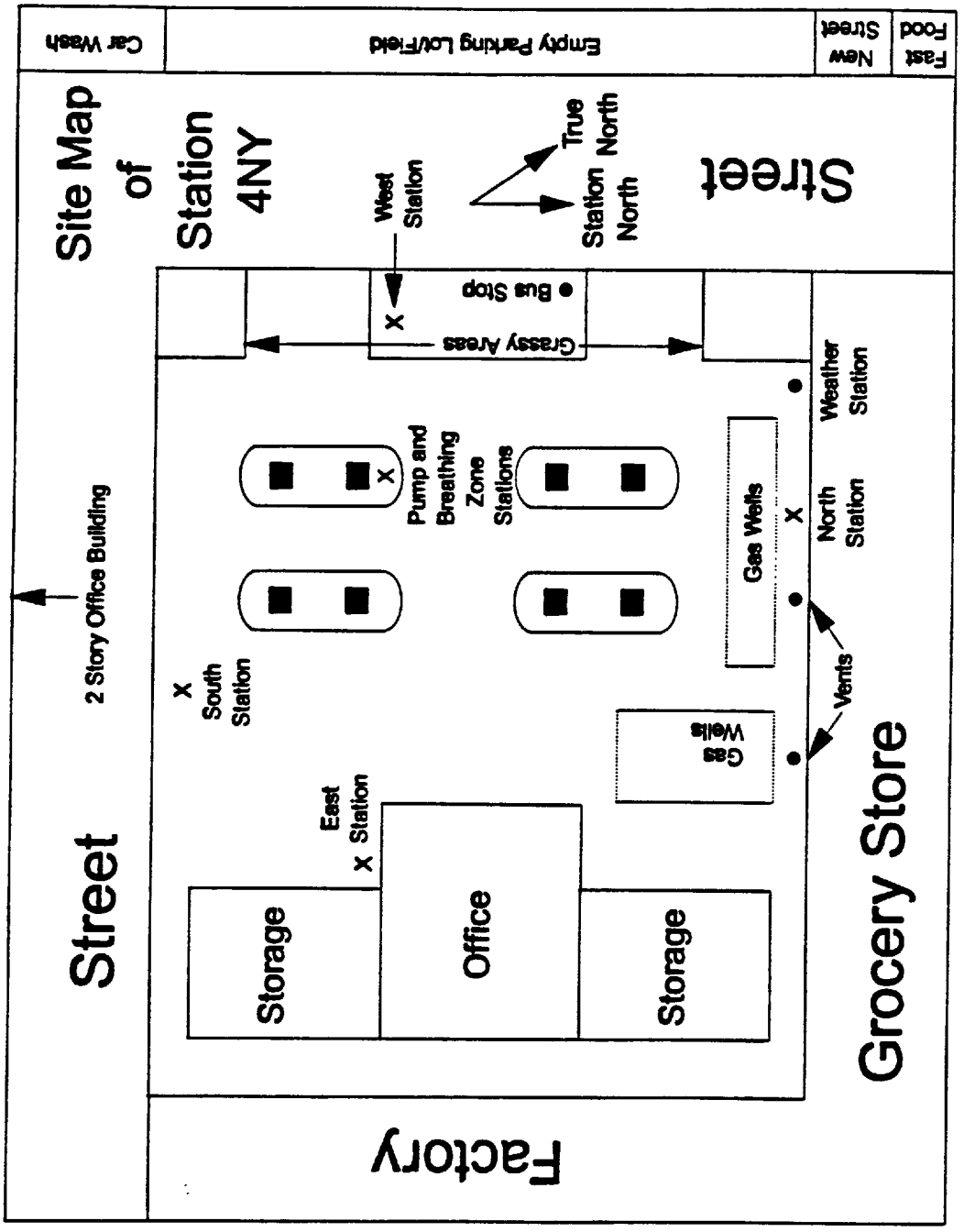
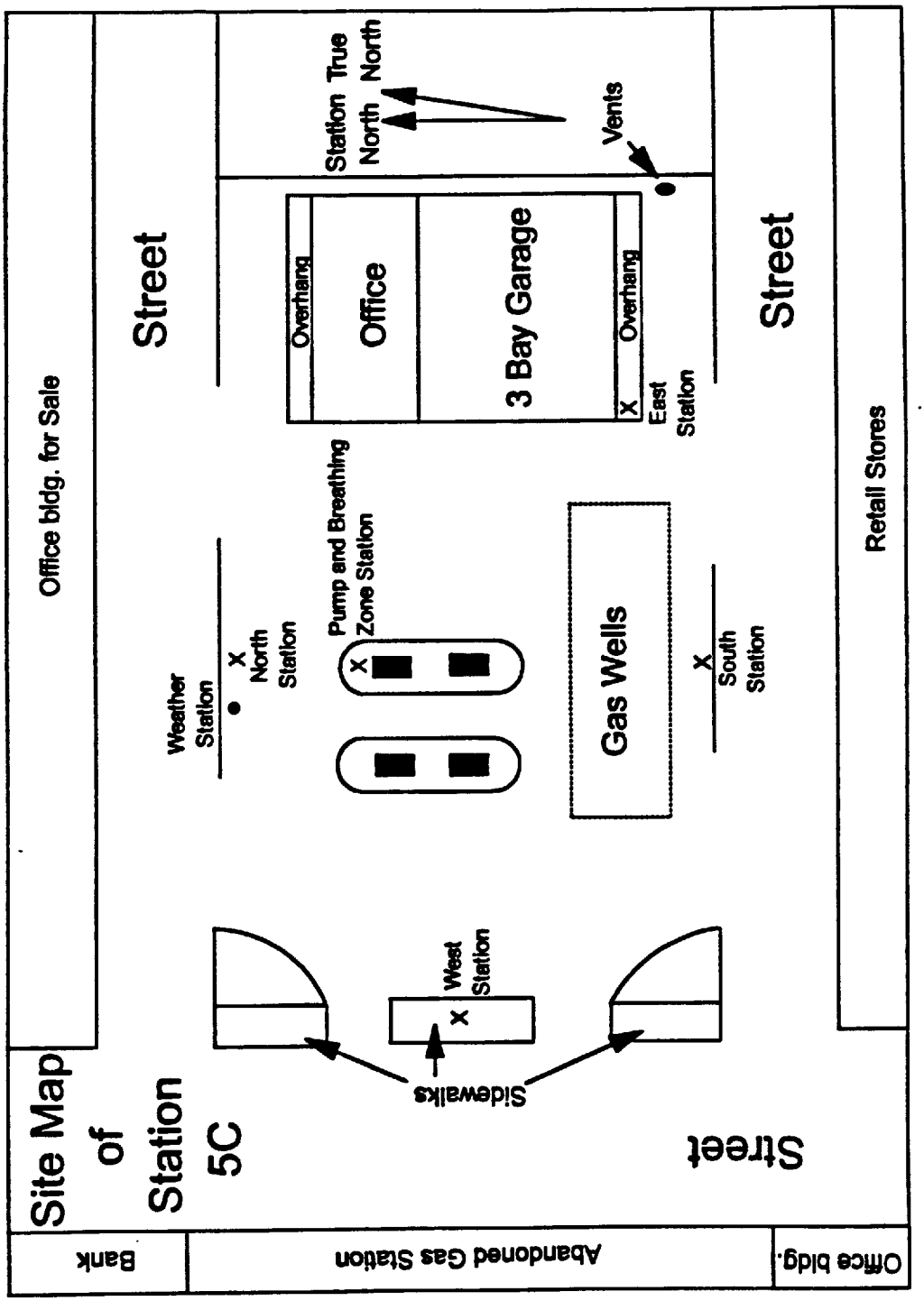
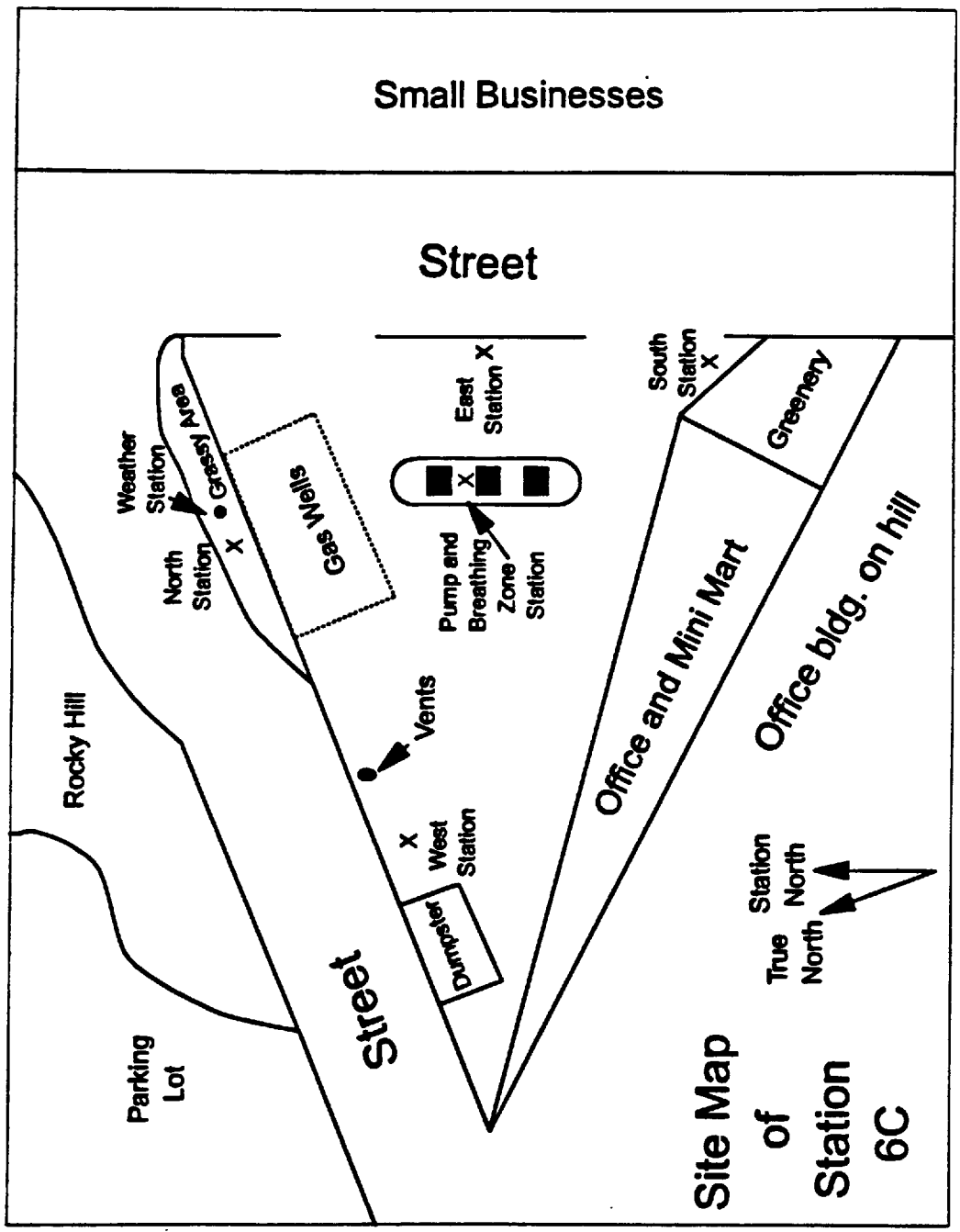
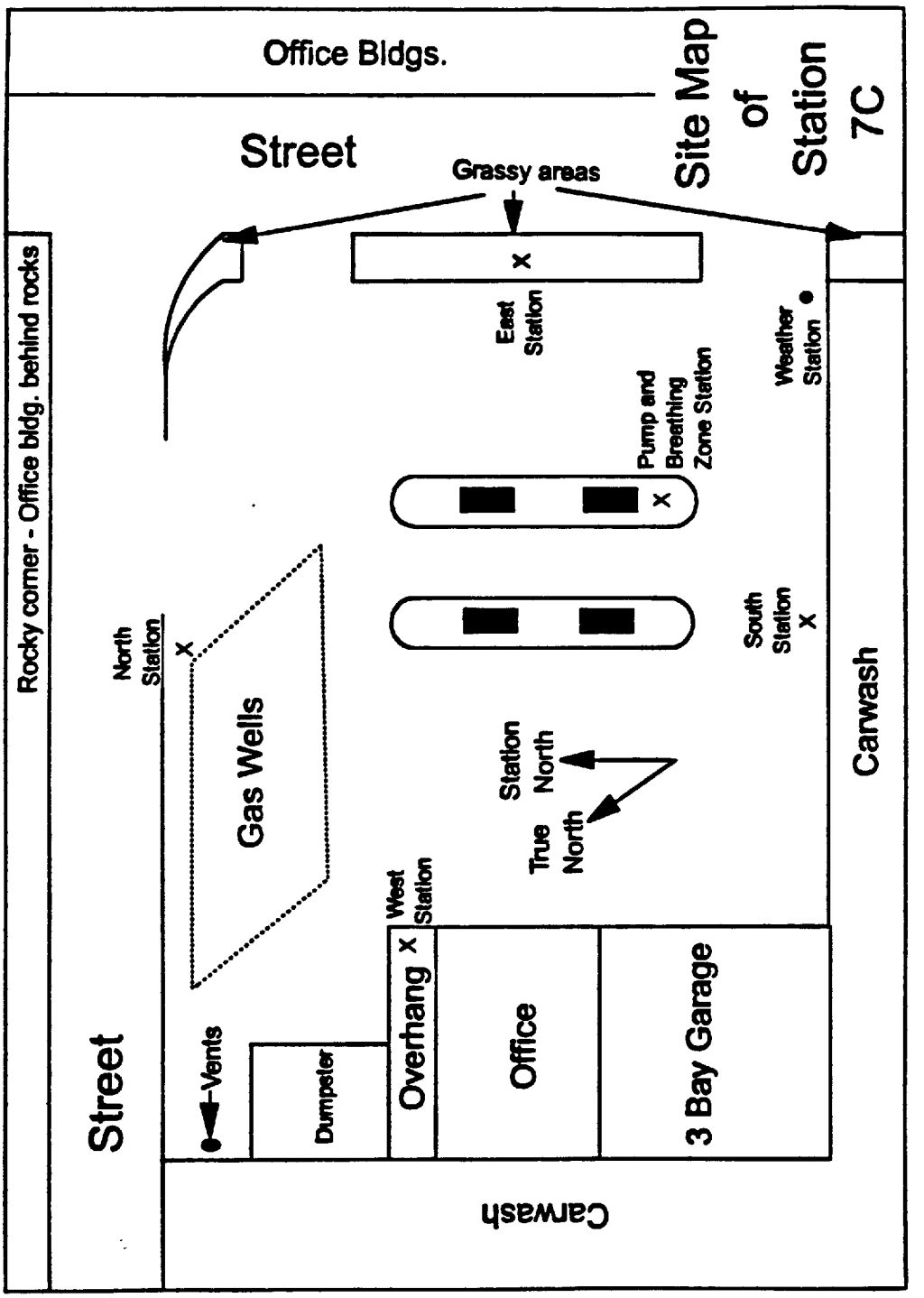


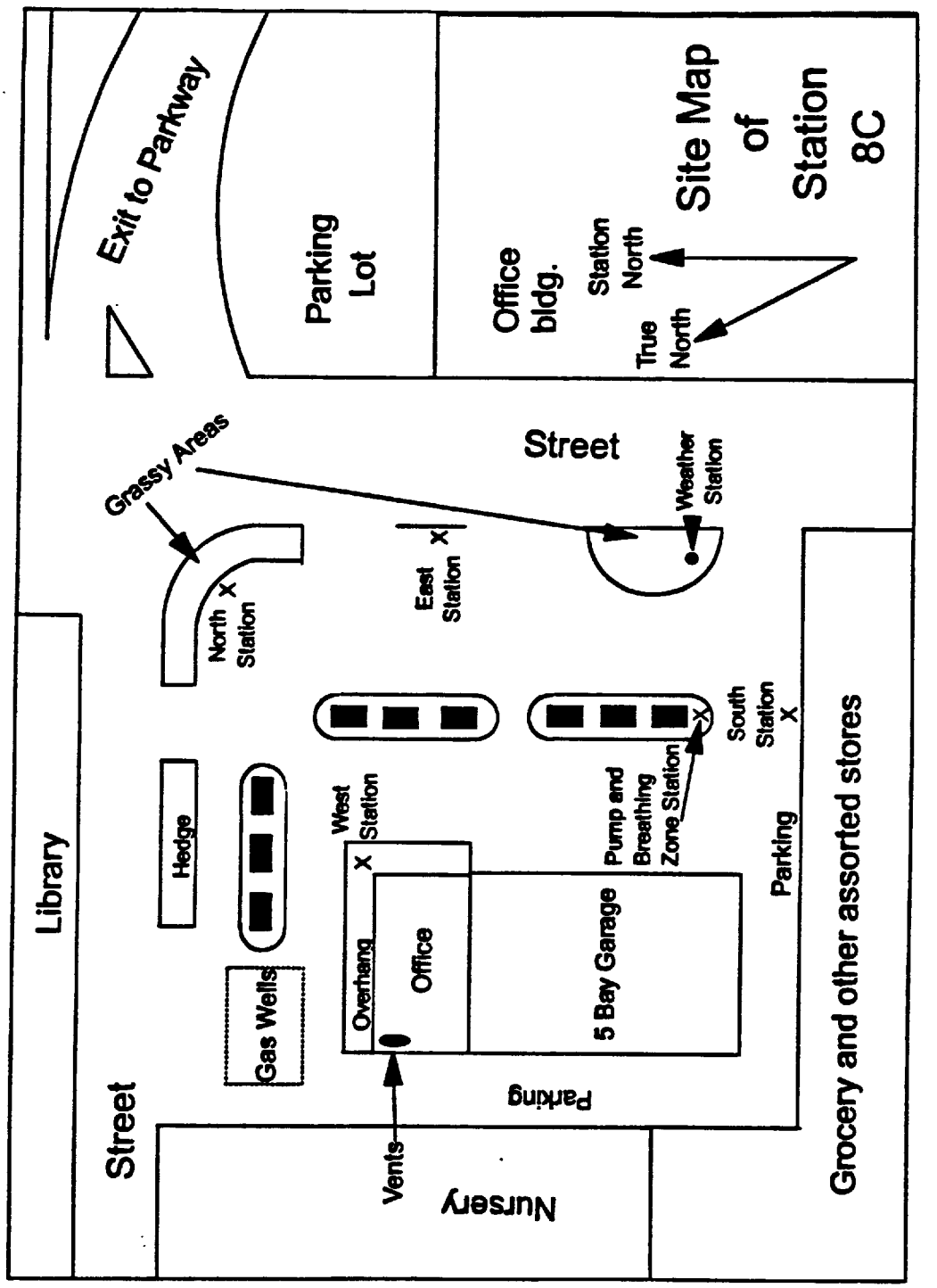


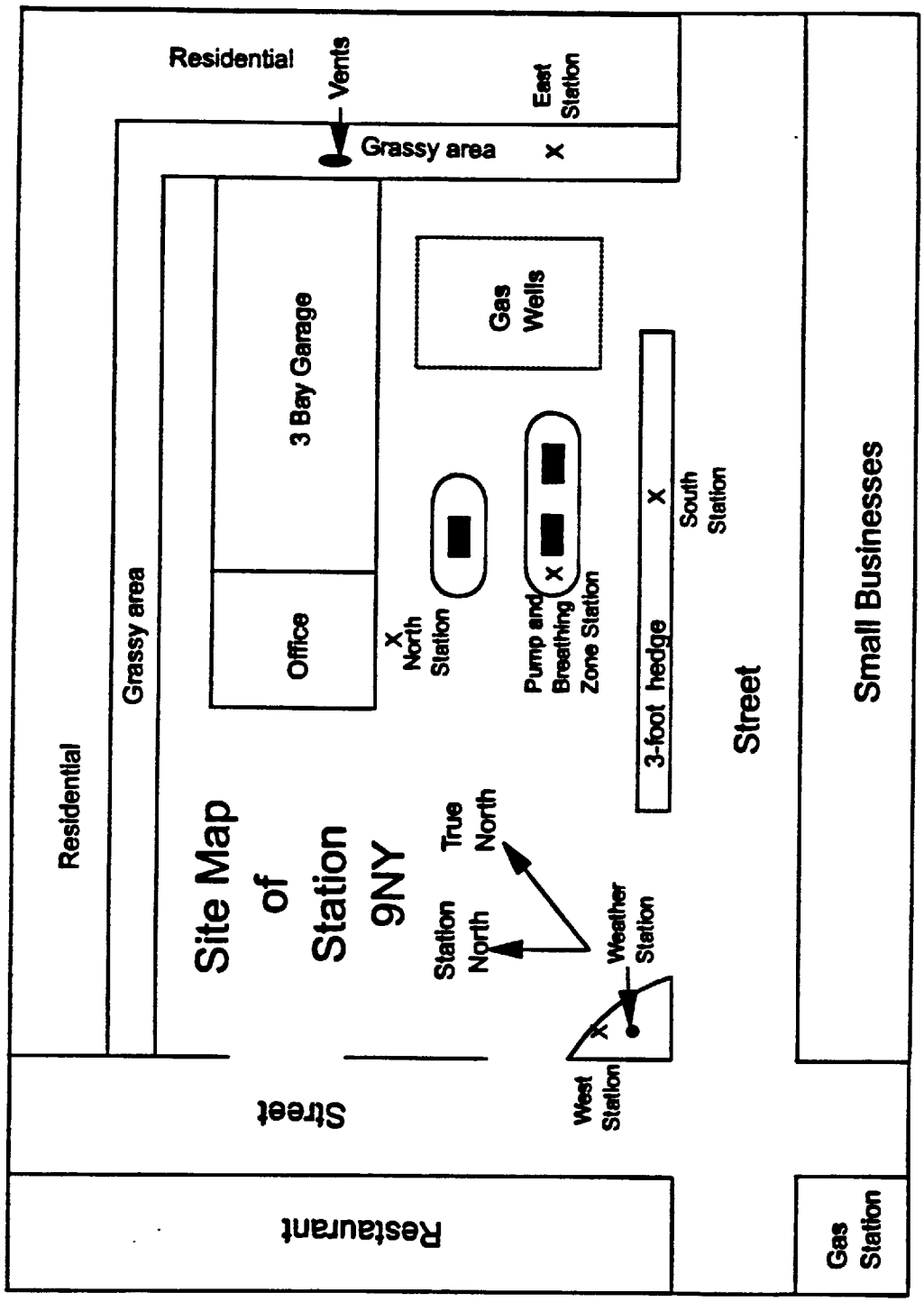


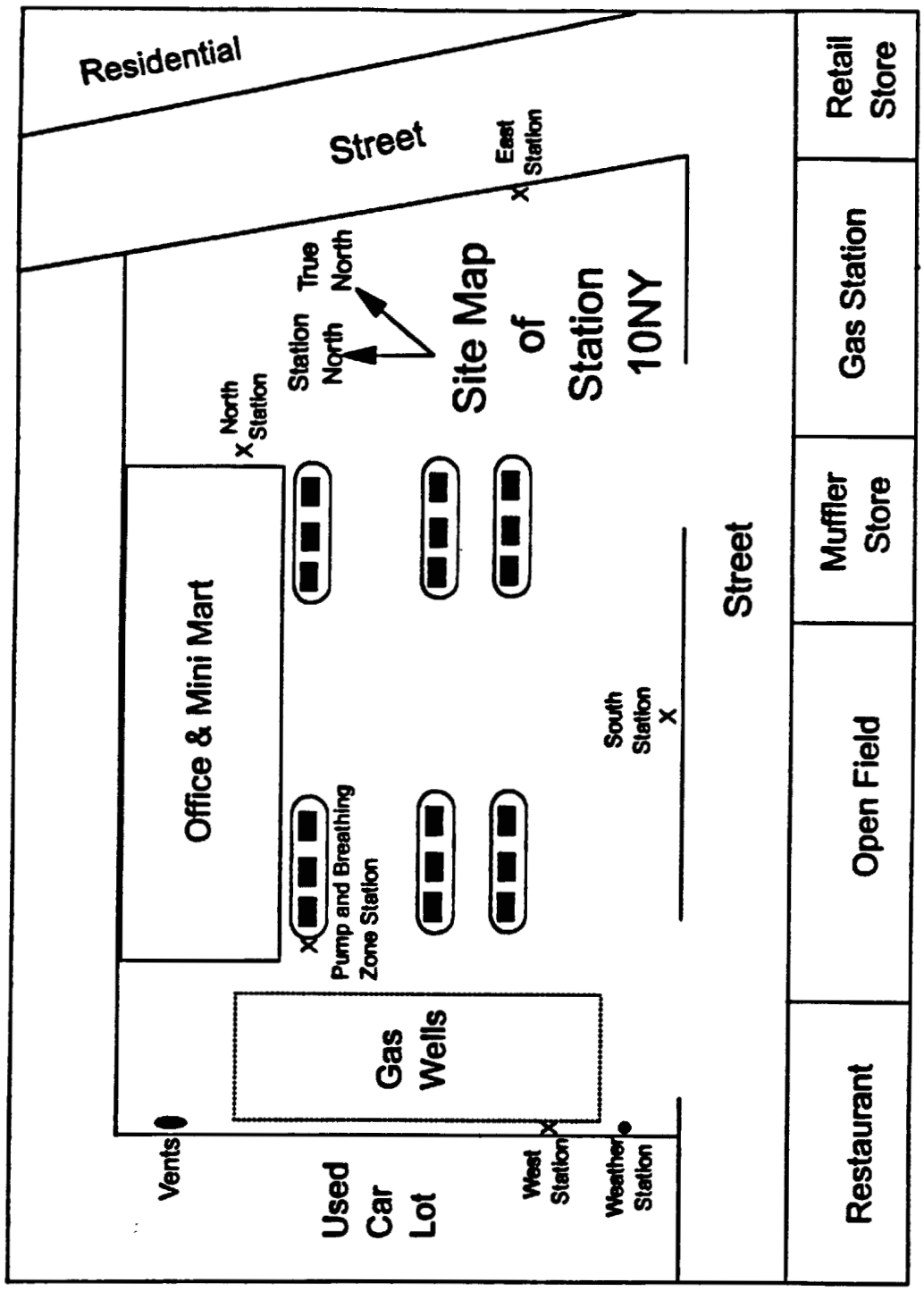












APPENDIX B

NOTABLE EVENTS LOG

Table B-1
Significant Event Log for Service Station 1NJ
4/7/93

General Events	
Weather: AM - Clear and approximately 40°F; PM - Clear and approximately 60°F Initiation of the morning sampling period was slightly delayed.	
Specific Events	
Time	Event
945	A gasoline delivery occurred.
1355	The strip chart for the breathing zone OVA measurements ran out of paper.

Table B-2
Significant Event Log for Service Station 2NJ
4/8/93

General Events
Weather: AM - Clear and approximately 48°F; Noon - Clear and approximately 62°F; PM - Clear and approximately 40°F The van was left running when the camera was in operation. As a consequence, the north site hydrocarbon readings may be high.

Specific Events	
Time	**Event**
1800	A spill of approximately 500ml occurred, while collecting a bulk sample.
1815	Approximately 250ml of gasoline and water mix remained in front of the breathing zone and pump sampling areas.
1858	A car was left running while parked at the pump island.

Table B-3
Significant Event Log for Service Station 3C
4/12/93

General Events
Weather: AM - Clear and approximately 49°F; PM - Clear to cloudy, approximately 55°F, and light rain The traffic rush period appeared to be from 7:00 to 8:30, while the sampling team is setting up.

Specific Events	
Time	Event
825	The CO monitor battery was recharged.
1035-1048	The strip chart recorder for the breathing zone OVA measurements ran out of paper.
1117	The strip chart recorder for the pump OVA measurements ran out of paper.
1550	Light rain began.
1630	Light rain ended.
1720	Observation: The OVA background readings are high when the service station garage bay doors are open.

Table B-4
Significant Event Log for Service Station 4NY
4/13/93

General Events	
Weather: AM - Clear, cold, and windy; PM - Clear, cool, and windy The service station is near an operating bus stop.	
Specific Events	
Time	Event
900-904	A spill of approximately 500ml occurred.
925-926	One car was refueled. One gas container was filled and a spill of approximately 40ml occurred.
1017-1020	The EOSHI car was refueled.
1053	Two pieces of equipment were refueled.
1100-1104	Two cars were refueled. One car had a minimal fuel overflow.
1433	The curbs near the monitoring area were painted.

Table B-5
Significant Event Log for Service Station 5C
4/15/93

General Events	
Weather: AM - Cool and cloudy; PM - Cool and light rain A car battery was charged near the east site between 8:00 and 13:00.	
Specific Events	
Time	Event
805	The formaldehyde pump at the east site was replaced.
837	One car refueled and spilled approximately 50ml.
935-945	The breathing zone OVA was turned off.
939	One car refueled and spilled approximately 10ml.
1001-1002	The EOSHI car was refueled.
1210-1417	The curbs near the monitoring area were painted.
1500	A slight drizzle began.
1509	A painter was painting in the northeast corner of the station lot.
1803	A CO peak was recorded when a car started its engine.

Table B-6
Significant Event Log for Service Station 6C
4/16/93

General Events	
Weather: Cool and cloudy	
Specific Events	
Time	**Event**
815-830	The CO monitor went offline.
913	Two cars refueled and spilled approximately 100ml.
937-940	The EOSHI car was refueled.
1454	The tube to the south station formaldehyde sampler was lost at an unknown time. The error was discovered and the tube was reattached.

Table B-7
Significant Event Log for Service Station 7C
4/19/93

General Events
Weather: AM - Clear and approximately 65°F; Noon - Clear and approximately 70°F; PM - Clear and approximately 75°F A sewage vent was located near the west station in front of the building. A car wash with an outdoor pressure sprayer was located near the south site. As a consequence, excessive moisture may have been sampled at that location. All three garage bays were open and busy. In the bay farthest from the office a cleaning 'solvent' pan was present.

Specific Events	
Time	Event
848	The breathing zone formaldehyde pump was replaced due to low flow.
1727-1732	The breathing zone OVA was replaced.
1740	The refueling hose leading from the regular unleaded gas pump #5 caticorner to the monitored pump, broke.
1820-1825	Station attendant disposed of used motor oil approximately five feet away from the south site.

Table B-8
Significant Event Log for Service Station 8C
4/20/93

General Events	
Weather: Clear and approximately 55°F Four of the five garage bays were open.	
Specific Events	
Time	Event
630	A city work truck sprayed the trees across from the station.
1022-1030	The battery in the breathing zone OVA was replaced.
1415-1435	A worker painted the hub caps of a vehicle with black spray paint.

Table B-9
Significant Event Log for Service Station 9NY
4/22/93

General Events
Weather: AM - Cloudy and approximately 55°F; PM - Cloudy and approximately 50°F The service station is a remediation site. Monitoring wells were located around the underground gasoline tanks to check for possible tank leaks. Formaldehyde samplers were not in operation during the morning test period.

Specific Events	
Time	Event
800-843	Shut down sampling due to rain.
1407-1432	The breathing zone OVA was off, while the strip chart recorder was running.

Table B-10
Significant Event Log for Service Station 10NY
4/23/93

General Events	
Weather: AM - Rain/sleet and approximately 43°F; PM - Cloudy and light rain	
Specific Events	
Time	Event
917-934	The OVA strip charts were off.
1145	A gasoline delivery occurred.
1530-1539	The breathing zone OVA battery was replaced.
1605	Special study #1 began.
1648	The pump OVA battery was replaced.
1705	Special study #1 ended.
1713	Special study #2 began.
1815	Special study #2 ended.

ATTACHMENT

PRESENTATION OF PRELIMINARY SERVICE STATION EXPOSURE FINDINGS

EPA CONFERENCE ON MTBE AND OTHER OXYGENATES A RESEARCH UPDATE

JULY 26-28, 1993 FALLS CHURCH, VA

SERVICE STATION MONITORING STUDY

American Petroleum Institute
Washington, DC

Ted Johnson
IT Corporation
Durham, North Carolina

Abstract

The compound methyl tertiary butyl ether (MTBE) is routinely added to gasoline during the winter driving season to reduce carbon monoxide (CO) emissions from motor vehicles in CO nonattainment areas. MTBE is also added to gasoline during other seasons to increase octane rating. In 1992, the U.S. Environmental Protection Agency (EPA) began receiving complaints of headaches, nausea, and other symptoms following alledged wintertime exposures to MTBE. In early 1993, EPA began planning a series of clinical research studies to investigate the validity of these claims. To properly design these studies, EPA required estimates of typical air concentrations of MTBE that motorists and attendents may experience during refueling at service stations that dispense gasoline containing MTBE. EPA also expressed interest in determining typical MTBE concentrations at the property boundaries of these service stations.

In response to these needs, the American Petroleum Institute (API) funded a field study in which IT Air Quality Services (ITAQS) measured ambient MTBE concentrations at 10 service stations in the New York metropolitan area. The stations included

1. Two full-service stations with Stage II vapor recovery on a commuting route near East Brunswick, New Jersey;

2. Three self-service stations with Stage II vapor recovery in Westchester County, New York; and

3. Five self-service stations without Stage II vapor recovery in Fairfield County, Connecticut.

The selection of full-service stations in New Jersey was mandatory, as self-service stations are not permitted in that state.

Each station was monitored on a different day between April 7, 1993 and April 23, 1993. The monitoring activities at each station were conducted during two four-hour periods, nominally 8 a.m. to 12 a.m. and 2 p.m. to 6 p.m. Four-hour canister and impinger samples were collected at four perimeter locations (north, east, south, and west) and one pump location at each station, in customer breathing zones at the New York and

Connecticut stations, and in attendent breathing zones at the New Jersey stations. In addition, four-hour charcoal tube samples were collected in the breathing zones of all stations. These samples were analyzed for MTBE, BTEX (benzene, toluene, ethylbenzene, xylene), and formaldehyde.

Continuous carbon monoxide measurments were made in the pump area of each station using a Metrosonics pm-7700 monitor. Organic vapor analyzers (OVA) were used to continuously monitor total hydrocarbon (THC) concentrations in the pump areas and breathing zones. These measurements were made as a means of identifying individual refueling events which could not be distinguished in the four-hour samples collected by the canister samplers.

Field personnel monitored meteorological parameters, gasoline composition (oxygenate content, Reid vapor pressure, BTEX), and gasoline sales and deliveries during each sampling period. Personnel also noted the time each vehicle was refueled and conducted regular counts of traffic on nearby roadways. Gasoline pumping activities were continuously recorded by a stationary video camera.

Research findings presented on July 27, 1993, at the MTBE Workshop were limited to the results of analyzing (1) MTBE data collected by canisters and (2) continuous THC data collected by OVA. The principal findings are summarized below.

1. Mean and maximum four-hour average MTBE concentrations generally decrease from breathing zone to pump island to perimeter, suggesting that refueling activities are the principal source of MTBE measured at service stations.

2. MTBE concentrations are generally lower at stations with Stage II vapor controls.

3. Mean four-hour MTBE concentrations are below 1 ppm at breathing zone and pump island locations and below 0.02 ppm at the station perimeters.

4. Maximum four-hour MTBE concentrations are below 2.6 ppm at breathing zone and pump island locations and below 0.2 ppm at station perimeters.

5. The canister breathing zone measurements may underestimate actual breathing zone concentrations during fuel dispensing by station-specific factors ranging from 1 to 3. Most factors fall between 1.0 and 1.4.

During the ITAQS service station study, a research team headed by Dr. Paul Lioy collected air samples in the passenger compartments of automobiles during typical home-to-work commutes. Automobiles

in this companion study were refueled at stations included in the service station study. Breathing zone MTBE concentrations measured by the Lioy team during these refueling events were generally comparable to breathing zone measurements made by the ITAQS team.

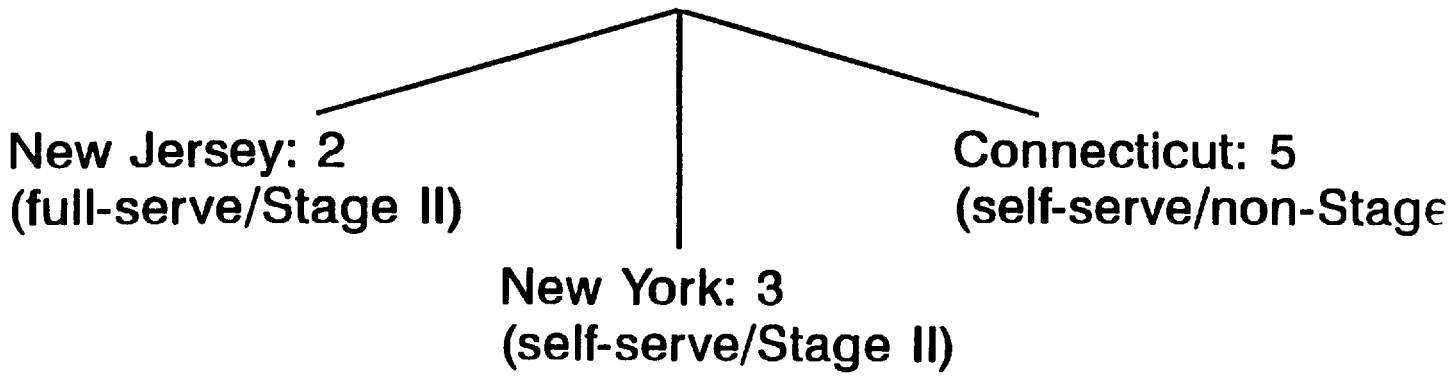
American Petroleum Institute Service Station Monitoring Study

Ted Johnson, IT Corp

July 27, 1993

Service Station Monitoring Study

- Designed to characterize MTBE air concentrations at typical stations dispensing gasoline containing MTBE
- Monitoring Period: mid-April, 1993
- 10 stations monitored:



Service Station Exposure Monitoring

Sampled:

- breathing zone
- pump island
- station perimeter

Analyzed:

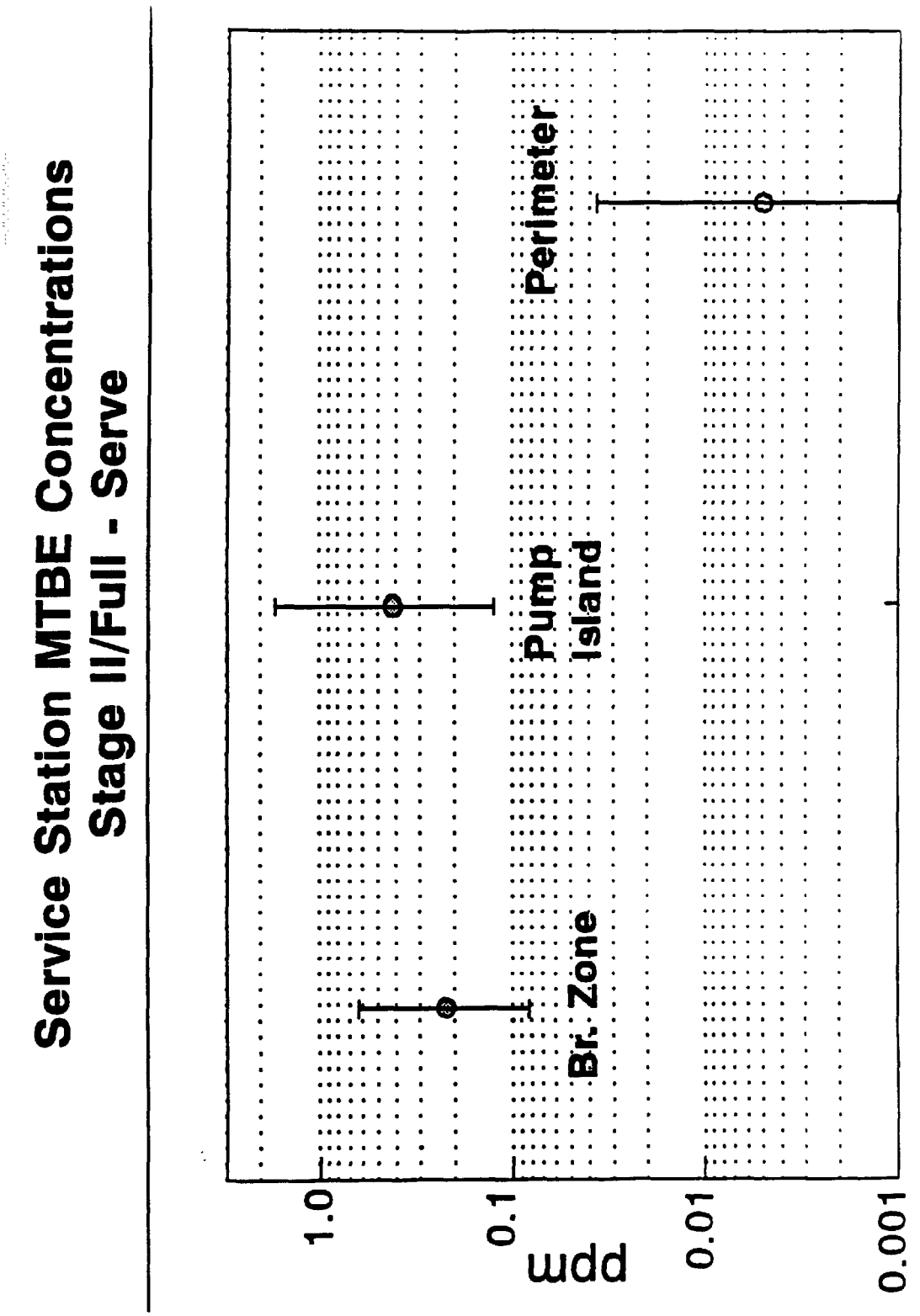
- air
  - MTBE, BTEX
  - formaldehyde
  - CO, total hydrocarbons
- fuel
  - oxygenate content
  - RVP
  - BTEX

Conditions:

- am/pm rush hour (4 hr samples)

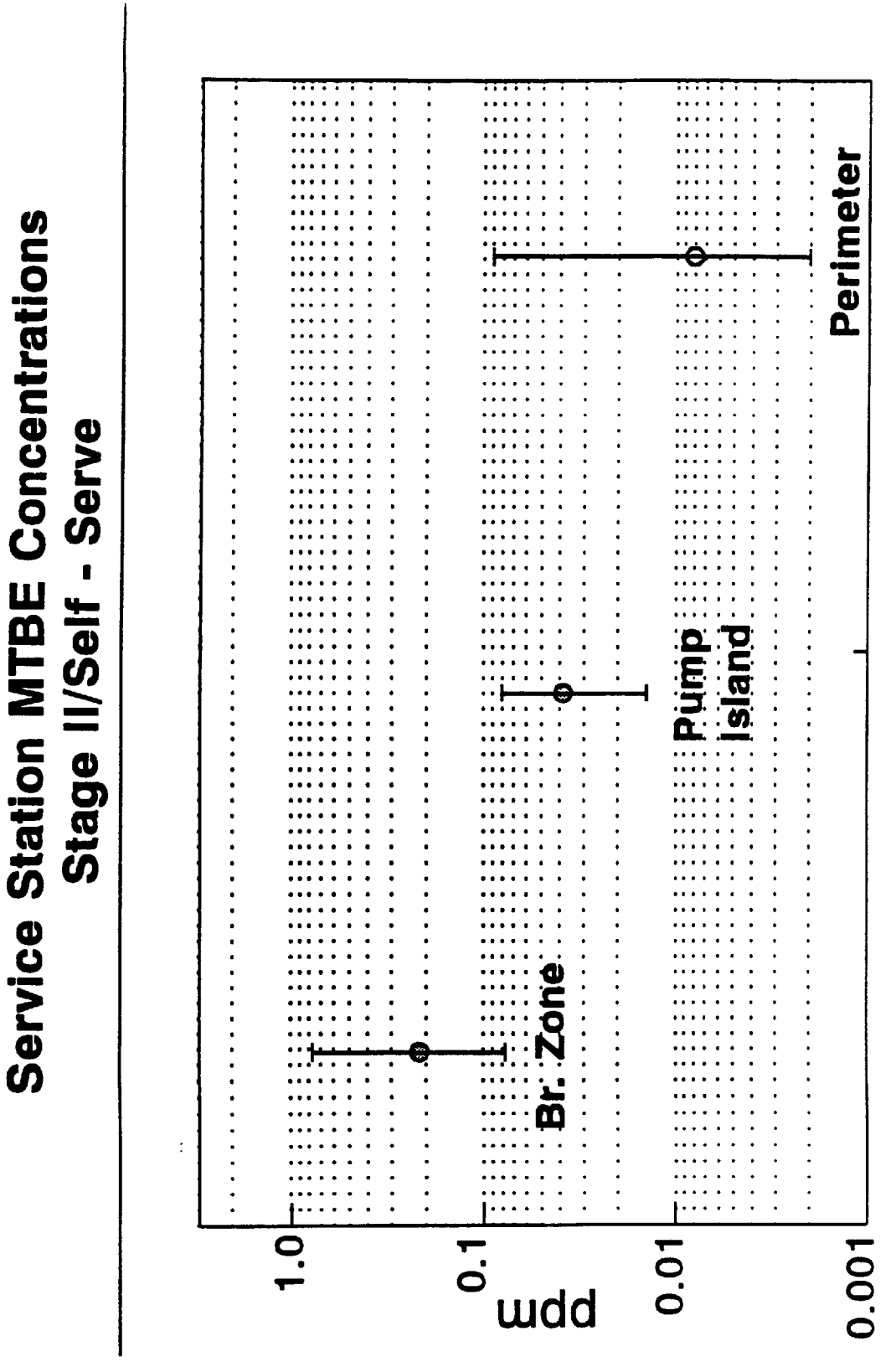
Service Station MTBE Concentrations
Stage II/Full - Serve

Location	No. Values		Concentration, ppm				
	All	N.D.	Min.	Max.	Median	Geometric Mean	Geomet Std. De
Br. Zone	4	0	0.084	0.520	0.245	0.224	2.15
Pump Island	4	0	0.120	1.600	0.440	0.409	3.16
Perimeter	16	1	0.001	0.036	0.003	0.005	3.48



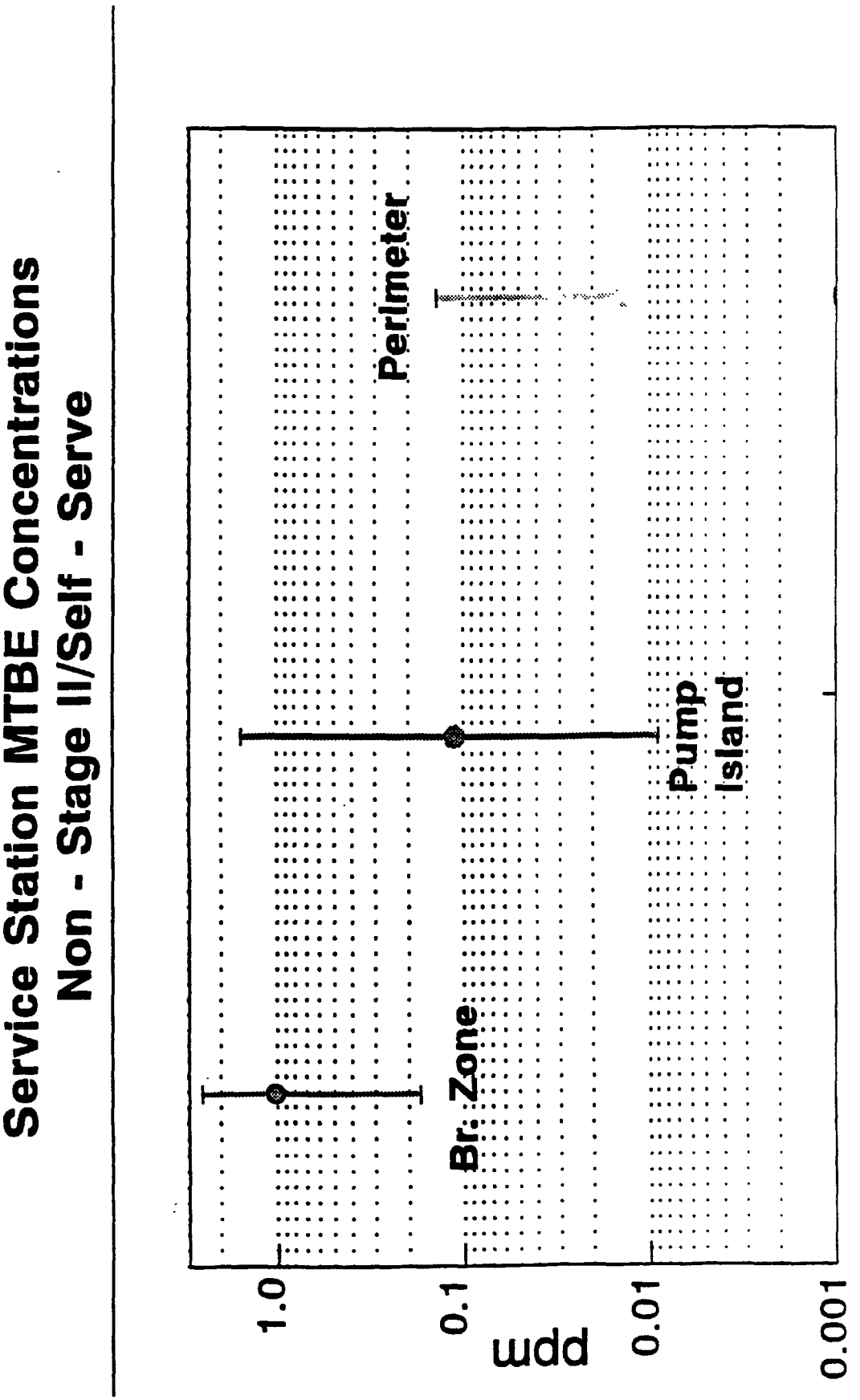
Service Station MTBE Concentrations
Stage II/Self - Serve

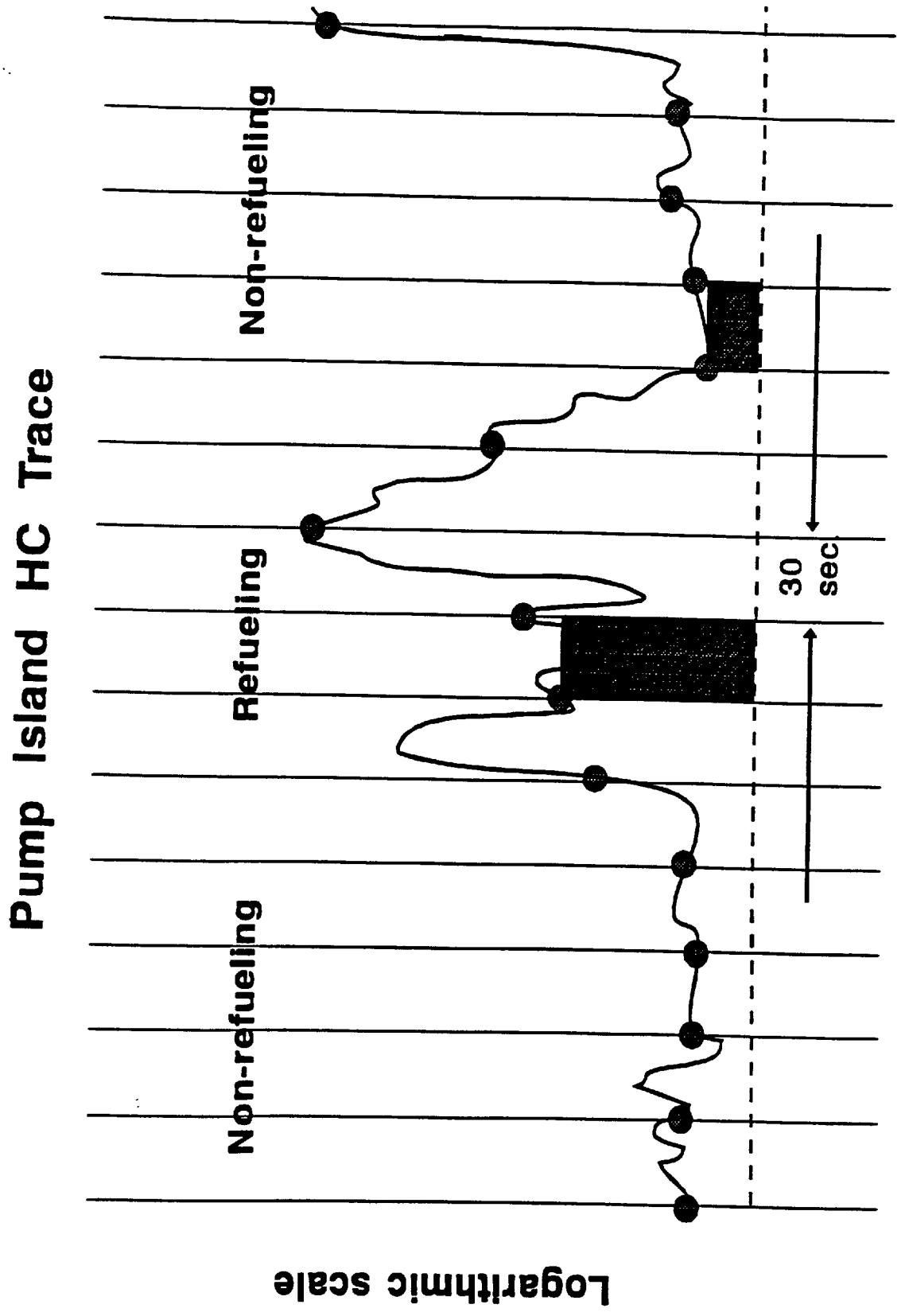
Location	No. Values		Concentration, ppm				
	All	N.D.	Min.	Max.	Median	Geometric Mean	Geometric Std. Dev.
Br. Zone	6	0	0.077	0.780	0.205	0.204	2.31
Pump Island	6	0	0.014	0.080	0.048	0.038	2.18
Perimeter	24	0	0.002	0.083	0.007	0.008	3.03



Service Station MTBE Concentrations
Non - Stage II/Self - Serve

	No. Values		Concentration, ppm				
Location	All	N.D.	Min.	Max.	Median	Geometric Mean	Geometric Std. Dev.
Br. Zone	10	0	0.170	2.600	1.500	0.978	2.73
Pump Island	10	1	0.009	1.500	0.170	0.109	5.05
Perimeter	40	2	0.001	0.140	0.014	0.014	3.61





Estimation of Breathing Zone MTBE Concentrations during Refueling Events Only

- Separate 4 hour mean THC recordings into mean refueling and non-refueling concentrations
- Adjust calculated 4 hour mean THCs to equal canister values
- Breathing zone MTBE concentration during refueling events =

  adjusted mean THC values during refueling
  x canister MTBE/THCs ratios

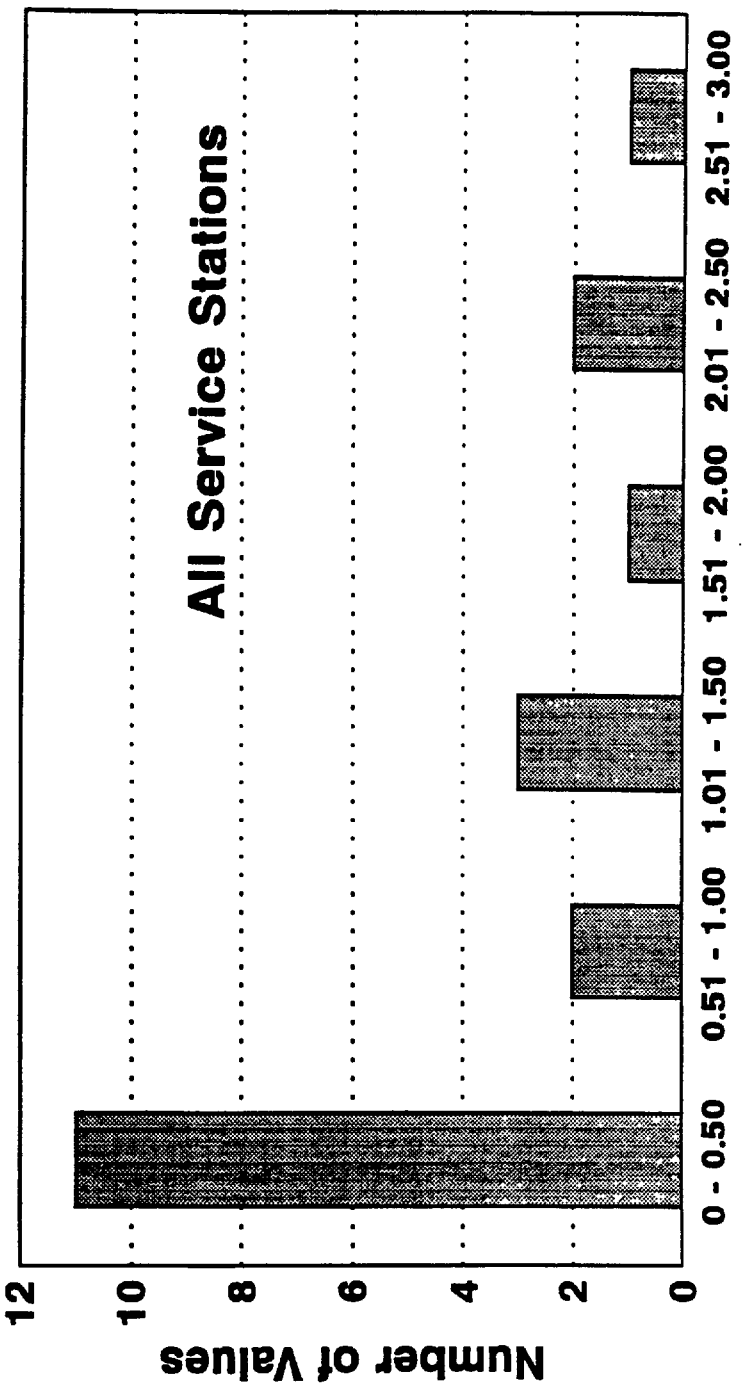
Service Station Breathing Zone Concentrations

Station No. (type)	MTBE - ppm	
	Integrated 4-hr sample	During fuel dispensing only
4 (Stage II/self-serve)	0.10	0.1
5 (non-Stage II/self-serve)	1.20	3.9
6 (non-Stage II/self-serve)	0.17	0.21
7 (" " ")	1.50	2.06
10 (Stage II/self-serve)	0.16	0.15

Individual Service Station Breathing Zone Comparison during Refueling

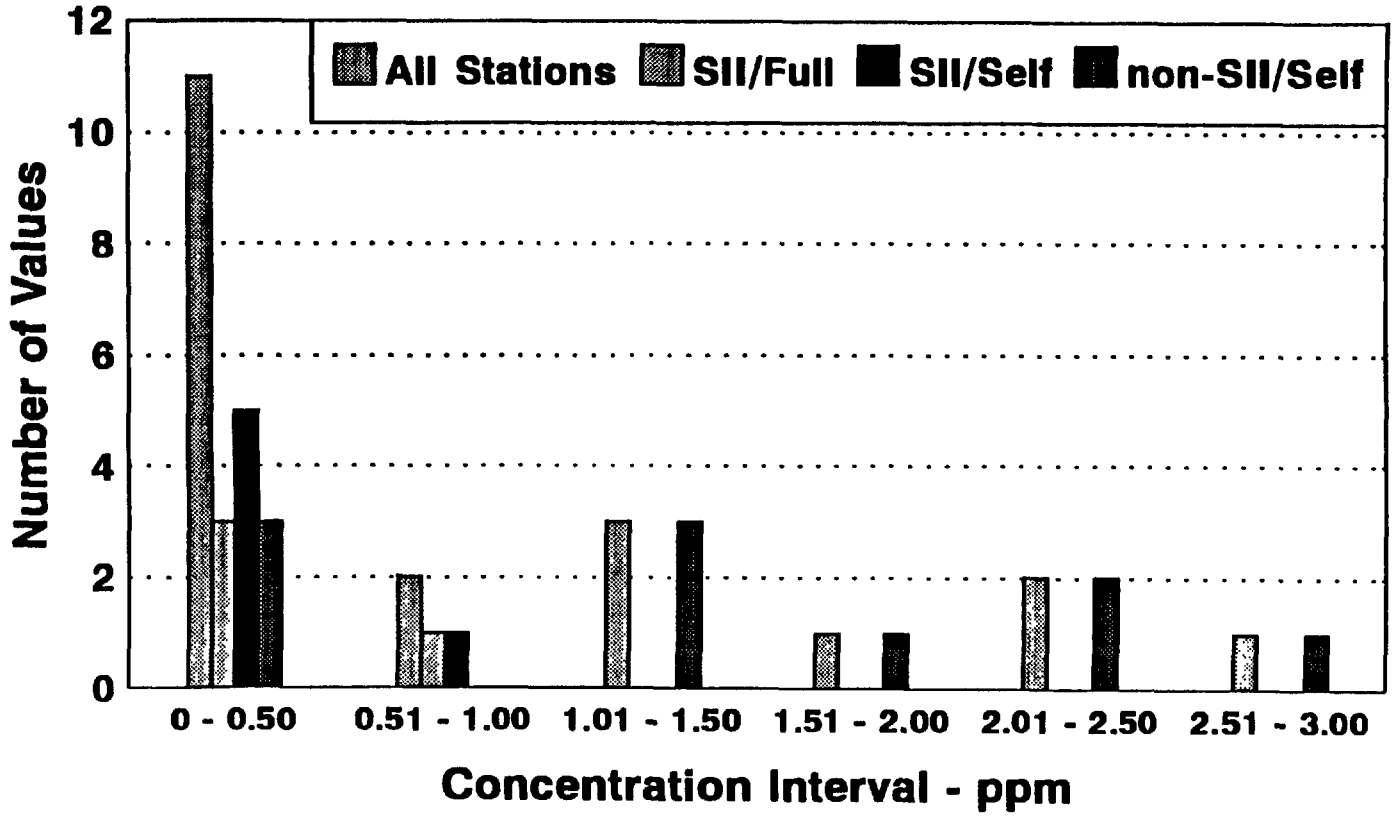
Station No. (type)	MTBE - ppm	
	During EOSHI fuel dispensing	EOSHI Values
4 (Stage II/self-serve)	0.11	0.35
5 (non-Stage II/self-serve)	0.17	0.13
6 (non-Stage II/self-serve)	0.23	--
7 (" ")	?	0.59
10 (Stage II/self-serve)	?	0.09

Distribution of Service Station Breathing Zone Data



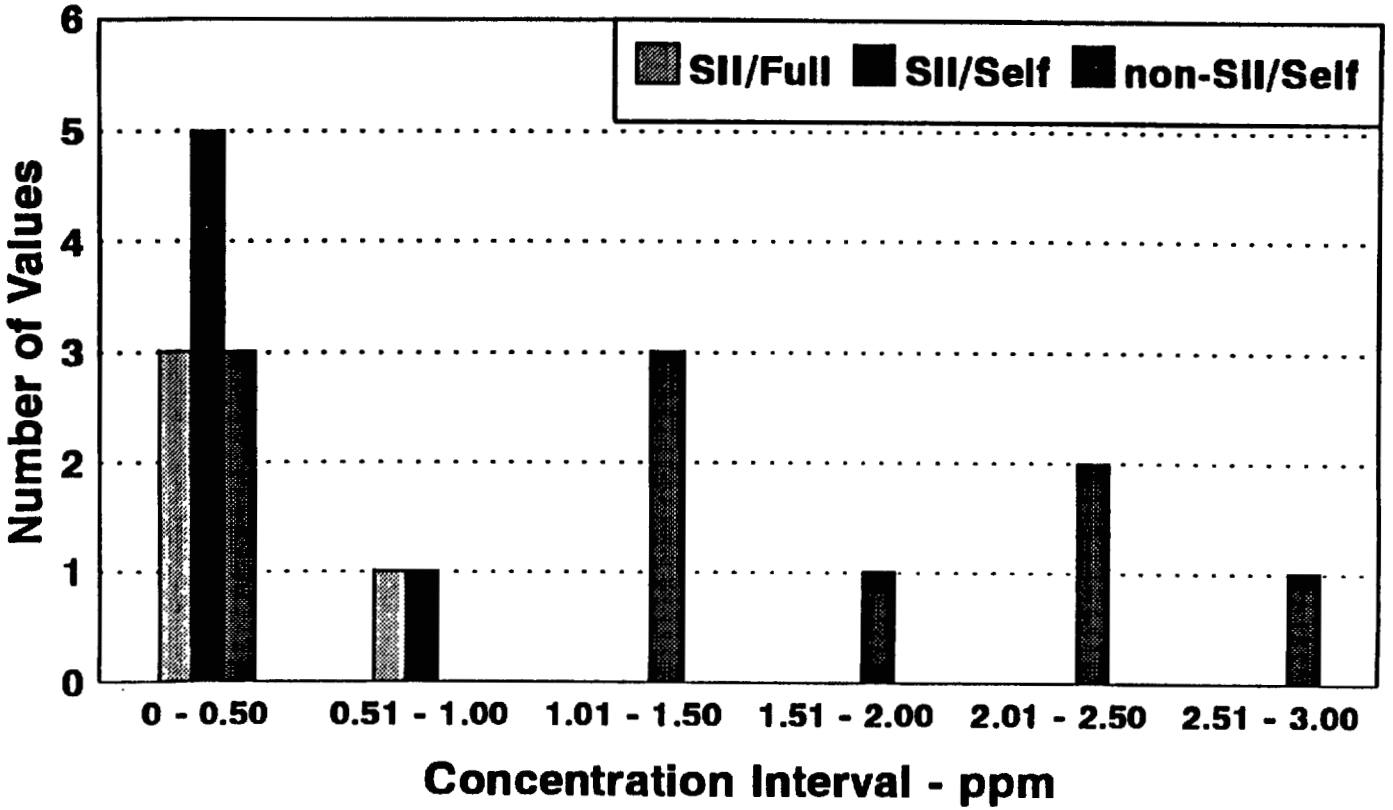
MTBE13

Distribution of Service Station Breathing Zone Data



MTBE14

Distribution of Service Station Breathing Zone Data



MTBE15

Summary

- Maximum and mean 4-hour average MTBE concentrations decrease from breathing zone to pump island to station perimeter and are lower at Stage II controlled stations.
- Mean 4-hour average MTBE concentrations are below 1 ppm at breathing zone and pump island location and are below 0.02 ppm at the station perimeters.
- Maximum 4-hour average MTBE concentrations are below 2.6 ppm at breathing zone and pump island locations and are below 0.2 ppm at station perimeters.
- Breathing zone measurements underestimate actual breathing zone concentrations during fuel dispensing by station-specific factors ranging between 1 and 3 for monitoring periods analyzed to date. Most factors (4 of 5) range between 1 and 1.4.

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Related API Publication ...

Publication 4553, Gasoline Vapor Exposure Assessment at Service Stations, May 1993

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