

October 1977

HUMAN EXPOSURES TO ATMOSPHERIC BENZENE

By: SUSAN J. MARA
SHONH S. LEE

Prepared for:

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RESEARCH AND DEVELOPMENT
WASHINGTON, D.C. 20460

Project Officer: ALAN P. CARLIN
Technical Monitor: RICHARD J. JOHNSON

CONTRACT 68-01-4314

CENTER FOR RESOURCE AND ENVIRONMENTAL SYSTEMS STUDIES
Report No. 30



STANFORD RESEARCH INSTITUTE
Menlo Park, California 94025 • U.S.A.



STANFORD RESEARCH INSTITUTE
Menlo Park, California 94025 • U.S.A.

October 1977

HUMAN EXPOSURES TO ATMOSPHERIC BENZENE

By: SUSAN J. MARA
SHONH S. LEE

Prepared for:

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RESEARCH AND DEVELOPMENT
WASHINGTON, D.C. 20460

Project Officer: ALAN P. CARLIN
Technical Monitor: RICHARD J. JOHNSON

CONTRACT 68-01-4314

SRI Project EGU-5794

CENTER FOR RESOURCE AND ENVIRONMENTAL SYSTEMS STUDIES
Report No. 30

NOTICE

This is a preliminary draft. It has been released by the U.S. Environmental Protection Agency (EPA) for public review and comment and does not necessarily reflect Agency policy. This report was provided to EPA by SRI International, Menlo Park, CA, in fulfillment of contract No. 68-01-4314. The contents of this report are reproduced herein as received by SRI after comments by EPA. The opinions, findings, and conclusions expressed are those of the authors and not necessarily those of EPA. Mention of company or product names is not to be considered as an endorsement by the EPA.

CONTENTS

LIST OF ILLUSTRATIONS	v
LIST OF TABLES	vii
PREFACE	ix
ACKNOWLEDGMENTS	xi
I SUMMARY	1
II BENZENE IN THE ENVIRONMENT	5
A. Introduction	5
B. Chemical and Physical Properties of Benzene	8
III CHEMICAL MANUFACTURING FACILITIES	13
A. Sources	13
B. Methodology	19
C. Exposures	26
IV COKE OVENS	29
A. Sources	29
B. Methodology and Exposures	31
V GASOLINE SERVICE STATIONS	39
A. Sources	39
B. Methodology and Exposures	41
VI PETROLEUM REFINERIES	53
A. Sources	53
B. Methodology	54
C. Exposures	59
VII SOLVENT OPERATIONS	63
A. Sources	63
B. Methodology and Exposure	65

VIII	STORAGE AND DISTRIBUTION OF BENZENE AND GASOLINE	77
	A. Sources	77
	B. Methodology and Exposures	77
IX	URBAN EXPOSURES RELATED TO AUTOMOBILE EMISSIONS	85
	A. Sources	85
	B. Methodology and Exposures	86
	BIBLIOGRAPHY	95
APPENDICES		
A	DIAGRAMS OF VARIOUS BENZENE-RELATED OPERATIONS . . .	101
B	EMISSION RATES AND POPULATION EXPOSURES FROM CHEMICAL MANUFACTURING FACILITIES	113
C	POPULATION EXPOSURES FROM COKE OVEN OPERATIONS BY LOCATION	121
D	POPULATION EXPOSURES FROM PETROLEUM REFINERIES BY LOCATION	127

ILLUSTRATIONS

III-1	Benzene Derivatives and Their Uses	17
III-2	Dispersion Modeling Results for Each Type of Source Category	23
IV-1	Dispersion Modeling Results for Coke Oven Operations	35
VI-1	Monitoring Data for Gulf Alliance Refinery, Belle Chasse, Louisiana	55
VI-2	Dispersion Modeling Results for Three Size Categories of Petroleum Refineries	58
VII-1	Sampling Data for Three Solvent Operations	66
VIII-1	The Gasoline Marketing Distribution System in the United States	81
VIII-2	Vapor and Liquid Flow in a Typical Bulk Terminal	82
IX-1	Isopleths (m/sec) of Mean Annual Wind Speed Through the Morning Mixing Layer	88

TABLES

I- 1	Summary of Human Exposures to Atmospheric Benzene from Emission Sources	3
I- 2	Comparison of Benzene Exposures Among Sources	4
II- 1	Estimated Benzene Levels in Food	8
II- 2	Properties of Benzene	10
III- 1	Locations and Capacities of Plants Using Benzene as an Intermediary Agent in the Manufacture of Various Chemical Compounds	14
III- 2	Emission Factors and Characterizations for Benzene-Consumption Plants	18
III- 3	Rough Estimates of Ambient Ground-Level Benzene Concentrations (8-hour Average)	20
III- 4	Rough Estimates of Ambient Ground-Level Benzene Concentrations (8-hour Average) per 100 g/s Emission Rate	21
III- 5	Estimates of 8-hour Worst Case Benzene Concentrations Based on Average of Three Emission Source Categories . .	22
III- 6	Population Exposed to Benzene from Chemical Manufacturing Facilities by State	27
IV- 1	Estimated Size and Productive Capacity of By-Product Coke Plants in the United States on December 31, 1975 . .	30
IV- 2	Ambient Levels of Benzene Within a Coal-Derived Benzene Production Plant	31
IV- 3	Atmospheric Benzene Emission from the Coking and Recovery Plants in Czechoslovakia	32
IV- 4	Rough Estimates of 8-hour Worst Case Benzene Concentrations per 100 g/s Emission Rate Using the PAL Dispersion Model.	34
IV- 5	Estimated Population Exposed to Benzene from Coke Ovens	38
V- 1	Typical Liquid Volume Percent of Benzene in Gulf U.S. Gasolines, October 1976	39
V- 2	Benzene Concentration in Different Grades and Seasonal Blends of Gasoline	40
V- 3	Self-Service Operations	42

V- 4	Gasoline Market Share of Self-Service Stations in Four AQCRs, Spring 1977	43
V- 5	Gasoline Market Share of Self-Service Stations in Two Metropolitan Areas, 1976	44
V- 6	Sampling Data from Self-Service Gasoline Pumping	45
V- 7	Rough Dispersion Modeling Results for Gasoline Service Station	48
V- 8	Service Station Density in Four Metropolitan Areas . . .	49
V- 9	Summary of Population Exposed to Benzene from Gasoline Service Stations	51
VI- 1	Petroleum Refineries Producing Aromatics, by State . . .	54
VI- 2	Calculation of Emission Factors for Petroleum Refineries	57
VI- 3	Estimated Population Exposed to Benzene from Petroleum Refineries by State	61
VII- 1	Industries and Manufactured Products Possibly Using Benzene as a Solvent	65
VII- 2	Average Number of Employees per Plant for Selected Solvent Operations	68
VII- 3	Number of Plants and Employees for Solvent Operations with High Potential for Benzene Emissions . .	69
VII- 4	Estimated Average Annual Benzene Concentrations in the Vicinity of an Average Size Solvent Operation in Rubber-Related Manufacture	71
VII- 5	States with the Highest Potential for Atmospheric Benzene from Solvent Operations	72
VII- 6	Estimated Potential Population Exposures from Solvent Operations in Rubber-Related Manufacturing . . .	74
IX- 1	Estimates of Annual Average Benzene Concentrations in Four Urban Areas	87
IX- 2	Estimates of Average Annual Benzene Concentrations for Cities with Populations Exceeding 1,000,000	90
IX- 3	Estimates of Average Annual Benzene Concentrations for Selected SMSAs	92
IX- 4	Urban Exposures Related to Automotive Emissions	93

PREFACE

There is substantial evidence that concentrations of benzene encountered in the workplace (both in the United States and elsewhere) have caused blood and bone marrow diseases (e.g., blood dyscrasia, pancytopenia) and leukemia (especially myelogenous leukemia). As current U.S. Environmental Protection Agency (EPA) policy states that there is no zero risk level for carcinogens, benzene has been listed by EPA under Section 112 of the Clean Air Act as a hazardous air pollutant. To determine what regulatory action should be taken by EPA on atmospheric emissions of benzene, three reports have been prepared: (1) a health effects assessment, (2) a population exposure assessment, and (3) a risk assessment document based on the data in the first two assessments. This document is the human population exposure assessment and presents estimates of the numbers of people in the general population of the United States exposed to atmospheric concentrations of benzene from specific sources.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the cooperation and guidance given by several individuals of the U.S. Environmental Protection Agency. Dr. Alan Carlin, Office of Research and Development, was project officer. Mr. Richard J. Johnson, Office of Air Quality Planning and Standards, Strategies and Air Standards Division, generously provided data and direction throughout the study. Messrs. Philip L. Youngblood and George J. Schewe (Office of Air Quality Planning and Standards, Monitoring and Data Analysis Division) conducted dispersion modeling, offered guidance about the application of their results, and reviewed draft documents.

Mr. Benjamin E. Suta, SRI project leader, gave vital support and provided useful input throughout the study. Mr. Michael Smith patiently edited the study. Ms. L. H. Wu and Ms. Grace Y. Tsai were responsible for all graphics.

I SUMMARY

This report is one in a series that SRI International is conducting on a quick-response basis for the U.S. Environmental Protection Agency (EPA). Populations at-risk to selected pollutants are being quantified for input to other, more inclusive studies. This study was undertaken to quantify the environmental exposure of the general population to atmospheric benzene emissions.

Although recent reports have identified benzene in water, food, and soil in some locations, the available data do not indicate that widespread exposures occur from these environmental pathways. Therefore, the main exposure pathway considered in this report is air. The seven primary sources of atmospheric benzene emissions are chemical manufacturing plants, coke ovens, gasoline service stations, petroleum refineries, solvent operations, storage and distribution of benzene and gasoline, and urban exposures related to automobile emissions.

The quantitative nature of this study has necessitated reliance on very limited data. When data were available, source locations were identified and benzene emission rates were calculated. Atmospheric environmental concentrations of benzene were then estimated by applying approximate, dispersion modeling results developed by EPA. Population exposed to concentrations of 0.1 ppb (the detection limit of current sampling techniques) and greater were estimated. When data were unavailable, best estimates were developed to provide a reasonable basis for comparison.

All estimates given in the report are subject to considerable uncertainty as to: 1) the quantity of benzene emissions, (2) benzene production and consumption levels, (3) source locations, (4) control technologies employed, (5) deterioration of control technologies over time and, (6) the physical parameters (e.g., stack height) of benzene sources. As a result, the accuracy of the modeling results could not

be assessed quantitatively. Nevertheless, the estimates, although not precise, do provide an approximate estimate of expected conditions. Because of averaging techniques, the summary results for each source category are expected to be well within 1 order of magnitude.

Table I-1 summarizes results of the study. Urban exposures and exposures from gasoline service stations constitute the two largest sources. Coke ovens are third with more than 16 million people exposed over a wide range of exposure levels. Chemical manufacturing plants and petroleum refineries are sources of benzene exposures for more than 5 million people.

For comparative purposes, Table I-2 lists each source. For approximate comparison of different emission sources, exposures are calculated in similar units by multiplying the number of exposed population by the annual average benzene concentration within each range. These values were then summed for each emission source. Thus, the units become ppb-person-years. For self-service gasoline exposures the exposure time was 1.5 hr/person/year; the units became ppb-person-hours and were then divided by the number of hours per year to determine ppb-person-years.

The results presented in Table I-2 show that urban exposures and gasoline service stations have the highest weighted human exposures. Next are chemical manufacturing plants, followed by coke ovens. These results differ from Table I-1 because they are weighted by the number of people exposed to a particular level of atmospheric benzene. Thus, they provide a more useful basis for comparison.

As indicated above, the estimates given in this report are subject to considerable uncertainty; they thus require further monitoring and sampling data for a more complete assessment. Despite the insufficiency of data, however, the fact remains that the population exposed is substantial. Potential health effects from the estimated exposures will be addressed in another report being prepared by the EPA Cancer Assessment Group.

Table I-1
SUMMARY OF HUMAN EXPOSURES TO ATMOSPHERIC BENZENE FROM EMISSION SOURCES

Population Exposed to Benzene Concentrations (ppb) ^a						Total ^b Exposed Population
8-hour Worst Case:	1.0 - 10.0	10.1 - 20.0	20.1 - 40.0	40.1 - 100.0	>100.0	
Annual Average:	0.1 - 1.0	1.1 - 2.0	2.1 - 4.0	4.1 - 10.0	>10.0	
Source						
Chemical manufacturing	7,497,000	970,000	453,000	644,000	319,000	9,883,000
Coke ovens	15,726,000	521,000	50,000	2,000		16,299,000
Gasoline service stations						
1. People using self-service					c	37,000,000
2. People living in the vicinity	87,000,000	31,000,000				118,000,000
Petroleum refineries	6,529,000	64,000	4,000	d		6,597,000
Solvent operations ^e	208,000	5,000	2,000	d		215,000
Storage and distribution	f					
Urban exposures	68,337,000	45,353,000				113,690,000

Source: SRI estimates

^aTo convert to $\mu\text{g}/\text{m}^3$, multiply each exposure level by 3.2.

^bPopulation estimates are not additive vertically, because some double-counting may exist.

^cEstimated at 245 ppb for 1.5 hr/yr/person.

^dLess than 500 people exposed.

^eExact determination is impossible. This represents a crude population estimate (see Chapter VII).

^fEstimated at $\ll 0.1$ ppb annual average. The population exposed was not determined but is assumed to be very small.

Table I-2

COMPARISON OF BENZENE EXPOSURES AMONG SOURCES
(10⁶ ppb-person-years)

<u>Source</u>	<u>Exposure</u>
Chemical manufacturing	15.9
Coke ovens	8.8
Gasoline service stations	
1. People using self-service	1.6
2. People living in the vicinity	90.0
Petroleum refineries	3.4
Solvent operations	0.1
Storage and distribution	*
Urban exposures from automobile emissions	102.2

* Minimal

Source: SRI estimates

II BENZENE IN THE ENVIRONMENT

A. Introduction

The primary objective of this study was to quantify the environmental atmospheric exposure of the general human population to benzene emissions.

This is one in a series of studies being conducted by SRI for the U.S. Environmental Protection Agency (EPA) to quantify populations at-risk to selected pollutants. These studies are generally conducted on a quick-response basis to provide input to other, more inclusive studies. The procedure used here was to identify sources of benzene emissions, to estimate atmospheric environmental concentrations of benzene resulting from these sources, and to estimate human populations exposed to various levels of benzene concentrations. This study has not considered the degree of biological sorption of material. No attempt was required or has been made in this input report to assess potential health effects.

Atmospheric sources of benzene are widespread and include natural sources such as forest fires and man-made sources such as automobile emissions. Although benzene is not sampled regularly in any air quality monitoring program, some sampling data do exist. EPA has also conducted dispersion modeling that is applicable to most of the major sources. On the other hand, sample data of benzene concentrations in water, food, and soil are sparse, and those measurements that have been taken have been infrequent and inconsistent. Therefore, because information on other environmental pathways is generally lacking, only atmospheric sources are evaluated in this report.

Benzene is commercially produced mainly by petrochemical operations (92%) and on a much smaller level as a coke-oven by-product (8%). Total

benzene production in 1976 was approximately 7500×10^6 lb (3400×10^6 kg) (SRI estimates). Benzene is used primarily as an additive in gasoline, in chemical manufacturing processes, and in solvent operations. Of all benzene used in chemical and solvent operations, more than 97% is used in chemical processing (SRI estimates).

For this report, seven sources of atmospheric benzene were evaluated: chemical manufacturing plants, coke ovens, gasoline service stations, petroleum refineries, solvent operations, storage and distribution of benzene and gasoline, and urban exposures related to automobile emissions. These sources have been identified as the major sources of atmospheric benzene (PEDCo, 1977; Johnson, 1977). Although oil spills and discharges represent a potentially significant source of benzene in the environment, the most significant of these occur in remote locations or along coastal areas where population density is low, and the benzene released to the atmosphere from each occurrence is very small. Potential human exposure to atmospheric benzene from these sources is negligible.

It is not within the scope of this study to evaluate human exposures to benzene from water, food, or other environmental pathways. However, it is useful to review the available data to provide some basis for comparison.

Only limited data on benzene in water are available. A review of benzene sampling data by Howard and Durkin (1974) found that the few freshwater samples analyzed by that time showed only trace levels of benzene. For example, a 1972 EPA study cited in the report identified 53 organic chemicals, ranging from acetone to toluene, in the finished waters and organic waste effluents in 11 plants (of 60 sampled) discharging into the Mississippi River. Benzene was not detected in the effluents, but the trace detected in the finished waters suggested another source than effluent discharge.

A recent sampling of five benzene production or consumption plants

by Battelle (1977) found benzene levels in water ranging from <1.0 to 179 ppb in one plant's effluent. The concentrations at 13 upstream and downstream sample locations in nearby receiving waters, however, ranged from <1.0 to 13.0 ppb, with an average of 4.0 ppb.

A recent report by the National Cancer Institute (1977) noted benzene levels of 0.1 to 0.3 ppb in four U.S. city drinking water supplies. One measurement from a groundwater well in Jacksonville, Florida showed levels higher than 100 ppb. No indication is given in the report of the sampling methods or the analytical procedures. However, study of the behavior of benzene in the groundwater system and in the drinking water supply system is clearly warranted.

One possible source of benzene in the aquatic environment is from cyclings between the atmosphere and water (Mitre, 1976). Benzene is fairly volatile (high vapor pressure of 100 mmHg at 26°C) and has a relatively high solubility (1780 mg/L* at 25°C). Consequently, it is reasonable to believe that benzene will be washed out of the atmosphere with rainfall and then evaporated back into the atmosphere, causing a continuous recycling between the two media.

The distribution of benzene in the aquatic system is not well-known. Needy et al. (1974) demonstrated a relationship between octanol-water partition coefficients and bioaccumulation potential in fish. The partition coefficient for benzene which is estimated to be very low, suggests that the bioaccumulation potential in fish is minimal. Benzene uptake by aquatic vegetation has not been studied.

Only one study of benzene levels in soil has been conducted. Battelle (1977) sampled soils in the vicinity of five benzene consumption or production facilities. Their preliminary results from 14 samples showed levels ranging from <1.0 to 191.0 ppb, with an average of 53.0 ppb. In most cases, the highest levels of benzene were found in samples taken closest to the plant. These results indicate that the

* L = liter.

potential for accumulation of benzene in the soil is significant.

Human exposure to benzene in food is not addressed in this report. We note, however, the following information: those few available data that quantify benzene levels in food (Chinn, personal communication, 1977) indicate that it occurs naturally in fruits, fish, vegetables, nuts, dairy products, beverages, and eggs. However, data on concentrations are only available for cooked meat, rum, and eggs (see Table II-1). A report by the National Cancer Institute (1977) estimated that an individual could ingest as many as 250 μg /day from these foods.

Table II-1
ESTIMATED BENZENE LEVELS IN FOOD
($\mu\text{g}/\text{kg}$)

Heat treated or canned beef	2
Jamaican rum	120
Irradiated beef	19
Eggs	2100

Source: National Cancer Institute (1977)

The quantitative nature of this study has necessitated reliance on very limited data. All estimates given in the report are subject to a large degree of uncertainty related to: quantity of benzene emissions, benzene production and consumption level, source locations, control technology employed, deterioration of control technology over time, and dispersion modeling. Because monitoring data are insufficient, no quantitative assessment could be made of the accuracy of the modeling results. Consequently, although the estimates are not precise, they do provide a reasonable evaluation of expected conditions. And, because of averaging techniques, the summary results for each source category are expected to be well within 1 order of magnitude.

B. Chemical and Physical Properties of Benzene

Benzene, C_6H_6 , is a nonpolar, nonreactive, highly refractive cyclic aromatic hydrocarbon. In benzene, the C-C bond is 1.39 Å long and

the CH bond is 1.08 Å long (Ayers, 1964; MacKenzie, 1962). Under standard conditions, benzene is a clear, noncorrosive, colorless, and highly flammable liquid. Benzene possesses a characteristic odor, similar to that of gasoline. It is relatively soluble in water and is miscible with acetone, alcohol, chloroform, ether, carbon disulfide, carbon tetrachloride, glacial acetic acid, and oils. Pertinent physical properties of benzene are listed in Table II-2.

Benzene is quite thermodynamically stable because the resonance energy of its unsaturated bonds is due to the interaction of the six π electrons that form "doughnut" shaped electron orbitals above and below the plane of the ring.

Benzene solubility in water at 25°C is 1800 ppm (0.18 mg/g water). Variation of benzene solubility in water from 1730 to 1800 ppm has been noted (McAuliffe, 1963). The difference is believed to be attributable either to the temperature of the experiment or the precision of the technique. Both salting-in and salting-out (increase or decrease in solubility) phenomena have been observed for benzene in aqueous solution (Giacomelli, 1972). Benzene solubility in salt water and distilled water have been compared, and the results show that solubility decreases as the salt content of water increases (Sutton, 1974). A similar decrease in solubility of the water soluble fraction (including benzene) from crude oil was observed (Lee, 1974). These observations reveal that benzene is less soluble in salt water than in fresh water. The vapor pressure of benzene is an important property in assessing the benzene contamination in the gaseous phase. The vapor pressure of 100 mmHg at 26°C indicates that benzene exists environmentally only in the gaseous and the aqueous phases.

Benzene is highly stable. Consequently, chemical reactivity is limited unless the reactions take place under certain extreme conditions (and in the presence of the necessary reagents). When chemical reactions do take place, benzene behaves primarily as a nucleophilic agent, usually with substitution of individual hydrogen atoms rather than addition. The two most common substitutive reactions are

Table II-2
PROPERTIES OF BENZENE

<u>Constant</u>	<u>Value</u>
Freezing point, °C	5.553
Boiling point, °C	80.100
Density, at 25°C, g/mL	0.8737
Vapor pressure at 26.075°C, mm Hg	100
Refractive index, n_D^{25}	1.49792
Viscosity (absolute) at 20°C, cP	0.6468
Surface tension at 25°C, dyn/cm	28.18
Critical temperature °C	289.45
Critical pressure, atm	48.6
Critical density, g/mL	0.300
Flash point (closed cup), °C	-11.1
Ignition temperature in air, °C	538
Flammability limits in air, vol%	1.5-8.0
Heat of fusion, kcal/mole	2.351
Heat of vaporization at 80.100°C, kcal/mole	8.090
Heat of combustion at constant pressure and 25°C (liquid C_6H_6 to liquid H_2O and gaseous CO_2), kcal/g	9.999
Solubility in water at 25°C, g/100 g water	0.180
Solubility of water in benzene at 25C, g/100 g benzene	0.05

Source: Ayers and Muder (1964).

nitration and sulfonation. In additive reactions, other reactive chemical agents are added to the unsaturated bonds. Three types of additive reactions are most common: oxidation, hydrogenation, and halogenation.

The general environmental fate of benzene can be assessed by examining the degradation processes of oxidation, hydrolysis, photolysis, and microbial decomposition. Hydrolysis and microbial decomposition occur primarily in the aqueous phase, whereas oxidation and photolysis can occur in both the aqueous and the gaseous phases.

Benzene can be oxidized to a number of different products in the presence of catalysts or at elevated temperatures and pressures. Under extreme conditions, benzene has been observed to oxidize completely to water and carbon dioxide. In the environment, such extreme conditions rarely exist. Thus, it can be concluded that degradation of benzene by oxidation is probably negligible. Oxidation in the emission pathways from chemical plants and refineries is conceivable, but no such observations have been reported.

The benzene ring does not undergo reaction with water or hydroxyl ions (OH^-) unless substituted with a significant number of strong electronegative groups, or at elevated temperature and pressure. Thus, hydrolysis in the environment is assumed to be minimal.

Several studies have investigated the wavelength absorption properties of benzene. No appreciable amounts of light at wavelength longer than 280 nm (2800Å) were directly absorbed by benzene dissolved in cyclohexane. A slight shift, however, in wavelength absorption would be more representative of environmental media, such as dissolution in water or absorption on particular matter. Chien (1965) reported the ultraviolet absorption spectra of liquid benzene in the presence of oxygen under 1 atmosphere. Noyes et al. (1966) found that gaseous benzene only absorbs light at 275 nm or less. Because the atmospheric ozone layer effectively filters out wavelengths less than 290 nm, it appears that direct excitative photolytic reaction of benzene in

the environment is unlikely, unless a substantial wavelength shift occurs in the presence of other media. Indirect excitation of benzene may be possible in the presence of certain sensitizers in the water or soil.

Photolysis by light with a wavelength of less than 290 nm of benzene in the vapor phase and in oxygenated aqueous solution has been reported. Two types of products, 2-formyl-4H-pyran and cyclopentadiene-carboxaldehyde result (Luria, 1970; Kaplan et al., 1971). Matsuura and Omura (1974) have reviewed several investigations where atomic oxygen that had been photochemically generated from various sources reacted with benzene to form phenol. Atomic oxygen is generated, for instance, from the photodecomposition with nitrogen dioxide, which is frequently found in high concentration in heavily polluted air (Altshuller, 1971). Laboratory results conclude that benzene is not completely inert under smog conditions (Laity et al., 1973; Stephens, 1973).

The microbial degradation of benzene has received some attention in recent years and it is conceivable that biodegradation of benzene probably occurs under environmental conditions. Benzene has been found to biodegrade in a waste treatment plant, with the rate of degradation determined by the incubation period and acclimation of the microorganisms. It is safe to conclude, therefore, that benzene can be degraded--but at a very slow rate.

In summary, oxidation and hydrolysis of benzene in the environment are unlikely. Photolysis is possible in the natural environment, but the photolysis rate depends on wavelength adsorption and the presence of sensitizers. In a heavily polluted atmosphere, atomic oxygen may cause photochemical decomposition of benzene. Biodegradation of benzene in the environment is also possible, but the degradation rate is quite slow.

III CHEMICAL MANUFACTURING FACILITIES

A. Sources

In this section, generation of benzene emissions from the manufacturing of chemical compounds will be addressed. Producer companies of various compounds (excluding solvents) are listed in Table III-1; their locations and 1976 capacity productions are also included in the table. The Gulf Coast has the highest density of these benzene-consumption facilities.

Benzene is used commercially as an intermediate agent in the production of many chemical compounds. The emissions of benzene from such industrial uses are potentially significant sources of atmospheric benzene. Total U.S. consumption of benzene in 1975 was 108.4×10^7 gal ($4.1 \times 10^6 \text{ m}^3$) (Anderson, 1976). Figure III-1 illustrates the benzene derivatives and their uses. Primary use involves the manufacture of such chemicals as nitrobenzene, ethylbenzene, maleic anhydride, cumene, phenol, chlorobenzene, cyclohexane, and detergent alkylate. Appendix A contains flow diagrams for some of these processes.

To assess the ambient benzene concentrations in the vicinity of chemical manufacturing facilities, two factors must be estimated: benzene emission rates at each location; and atmospheric dispersion of benzene in the vicinity of the plants. The emission rates can be estimated if the emission factors and total production are available. Table III-2 gives the emission factors used in the analysis and emission characterization. The emission factors were selected to represent averages. Because little is known about benzene emissions from chemical manufacturing facilities, these emission factors are considered order-of-magnitude estimates. Maleic anhydride and aniline have the highest emission factors related to the specific manufacturing processes and reaction kinetics of each compound.

Table III-1

**LOCATIONS AND CAPACITIES OF PLANTS USING BENZENE AS AN INTERMEDIARY
AGENT IN THE MANUFACTURE OF VARIOUS CHEMICAL COMPOUNDS ***

STATE	LOCATION	COMPANY	CAPACITY PRODUCTION JANUARY 1, 1976 (millions of kg)										
			NITRO- BENZENE	ANILINE	ETHYL- BENZENE	STYRENE	MALEIC ANHYDRATE	CUMENE	PHENOL	MONO- CHLORO- BENZENE	DICHLORO- BENZENE (O- and P-)	CYCLO- HEXANE	DETERGENT ALKYLATE (Linear and Branch)
ALABAMA	TUSCALOOSA	REICHOLD CHEM., INC.							68				
CALIFORNIA	CARSON	WITCO CHEM.											25
	EL SEGUNDO	STD. OIL CO. OF CALIF.						45					
	IRVINDALE	SPECIALTY ORGANICS, INC.									1		
	RICHMOND	STD. OIL CO. OF CALIF.							25 N.A.				100
DELAWARE	SANTA FE SPRINGS	FERRO CORP.											
	DELAWARE CITY	STD. CHLORINE CHEM CO., INC.								34	27 ^b		
GEORGIA	CARTERSVILLE	CHEM. PRODUCTS CORP.									10 ^a		
ILLINOIS	BLUE ISLAND	CLARK OIL & REFINING						50	40				
	CICERO	KOPPEIS CO., INC.					.5						
	MORRIS	REICHOLD CHEM., INC.					27						
	SAUGET	MONSANTO	5							52	13		
KANSAS	EL DORADO	SKELLY OIL CO.						61	63				
KENTUCKY	ASHLAND	ASHLAND OIL, INC.						160					
LOUISIANA	BATON ROUGE	FOSTER GRANT CO.			440	372							
	CORVILLE	COSMAR, INC.			327	272							
	CHALMETTE	TENNECO, INC.			12								
	GEISMAR	RUBICON CHEM., INC.	34	25									
	PLAQUEMINE	GEORGIA PACIFIC CORP.							120				
	WELCOME	GULF OIL CORP.			250	238							
MARYLAND	BALTIMORE	CONTINENTAL OIL CO.											86
MASSACHUSETTS	MALDEN	SOLVENT CHEM. CO., INC.								N.A.	1 ^a		
MICHIGAN	MIDLAND	DOW CHEMICAL			280	182		4.5	18	136	29		
MISSISSIPPI	PASCAGOULA	FIRST MISSISSIPPI CORP.	61	45									
MISSOURI	ST. LOUIS	MONSANTO					48						
NEVADA	HENDERSON	MONTROSE CHEM. CORP. OF CAL.								32			
NEW JERSEY	BOUND BROOK	AMERICAN CYANAMID	38	27									
	BOUND BROOK	UNION CARBIDE											
	ELIZABETH	REICHOLD CHEM., INC.					14		66				
	FORDS	TENNECO, INC.					12						
	GIBBSTOWN	E. I. du PONT	91	58									
	KEARNY	STD. CHLORINE CHEM. CO.									7 ^a		
	WESTVILLE	TEXACO, INC.						118					

Table III-1 (Continued)

STATE	LOCATION	COMPANY	CAPACITY PRODUCTION JANUARY 1, 1976 (millions of kg)										
			NITRO- BENZENE	ANILINE	ETHYL- BENZENE	STYRENE	MALEIC ANHYDRATE	CUMENE	PHENOL	MONO- CHLORO- BENZENE	DICHLORO- BENZENE (O- and P-)	CYCLO- HEXANE	DETERGENT ALKYLATE (Linear and Branch)
NEW YORK	NIAGARA FALLS	ICC INDUSTRIES, INC.								N.A.	N.A.		
	NIAGARA FALLS	OCCIDENTAL PETROLEUM								7			
	NIAGARA FALLS	SOLVENT CHEM. CO.								N.A.	9		
	SYRACUSE	ALLIED CHEM. CORP.								11	9		
OHIO	HAVERHILL	UNITED STATES STEEL							90				
PENNSYLVANIA	BEAVER VALLEY	ARCO/POLYMERS, INC.				200							
	BRIDGEVILLE	KOPPELS CO., INC.					15						
	CLAIRTON	UNITED STATES STEEL							N.A.				
	FRANKFORD	ALLIED CHEMICAL CORP.					18		250				
	NEVILLE ISLAND	UNITED STATES STEEL						205				98	
PUERTO RICO	GUAYAMA	PHILLIPS PETROLEUM										209	
	PENUELAS	COMMONWEALTH OIL			73							118	
	PENUELAS	UNION CARBIDE CORP.						290	90				
TEXAS	BAYTOWN	EXXON CORP.										118	
	BEAUMONT	E. I. du PONT	141	91									
	BEAUMONT	UNION OIL CO. OF CALIFORNIA										100	
	BIG SPRING	AMERICAN PETROFINA			20	41						35	
	BORGER	PHILLIPS PETROLEUM										118	
	CHOCOLATE BAYOU	MONSANTO						295	227				102
	CORPUS CHRISTI	COASTAL STATES GAS						64					
	CORPUS CHRISTI	SUN OIL CO.			43	36		114					
	CORPUS CHRISTI	UNION PACIFIC CORP.										65	
	FREEPORT	DOW CHEMICAL			848	649							
	HOUSTON	ARCO/POLYMERS, INC.			45	45							
	HOUSTON	THE CHARTER CO.			16								
	HOUSTON	JOE OIL, INC.											
	HOUSTON	THE MFRICHEM CO.							N.A.				
	HOUSTON	PETRO-TEX CHEM. CORP.					23						
	ODESSA	EL PASO NATURAL GAS			125	68							
	OYSTER CREEK	DOW CHEMICAL							182				
	PHILLIPS	PHILLIPS PETROLEUM CO.										209	
	PORT ARTHUR	ARCO/POLYMERS, INC.			200								
	PORT ARTHUR	GULF OIL CORP.						205					
	PORT ARTHUR	TEXACO						118					
	SEADRIFT	UNION CARBIDE CORP.			155	136							
	SWEENEY	PHILLIPS PETROLEUM CO.										251	

Table III-1 (Concluded)

STATE	LOCATION	COMPANY	CAPACITY PRODUCTION JANUARY 1, 1976 (millions of kg)										
			NITRO- BENZENE	ANILINE	ETHYL- BENZENE	STYRENE	MALEIC ANHYDRATE	CUMENE	PHENOL	MONO- CHLORO- BENZENE	DICHLORO- BENZENE (O- and P-)	CYCLO- HEXANE	DETERGENT ALKYLATE (Linear and Branch)
TEXAS	TEXAS CITY	MARATHON OIL CO.						86					
	TEXAS CITY	MONSANTO			1450 ^c	590							
	TEXAS CITY	STANDARD OIL (INDIANA)			430	382		26					
WEST VIRGINIA	CHARLESTON	UNION CARBIDE CORP								N.A.		68	
	FOLLANSBEE	KOPPERS CO., INC.											
	MOUNDSVILLE	ALLIED CHEM CORP.	26				27						
	NATRIUM	PPG INDUSTRIES, INC.							41	23			
	NEW MARTINSVILLE	MOBAY CHEM CORP.	61	45									
	WILLOW ISLAND	AMERICAN CYANAMIDE	27	22									
WASHINGTON	ANACORTES	STINSON LUMBER CO.							N.A.				
	KALAMA	KALAMA CHEMICAL							26				
TOTAL			483	314	3894	3211	180	1720	1252	313	120	2706	393

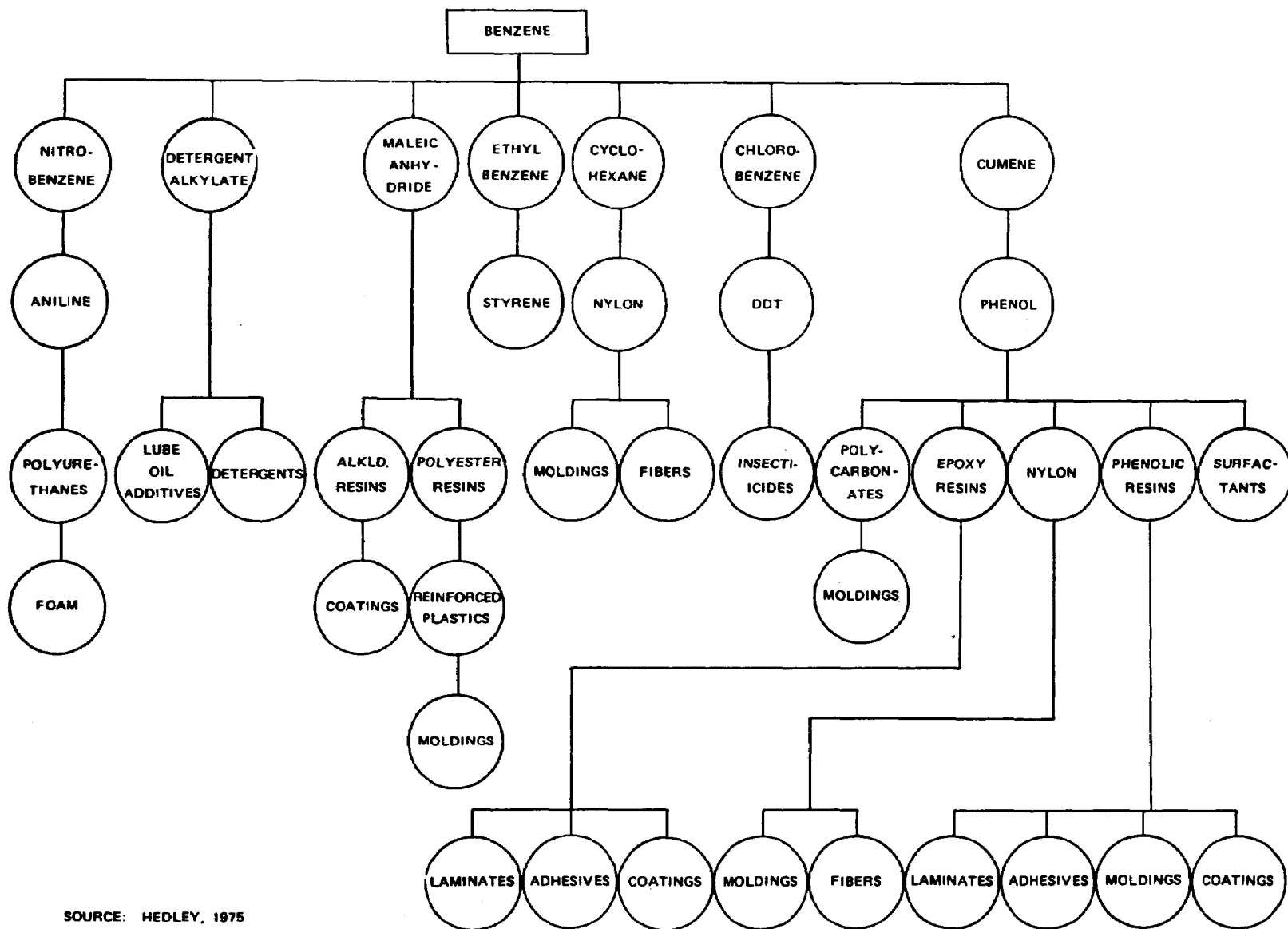
* SOURCE: SRI, 1976 DIRECTORY OF CHEMICAL PRODUCERS, as cited in PEDCO, 1977

N.A. - NOT AVAILABLE

a. PRODUCTION CAPACITY FOR O-DICHLOROBENZENE ONLY

b. PRODUCTION CAPACITY FOR P-DICHLOROBENZENE ONLY

c. 1976 DATA SHOWED COMBINED ESTIMATES OF ETHYLBENZENE PRODUCTION AT CHOCOLATE BAYOU, TEXAS AND AT TEXAS CITY, TEXAS.
1977 SRI ESTIMATES SHOW ETHYLBENZENE PRODUCTION ONLY AT THE TEXAS CITY PLANT.



SOURCE: HEDLEY, 1975

FIGURE III-1. BENZENE DERIVATIVES AND THEIR USES

Table III-2

EMISSION FACTORS AND CHARACTERIZATIONS
FOR BENZENE-CONSUMPTION PLANTS

Chemical	Emission Factor (10^{-3} kg of benzene/kg of product)	Emission Characterization
Aniline ^a	23.60	Fugitive
Cumene ^b	0.25	Fugitive
Cyclohexane ^a	2.80	Fugitive
Detergent Alkylate ^a (linear and branched)	2.20	Fugitive
Dichlorobenzene (p- and o-) ^b	8.60	Chlorinator, PDCD recovery system
Ethylbenzene ^b	0.62	Scrubber-vent
Maleic anhydride ^b	96.70	Product recovery scrubber
Monochlorobenzene ^b	3.50	Unknown
Nitrobenzene ^b	7.00	Point absorber
Phenol ^b	1.00	Unknown
Styrene ^b	1.50	Collection vent, emergency vent

^aSRI estimates

^bPEDCo estimates

The atmospheric dispersion of benzene is more difficult to assess.* Simply, source characteristics (e.g., stack dimensions) and meteorological conditions greatly influence the dispersion of benzene in the vicinity of the plants. Youngblood (1977a) made rough dispersion estimates from very limited data on source characteristics. He classified the processes according to three source categories: A--ground-level point source (effective stack height, 0 m); B--building source (effective stack height, 10 m); and C--elevated point source (effective stack height, 20 m). Emission rates were then calculated for each process by assuming a maximum production rate. Ambient ground-level concentrations were derived manually from Turner's workbook. One-hour worst-case concentrations were derived with the following meteorological conditions assumed: wind speed, 4 m/s; stability class, neutral (Pasquill Gifford "D"). For source category B, the results from Turner's workbook were adjusted to account for the initial dispersion of the pollutant in the building cavity. The one-hour estimates were then converted to 8-hour worst-case estimates (by multiplying by 0.5). The results of the dispersion modeling by Youngblood are given in Table III-3.

B. Methodology

Each chemical manufacturing plant has different production rates, chemical processes, geographic locations, pollution control technology, and meteorological conditions. Thus, detailed dispersion calculations are impractical, given the scope of the study. A simple method of assessment was therefore developed to allow for comparative analysis. Variations in geographic locations and meteorological conditions were not considered in the analysis. The results are not precise; rather, they provide a reasonable order-of-magnitude estimate of atmospheric benzene concentrations. A single dispersion curve was constructed and applied to all chemical manufacturing facilities, based on their emission rates. The derivation of this methodology is discussed below.

* Battelle-Columbus has monitored benzene concentrations in the vicinity of chemical manufacturing facilities. These data are now in draft form and should be available in the near future.

Table III-3
ROUGH ESTIMATES OF AMBIENT GROUND-LEVEL BENZENE CONCENTRATIONS (8-HOUR AVERAGE)*

Source	Emission Rate (g/s)	Source Category	Concentration ($\mu\text{g}/\text{m}^3$) at Given Distance					
			150 m	300 m	450 m	600 m	750 m	1600 m
Maleic anhydride	139.0	C	700	5000	5000	3900	2900	1100
Styrene	7.49	A	3800	1100	530	330	220	68
		B	850	460	290	210	160	55
Phenol from cumene	10.8	C	54	390	390	300	230	89
Benzene	0.179	A	90	26	13	8	5	2
		B	20	11	7	5	4	1
Cumene	2.34	A	1200	340	170	100	70	21
		B	260	140	91	66	49	17
Phenol from benzene	0.0691	A	35	10	5	3	2	1
		B	8	4	3	2	1	<1
		C	<1	2	2	2	1	<1
Nitrobenzene	31.20	A	16000	4500	2200	1400	940	280
		B	3500	1900	1200	870	650	230
		C	160	1100	1100	870	650	250
Ethyl benzene	16.60	A	8500	2400	1200	730	500	150
		B	1900	1000	650	460	350	120
Phenol from toluene	2.42	A	1200	350	170	110	73	21
		B	270	150	94	68	51	17
Chlorobenzene	15.10	A	7700	2200	1100	660	453	140
		B	1700	940	590	420	320	110
		C	76	540	540	420	320	120
o-dichlorobenzene	3.60	A	1800	500	250	160	110	32
		B	400	220	140	100	75	26
		C	18	130	130	100	75	28
p-dichlorobenzene	6.20	A	3200	900	440	270	190	39
		B	700	380	240	180	130	46
		C	31	220	220	170	130	49

*This is a worst-case estimate. It may be multiplied by 0.1 to give rough estimates of annual-average concentrations.
Key to Source Categories: A--Ground-level point source; B--Building source; C--Elevated point source.

Source: Youngblood, 1977a.

Table III-4

ROUGH ESTIMATES OF AMBIENT GROUND-LEVEL BENZENE CONCENTRATIONS
(8-HOUR-AVERAGE)* PER 100 g/s EMISSION RATE

Source Category	Concentrations ($\mu\text{g}/\text{m}^3$)											
	<u>0.15 km</u>	<u>0.3 km</u>	<u>0.45 km</u>	<u>0.6 km</u>	<u>0.75 km</u>	<u>1.6 km</u>	<u>2.5 km</u>	<u>4.0 km</u>	<u>6.0 km</u>	<u>9.0 km</u>	<u>14.0 km</u>	<u>20.0 km</u>
A	51,000	14,000	7,000	4,500	3,000	900	440	220	120	62	34	20
B	11,000	6,100	3,800	2,800	2,100	740	370	220	120	62	34	20
C	510	3,500	3,500	2,800	2,100	800	410	220	120	62	34	20

*To give rough estimates of annual-average concentration, multiply by 0.1.

Source: Youngblood (1977b).

As shown in Table III-3, ambient benzene concentrations in the vicinity of chemical manufacturing plants vary significantly in relation to the characteristics of the emission sources. Exhaust gas temperature, which is important in determining near-source concentrations, was not considered. Because of the generally high concentrations estimated at 1.6 km, Youngblood (1977b) extended his model calculations to a distance of 20 km with an emission rate of 100 g/s for each source category (see Table III-4).

The results of Youngblood's analysis are shown in Figure III-2. The ground-level (A) and building (B) sources are highest near the plant and decrease rapidly with distance. The elevated point source (C), however, shows low initial concentrations that increase to a peak followed by a decline. Although the differences due to source category are considerable at 150 m, the differences decrease rapidly with distance. Even as close as 300 m, the differences are within the range of uncertainty normally associated with dispersion calculations. In addition, distances less than 300 m are likely to be within the plant perimeter or to have low population densities. A single dispersion curve (Curve M in Figure III-2) was therefore developed to represent all three source categories, as suggested by Youngblood (1977b). This curve was derived by averaging the high and low values of the three emission source categories at each calculated distance. The resulting concentrations estimated by this method are shown in Table III-5.

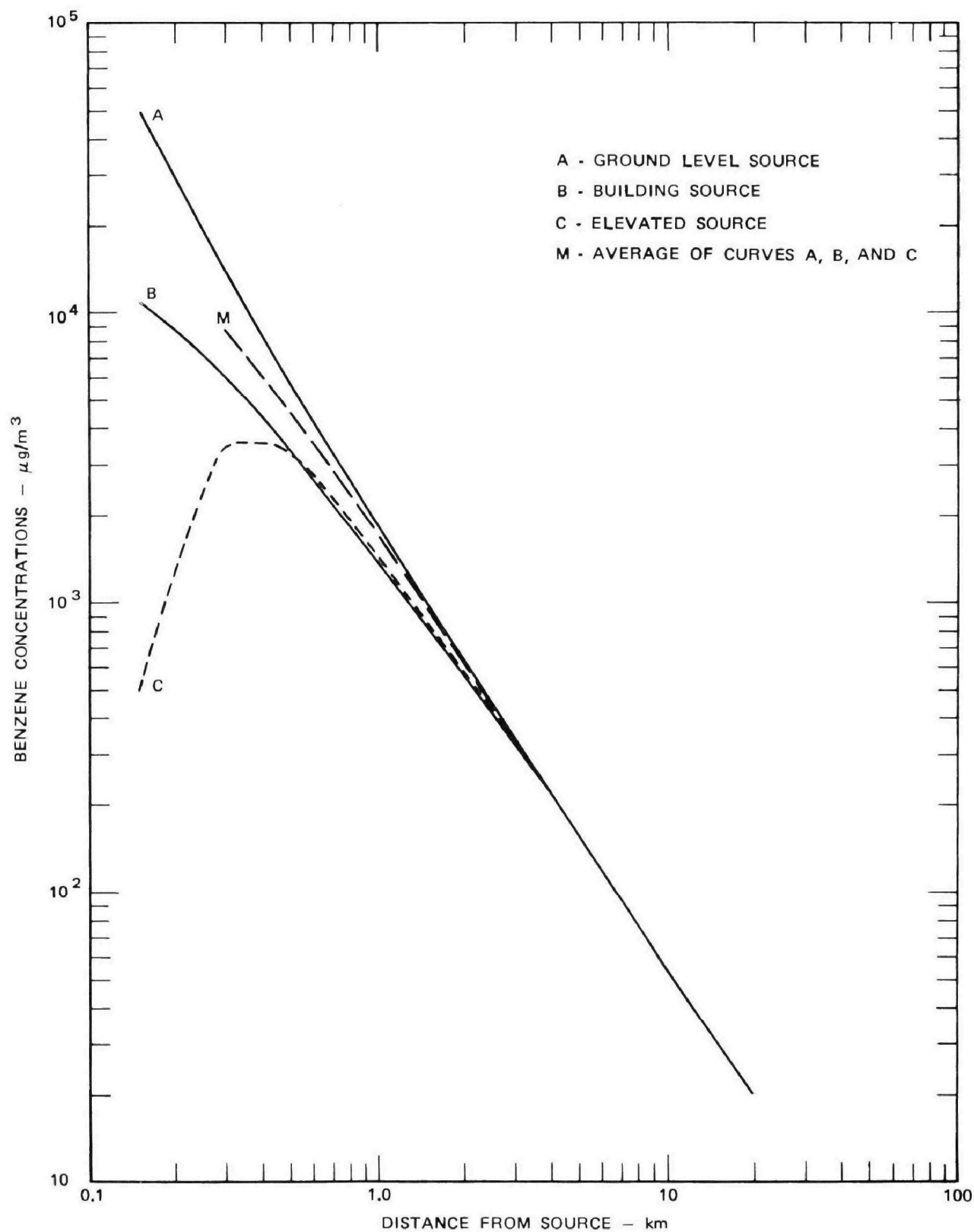
Table III-5
ESTIMATES OF 8-HOUR WORST CASE* BENZENE CONCENTRATIONS
BASED ON AVERAGE OF THREE EMISSION SOURCE CATEGORIES

<u>Distance (km)</u>	<u>Concentration ($\mu\text{g}/\text{m}^3$)**</u>
0.30	8800
0.45	5200
0.6	3600
0.75	2600
1.6	820
2.5	400
4.0	220
6.0	120
9.0	62
14.0	34
20.0	20

* To convert to annual average estimates, multiply concentrations by 0.1.

** To convert to ppb, divide concentrations by 3.2.

Source: Youngblood (1977b).



*Based on an emission rate of 100 g/s

Source: After Youngblood, (1977b)

FIGURE III-2. DISPERSION MODELING RESULTS FOR EACH TYPE OF SOURCE CATEGORY *

Regression analysis was used to develop an equation to characterize the single dispersion curve (Curve M). Equation (3.1) was derived from that analysis:

$$C = 1648 D^{-1.48} \quad (3.1)$$

where, C is the 8-hour worst-case benzene concentration in $\mu\text{g}/\text{m}^3$, and D is the distance from the source in km. Because equation (3.1) is only valid for an emission rate of 100 g/s, a normalized equation is given as follows:

$$C = 16.48 E_a D^{-1.48} \quad (3.2)$$

where, E_a , in g/s, is the emission rate for the location of interest.

The annual average concentration can be estimated by including a multiplier of 0.1 in the equation. Thus, the equation becomes:

$$C = 1.648 E_a D^{-1.48} \quad (3.3)$$

In this study, the ranges of benzene concentrations that follow and that apply to all sources have been established for the sake of uniformity:

0.1 - 1.0 ppb
 1.1 - 2.0 ppb
 2.1 - 4.0 ppb
 4.1 - 10.0 ppb
 >10.0 ppb

A computer program was developed to estimate the people exposed to concentrations within each range at each location. Equation (3.3) was rearranged as follows to determine the distance at which the specified concentrations are found:

$$D_i = 1.40 \left(\frac{E_a}{C_i} \right)^{0.6757} \quad (3.4)$$

where, C_i is the specified concentration (i.e., 0.1, 1.0, 2.0, and so on; input data, however, are in $\mu\text{g}/\text{m}^3$); D_i is the distance at which the specified concentration is found; and E_a is the emission rate at that location.

The population residing within a circle of radius D_i was then estimated by the following equation:

$$P_i = d \pi D_i^2 \quad (3.5)$$

where, d is the city or state population density, and P_i is the population exposed to concentration C_i or greater.

The three main assumptions included in this analysis are:

- The benzene source is in the center of the city
- The maximum allowable radius is 20 km
- When a city has more than one plant, it is assumed that these plants are co-located and their corresponding emission rates are summed.

To accommodate these assumptions the following steps were included in the computer program. The radius of each city was determined by Equation (3.6):

$$D_c = \left(\frac{P_c}{\pi d_c} \right)^{1/2} \quad (3.6)$$

where, D_c is the estimated radius of the city; P_c is the population of the city (1970 Bureau of Census data); and d_c is the average city density (1970 Bureau of Census data available for cities of population greater than 25,000).

When D_i calculated from Equation (3.4) is greater than D_c , or when no city density is available, Equation (3.7) is substituted for Equation (3.5) to calculate the exposed population on the basis of state density.

$$P_i = P_c + d_s \pi (D_i^2 - D_c^2) \quad (3.7)$$

where, d_s is average state population density; D_i is the distance at which concentrations C_i is found; D_c is the radius of the city calculated in Equation (3.6); and P_i is the population exposed to concentration C_i or greater. P_c and D_c equal 0 when no city density is available.

Because the dispersion modeling results are unverified at distances greater than 20 km from the source location, the computer program automatically cut off calculations when a distance of 20 km was attained and calculated the concentration (C_i) at 20 km.

The cumulative population totals resulting were then automatically subtracted, so that the total population within each range of concentrations was printed out. For example, for range 0.1 to 1.0 ppb, the program subtracted $P_{1.0}$ (a smaller number) from $P_{0.1}$ (a larger number). In other words, $P_{0.1}$ is the population exposed to concentrations of 0.1 ppb or greater. $P_{1.0}$ is the total population exposed to concentrations of 1.0 ppb or greater. By subtracting the two values, the total population exposed to concentrations between 0.1 and 1.0 ppb is determined.

Emission rates were estimated for each plant, based on the production estimates contained in Table III-1 and the emission factors in Table III-2. Because actual production data are unobtainable, capacity production and 24-hour (365 days) operation were assumed. Appendix B, Table B-1, lists the estimated emission rates for each chemical manufacturing facility.

C. Exposures

Ambient benzene concentrations and the exposed population for each source location were estimated, based on the methodology described above. Table B-2 in Appendix B presents the results of this analysis.

The population were obtained from density data derived from the 1970 census (U.S. Department of Commerce, Bureau of the Census, 1972 County and City Data Book). When the population density for a city was unavailable, the average statewide population density was used, even though population density in the vicinity of chemical manufacturing plants can vary widely. However, the methods employed here provide a reasonable overall estimate of the exposed population. Table III-6 presents the estimated population exposed to specified levels of atmospheric benzene for each state. More than 9 million people are exposed to annual average benzene concentrations of 0.1 ppb or greater.

Table III-6

POPULATION EXPOSED TO BENZENE
FROM CHEMICAL MANUFACTURING FACILITIES BY STATE

State	Population Exposed to Benzene (ppb) *				
	0.1-1.0	1.1-2.0	2.1-4.0	4.1-10.0	>10.0
Alabama	62,700	2,000	800	400	100
California	104,600	16,500	6,500	3,000	1,200
Delaware	76,200	2,200	1,300	800	300
Georgia	10,900	700	300	100	100
Illinois	204,000	27,600	39,400	31,700	15,500
Kansas	11,800	400	200	100	†
Kentucky	26,800	1,500	600	300	100
Louisiana	166,600	106,900	41,800	19,400	8,400
Maryland	800,400	46,500	18,200	8,300	3,400
Massachusetts	18,300	500	200	100	†
Michigan	65,400	6,200	21,500	10,100	4,100
Mississippi	21,000	18,600	7,300	3,300	1,400
Missouri	4,400	17,400	6,800	348,600	190,200
Nevada	18,000	1,000	400	200	100
New Jersey	1,523,400	110,200	43,100	84,500	38,700
New York	263,600	21,600	8,500	3,900	1,600
Ohio	11,400	300	100	100	†
Pennsylvania	1,986,900	141,400	55,300	27,800	12,700
Puerto Rico	805,500	25,000	10,000	4,500	1,900
Texas	1,169,200	406,600	182,700	93,600	38,200
West Virginia	144,200	16,400	7,700	3,500	1,400
Washington	1,200	100	100	†	†
Total Exposed Population	7,496,500	969,600	452,800	644,300	319,400

* To convert to $\mu\text{g}/\text{m}^3$, multiply by 3.2; to convert to 8-hour worst case, multiply by 10.

† Fewer than 50 people exposed.

Source: SRI estimates.

IV COKE-OVENS

A. Sources

In 1975, 57.2×10^6 tons of coke were produced in the United States. The yield of coke from coal, averaging 68.4% in 1975, has remained fairly constant during the past decade (Sheridan, 1976). Coke is produced by 65 plants in the United States (Suta, 1977). The 65 plants, which are listed in Appendix C, consist of an estimated 231 coke-oven batteries containing 13,324 ovens. Their theoretical maximum annual productive capacity is 74.3×10^6 tons. Table IV-1 shows the estimated size and productive capacity in each state.

Although coke-ovens producing benzene as a by-product account for only about 5 to 8% of the total benzene production in the United States, they are a potentially significant source of benzene emissions. About 0.66% by volume benzene, 0.13% toluene, 0.05% xylene, and less than 0.10% of other aromatics have been identified in the coal gas generated from coking operations (Faith, 1966). The higher the temperatures in coking operations, the larger the amounts of aromatic hydrocarbons produced, particularly benzene. Reduction in quantities of paraffinic naphthenic (saturated alicyclic) and unsaturated hydrocarbons in the production is observed at high temperatures (Faith, 1966; McGannon, 1970). Carbonizing 1 ton of coal in coke-ovens to produce blast furnace coke yields 3 to 4 gallons of light oil. The principal constituent of this oil is benzene, which comprises about 60 to 80% of the total composition. This crude light oil is then distilled to produce benzene, toluene, and xylene. The typical amount of benzene recovered from coke-oven gas is 1.85 gal/ton of coal carbonized (U.S. Public Health Service, 1970).

The distillation of coal tar is one additional source of benzene production. The amount of benzene produced varies with the coking and recovery processes and the grade of the raw coal. In general, the light

Table IV-1

**ESTIMATED SIZE AND PRODUCTIVE CAPACITY OF BY-PRODUCT COKE PLANTS
IN THE UNITED STATES ON DECEMBER 31, 1975**

<u>State</u>	<u>Number of Plants *</u>	<u>Number of Batteries</u>	<u>Number of Ovens</u>	<u>Maximum Annual Theoretical Productive Capacity (tons)</u>	<u>Coke Production in 1974 (tons)</u>
Alabama	7	28	1,401	6,961,000	5,122,000
California	1	7	315	1,547,000	(¹)
Colorado	1	4	206	1,261,000	(¹)
Illinois	4	9	424	2,523,000	1,912,000
Indiana	6 (7)	31	2,108	11,925,000	9,073,000
Kentucky	1	2	146	1,050,000	(¹)
Maryland	1	12	758	3,857,000	(¹)
Michigan	3	10	561	3,774,000	3,259,000
Minnesota	2	5	200	784,000	(¹)
Missouri	1	3	93	257,000	(¹)
New York	3	10	648	4,053,000	(¹)
Ohio	12	35	1,795	9,960,000	8,842,000
Pennsylvania	12 (13)	51	3,391	18,836,000	16,318,000
Tennessee	1	2	44	216,000	(¹)
Texas	2	3	140	839,000	(¹)
Utah	1	4	252	1,300,000	(¹)
West Virginia	3 (4)	13	742	4,878,000	3,555,000
Wisconsin	1	2	100	245,000	(¹)
Undistributed	-	-	-	-	12,656,000
Total	62 (65)	231	13,324	74,266,000	60,737,000

¹ Included in Undistributed.

* 3 plants are co-located.

Source: Sheridan (1976).

Table IV-2

AMBIENT LEVELS OF BENZENE WITHIN A COAL-DERIVED
BENZENE PRODUCTION PLANT

Occupation	8-hour Time-Weighted average (ppm)	Range (ppm)
Agitator operator	6.0	0.5 - 20
Benzene loader and loader helper	4.0	0.5 - 15
Benzene still operator	4.0	1 - 15
Light oil still operator	2.5	1 - 15
Naphthalene operator	10	2 - 30
Analyst	10	4 - 30
Chemical observer	10	4 - 50
Foreman	1.5	1 - 10

Source: Bethlehem Steel Corporation data (NIOSH, 1974).

oil distilled from coal tar is added to the major portion of light oil recovered from coal gas and refined for its benzene content.

The basic coke-oven sources of air pollutant emissions include charging and topside emissions, emissions from doors during the coking cycle, waste gas stack emissions, pushing emissions, and quenching emissions. Appendix A contains a diagram of a typical coke-oven operation. The only ambient benzene concentration data available are occupational exposure data. Table IV-2 gives the typical ambient benzene concentration ranges per occupation, within a coal-derived benzene recovery plant (NIOSH, 1974). Measurements of benzene in Czechoslovakia coke-oven plants are tabulated in Table IV-3. In the recovery plant, the benzene concentration can reach as high as 145 mg/m^3 .

Data on benzene concentration in the vicinity of coke-oven and benzene recovery plants are unavailable. In coke-oven operations, the charging of coal is regarded as the potentially largest source of benzene emissions.

Table IV-3

ATMOSPHERIC BENZENE EMISSION FROM THE COKING AND RECOVERY PLANTS IN CZECHOSLOVAKIA	
Areas	Benzene Concentration $\mu\text{g/m}^3$
Coke-oven battery	$50. - 13 \times 10^3$
Recovery plant	$50. - 145 \times 10^3$
Tar processing	3×10^2

Source: Maskek (1972).

B. Methodology and Exposures

To estimate the at-risk population to benzene from coke-oven emissions, the number of people residing around the coke-oven plants and the ambient

benzene concentration must be determined. The general methodology discussed in Chapter III was used as the basis for determining exposure levels from coke-ovens. Variations in geographic locations, meteorologic conditions and control technology were not considered in the analysis.

Crude* dispersion modeling was conducted by Youngblood of EPA (1977c). Coke oven operations usually cover a large area and benzene emissions are distributed widely throughout. Consequently, the point source model used by Youngblood to estimate downwind concentrations resulting from chemical manufacturing emissions is not applicable. To account for the emissions distributed over a large area, Youngblood used the PAL (Point, Area, and Line Source) Dispersion Model (Turner et al., 1975) that results in lower ambient impact for a given emission rate. The benzene emissions were assumed to occur primarily from oven leaks. The model assumptions were as follows: square plant area; uniform distribution of emissions throughout the area; effective stack height, 10 m; wind speed, 4 m/s; stability class, neutral (Pasquill Gifford "D"). Maximum, one-hour-average concentrations at selected downwind distances for a given emission rate of 100 g/s were obtained from PAL. These were divided by two to represent maximum eight-hour-averages. These are shown Table IV-4.

The plant size most applicable to coke-oven operations is 0.25 km² (500 m on a side). The curve corresponding to this plant size is shown in Figure IV-1. An equation was developed through regression analysis to characterize this curve:

$$C = 403 D^{-0.91} \quad (4.1)$$

where C is the 8-hour worst case benzene concentration in $\mu\text{g}/\text{m}^3$; and D is the distance from the source in km.

* In this report, "crude" is used to mean approximate and extrapolatable.

Table IV-4

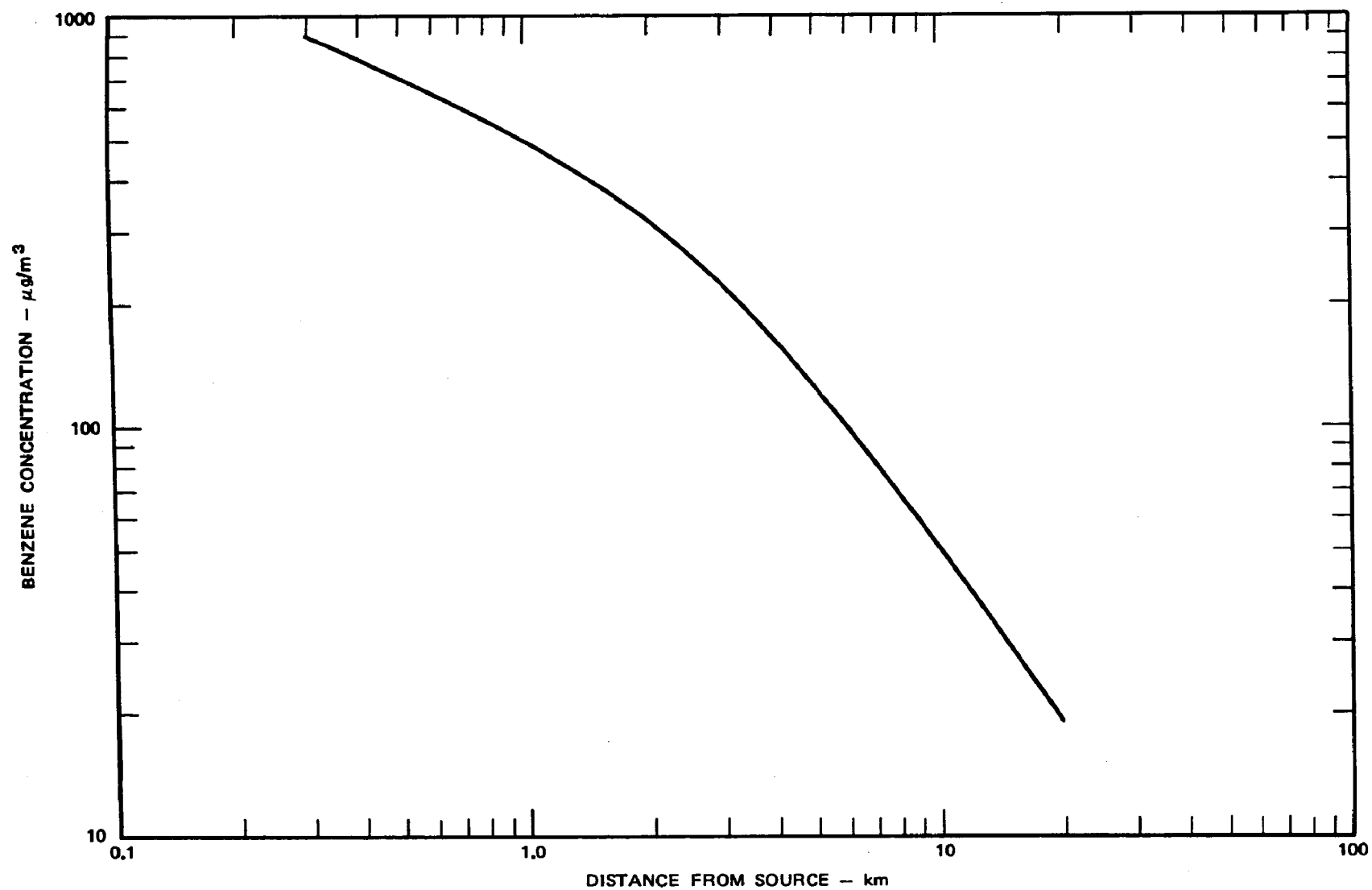
ROUGH ESTIMATES OF 8-HOUR WORST CASE BENZENE
CONCENTRATIONS PER 100 g/s EMISSION RATE
USING THE PAL DISPERSION MODEL

Distance from Source Area (km)	(Concentration $\mu\text{g}/\text{m}^3$)* for Given Plant Area						
	<u>0.01 km²</u>	<u>.06 km²</u>	<u>0.25 km²</u>	<u>1 km²</u>	<u>4 km²</u>	<u>9 km²</u>	<u>25 km²</u>
0.3	5,000	2,000	900	365	145	80	39
0.45	3,850	1,700	750	325	130	75	37
0.60	2,850	1,450	650	290	120	70	34
0.75	2,150	1,250	595	260	110	65	33
1.6	800	600	390	190	85	50	27
2.5	405	360	270	150	70	43	23
4.0	205	190	165	110	50	35	20
6.0	110	110	100	80	45	29	17
9.0	60	60	55	50	34	23	14
14.0	33	32	32	29	23	18	11
20.0	20	20	19	18	16	13	9

* To give rough estimates of annual-average concentrations multiply by 0.1;

To convert to ppb, divide concentrations by 3.2.

Source: Youngblood (1977c).



*Based on an emission rate of 100 g/s

Source: After Youngblood (1977c)

FIGURE IV-1. DISPERSION MODELING RESULTS FOR COKE OVEN OPERATIONS*

Equation (4.1) was then normalized to annual average conditions and to individual emission rates (the Youngblood model was based on an emission rate of 100 g/s):

$$C = 0.4 E_a D^{-0.91} \quad (4.2)$$

To estimate the number of people exposed to benzene concentrations within each range at each location, Equation (4.2) is rearranged as follows to determine the distance at which the specified concentrations are found:

$$D_i = 0.36 \left(\frac{E_a}{C_i} \right)^{1.10} \quad (4.3)$$

where C_i is the specified concentration (i.e., 0.1, 1.0, 2.0, and so on; input data, however are in $\mu\text{g}/\text{m}^3$); and D_i is the distance at which the specified concentration is found.

Detailed population estimates for as far as 15 km from each location were available from an on-going SRI study (Suta, 1977). Consequently, once distances (D_i) were determined, the population exposed to benzene concentrations within each range was easily determined. Geographic coordinates for most of the coke plants were obtained from the U.S. EPA-NEDS data system. The remainder were obtained from consulting maps or by telephone conversation. The population residing within a 15-km radius about each coke plant was calculated by use of the Urban Decisions Systems, Inc., Area Scan Report. This computer data system contains the 1970 census data in the smallest area available (city blocks and census enumeration districts).

Emission rates for each coke-oven operation were estimated by basing them on the capacity and the emission factor of 0.09 lb benzene/ton of coal* obtained from EPA document AP-42 (EPA, 1976). Because actual production data are unobtainable, capacity production and 24-

* Estimated by multiplying the hydrocarbon emission factor (6.9 lb/ton of coal) by the fraction of benzene in the total hydrocarbon emissions (0.0132).

hour (365 days) operation were assumed. Appendix C lists the estimated emission rates for each coke-oven operation. Exact plant locations are unknown. Thus, when more than one operation is found within one city, these plants were assumed to be co-located and their corresponding emission rates were summed. Because no background benzene concentrations are available, the emissions of benzene from the coke plants were assumed to be the sole contributors of benzene to the atmosphere in the vicinity of the oven.

Table IV-5 summarizes people exposed to various annual average benzene concentrations by state. More than 500,000 people are exposed to annual average concentrations greater than 1.1 ppb (8-hr worst case concentration greater than 10.1). Pennsylvania has the highest number of exposed population, followed by Ohio and Michigan.

Table IV-5

ESTIMATED POPULATION EXPOSED TO
BENZENE FROM COKE OVENS^{††}

State	<u>Population Exposed[*] to Benzene (ppb)^{**}</u>				
	0.1 - 1.0	1.1 - 2.0	2.1 - 4.0	4.1 - 10.0	>10.0
Alabama	822,700	23,900			
California	222,300	1,400			
Colorado	0				
Illinois	616,300	800			
Indiana	2,074,500	48,600	200		
Kentucky	50,600	600			
Maryland	579,900		19,400	†	
Michigan	2,957,000	36,100	100		
Minnesota	77,900				
Missouri	36,600				
New York	994,100	20,900	3,100		
Ohio	3,378,800	116,600	4,400		
Pennsylvania	3,413,600	251,300	22,600	2,400	
Tennessee	6,700				
Texas	5,900				
Utah	104,100		†		
West Virginia	117,100	21,000	†		
Wisconsin	267,400				
Total	15,725,500	521,200	49,800	2,400	

Total exposed population = 16,298,900

* Totals are rounded; a zero indicates that a coke oven(s) is present, but exposure levels are below 0.1 ppb.

** To convert to 8-hr worst case, multiply concentration by 10; to convert to $\mu\text{g}/\text{m}^3$, multiply by 3.2

† Fewer than 50 people exposed.

†† Because of averaging techniques and the population data base used, some ranges of concentration show no exposed population.

Source: SRI estimates

V GASOLINE SERVICE STATIONS

A. Sources

Gasoline contains varying amounts of benzene depending, among other things, on lead content and refinery source. Before 1974, the average benzene content in U.S. gasoline was less than 1% by liquid volume (Runion, 1975). Recent data (Runion, 1976) indicate that the average benzene content has been increased to maintain octane levels while reducing lead content. Current estimates of average benzene content in gasoline range from 1.24 to 2.5% by liquid volume (PEDCo, 1977). Tables V-1 and V-2 show the results of analyses of gasoline from different refinery sources that indicate substantial variation among refineries and types of blends.

Table V-1

TYPICAL LIQUID VOLUME PERCENT OF BENZENE IN GULF U.S. GASOLINES, OCTOBER 1976

<u>Refinery Source</u>	<u>Vol% Benzene</u>		
	<u>Good Gulf</u>	<u>Gulf Crest</u>	<u>No-Nox</u>
A	0.54	0.88	1.16
B	1.99	1.45	0.85
C	1.19	1.21	0.81
D	1.59	1.18	1.49
E	1.25	1.98	2.39
F	0.85	0.82	0.88
Average	1.24	1.25	1.26
Standard Deviation	0.52	0.43	0.61

Source: Runion, 1976 (as cited in PEDCo, 1977).

Table V-2

BENZENE CONCENTRATION IN DIFFERENT GRADES AND
SEASONAL BLENDS OF GASOLINE

Company-- Typical Service Station	Gasoline Grade	Vol% Benzene in Bulk Sample		Average Vol% Benzene
		Summer	Winter	
Tresler-Comet	Premium	1.11	1.10	1.11
	Regular	1.21	1.00	1.11
	Unleaded	1.41	1.60	1.51
Bonded	Regular	0.88	0.88	0.88
	Unleaded	1.19	1.60	1.40
Bonded	Regular	0.88	0.88	0.88
	Unleaded	1.20	1.60	1.40
Clark	Regular	0.97	2.00	1.49
	Unleaded	1.09	1.10	1.10

Source: National Institute of Occupational Safety
and Health, 1976 (as cited in PEDCo, 1977).

Because benzene is one of the more volatile gasoline constituents, evaporation from gasoline represents a significant source of human exposure. In this chapter, human exposure from gasoline service stations is considered. (Chapter IX examines general urban exposures related to automotive emissions, including gasoline evaporation from automobiles.) Two main pathways of exposure are examined: (1) obtaining gasoline at self-service pumps; and (2) residing in the vicinity of gasoline service stations.

Although few exposure data about gasoline service stations are available, Battelle recently obtained (1977) a few monitoring data of benzene concentrations in the breathing zone at self-service operations. Limited data of ambient benzene concentrations in the vicinity of gasoline stations are also available. In addition, some rough estimates of benzene concentrations within 300 m of gasoline service stations have been projected by dispersion modeling (Youngblood, 1977d). In the following section, the available sample data and the estimating techniques for the two pathways identified will be discussed separately.

B. Methodology and Exposures

1. Self-Service Operations

Service stations are characterized by their services and business operations: full-service stations, split island stations, self-service stations, and convenience store operations. In full-service stations, attendants offer all services, including gasoline pumping and other mechanical check-ups. If fuel is obtained at any of the last three classes of stations, the customers may fill up their tanks themselves. In split island stations, both self-service and full-service are offered. At the two remaining types of stations, only self-service is available. While pumping gasoline, an individual is exposed to high benzene levels released as vapor from the gasoline tank.* Although occupants in the car at both self-service and full-service operations receive some benzene exposures, the highest exposures are received by the individual pumping the gas. Because it is difficult to estimate level and length of exposure for occupants, only those individuals obtaining gasoline from self-service pumps are considered. (It is not within the scope of this report to evaluate occupational exposures.)

Benzene content of evaporative gases increases and decreases during evaporation, depending on the system temperature and the relative volatilities of all the components of the fuel (Mitre, 1976). Recent information indicates that gases released during automobile fill-ups have little relationship to the benzene content in the gasoline. Rather, the ambient temperature relative to the temperature of the gasoline has the most significant effect, and most of the exposure results from the benzene vapor trapped within the tank, not from the gasoline being pumped (Johnson, personal communication, 1977). If the gasoline is cold relative to the tank (as in summer), most of the benzene vapor will be absorbed into the gasoline. On the other hand, if the gasoline is warm relative to the

* Vapor recovery systems can reduce exposure levels significantly, if properly working and operated. Such systems are required for service stations in parts of California.

tank (as in winter), the benzene vapor will be displaced rather than absorbed and more significant exposures will result.

Self-service dispensing of gasoline is a relatively new marketing method pioneered by independent operators on the West Coast and in the southern United States. Today, it accounts for 30% of gasoline sold. The national market-share of the major gasoline producers has decreased recently as independents and others specializing in high-volume, low-margin sales capture a larger percentage. Of the approximately 184,000 conventional service stations and tie-in gasoline operations in the United States, service stations with some self-service operations account for 39% (ADL, 1977b). Table V-3 indicates the types of service stations offering self-service gasoline.

Table V-3

SELF-SERVICE OPERATIONS

<u>Outlets Offering Self-Service</u>	<u>Percent of U.S. Total</u>
Total self-service	9
Split island with self-service	26
Convenience stores	<u>4</u>
Total Outlets with Self-Service	39

A recent ADL report (1977b) revealed that there are 71,300 outlets with self-service gasoline. Gasoline sold for the year ending May 30, 1977, equals approximately 87.4×10^9 gal in the United States. Of this amount, 27.0×10^9 gal (31%) was dispensed at self-service pumps. The market-share of self-service stations was surveyed for four metropolitan Air Quality Control Regions (AQCR): Boston, Dallas, Denver, and Los Angeles. The market-share held by self-service operations varied from 9% in Boston to 45% in Denver (see Table V-4). Another study by Applied Urbanetics, Inc. (1976) surveyed Baltimore and Madison, Wisconsin. The results of this study are shown in Table V-5. It appears that about 40% of the market in urban areas is accounted for by self-service operations.

Table V-4

GASOLINE MARKET SHARE OF SELF-SERVICE STATIONS
IN FOUR AQCRs,
SPRING 1977

<u>Type of Operation</u>	<u>Number of Outlets</u>	<u>Sales Volume (10⁶ gal/yr)</u>	<u>Market Sharing Percent</u>
<u>Boston AQCR</u>			
Full-service	2,253	1,045.1	91%
Self-service (total)	100	108.6	9%
Split island	8 ^a		
Self-service	92		
Convenience stores	--		
<u>Dallas AQCR</u>			
Full-service	2,094	924.6	61%
Self-service (total)	1,124	593.8	39%
Split island	480 ^a		
Self-service	444		
Convenience stores	200		
<u>Denver AQCR</u>			
Full-service	621 ^b	292.1	55%
Self-service (total)	656	235.7	45%
Split island	310 ^a		
Self-service	226		
Convenience stores	120		
<u>Los Angeles AQCR</u>			
Full-service	2,518	2,472.6	53%
Self-service (total)	4,780	2,154.8	47%
Split island	3,632 ^a		
Self-service	1,022		
Convenience stores	126		

^aSplit island operations offering full service and self-serve islands.

^bOf these 445 are split island operations that offer full service and mini-serve (attendant-operated) islands.

Source: ADL (1977b).

Table V-5

GASOLINE MARKET SHARE OF SELF-SERVICE
STATIONS IN TWO METROPOLITAN AREAS, 1976

<u>Type of Operation</u>	<u>Sales Volume (10⁶ gal/yr)</u>	<u>Market Sharing Percent</u>
<u>Baltimore SMSA</u>		
Full-service	111.5 ^a	55%
Self-service (total)	90.5	45%
Split island	25.5	
Self-service	65.0	
<u>Madison SMSA</u>		
Full-service	56.0 ^a	42%
Self-service (total)	77.0	58%
Split island	17.0	
Self-service	60.0	

^aIncludes the sales from mini-serve (attendant-operated) stations and 50% of the sales from split islands.

Source: Applied Urbanetics, Inc. (1976).

To estimate the people exposed to benzene from this source, several assumptions were necessary. The gasoline pumped through self-service outlets is estimated at 27.0×10^9 gal. The annual average fuel consumption per vehicle is 736 gal (U.S. Federal Highway Administration, 1974). If it is assumed that on the average, a person who primarily uses self-service gasoline makes one trip there per week, an average fill-up amount of 14 gal is determined by dividing 736 gal/vehicle/yr by 52 wk/yr. By dividing the average fill-up into the self-service gallons pumped, we estimate trips per year to self-service operations at 1.9×10^9 . When this number is divided by 52 trips per person per year, the people exposed to benzene from this source is estimated at 37×10^6 . This estimate of the population exposed assumes that the individuals using self-service gasoline never obtain gasoline at full-service stations.

Battelle conducted a preliminary study (1977) to determine the benzene exposure levels from self-service gasoline pumping. Three samples of ambient air were taken in the breathing zone of persons filling their tanks. The results, shown in Table V-6, indicate a wide range in the benzene concentrations of the emissions. The variations seem to be related to the subject's position in relation to the tank opening and the wind direction. Because all measurements were taken on the same day and at approximately the same time, ambient temperature did not cause the variation. Basically, if the subject was downwind of the tank opening, higher levels were recorded. The time-weighted average concentration of benzene from the three samples is 245 ppb. The average length of time taken to fill up a gasoline tank is 1.7 min. Although 14 gal per fill-up is assumed, the wide range in pumping speeds does not allow a precise estimate of time required per fill-up.

Table V-6
SAMPLING DATA FROM SELF-SERVICE GASOLINE PUMPING

Customer	Sampling Rate (mL/min)	Nozzle Time (min)	Gallons Pumped	Sample Volume (L)	Benzene Level	
					$\mu\text{g}/\text{m}^3$	ppb
1	31	2.5	14	78	115	43
2	31	1.1	8	34	324	121
3	31	1.6	9	50	1740	647

Source: Battelle (1977).

The estimated exposure levels are based on the information contained in Table V-6. It is recognized that these data are quite limited and highly variable. In states where vapor recovery systems are used, the estimated exposure level may be much lower, these levels do allow an order-of-magnitude estimate of expected exposure levels from self-service gasoline pumping. It can be estimated that approximately 37×10^6 persons use self-service stations. While filling their tanks once a week, they are exposed to a benzene level of 245 ppb for 1.7 minutes. Their annual exposure is estimated at 1.5 hr. (Table V-9 summarizes this information.)

2. Vicinity of Service Stations

People residing in the vicinity of service stations are exposed to benzene from gasoline evaporation. Benzene emissions result from gasoline pumping by attendants and customers, and from gasoline loading by distribution trucks. The amount of benzene emitted depends on the ambient temperature, vapor recovery controls, and the benzene content in gasoline. The United States has approximately 184,000 service stations, and it is expected that many people are exposed to benzene from these sources. Because density of service stations in urban areas is high and is expected to correlate well with urban population density, only urban areas are considered in this analysis.

Available monitoring data^{*} for one location (Battelle, 1977b) indicate that benzene concentrations are below 1.0 ppb within 300 m of a service station. Higher benzene concentrations may be observed in the direction of the prevailing winds. These results are generally supported by dispersion modeling estimates developed by EPA.

Dispersion modeling for a worst case condition was conducted by EPA (Youngblood, 1977d) using the Single Source (CRSTER) Model. Meteorological data for Denver, Colorado, were used to represent a reasonable worst-case location. The model was executed in such a way that night-time

^{*}The American Petroleum Institute and Battelle are currently conducting monitoring studies; the data should soon be available.

inversions were eliminated, resulting in enhanced dispersion and, for low-level sources such as service stations, lowered ground-level concentrations. Table V-7 presents the results of the dispersion modeling. Note that the operating conditions, pumping volumes, and the chosen location all represent worst-case conditions. Consequently, extrapolation of these results to average conditions is difficult. Nevertheless, it is reasonable to conclude that individuals residing within 300 m of a service station may be exposed to annual-average concentrations of 1.0 ppb or more, whereas those residing beyond 300 m are expected to be exposed to less than 1.0 ppb on an annual-average basis.

The number of service stations in urban areas can be estimated, based on service station density and total U.S. population in urban areas; service station density in urban areas can be extrapolated from the data presented in Table V-8. The service station density shown for four metropolitan AQCRs is somewhat variable, with no apparent regional pattern evident. Based on these data, an average of 0.7 service station per 1000 population was estimated. It is believed that this number can be applied generally to urban areas throughout the United States. Urbanized areas* provide the best population base. The 1970 population residing in urbanized areas was 118,447,000 (Bureau of the Census, 1975). Thus, service stations in urbanized areas are estimated at 82,900, or 45% of all stations.

There are many difficulties inherent in applying the available dispersion modeling data to urbanized areas. For example, it is impossible to determine the distance at which the benzene levels fall below 0.1 ppb. In the absence of this information, we developed an approach for estimating the maximum possible radius between service stations in which none overlap. This approach assumes (1) that service stations are uniformly distributed throughout the urbanized area, and (2) that levels fall below 0.1 ppb at

* Defined by the Bureau of Census as the central city or cities and surrounding closely settled territories. All sparsely settled areas in large incorporated cities are excluded by this definition. Densely populated suburban areas, however, are included (U.S. Department of Commerce, Bureau of the Census, 1972 County and City Data Book).

Table V-7

ROUGH DISPERSION MODELING RESULTS FOR GASOLINE SERVICE STATIONS

Station *	Hours of Operation	% Benzene in Gasoline Vapor	Calculated Emission Rate (g/s)	Distance (m)				
				50	100	150	200	300
				<u>8-Hour Worst-Case Concentration (ppb) **</u>				
A1	8 a.m. - 4 p.m. 6 days/week	0.7	0.019	27	13	8	5	3
A2	8 a.m. - 4 p.m. 6 days/week	3.0	0.080	117	57	34	23	12
				<u>Annual Average Concentration (ppb) **</u>				
B1	24 hours/day 7 days/week	0.7	0.0053	1	<1	<1	<1	<1
B2	24 hours/day 7 days/week	3.0	0.023	2	1	1	<1	<1

* Pumping rate for all stations is 200,000 gal/month uniformly over hours of operation;
rate of evaporative loss for all stations is 10 g/gal pumped.

** To convert to $\mu\text{g}/\text{m}^3$, multiply concentrations by 3.2.

Source: Youngblood, 1977d.

Table V-8
SERVICE STATION DENSITY IN FOUR METROPOLITAN AQCRs

AQCR	Number of [*] Service Stations (1977)	AQCR ^{**} Population (1975)	Service Station [†] Density (number/1000 population)
Boston	2,353	4,039,800	0.6
Dallas	3,218	2,970,900	1.1
Denver	1,277	1,389,000	0.9
Los Angeles	7,298	14,072,400	0.5

Source:

* ADL

** U.S. Department of Commerce, Bureau of Economic Analysis, 1973.

† SRI estimates.

the distance of the maximum radius. The maximum possible radius is estimated as follows:

$$(\pi r^2) \text{ (number of service stations)} = \text{urbanized area}$$

where, urbanized area = 90,860 km² (35,081 mi²); and
service stations = 82,900.

$$r = \sqrt{\frac{90,860 \text{ km}^2}{\pi 82,900}}$$

$$r = 0.59 \text{ km}$$

Thus, for this analysis, the average annual benzene concentration in the vicinity of gasoline service stations is assumed to range between 1.0 and 2.0 ppb within 300 m, and between 0.1 and 1.0 ppb from 300 to 590 m.

The population residing within 300 m of gasoline service stations is estimated by the following equation:

$$\pi (0.3 \text{ km})^2 (1318 \text{ people/km}^2) (82,900) = 31,000,000;$$

where, 1318 is the average population density in urbanized areas (1970).

The population residing within from 300 to 590 m of a service station is estimated as follows:

$$(\pi [0.59 \text{ km}]^2 - \pi [0.3 \text{ km}]^2) (1318 \text{ people/km}^2) (82,900) = 87,000,000$$

The summary results are presented in Table V-9. It is recognized that these estimates are only rough approximations, based on assumptions of uniform distribution of service stations in urbanized areas, uniform pumping volume, and average population density. In reality, more service stations are located in commercial areas than in residential areas, and pumping volumes vary substantially. In addition, it is likely that several service stations are located in the same general area. If these areas are considered to be commercial, they may have either a higher than average population density within 600 m (because of a high percentage of apartments nearby), or one much lower than average (because of a high percentage of businesses and few residences of any kind). People residing near areas with co-located service stations may be exposed to higher annual average benzene concentrations than those estimated. It is likely from this analysis that population exposed is overestimated, whereas the exposure levels may be underestimated. Further study is warranted to determine a more accurate estimate of exposure levels based on pumping volumes, co-location of service stations, their distribution within an urban area, and emission rates.

Table V-9
SUMMARY OF POPULATION EXPOSED TO BENZENE
FROM GASOLINE SERVICE STATIONS

EXPOSURE TYPE	EXPOSURE TIME	ANNUAL EXPOSURE	POPULATION EXPOSED TO BENZENE CONCENTRATIONS (ppb)*			
			0.1 – 1.0	1.0 – 2.0	245.0	TOTAL
SELF-SERVICE PUMPING	1.7 MIN.	1.5 HR.	—	—	37,000,000	37,000,000
RESIDING IN THE VICINITY	24 HR.	ANNUAL AVERAGE**	87,000,000	31,000,000	—	118,000,000

* To convert to $\mu\text{g}/\text{m}^3$, multiply concentrations by 3.2.

** To convert annual average exposures to 8-hour worst case, multiply concentrations by 10.

Source: SRI estimates.

VI PETROLEUM REFINERIES

A. Source

Petroleum refineries appear to be a significant source of atmospheric benzene emissions. Benzene is produced as a by-product of the refining process, used in the formulation of gasoline, and emitted from distillation of crude oil. Benzene emissions from a refinery include: (1) process emissions from crude unit light and heavy naphtha streams, fluid catalytic cracking units, hydrocracking units, and gasoline treating units; and (2) nonprocess sources such as wastewater treatment facilities, heaters and boilers, and facilities for storage and handling of benzene and gasoline (PEDCo., 1977).

Benzene produced from catalytic reforming extraction by petroleum refineries accounted for 50% of the benzene supply in the United States in 1976 (SRI estimates). Because the average distribution of aromatics in reformat is 10% benzene, 40% toluene, and 50% xylene, toluene dealkylation processes are being used more frequently to increase the benzene fraction. (Faith et al., 1966). Toluene dealkylation to produce benzene currently accounts for 27% of the benzene supply in the United States (SRI estimates). This process is most common in petrochemical complexes, rather than in the petroleum refineries. Table VI-1 lists the petroleum refineries in each state that extracts aromatics from the reformat produced in catalytic reforming. Texas and Louisiana account for 84% of the total production of benzene, toluene, and xylene.

The composition of crude oil varies widely, but commonly contains about 0.15% benzene by volume (Dickerman et al., 1975). Consequently, benzene is emitted during the refining process. However, only 34 out of a total of 266 refineries actually produce benzene as a salable item. We have assumed that those producing benzene as a salable by-product have larger benzene emissions than those that do not because of the processing and handling involved. This assumption is basic

to the methodology discussed in subsection VI-B.

Sample data from one refinery producing benzene as a by-product is shown in Figure VI-1. The extreme variability of the measurements is evident. All samples were collected during the same day. The limited nature of these data makes extrapolation unreliable.

Table VI-1

PETROLEUM REFINERIES PRODUCING AROMATICS,*
BY STATE

<u>State</u>	<u>Number of Plants</u>	<u>Quantity[*] (bbl/stream day)</u>
California	3	5,990
Illinois	2	6,700
Kansas	1	1,400
Kentucky	1	4,000
Louisiana	3	19,100
Mississippi	1	6,000
New York	1	3,000
Oklahoma	1	2,000
Pennsylvania	3	9,700
Texas	<u>18</u>	<u>122,525</u>
Total	34	180,415

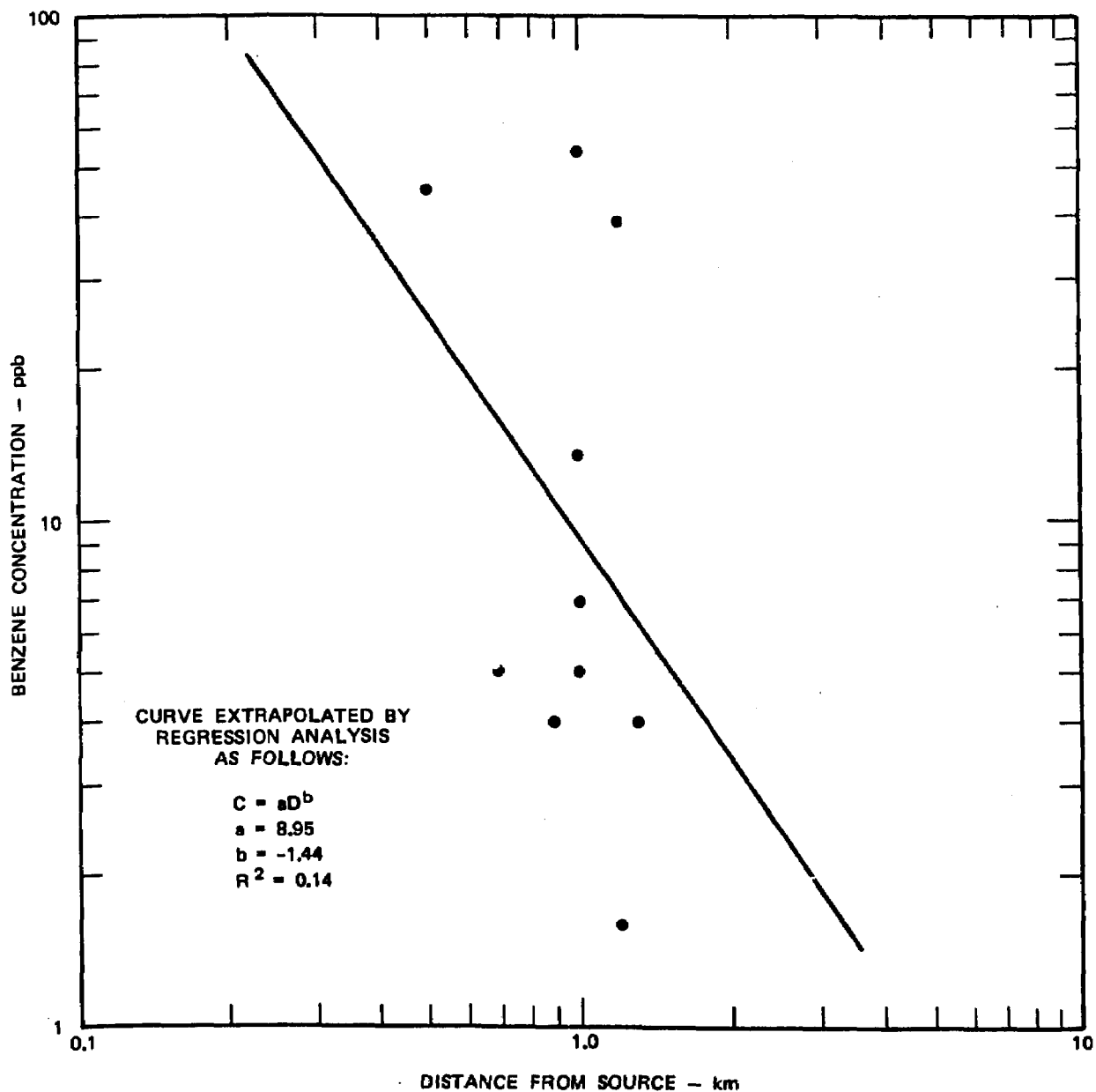
* Total quantity of benzene, toluene, and xylene produced.

Source: Oil & Gas Journal (May 28, 1977)

Four states have 60% of the refining capacity in the United States: California (14%), Illinois (7%), Louisiana (13%), and Texas (26%). Pennsylvania (5%) and New Jersey (4%) bring the total to 69%. Thus, 15% of the states (6 out of 39 states) with petroleum refineries account for 69% of the refining capacity.

B. Methodology

The general methodology discussed in Chapter III was used as the basis for determining exposure levels from petroleum refineries.



* Collected in activated charcoal tubes and analyzed by gas chromatograph with a flame ionization detector. Detection limit was approximately 0.1 μg of benzene/100 mg charcoal.

Source: EPA, 1977

FIGURE VI-1. MONITORING DATA* FOR GULF ALLIANCE REFINERY,
BELLE CHASSE, LOUISIANA

Youngblood of EPA conducted dispersion modeling (1977c) to characterize benzene emissions from petroleum refineries. The results were then applied to each refinery by computer program to estimate the exposed population. Emissions are highly variable, depending on the size and age of the plant and on the control technology employed; however, because specific emission factors were unavailable, general averages were used. Because actual production data are unobtainable, capacity production and 24-hr (365 days) operation were assumed. Variations in geographic location and meteorological conditions were not considered. The results are not meant to be precise: rather, they provide a reasonable order-of-magnitude estimate of expected exposure levels.

Estimates of refinery emission factors were based on average hydrocarbon emissions and the percent of the total hydrocarbon emissions attributed to benzene. Evaluations of available information and discussions with EPA (Radian Corporation, 1975; Hustvedt, personal communication, June 1977a) resulted in the selection of the following factors:

- Total hydrocarbon emissions from petroleum refineries
= 920 lb/1,000 bbl
- Estimated percentage of hydrocarbon emissions attributed to benzene from refineries without catalytic reforming = 0.5
- Estimated percentage of hydrocarbon emission attributed to benzene from refineries with catalytic reforming = 1.0

These emissions result from storage losses ($\approx 50\%$) and from leaks and stacks ($\approx 50\%$). Table VI-2 presents the calculations of emission factors from the two types of petroleum refineries identified. The listing of U.S. petroleum refineries, shown in Appendix D, was obtained from the Annual Refining Survey published in the Oil & Gas Journal (March 28, 1977). This listing includes a breakdown of refineries that extract benzene, toluene and xylene from the reformat as well as the plant capacities. The emission rate in g/s for each plant was estimated, based on the plant capacity and the emission factor. The emission rate for each plant is shown in Appendix D.

Table VI-2

CALCULATION OF EMISSION FACTORS FOR PETROLEUM REFINERIES

Refineries with catalytic reforming:

$$\frac{0.92 \text{ lb/bbl} \left(\frac{\text{total hydro-carbon emissions}}{\text{carbon emissions}} \right) \times 0.01 \left(\frac{\text{percent benzene}}{\text{benzene}} \right) \times 10^3 \text{ g/kg}}{0.159 \text{ m}^3/\text{bbl} \times 2.2 \text{ lb/kg}} = 26 \text{ g/m}^3$$

Refineries without catalytic reforming:

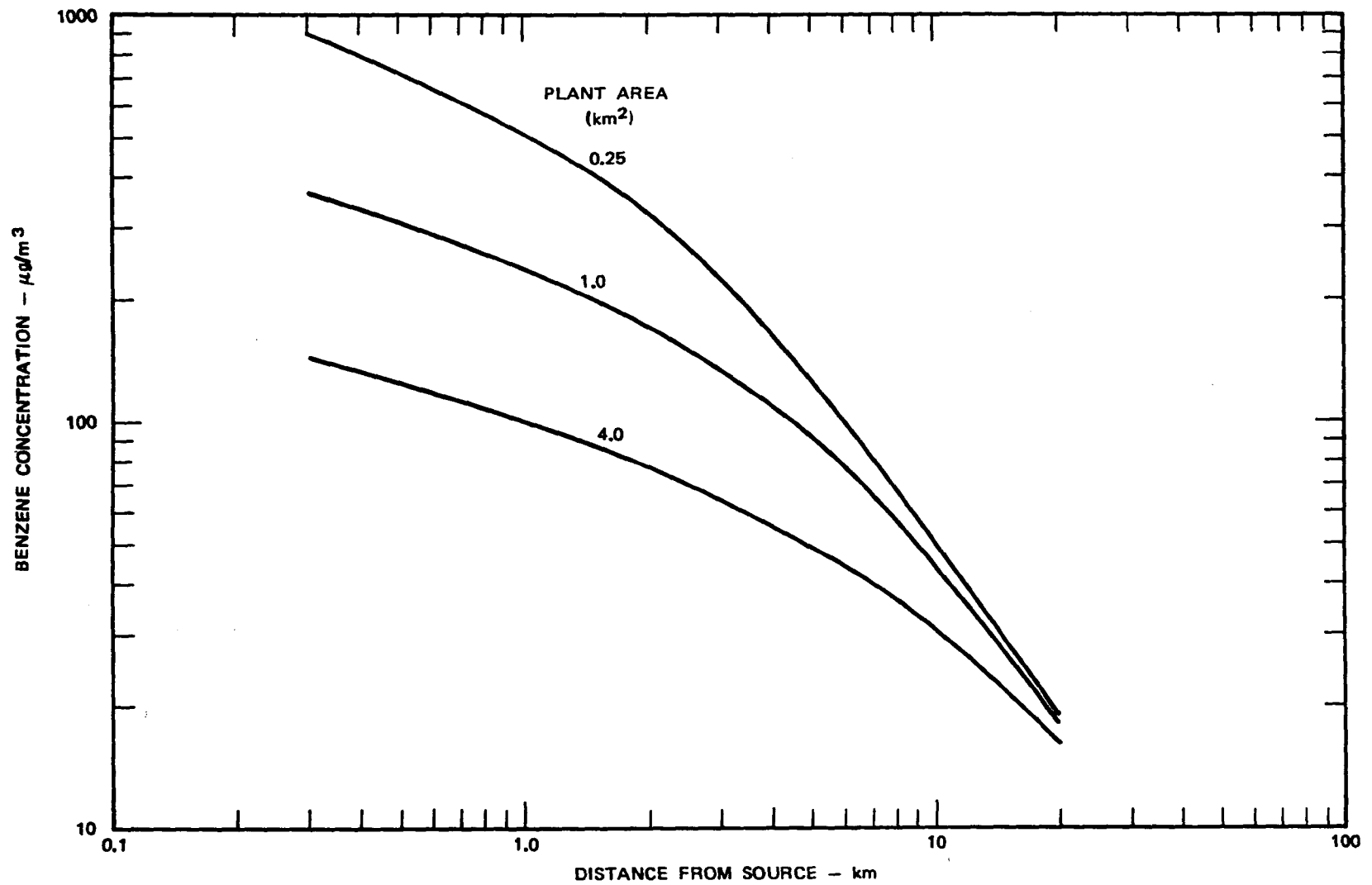
$$\frac{0.92 \text{ lb/bbl} \left(\frac{\text{total hydro-carbon emissions}}{\text{carbon emissions}} \right) \times 0.005 \left(\frac{\text{percent benzene}}{\text{benzene}} \right) \times 10^3 \text{ g/kg}}{0.159 \text{ m}^3/\text{bbl} \times 2.2 \text{ lb/kg}} = 13 \text{ g/m}^3$$

Because petroleum refineries are large and benzene emissions are distributed widely throughout the plant area, Youngblood used the PAL (Point, Area, Line Source) Dispersion Model (Turner et al.) to estimate approximate downwind concentrations. The modeling assumptions and procedure were the same as those described for coke ovens (pages IV-5 and IV-6). Table IV-4 applies to petroleum refineries as well as to coking plants.

Three of the size categories are applicable to petroleum refineries (Hustvedt, personal communication, 1977b):

<u>Plant Area (km²)</u>	<u>Capacity (bbl/day)</u>
0.25	< 35,000
1.00	35,000 - 200,000
4.00	>200,000

Figure VI-2 shows the curves corresponding to the three plant sizes. Because the differences between the curves are within the range of uncertainty associated with dispersion analysis, the middle curve (1.0 km²) was used to represent the dispersion characteristics of all refineries at the suggestion of Youngblood (personal communication, August 1977).



*Based on an emission rate of 100 g/s

Source: After Youngblood (1977c)

FIGURE VI-2. DISPERSION MODELING RESULTS FOR THREE SIZE CATEGORIES OF PETROLEUM REFINERIES*

The computer program discussed in Chapter III was applied to petroleum refineries by substituting a new equation developed through regression analysis to characterize the 1.0-km^2 curve. This equation can be written as follows:

$$C = 200 D^{-0.51} \quad (6.1)$$

where, C is the 8-hour worst-case benzene concentration in $\mu\text{g}/\text{m}^3$; and D is the distance from the source in km.

Equation (6.1) was then normalized to annual average conditions, and individual emission rates (the Youngblood model was based on an emission rate of 100 g/s):

$$C = 0.2 E_a D^{-0.51} \quad (6.2)$$

where, E_a is the emission rate for the location of interest.

To estimate the people exposed to benzene concentrations within each range at each location, Equation (6.2) is rearranged as follows to determine the distance at which the specified concentrations are found:

$$D_i = 0.0426 \left(\frac{E_a}{C_i} \right)^{1.96} \quad (6.3)$$

where C_i is the specified concentration (i.e. 0.1, 1.0, 2.0, and so on; input data, however are in $\mu\text{g}/\text{m}^3$); and D_i is the distance at which the specified concentration is found. The remaining steps in the methodology are discussed in Chapter III.

If more than one refinery was located in a particular city, we assumed that the refineries were co-located, and we summed their emission rates. Although several cities had three or more refineries, it is also true that few people generally live near such complexes. Thus, with this method, the exposed population is minimized, whereas the exposure level is maximized for a particular city.

C. Exposures

The population exposed to atmospheric benzene from petroleum refineries by plant location is shown in Appendix D. A state summary

of annual average benzene concentrations and exposed population is shown in Table VI-4. Pennsylvania, which is fifth in number of refineries, has the highest exposed population with 2,171,300; Texas is second with 1,881,000 people exposed. Of the states with petroleum refineries, 21 (54%) have less than 5,000 people exposed, and 9 (23%) have more than 100,000 people exposed. More than 6×10^6 people are exposed to benzene from petroleum refineries. More than 68,000 people are exposed to an annual average concentration of 1.0 ppb or more (8-hr worst case level of 10 ppb or more). Although the exposure levels and population estimates are rough approximations, they can be considered to be a reasonable estimate of expected conditions.

Table VI-3

ESTIMATED POPULATION EXPOSED TO BENZENE
FROM PETROLEUM REFINERIES BY STATE

State	Population Exposed* to Benzene (ppb)**				
	0.1 - 1.0	1.1 - 2.0	2.1 - 4.0	4.1 - 10.0	>10.0
Alabama	100				
Alaska	†				
Arizona	0				
Arkansas	500				
California	555,200	4,800	300	†	†
Colorado	400				
Delaware	6,400	†			
Florida	0				
Georgia	0				
Hawaii	100				
Illinois	203,000	200	†	†	
Indiana	118,400	†	†		
Kansas	20,100	†			
Kentucky	24,600	†			
Louisiana	322,700	1,600	100	†	
Maryland	500				
Michigan	12,100	†			
Minnesota	800				
Mississippi	49,500	1,000	100	†	
Missouri	500				
Montana	22,500	†			
Nebraska	0				
New Hampshire	0				
New Mexico	†				
New York	40,500	†			
New Jersey	465,400	200	†		
North Dakota	†				
Ohio	537,100	200	†	†	
Oklahoma	127,200	†	†		
Oregon	†				
Pennsylvania	2,137,700	31,300	2,100	200	†
Tennessee	700				
Texas	1,854,800	24,500	1,600	100	†
Utah	10,200	†			
Virginia	100				
Washington	4,800				
West Virginia	0				
Wisconsin	†				
Wyoming	13,200	†			
Total	6,529,100	63,800	4,200	300	†

Total Exposed Population - 6,597,400

* Totals are rounded; a zero indicates that a refinery(ies) is present in the state, but exposure levels were below 0.1 ppb.

** To convert to 8-hr worst case, multiply concentration by 10;
to convert to $\mu\text{g}/\text{m}^3$ multiply by 3.2

† Fewer than 50 people exposed.

Source: SRI estimates.

VII SOLVENT OPERATIONS

A. Sources

Little is known about benzene used in solvent operations. Recent publications evaluating benzene in the workplace have identified industries in which benzene may be used as a solvent, but the studies were unable to quantify actual volumes of use (Arthur D. Little, Inc., 1977; PEDCo, 1977; Mitre, 1976). The Occupational Safety and Health Administration (OSHA) is currently evaluating industries for benzene hazards under their emergency temporary standards (Brinkerhoff, personal communication, 1977). Table VII-1 lists major industries that OSHA is investigating to determine whether benzene is used as a solvent in their operations.

Some indication of the maximum possible volume of benzene used in solvent operations can be obtained by evaluating benzene consumption data for the United States. More than 95% of all benzene used as a raw material is consumed by seven chemical manufacturing processes (see Chapter III). Only 2.8% (3.05×10^8 lb [1.39×10^8 kg]) is consumed by other uses (SRI estimates, 1977). Other uses include benzene for: anthraquinone, benzene hexachloride, benzene sulfonic acid (primarily for phenol), diphenyl, hydroquinine, nitrobenzene (other than that used for aniline), resorcinol, and solvent applications. Because three of the uses (resorcinol, nitrobenzene, and benzene sulfonic acid) account for approximately 50% of the benzene consumed by all other uses, solvent operations must consume much less than 150×10^6 lb/yr (68.0×10^6 kg). In fact, many operations have switched to other solvents because of the toxicity hazard associated with benzene. The amount of benzene used by solvent operations is consumed in many, small volume markets (SRI estimates, 1977).

Table VII-1

INDUSTRIES AND MANUFACTURED PRODUCTS
POSSIBLY USING BENZENE AS A SOLVENT

Rubber tires
Miscellaneous rubber products
Adhesives
Gravure printing inks
Printing and publishing
Trade and industrial paints
Paint removers
Miscellaneous industrial uses
Coated fabrics
Synthetic rubber
Leather and leather products
Floor covering

Source: Brinkerhoff, personal communication (1977)

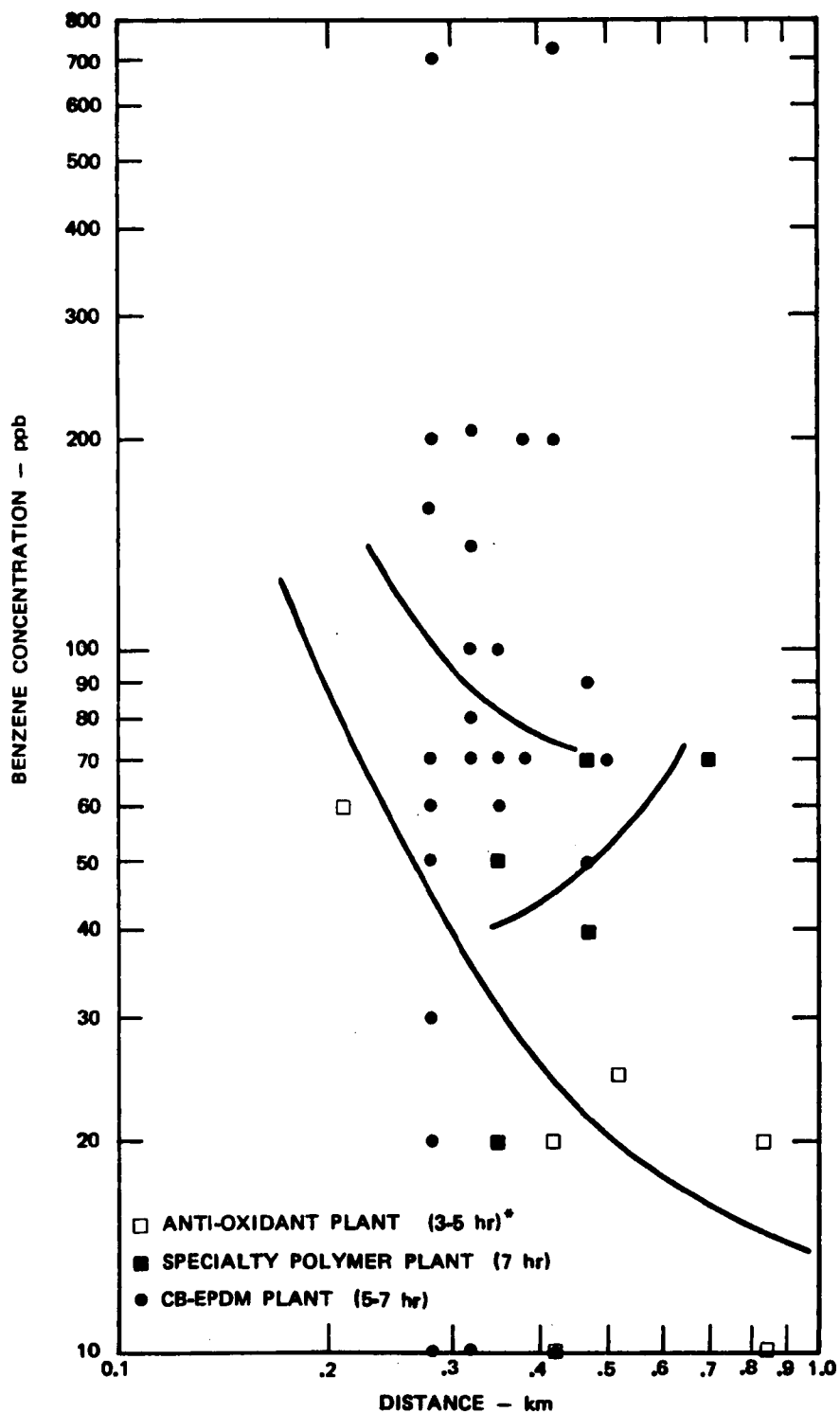
A recent study by Arthur D. Little (ADL) (1977a) identified the manufacture of rubber tires and of miscellaneous rubber products using synthetic rubber and adhesives as possible major sources of occupational exposures. Although industry sources indicate that benzene has been removed from many of the operations within the rubber industry, the ADL study reported that substantial quantities are still being used in the manufacture of synthetic rubbers, production of phenolic antioxidants, polymerization of hydrophilic polymers, and manufacture of rubber adhesives. However, these operations may take place in locations apart from the location where the final product is produced.

Toluene has often been substituted as a solvent for benzene (Brinkeroff, personal communication, 1977). However, it contains significant quantities of benzene contamination ranging from 2 to 15% by weight. The proposed OSHA standard will reduce this level to 1% by the end of 1977 and to 0.1% by the end of 1978.

Limited monitoring data are available. NIOSH is currently conducting a sampling program in the vicinity of solvent operations using benzene (Hardel, personal communication, 1977). Sampling data for three B. F. Goodrich Chemical Company solvent operations were recently submitted to EPA. Figure VII-1 displays the measured benzene concentrations at various sampling sites within 1 km of the source. (The wide variability probably occurred because the wind was gusty, averaging between 10 to 15 mph throughout the sampling period.) Benzene concentrations as high as 700 ppb were measured within 420 m of the source--an indication that significant potential exists for high environmental exposure to benzene from solvent operations.

B. Methodology and Exposure

Because of the extremely limited information on operations using benzene as a solvent, amount used, and probable emission factors, any exposure estimates are necessarily crude. The primary assumption is that only the largest plants will have significant potential for high



* The hours shown in parenthesis are approximate averaging times for the samples taken at each plant.

FIGURE VII-1. SAMPLING DATA FOR THREE SOLVENT OPERATIONS

environmental exposure. The 1972 Census of Manufacturers (Bureau of the Census) was used to determine those operations that have the largest average plant size. Table VII-2 lists the major operations and average number of employees per plant. Five operations that averaged more than 100 employees per plant were selected for further analysis. Table VII-3 lists the number of plants and average number of employees per plant for each of the five operations by state. Georgia and California have the largest number of plants together comprising 32% of the total. Based on Table VII-3 it can be assumed that the population in those states with the most plants, have the greatest risk of benzene exposure from the solvent operations identified.

A rough estimate of the level of risk associated with each plant can be obtained by approximating the benzene use by each operation. As discussed in the previous section, it is known that 150×10^6 lb/yr of benzene (68×10^6 kg) is used for other unidentified uses, including solvent applications. If it is assumed that 75% of this figure represented solvent use, the total is 110×10^6 lb/yr (50×10^6 kg/yr). Because it is expected that the largest single solvent application is in rubber tires and miscellaneous rubber products, it is further assumed that 80% of the total estimated solvent use is found in rubber-related manufacturing. Therefore, the amount allocated to rubber tires and miscellaneous rubber products is estimated to be 88.0×10^6 lb/yr (40×10^6 kg/yr). Table VII-3 shows 360 plants in rubber-related manufacturing. Using this total, the average benzene consumption per plant is estimated at 0.24×10^6 lb/yr (0.11×10^6 kg/yr).

The next step is to estimate an emission factor. By careful analysis the data in Figure VII-1 can be compared with the dispersion modeling data presented in Chapter III (see Table III-3). At 300 m, the average benzene concentration for the three monitored solvent operations ranges between 50 and 100 ppb. If these data are assumed to represent annual average conditions, the concentrations approximate the annual average concentrations of p-dichlorobenzene (56 ppb) and chlorobenzene (137 ppb) at 300 m for ground-level sources. However, comparing the

Table VII-2

AVERAGE NUMBER OF EMPLOYEES PER PLANT
FOR SELECTED SOLVENT OPERATIONS

<u>Sic Number</u>	<u>Item</u>	<u>Average Number of Employees/Plant</u>
221	Floor covering mills	113
229	Miscellaneous textile goods	60
278	Blankbooks and bookbinding	35
282	Plastics materials, synthetics	351
285	Paints and allied products	41
301	Tires and innertubes	522
302	Rubber and plastics footwear	295
303	Reclaimed rubber	45
304	Rubber, plastic hose, and belting	354
306	Fabricated rubber products	89
307	Miscellaneous plastic products	45
31	Leather and leather products	84
379	Miscellaneous transportation equipment	38

Source: adapted from 1972 Census of Manufacturers.

Table VII-3

NUMBER OF PLANTS AND EMPLOYEES FOR SOLVENT OPERATIONS
WITH HIGH POTENTIAL FOR BENZENE EMISSIONS

	Tires and Innertubes		Rubber, Plastic Hose and Belting		Rubber and Plastic Footware		Plastics Materials, Synthetics		Floor Covering Mills		Number of Plants
	#	E	#	E	#	E	#	E	#	E	
Alabama	10	800					9	400	7	300	26
Arkansas	5	400	1	300	1	300			5	150	12
California	22	500*	8	750	3	100	51	40	62	100*	146
Colorado	2	900	1	350	1	300					4
Connecticut	1	1800	2	100	3	1200	9	200			15
Delaware			2	900			6	700			8
Florida					4	450	10	580			14
Georgia	9	200			3	600	11	100	247	100	270
Illinois	10	500*	4	400	2	375	27	100	7	100	50
Indiana	5	360	3	100	3	250	9	160	2	100	22
Iowa	5	700					3	100			8
Kansas	2	1750	1	200			3	100			6
Kentucky	3	600	1	750			10	450	3	100	17
Louisiana							14	264			14
Maine					5	360					5
Maryland	2	1750			3	1200	5	580			10
Massachusetts	6	600	4	450	12	300	21	200	10	100	53
Michigan	6	600					13	300			19
Minnesota			2	100			4	200			6
Mississippi	3	600					5	150	1	1800	9
Missouri	4	100	2	600	4	100	4	50			14
Nebraska			3	600							3
New Hampshire					7	250	3	70	2	150	12
New Jersey			18	350*	5	150	35	150	3	100	61
New York			5	360	10	180	20	100	17	20	52
North Carolina	7	400	2	900	4	450	22	700			35
North Dakota									38	100	38
Ohio	27	1000	15	600	6	50	37	200			85
Oklahoma	7	600	1	300					6	200	14
Pennsylvania	14	500*	4	200	9	250	27	400	27	200	81
Rhode Island					2	900			8	25	10
South Carolina			1	300	1	200	15	1100	30	100	47
Tennessee	12	460	1	750	5	150	15	1400	20	80	53
Texas	11	500*					35	280	4	100	50
Utah			2	150							2
Virginia	5	360			1	200	10	1800	3	600	19
West Virginia					2	150	6	1200			8
Wisconsin	2	1750			1	750	10	100			13
Total	180		83		97		502		449		1311

= Number of plants

E = Average number of employees per plant

* = The average plant size for the category. This was used when it was not possible to determine an average plant size for the State from the listed information.

Source: 1972 Census of Manufacturers, Bureau of the Census; 1975 Statistical Abstract of the United States, Bureau of the Census.

annual production rates of 150,000 ton/yr for chlorobenzene and 30,000 ton/yr for p-dichlorobenzene to 120 ton/yr per plant of estimated average benzene consumption for rubber and tire manufacturing, it is evident that the emission factor for solvent operations must be much higher than those for chemical processes to account for the measured benzene concentrations. For this analysis, we assume an emission factor of 100×10^{-3} kg/kg.

With the assumed emission factor and the estimated average plant size, the following calculations can be made:

$$\begin{aligned}\text{Average benzene consumption per plant} &= 0.11 \times 10^6 \text{ kg/yr} \\ \text{Emission factor} &= 100 \times 10^{-3} \text{ kg/kg benzene used} \\ \text{Total emissions} &= 0.011 \times 10^6 \text{ kg benzene/yr} \\ \text{Estimated emission rate} &= 0.35 \text{ g/s}\end{aligned}$$

The dispersion modeling results presented in Chapter III can be used to estimate the ambient benzene concentrations near a plant of average size. (See Table VII-4). The results of the calculations indicate that average annual concentrations >1 ppb can be expected within 1 km of the average solvent operation under our previously stated assumptions. Consequently, further analysis is required.

The states containing the most plants with high potential for atmospheric benzene emissions are identified in Table VII-5. It is impossible to discern with certainty whether or not benzene is actually used at these facilities. The probability of benzene use is high, however, and, if used, the probability of annual average benzene concentrations of 0.1 ppb or greater is significant. In fact, all the plants identified in Table VII-5 are at least two times larger than the average plant size in their category (based on total number of employees).

A crude estimate of exposed population is possible by assuming an annual benzene consumption and a general emission factor for each plant listed in Table VII-5. As before, the emission factor used is 100×10^{-3} kg/kg. The total benzene use for each plant is estimated

Table VII-4

ESTIMATED AVERAGE ANNUAL* BENZENE CONCENTRATIONS
IN THE VICINITY OF AN AVERAGE SIZE SOLVENT OPERATION
IN RUBBER-RELATED MANUFACTURING

Distance From Source (km)	Benzene Concentrations		Distance From Source (km)	Benzene Concentrations	
	ppb	$\mu\text{g}/\text{m}^3$		ppb	$\mu\text{g}/\text{m}^3$
0.15	1.2	3.8	2.5	0.04	0.1
0.30	0.7	2.2	4.0	0.02	0.06
0.45	0.4	1.3	6.0	0.01	0.03
0.60	0.3	1.0	9.0	0.007	0.02
0.75	0.2	0.6	14.0	0.004	0.01
1.6	0.08	0.3	20.0	0.002	0.006

* To convert to 8-hour worst case, multiply concentrations by 10.

Source: Extrapolated from dispersion modeling results using curve B (Building Source). (see Chapter III, Table III-4).

Table VII-5

STATES WITH THE HIGHEST POTENTIAL FOR ATMOSPHERIC BENZENE
FROM SOLVENT OPERATIONS

State	Number of Plants	Average Number of Employees Per Plant	Average State Density (1974) (People/km ²)	Plant Size as Compared to Estimated Average Plant *
<u>Tires and innertubes</u>				
Connecticut	1	1,800	244	3x
Kansas	2	1,750	11	3x
Maryland	2	1,750	159	3x
Ohio	27	1,000	101	2x
Wisconsin	2	1,750	32	3x
<u>Rubber, plastic hose, and belting</u>				
California	8	750	52	2x
Delaware	2	900	111	2.5x
Kentucky	1	750	33	2x
North Carolina	2	900	42	2.5x
Tennessee	1	750	38	2x
<u>Rubber and plastics footwear</u>				
Connecticut	3	1,200	244	4x
Georgia	3	600	32	2x
Rhode Island	2	900	343	3x
Wisconsin	1	750	32	2.5x

* See text for discussion of the estimated average plant size.

Source: 1972 Census of Manufacturing and 1975 Statistical Abstract of the United States (Bureau of Census).

by scaling up the estimated use at a plant of average size, based on the comparative size factors shown in Table VII-5. Because plant locations were unknown, average state densities were used to determine the exposed population. The dispersion modeling curve B (building source) developed by Youngblood (1977b) was used as the basis for extrapolation (see Chapter III, Table III-4). The population exposed to five ranges of benzene concentrations were estimated for each plant in a particular state. These estimates were then multiplied by the total number of plants in the state (see Table VII-6). Note that, even for large plants nearly all of the estimated exposure levels range from 0.1 to 1.0 ppb.

Ambient benzene concentrations for the remaining rubber-related manufacturing facilities were then estimated, based on the analysis above. The 57 plants listed in Table VII-6 represent 16% of the rubber-related manufacturing plants originally identified. Their combined benzene consumption accounts for 35% of the estimated consumption for this category (based on our earlier assumptions). Assuming some benzene use as a solvent in all plants, it can be concluded that the remaining 303 plants probably use amounts equal to or less than the estimated average. Thus, the population exposed to levels of 0.1 ppb and above live within 1 km of the plant (from Table VII-4). Table VII-6 shows the results of this analysis. The results were derived by using average 1974 state densities (Table VII-3) to estimate the population residing within 1 km and then multiplying that population by the plants in each state.

This same methodology can be used to determine potential exposures in the remaining two categories: plastics materials, synthetics, and floor covering mills. If it can be assumed that they account for 15% of benzene consumed for solvents, the total use for these two manufacturing processes is estimated to be 17.0×10^6 lb/yr (8×10^6 kg/yr).

The calculations follow: (on page 75)

Table VII-6
ESTIMATED POTENTIAL POPULATION EXPOSURES
FROM
SOLVENT OPERATIONS IN RUBBER-RELATED MANUFACTURING

State	Population Exposed To Annual Average Benzene Concentrations (ppb)*				Total [†]
	0.1 - 1.0	1.0 - 2.0	2.0 - 4.0	4.0 - 10.0	
<u>Tires and Inner-tubes</u>					
Connecticut	4,600	200	70		4,900
Kansas	400	18	6		400
Maryland	6,000	260	80		6,300
Ohio	57,600	1,000	800		59,400
Wisconsin	1,200	52	18		1,300
<u>Rubber, plastic hose, and belting</u>					
California	8,000	1,400	120		9,500
Delaware	4,200	80	62		4,300
Kentucky	600	12	9		600
North Carolina	1,600	30	24		1,700
Tennessee	700	14	11		700
<u>Rubber and plastic footwear</u>					
Connecticut	20,600	900	420	51	22,000
Georgia	1,800	36	27		1,900
Rhode Island	13,000	600	192		13,800
Wisconsin	600	12	9		600
Subtotal [†]	120,900	4,600	1,800	100	127,400
Remaining 303 plants	87,000				87,000
Total [†]	207,900	4,600	1,800	100	214,400

* To convert to 8-hour worst case, multiply concentrations by 10.
To convert to $\mu\text{g}/\text{m}^3$, multiply concentrations by 3.2.

† All totals are rounded.

Source: SRI estimates, based on dispersion modeling of a building source by Youngblood (1977b).

Plants	= 951
Average benzene consumption per plant	= 0.008×10^6 kg/yr
Emission factor	= 100×10^{-3} kg/kg benzene consumed
Total emissions	= 0.0008×10^6 kg benzene/year
Estimated emission rate	= 0.025 g/s
8-hour worst case benzene concen- tration within a 150 m radius of emission source*	= 0.9 ppb
Annual average benzene concen- tration within 150 m radius	= 0.09 ppb

* Extrapolated from dispersion modeling results of Youngblood (1977b) using curve for building source (see Chapter III, Table III-4).

Thus, if the estimated percentage of benzene use attributed to the rubber industry versus other solvent uses is correct, the exposures related to other solvent operations are minimal. As noted earlier, use of benzene as a solvent in operations other than the rubber industry is generally declining. Although it is also declining in the rubber industry, the use volume is still presumed to be high (ADL, 1977).

In summary, although little is known about the use of benzene as a solvent present indications are that its use for this purpose is declining. However, benzene may substantially contaminate other organic solvents. The monitoring data presented in Figure VII-1 indicates that the potential for environmental exposures is significant. Crude estimates of the potential population exposed to benzene from this source category can be derived, based on estimates of benzene use, of an emission factor, and of dispersion characteristics. Our assumptions gave results that indicate some overall potential for exposures from solvent operations. Rubber-related manufacturing is estimated to be the largest source of population exposures in this source category and may potentially effect more than 200,000 people.

Because it is not known how many plants use benzene as a solvent, these estimates only roughly approximate actual population exposures. Further study of solvent operations is thus warranted.

VIII STORAGE AND DISTRIBUTION OF BENZENE AND GASOLINE

A. Sources

Storage and distribution of benzene and gasoline represent potential sources of atmospheric benzene in the environment. There are two main emission pathways: (1) evaporation and spills during loading and unloading benzene and gasoline and (2) spills from collisions in transportation.

Benzene transfers normally occur at petrochemical complexes and at major transportation nodal points. The majority of benzene is transported by barge, with smaller amounts handled by rail and truck. The operations involved in loading and unloading liquid benzene are similar for barge, rail, and truck shipments. Emissions from these sources would depend on the quantity of benzene being transferred, the rate of transfer, the purity of the raw material, and the efficiency of the transfer.

Gasoline transfers normally occur at petroleum refineries and at numerous storage sites throughout the United States. Gasoline is usually stored in closed containers located in remote locations. Although evaporation loss from storage tanks has been observed, most of the benzene released into the environment is believed to result from the operations of loading and unloading the gasoline. Spills from collisions involving gasoline transfer vehicles account for negligible benzene losses.

B. Methodology and Exposures

1. Storage

Storage facilities consist of closed storage vessels, including pressure, fixed-roof, floating-roof, and conservation tanks. Ordinary fixed-roof tanks store less volatile petroleum products, whereas floating-roof tanks are most commonly used to store gasoline and benzene. Diagrams of several of these tanks are shown in Appendix A.

Emissions of benzene from storage in a floating-roof tank occur primarily from standing and withdrawal (wetting) losses. Fixed-roof tanks have "breathing" losses caused by expansion and contraction of the vapors due to diurnal changes in atmospheric temperature. Because of the low volume of gasoline and benzene stored in fixed-roof tanks, breathing losses are not considered to be a significant source of atmospheric benzene.

Limited data have been reported on benzene exposures adjacent to storage facilities. A survey of industry reported an average of 375 ppm of benzene measured next to the sampling port on top of a benzene storage tank (Young, 1976).

Standing emissions are caused by improper fit of the seal and shoe to the vessel shell. Small losses also occur when vapor escapes between the flexible membrane seal and the roof. Withdrawal or wetting losses are caused by evaporation from the tank walls as the roof descends during emptying operations (PEDCo, 1977).

Emission factors of benzene as a result of these losses were recently estimated by PEDCo (1977, p. 4-65) as follows:

<u>Storage</u>	<u>Emission Factor (kg/m³)</u>
Gasoline	
Standing losses	3.3×10^{-5}
Withdrawal losses	<u>2.6×10^{-5}</u>
Total	5.9×10^{-5}
Benzene	
Standing losses	1.3×10^{-5}
Withdrawal losses	<u>8.6×10^{-4}</u>
Total	8.7×10^{-4}

Benzene storage tanks are located near the producers and users of the chemical and the exposure estimates for those locations have been determined in Sections III, IV, and VII. The very small emissions related to storage losses are insignificant when compared with production emissions.

Gasoline bulk storage terminals, however, are generally near urban demand centers, commonly in highly industrialized areas or on the city periphery where population density is low.

Rough ambient benzene concentration estimates for the vicinity of storage sites can be based on the emission factors, assumed storage volumes, and the dispersion modeling results discussed in Chapter IV. An average gasoline storage terminal is assumed to have the following characteristics: average tank size, $8.7 \times 10^3 \text{ m}^3$; 30-day retention time; 10 gasoline storage tanks of average size; and facility size, 0.25 km^2 . The emission rate is calculated as follows:

$$\begin{aligned} (\text{emission factor}) \times (\text{tank volume}) \times (\text{number of tanks}) &= (\text{emission rate}) \\ \text{that is, } (5.9 \times 10^{-5} \text{ kg/m}^3) (8.7 \times 10^3 \text{ m}^3) (10) &= 5.13 \text{ kg/30 days} \\ &= 62 \text{ kg/yr} \\ &= 1.97 \times 10^{-3} \text{ g/s} \end{aligned}$$

The ambient benzene concentrations can be estimated from the dispersion modeling calculations of Youngblood (1977c) that assume uniform emissions throughout the terminal area. By applying the estimated emission rate to the results presented in Table IV-4 (Chapter IV) for the indicated terminal area of 0.25 km^2 , the following estimate can be made:

8-hr Worst-Case Exposure Levels at 300 m

$$\left(\frac{1.97 \times 10^{-3} \text{ g/s}}{100 \text{ g/s}} \right) \left(\frac{900 \text{ } \mu\text{g/m}^3}{3.2 \text{ } \mu\text{g/m}^3 \text{ ppb}} \right) \ll 0.1 \text{ ppb}$$

Therefore, annual average and 8-hr worst-case concentrations within 300 m of the site are well below the detectable level of 0.1 ppb. From this analysis, it appears that the number of people exposed to ambient benzene concentrations in the vicinity of gasoline storage terminals is negligible.

2. Distribution Systems

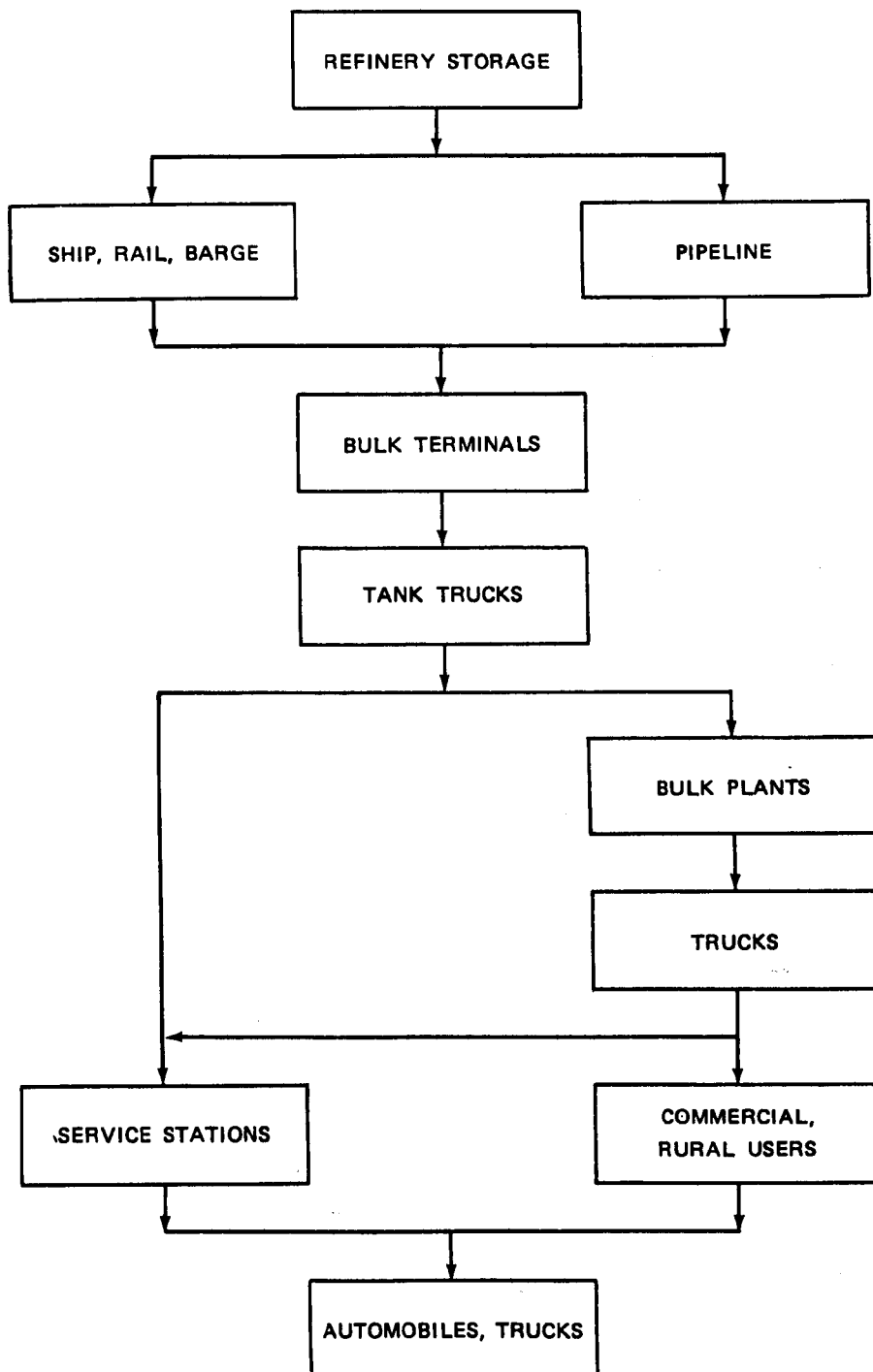
The gasoline distribution system involving transport from the

petroleum refineries to the consumer may also be a significant source of atmospheric benzene. The benzene distribution system, on the other hand, involves much lower quantities and transfers at manufacturing and consuming facilities. Because they have already been evaluated, benzene distribution systems will not be considered in this chapter.

The U.S. gasoline distribution system is illustrated in Figure VIII-1. Bulk terminals represent intermediate stations set up to serve near-source regional markets. Gasoline at bulk terminals is transferred directly from refinery by ships, rail tank cars, barges, and pipelines. Bulk plants, on the other hand, are designed for local markets and their supplies are distributed by tank trucks. Service stations that fuel public motor vehicles are supplied by tank trucks from either bulk terminals or bulk plants. Privately owned commercial operations, such as those providing fuel for vehicles of a company fleet, are generally supplied by tank trucks from an intermediate bulk installation.

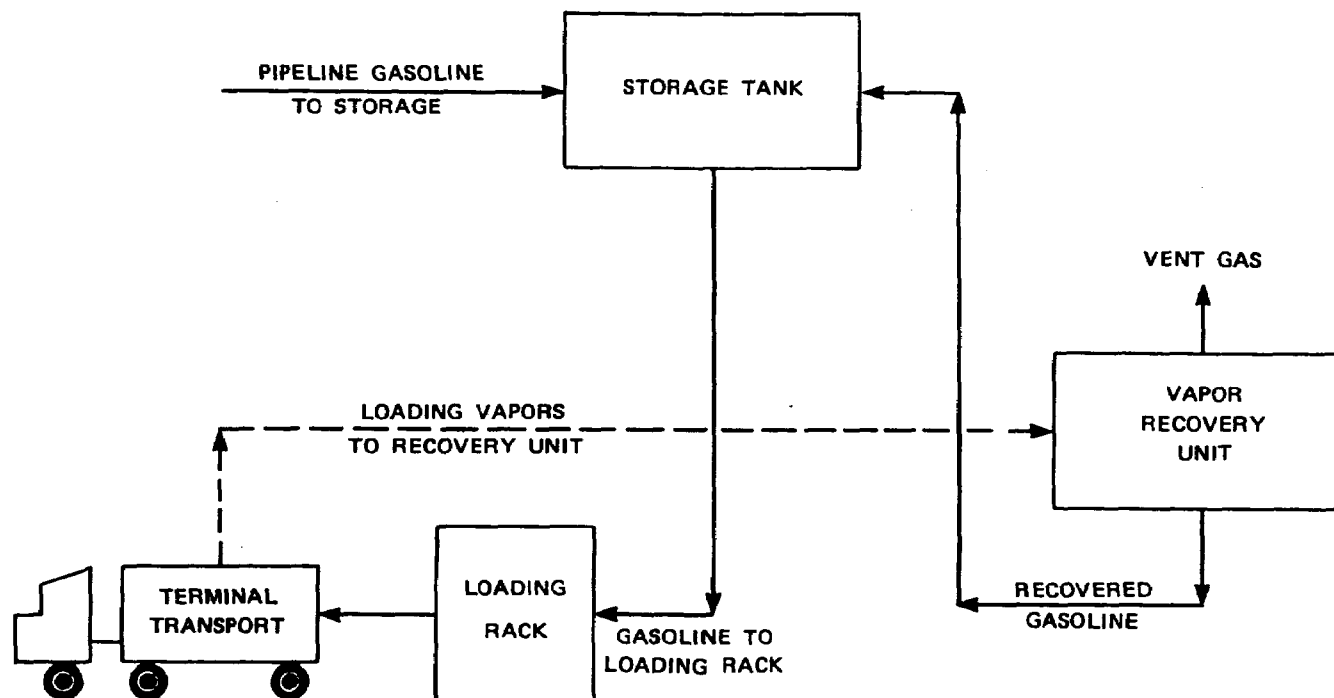
Most of the emissions take place during transfers of the gasoline to tanks and tank trucks. These losses occur at a rate directly proportional to the amount of gasoline passing through the particular location. Because many tank trucks are filled with one bulk terminal or plant, benzene emissions from that procedure are potentially much greater. As empty tank trucks are filled, hydrocarbons in the vapor space are displaced to the atmosphere unless vapor collection facilities have been provided. The quantity of hydrocarbons contained in the displaced vapors depends on the vapor pressure, temperature, method of tank filling, and conditions under which the truck was previously loaded. Figure VIII-2 is a schematic drawing of liquid and vapor flow through a typical bulk terminal.

All monitoring data collected to date have concerned possible occupational exposures. Measurements at several bulk loading operations in Britain showed ambient benzene concentrations ranging from 0.1 to 7.7 ppm (NIOSH, 1974). In the same study, NIOSH also evaluated worker exposure during loading and weighing of rail tankers with gasoline



SOURCE: PEDCo, 1977

FIGURE VIII-1. THE GASOLINE MARKETING DISTRIBUTION SYSTEM IN THE UNITED STATES



SOURCE: PEDCo, 1977

FIGURE VIII-2. VAPOR AND LIQUID FLOW IN A TYPICAL BULK TERMINAL (Floating-Roof Tank)

from storage tanks. An exposure equivalent to 14 ppm over an 8-hr workday was estimated. Thus, environmental exposure to benzene from gasoline distribution systems appears to require some evaluation.

Gasoline is loaded from storage tanks to transport trucks (tank cars) by two basic methods: top loading and bottom loading (PEDCo, 1977). Top loading can be done by splash fill or submerged fill. The former method involves free fall of gasoline droplets and thus promotes evaporation and possibly liquid entrainment of these droplets in the expelled vapors. In subsurface or submerged filling, the gasoline is introduced below the liquid surface in the tank. Bottom loading of gasoline is comparable to submerged top loading.

Vapor recovery systems are designed to reduce the overall hydrocarbon emission losses (including benzene) for both loading and unloading. For bottom loading, the vapor recovery system may achieve 100% efficiency (PEDCo, 1977). Although it is difficult to quantify, vapor collection for top loading is generally not so efficient as that for bottom loading. An overall 95% efficiency of vapor recovery and containment can be assumed for both loading and unloading (PEDCo, 1977, p. 4-60).

Rough ambient benzene concentrations estimates related to gasoline distribution can be based on emission factors, assumed transfer volumes, and the dispersion modeling results discussed in Chapter III. Emission factors related to the loading and unloading of gasoline were estimated by PEDCo (1977, p. 4-65). A gasoline bulk storage terminal of the same characteristics as described in the previous section is assumed. In addition, continuous loading and unloading operations are assumed over an 8-hr work day. Average retention time for each tank is 30 days. The emission rate is calculated as follows:

Loading of Storage Tanks

(Emission factor) x (Volume Pumped/Day) x (# of Tanks) = Emission Rate
that is,

$$\begin{aligned} (1.1 \times 10^{-4} \text{ kg/m}^3) (8.7 \times 10^3 \text{ m}^3/30 \text{ days})(10) &= 3.2 \times 10^{-1} \text{ kg/day} \\ &= 1.1 \times 10^{-2} \text{ g/s} \end{aligned}$$

Unloading of Storage Tanks

$$(1.1 \times 10^{-5} \text{ kg/m}^3) (8.7 \times 10^3 \text{ m}^3/30 \text{ days}) (10) = 3.2 \times 10^{-2} \text{ kg/day} \\ = 1.1 \times 10^{-3} \text{ g/s}$$

$$\text{Total emission rate} = 1.2 \times 10^{-2} \text{ g/s}$$

The ambient benzene concentration can be estimated from the dispersion modeling calculation of Youngblood (1977b) by assuming ground-level point source emissions (Curve A). When the estimated emission rate is applied to the results presented in Table III-4 (p. III-10), the following estimate can be made:

8-hr Worst-Case Exposure Levels at 300 m

$$\left(\frac{1.2 \times 10^{-2} \text{ g/s}}{100 \text{ g/s}} \right) \left(\frac{14,000 \mu\text{g/m}^3}{3.2 \frac{\mu\text{g/m}^3}{\text{ppb}}} \right) = 0.5 \text{ ppb}$$

$$\text{Approximate annual average concentration} = 0.05 \text{ ppb}$$

From this analysis, it appears that annual average concentrations, which result from loading and unloading gasoline, are generally below 0.1 ppb within 300 m of a bulk storage terminal. Concentrations may be higher in some cases if a large volume of gasoline (larger than the average value used in this analysis-- $2.9 \times 10^3 \text{ m}^3/\text{day}$ loaded and unloaded) is loaded and unloaded during one 8-hr period. Thus, although occupational exposures may be high, exposures to the general public are considered to be minimal.

IX URBAN EXPOSURES RELATED TO AUTOMOBILE EMISSIONS

A. Sources

Urban exposures to benzene come from many sources, including chemical manufacturing plants, automobile exhaust, gasoline service stations, gasoline evaporation, and losses through transportation and storage of benzene and gasoline. However, benzene is not routinely monitored in the ambient air, and few sampling data exist. A study by Altshuller (1969) estimated normal benzene concentrations at between 10 and 50 ppb. These concentrations appear to be quite high, however, when they are compared with other benzene sources discussed previously. A study of atmospheric benzene and toluene levels in Toronto found a maximum concentration of 98 ppb with an average concentration of 13 ppb (Pilar and Graydon, 1973). That study concluded that benzene contamination of the air was related to automobile emissions based on three factors: (1) the ratio of benzene to toluene, (2) the presence of distinct peak periods for both hydrocarbons at rush hour periods, and (3) the relative concentrations detected at various sampling stations.

To determine average urban exposures throughout the United States it is necessary to restrict the analysis. Although substantial variation from one urban area to another occurs, it is nonetheless possible to determine a reasonable order-of-magnitude estimate of exposures related to two definitive sources: emission from tailpipes, and evaporation from gasoline tanks. This analysis does not estimate urban exposures per se, but does analyze possible ambient conditions related to automobile emissions.

As previously discussed, the benzene content in gasolines varies widely, with an average of approximately 1.24% by liquid volume. In addition, catalytic converters on automobiles can reduce benzene in vehicle exhaust by 30 to 80% (Johnson, personal communication 1977). Thus, evaporation

from gasoline and emissions from vehicle exhaust will also vary substantially. Dispersion modeling of these sources has been conducted by EPA. In the Hanna-Gifford dispersion model used by Schewe of EPA (1977) concentration depends on areawide emissions and wind speed. An empirical factor is also applied. By applying generalized emission factors, areawide emissions were estimated from vehicle miles traveled (the total number of miles traveled in a given area in a year) and from the number of registered automobiles. Table IX-1 presents the results of this study. In central cities, the concentrations range from 1.0 ppb to 4.0 ppb, whereas in suburban areas the concentrations are generally below 1.0 ppb.

B. Methodology and Exposures

Limited data are available concerning urban exposures from automobile emissions. Consequently, it is difficult to develop accurate techniques to predict benzene levels in urban areas. Uncertainties include: benzene content in gasoline; control technology; deterioration of the control technology over time; and dispersion characteristics of benzene under variable meteorological conditions. Thus, a simplified model is employed to provide general estimates of ambient concentrations.

The Hanna-Gifford dispersion model (Gifford and Hanna, 1973) as applied by Schewe (1977) is used for this analysis. Inputs to the model include: number of vehicle registrations, total number of vehicle miles traveled (VMT), area size, and average annual wind speed.

The tailpipe emissions are estimated by the following equation (Schewe, 1977):

$$Q_{\text{tail}} (\text{g/s-m}^2) = \frac{0.22 \text{ g}}{\text{mile}} \frac{\text{VMT}}{\text{s}} \frac{1}{\text{Area of study (m}^2\text{)}} \quad (9.1)$$

The emission factor of 0.22 g benzene per mile is a composite emission factor for 1976 (Schewe, 1977).

The evaporative emissions are calculated as follows:

$$Q_{\text{evap}} (\text{g/s-m}^2) = \frac{0.148 \text{ g}}{\text{trip}} \frac{3.3 \text{ trips}}{\text{veh.-day}} \frac{\text{\#veh.}}{1} \frac{365 \text{ days}}{\text{year}} \frac{\text{year}}{3.154 \times 10^7 \text{ s}} \frac{1}{\text{area}} \quad (9.2)$$

Table IX-1

ESTIMATES OF ANNUAL AVERAGE BENZENE CONCENTRATIONS
IN FOUR URBAN AREAS

City	10^9 Vehicle Miles Traveled	Registered Automobiles	Land Area (10^8 m ²)	Q_{evap} (10^{-9} g/s m ²)	Q_{tail} (10^{-9} g/s m ²)	Q_T (10^{-9} g/s m ²)	Average Annual Wind Speed (m/s)	Benzene Concentration ($\mu\text{g}/\text{m}^3$)	Benzene Concentration (ppb)
Dallas									
City	6.14	619,684	6.9	5.08	62.2	67.3	5	3.03	.95
Suburbs	5.36	540,786	43.0	.719	8.80	9.52		0.43	.13
Los Angeles									
City	10.2	2,044,203	12.0	9.63	59.3	68.9	2	7.75	2.4
Suburbs	21.5	4,299,073	54.0	4.53	28.0	32.5		3.66	1.1
St. Louis									
City	2.86	378,280	1.6	13.5	126.0	140.0	4	7.88	2.5
Suburbs	7.71	1,020,219	61.0	.944	8.80	9.74		0.55	.17
Chicago									
City	18.8	1,860,292	5.8	18.2	227.0	245.0	4	13.78	4.3
Suburbs	23.5	2,327,206	88.0	1.49	18.6	20.1		1.13	.35

* 1976 projections

Q_{evap} = Evaporative emissions from automobiles.

Q_{tail} = Tailpipe emissions from automobiles.

Q_T = Total automobile emissions

Source: Schewe, 1977

By multiplying the constants in this equation we get the following:

$$Q_{\text{evap}} (\text{g/s-m}^2) = \frac{5.653 \times 10^{-6} \text{ g}}{\text{veh. s}} \frac{\# \text{ veh.}}{\text{area of study (m}^2\text{)}} \quad (9.3)$$

This technique assumes that each vehicle emits 0.148 g of benzene per trip and that the average vehicle travels 3.3 trips per day (Schewe, 1977).

The total emissions for automobiles can be expressed as follows:

$$Q_T = Q_{\text{tail}} + Q_{\text{evap}} \quad (9.4)$$

Equation (9.4) is essentially the summation of Equations (9.1) and (9.3).

To calculate the average annual areawide benzene concentration, Equation (9.5) is used:

$$\chi_A = \frac{225 Q_T}{u (\text{m/s})} \quad (9.5)$$

The average annual wind speed, u , in the area of study was obtained from Figure IX-1. Because wind speed (and thus dispersion) increases in the afternoon, the morning values were used to estimate higher concentrations. The number 225 is an empirical factor derived from several studies that gave very good results for long-term averages; it applies to light-duty vehicles such as passenger cars.

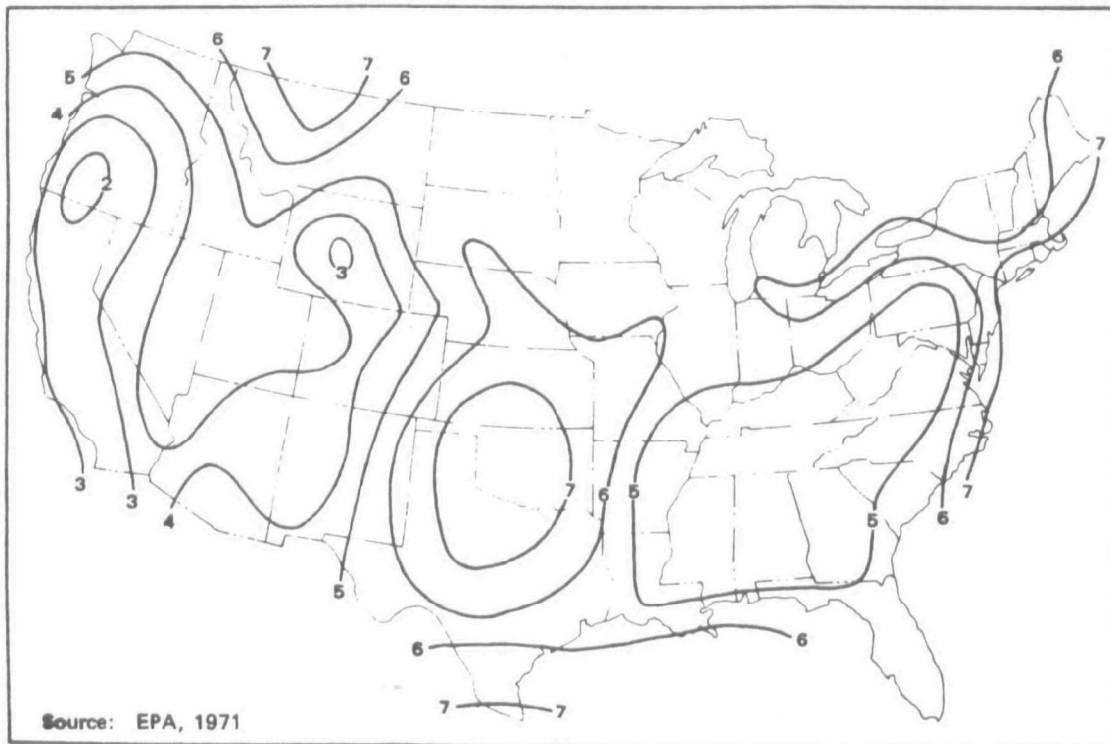


FIGURE IX-1. ISOPLETHS (m/sec) OF MEAN ANNUAL WIND SPEED THROUGH THE MORNING MIXING LAYER

Because of the general unavailability of 1976 data for all urban areas, 1973 data were used as much as possible in this estimation. Comparisons of 1973 with 1976 data indicated that the change was less than 3% and had a negligible effect on the final results. The following data sources were used:

- 1973 Standard Metropolitan Statistical Area (SMSA) and county populations--U.S. Bureau of the Census, 1976, Series P-25, No. 618.
- 1973 SMSA and county automobile registrations--U.S. Department of Transportation, Federal Highway Administration, 1974, Table MV-21.
- Average annual vehicle miles traveled by size of SMSA--Federal Highway Administration, 1972, Nationwide Personal Transportation Study, Report No. 2, Table 9.
- Average annual wind speed--EPA, 1972, Publication No. AP-101.
- SMSA, county and city land areas--Bureau of the Census, 1972 County and City Data Book.

A detailed analysis was conducted for the six largest cities in the U.S. (populations of more than 1 million). Table IX-2 presents the results. Because input data were slightly different, the results differ somewhat from those shown in Table IX-1. For example, the suburban area used in this estimate may include a larger area than that used in the Schewe estimates. Suburban areas are defined as those areas outside the central city but within the SMSA. Because no VMT and registration data were available at the city level, they were extrapolated either from SMSA data or county data and were based on the fraction of the population residing in each area. The results show that the estimated benzene concentrations in city and suburban areas range from 0.7 to 2.7 ppb and 0.2 and 1.5 ppb, respectively. The composite benzene concentrations in the six corresponding SMSAs ranged from 0.5 to 2.0 ppb.

It is expected that people living in urban areas are exposed to higher levels of benzene from automotive emissions than those living in rural areas. Consequently, our approach was designed to maximize the urban population considered in the analysis. Although 43% of the total urban population resides in central cities (as defined by the Bureau of the Census), 83% of the total urban population resides in SMSAs. Thus, a greater

Table IX-2

ESTIMATES OF AVERAGE ANNUAL BENZENE CONCENTRATIONS
FOR CITIES WITH POPULATIONS EXCEEDING 1,000,000

City	SMSA Population 10^3	City Population 10^3	City Area 10^9 m^2	Automobile Registration	VMT/ vehicle 10^3	VMT 10^{10}	u (m/s)	Q_{tail} 10^{-7} g/s-m ²	Q_{evap} 10^{-8} g/s-m ²	Q_{T} 10^{-7} g/s-m ²	Benzene Concentration			
											Central $\mu\text{g}/\text{m}^3$	City ppb	Suburban ppb	Composite ppb
Chicago	6,999.8	3,173	0.57	1,324,171	11.5	1.5	5	1.8	1.3	1.9	8.6	2.7	1.1	1.9
Detroit	4,446.3	1,387	0.35	675,065	11.5	0.77	6	1.5	1.0	1.6	6.0	1.8	1.2	1.5
Houston	2,163.4	1,320	1.1	701,766	14.0	0.98	6	0.63	0.36	0.66	2.5	0.7	0.23	0.5
Los Angeles	6,938.3	2,747	1.2	1,490,483	11.5	1.7	3	0.98	0.67	1.0	7.5	2.3	0.4	1.3
New York	9,746.4	7,647	0.77	1,707,891	11.5	1.9	7	1.7	1.2	1.8	5.9	1.8	0.3	1.0
Philadelphia	4,826.3	1,862	0.33	944,660	11.5	1.0	6	2.0	1.5	2.1	8.0	2.5	1.5	2.0

Source: SRI estimates based on Hanna-Gifford model as applied by Schewe (1977);
data sources listed in text.

percentage of the urban population is captured by using SMSAs as study areas. The six largest cities are in SMSAs with more than 2 million population. To analyze the remaining SMSAs, the following population size categories were employed (U.S. Bureau of the Census, 1976, Series P-25, No. 618):

<u>SMSA Population Size Category</u>	<u>Number of Areas</u>
2,000,000 or more	15
1,000,000 - 2,000,000	20
500,000 - 1,000,000	37
250,000 - 500,000	63
less than 250,000	124

SMSA composite benzene concentrations were estimated for seven areas that represent four population size categories (see Table IX-3). For SMSAs with population exceeding 500,000, the composite average annual benzene concentrations ranged between 0.1 and 0.4 ppb. However, SMSAs of less than 500,000 were below 0.1 ppb. It may be assumed from this analysis that the SMSAs with population less than 500,000 have average annual benzene concentrations less than 0.1 ppb.

The estimates of urban exposures from automobile emissions are order-of-magnitude estimates that are based on a simple dispersion model. Note that, in certain locations and under certain meteorological conditions, benzene concentrations may be a factor of 10 higher than those listed. In addition, central city areas (as shown in Table IX-2) may have consistently higher levels than surrounding areas because of traffic density, frequency of intersections, and street density. Because the model only includes automobile emissions, areas with substantial commercial or bus transportation may have higher levels than estimated. Also, the model is extremely sensitive to area size as Table IX-2 indicates. Thus, composite SMSA benzene concentrations provide the most reasonable estimate of the average annual exposures for an urbanized area.

The total estimated urban population exposed to benzene in concentrations greater than 0.1 ppb from automobile emissions is shown in Table IX-4. The 1974 SMSA populations for Chicago, Detroit, Los Angeles,

Table IX-3

ESTIMATES OF AVERAGE ANNUAL BENZENE CONCENTRATIONS FOR SELECTED SMSAs

SMSA	Population	Area (m ²)	Automobile Registration	VTM/ vehicle 10 ³	VTM 10 ⁹	u m/s	Q _{tail} 10 ⁻⁹ g/s-m ²	Q _{evap} 10 ⁻¹⁰ g/s-m ²	Q _{T-9} 10 ⁻⁹ g/s-m ²	Benzene Concentration	
										μg/m ²	ppb
<u>SMSAs</u>	<u>>2,000,000</u>										
Pittsburgh	2,333,600	7.8 x 10 ⁹	2,358,600	11.3	26.0	5	23.0	17.0	25.0	1.1	.4
San Francisco	3,135,900	6.2 x 10 ⁹	688,300	11.5	7.7	3	8.5	6.2	9.1	.68	.2
<u>SMSAs</u>	<u>1,000,000 - 2,000,000</u>										
Columbus	1,055,900	6.2 x 10 ⁹	567,803	11.3	6.4	5	7.2	5.1	7.8	.35	.1
Milwaukee	1,423,200	3.7 x 10 ⁹	642,531	11.3	7.2	5	13.0	9.8	14.0	.62	.2
<u>SMSAs</u>	<u>500,000 - 1,000,000</u>										
Sacramento	851,300	8.7 x 10 ⁹	439,803	11.3	4.9	3	3.9	2.8	4.2	0.3	0.1
Providence- Warwick- Pawtucket	854,400	2.4 x 10 ⁹	869,100	11.3	9.8	7	28.0	20.0	30.0	0.9	0.3
<u>SMSAs</u>	<u>250,000 - 500,000</u>										
Wichita	375,600	6.2 x 10 ⁹	221,715	10.3	2.3	7	2.5	2.0	2.7	.08	<0.1
Harrisburg	425,500	4.1 x 10 ⁹	198,997	10.3	2.0	5	3.4	2.7	3.7	.16	<0.1

Source: SRI estimates using Hanna-Gifford dispersion model
as applied by Schewe (1977).

New York, and Philadelphia were summed to estimate the population exposed to average annual benzene concentrations of 1.1 to 2.0 ppb. The 1974 SMSA population of Houston plus the remainder residing in SMSAs with populations greater than 500,000 were summed to estimate the total population exposed to average annual benzene concentrations between 0.1 and 1.0 ppb. The results indicate that 114 million people, or 73% of the total SMSA population, are exposed to average annual benzene concentrations greater than 0.1 ppb.

Table IX-4

URBAN POPULATION EXPOSURES RELATED TO AUTOMOTIVE EMISSIONS

Source	Annual Average Benzene Concentration (ppb)*		Total
	0.1 - 1.0	1.1 - 2.0	
Automotive Emissions	68,337,000	45,353,000	113,690,000

*To convert to $\mu\text{g}/\text{m}^3$, multiply concentrations by 3.2.

Source: SRI estimates

BIBLIOGRAPHY

Applied Urbanetics, Inc. "Market Share Study," FEA Contract No. CO-06-60435, 200 pp. (1976).

Altshuller, A.P., and J.J. Bafalini, "Photochemical Aspects of Air Pollution: A Review," Environ. Sci. Technol., Vol. 5, No. 39 (1971).

Anderson, E. V., "Output of the Top 50 Chemical Drops Sharply," in Chemical and Engineering News, pp. 34-37, May (1976).

Arthur D. Little, Inc. "Technology Assessment and Economic Impact Study of an OSHA Regulation for Benzene," in U.S. Department of Labor, OSHA, Benzene, Volume I, Washington, D.C. (1977a).

_____, "Self-Serve Market Shares in Four Metropolitan Areas," memo to Richard J. Johnson, EPA, from E. Quakenbush and P. E. Mawn, June (1977b).

Ayers, G. W., and R. E. Muder, "Benzene," in Kirk-Othmer Encyclopedia of Chemical Technology, A. Stanton (Ed.), 2nd Edition, John Wiley and Sons, Inc., New York, Vol. 3, pp. 367-401 (1964).

Battelle-Columbus Laboratories, letter to Richard J. Johnson (Office of Air Quality Planning and Standards, EPA, Research Triangle Park), from C. W. Townley, concerning "Results of Self-Service Exposure Samples," May (1977).

_____, letter to Richard J. Johnson (EPA), from G. W. Kinzer, concerning "Results of Sampling in the Vicinity of Gasoline Service Stations," June (1977b).

Brinkerhoff, G., Compliance, Occupational Safety and Health Administration, personal communication, June (1977).

Chien, J.C.W., "On the Possible Initiation of Photooxidation of Charge-Transfer Excitation," J. Phys. Chem., Vol. 69, No. 12, pp. 4317-4325 (1969).

Chinn, Dr. H., Federation of American Societies for Experimental Biology Bethesda, Maryland, personal communication, August (1977).

Dickerman, J.C., T.D. Raye, and J.D. Colley, "The Petroleum Industry," Radian Corp., Austin, Texas (1975).

- Faith, W. L., D. B. Keyes, and R. L. Clark, Industrial Chemicals, 3rd Edition, John Wiley and Sons, Inc., New York (1966).
- Giacomelli, A. and M. Spinetti, "Salt Effects on the Activity of Benzene in Aqueous Solutions," Gazz. Chim. Ital., Vol. 102, No. 11, pp. 965-973 (1972).
- Gifford, F. A., and S. R. Hanna, "Technical Note: Monitoring Urban Air Pollution," in Atmospheric Environment, Pergamon Press, Vol. 7, pp. 131-136 (1973).
- Hardel, Richard, National Institute for Occupational Safety and Health, personal communication (1977).
- Hustvedt, K. C., Office of Air Quality Planning and Standards, Emission Standards and Engineering Division, U.S. Environmental Protection Agency, personal communications (1977a,b).
- Howard, P. H., and P. R. Durkin, "Sources of Contamination Ambient Levels, and Fate of Benzene in the Environment," EPA 560/5-75-005 (1974).
- Johnson, Richard J., Office of Air Quality Planning and Standards, Strategies and Air Standards Division, U.S. Environmental Protection Agency, personal communications (1977).
- Kaplan, L., L. A. Wendling, K. E. Wilzback, "Photooxidation of Aqueous Benzene, I. Identification of the Product as 1,3-Cyclopentadiene-1-Carboxaldehyde," J. Amer. Chem. Soc., Vol. 93, No. 15, pp-3819-3820 (1971).
- Laity, J. L., I. G. Burstein, B. R. Appel, "Photochemical Smog and the Atmospheric Reactions of Solvents," in Solvent Theory and Practice, Advances in Chemistry Series, No. 124, Amer. Chem. Soc., Washington, D.C., pp. 95-112 (1973).
- Lee, C. C. W. K. Craig, P. J. Smith, "Water Soluble Hydrocarbons from Crude Oil," Bull. Environ. Contam. Toxicol., Vol. 12, No. 2, pp. 212-217 (1974).
- Luria, M. and G. Stein, "The Photoproduct of Benzene in Oxygenated Aqueous Solution," J. Chem. Soc., p. 1650 (1970).
- MacKenzie, C. A., Unified Organic Chemistry, Harper and Row, New York, pp. 91-97 (1962).
- Matsuura, T. and K. Omura, "Photochemical Hydroxylation of Aromatic Compounds," Synthesis, Vol. 3, pp. 73-184 (1974).
- McAuliffe, C., "Solubility in Water of C₁ to C₉ Hydrocarbons," Nature, Vol. 200, No. 4911, pp. 1092-1093 (1963).
- McGannon, H. E. (Ed.), The Making, Shaping, and Treating of Steel, 9th Edition, U.S. Steel, Pittsburgh, pp. 104-177 (1970).

- Mitre Corporation, "Air Pollution Assessment of Benzene," Contract No. EPA-68-02-1495 (1976).
- National Cancer Institute, "On Occurrence, Metabolism, and Toxicity Including Reported Carcinogenicity of Benzene, Summary Report," Washington, D.C. (1977).
- National Institute for Occupational Safety and Health, "Criteria for a Recommended Standard Occupational Exposure to Benzene," NIOSH 74-137, (1974).
- Neely, W. B., D. R. Branson, and G. E. Blau, "Partition Coefficient to Measure Bioconcentration Potential of Organic Chemicals in Fish," Env. Sci. Techn., Vol. 8., No. 13, p. 1113 (1974).
- Noyes, W. A., W. A. Mulac and D. A. Harter, "Some Aspects of the Photochemistry of Benzene," J. Chem. Phys., Vol. 44, No. 5, pp. 2100-2106 (1966).
- PEDCo Environmental, "Atmospheric Benzene Emissions," prepared for U.S. Environmental Protection Agency, Research Triangle Park (1977).
- Pilar, S. and W. F. Graydon, "Benzene and Toluene Distribution in the Toronto Atmosphere," in Environ. Sci., Techn., Vol. 7, No. 7, pp. 628-631 (1973).
- Radian Corporation, "A Study of Vapor Control Methods for Gasoline Marketing Operations: Volume I--Industry Survey and Control Techniques," EPA-450/3-75-046-916, U.S. Environmental Protection Agency (1975).
- Runion, H. E., "Benzene in Gasoline," in Amer. Indus. Hygiene Assoc. Jr., Vol. 36, pp. 338-350 (1975).
- _____, "Benzene in Gasoline II, in International Workshop on Benzene, Paris, 9 p. (1976).
- Schewe, George J., Monitoring and Data Analysis Division, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, memos to Richard J. Johnson, Strategies and Air Standards Division, U.S. Environmental Protection Agency, concerning "Estimates of the Impact of Benzene from Automotive Sources," of June 20, August 9, August 12 (1977).
- Sheridan, E. T., "Supply and Demand for United States Coking Coals and Metallurgical Coke," U.S. Department of the Interior, Washington, D.C. (1976).
- Stanton, A. (ed.), Kirk-Othmer Encyclopedia of Chemical Technology, 2nd Edition, John Wiley and Sons, Inc., New York (1964).

Stephens, E. R., "Hydrocarbons in Polluted Air, " Summary Report, Coordinating Research Council Project CAPA-5-68, Statewide Air Pollution Research Center, University of California, Riverside, NTIS PB 230-993 (1973).

Suta, Benjamin E., "Human Population Exposures to Coke-Oven Atmospheric Emissions," SRI International, Menlo Park, CA (1977).

Sulton, C., and J. A. Calder, "Solubility of Higher Molecular Weight n-Paraffins in Distilled Water and Sea Water," Environ. Sci. Techn., Vol. 8, No. 654 (1974).

Turner, D. B., and W. B. Petersen, "A Gaussian-Plume Algorithm for Point, Area, and Line Sources," in Proc. of the 6th Int. Techn. Meeting on Air Pollution Modeling and its Application, NATO/CCMS, No. 42, pp. 185-228 (1975).

U.S. Department of Commerce, Bureau of the Census, "Population Estimates and Projections," Series P-25, No. 618, Washington, D.C. (1976).

_____, "1972 County and City Data Book," Washington, D.C. (1973).

_____, "Statistical Abstract of the United States," Washington, D.C. (1975).

_____, "1972 Census of Manufacturers," Washington, D.C. (1973).

U.S. Department of Commerce, Bureau of Economic Analysis, "Projections of Economic Activity for Air Quality Control Regulations," NTIS PB-259-870 (1973).

U.S. Department of Transportation, Federal Highway Administration, "Annual Miles of Automobile Travel," in Nationwide Personal Transportation Study, Report No. 2, 32 p. (1972).

_____, "Highway Statistics," Washington, D.C. (1974).

_____, "Motor Vehicle Registrations by Standard Metropolitan Statistical Areas," Table MV-21 (1974).

U.S. Environmental Protection Agency, "Mixing Heights, Wind Speeds, and Potential for Urban Area Pollution Throughout the Contiguous United States," in Publ. No. AP-101, Office of Air Programs, Research Triangle Park (1972).

_____, "Compilation of Air Pollution Emission Factors," 2nd Edition, Publ. No. AP-42, Research Triangle Park (1976).

U.S. Public Health Service, "Control Techniques for Carbon Monoxide, Nitrogen Oxide, and Hydrocarbon Emissions from Mobile Sources," Publ. No. AP-66, Washington, D.C. (1970).

Young, R., National Institute for Occupational Safety and Health, Cincinnati, Ohio (1976).

Youngblood, Phillip L., Monitoring and Data Analysis Division, U.S. Environmental Protection Agency, memo to Richard J. Johnson, Strategies and Air Standards Division, U.S. Environmental Protection Agency, concerning "Rough Estimates of Ambient Impact of Various Benzene Sources from Chemical Manufacturing Facilities," May 5 (1977a).

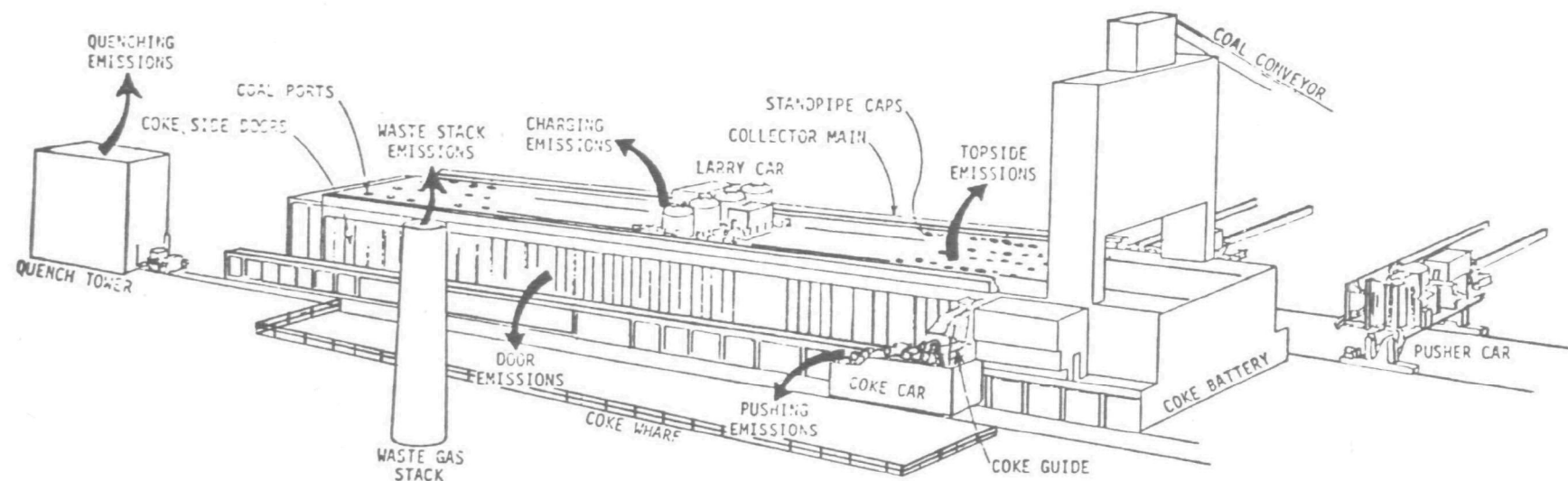
_____, memo to Richard J. Johnson, Strategies and Air Standards Division, U.S. Environmental Protection Agency, concerning "Use of Dispersion Calculations in Determining Population Exposures to Benzene From Chemical Plants," September 20 (1977b).

_____, memo to Richard J. Johnson, Strategies and Air Standards Division, U.S. Environmental Protection Agency, concerning "Population Exposures to Benzene from Petroleum Refineries and Large Coking Plants," September 21 (1977c).

_____, memo to Richard J. Johnson, Strategies and Air Standards Division, U.S. Environmental Protection Agency, concerning "Ambient Impact of Evaporative Benzene from Service Stations," February 17 (1977d).

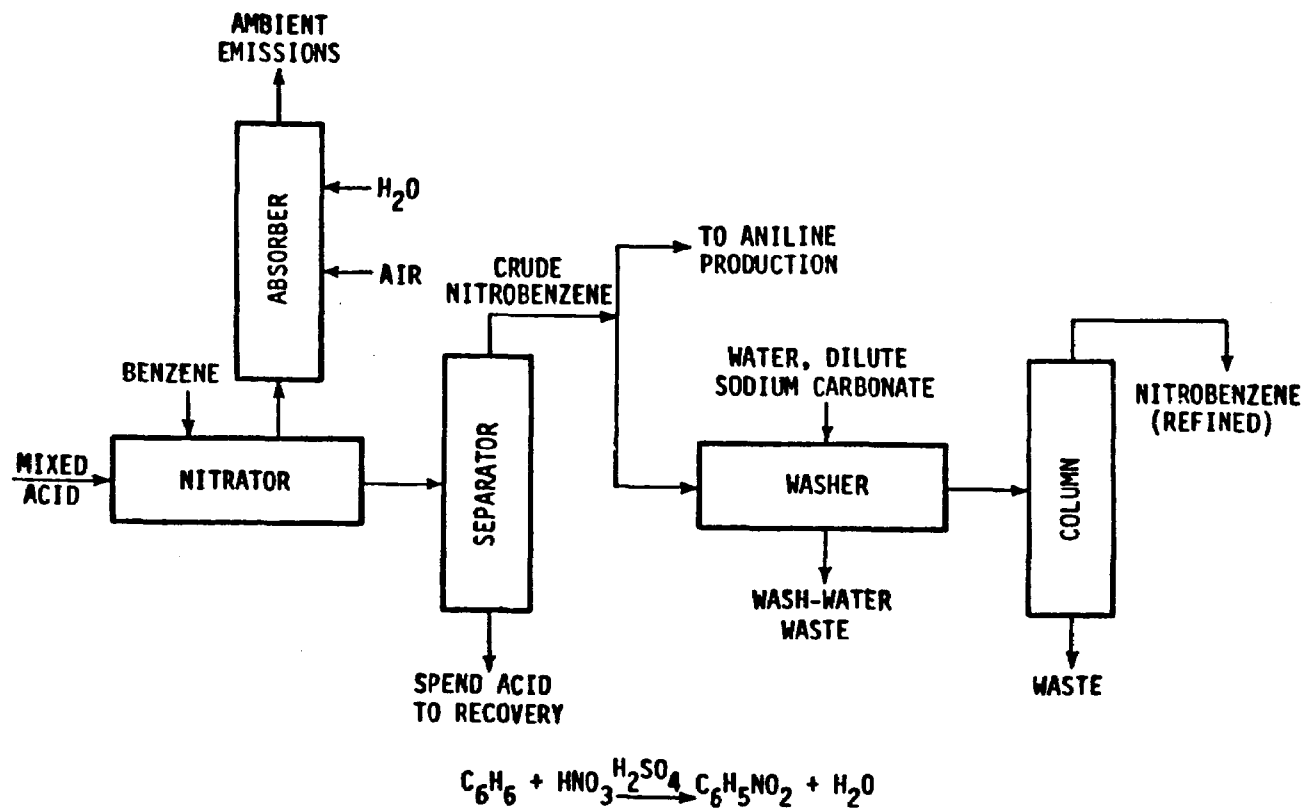
APPENDIX A

Diagrams of Various Benzene-Related Operations



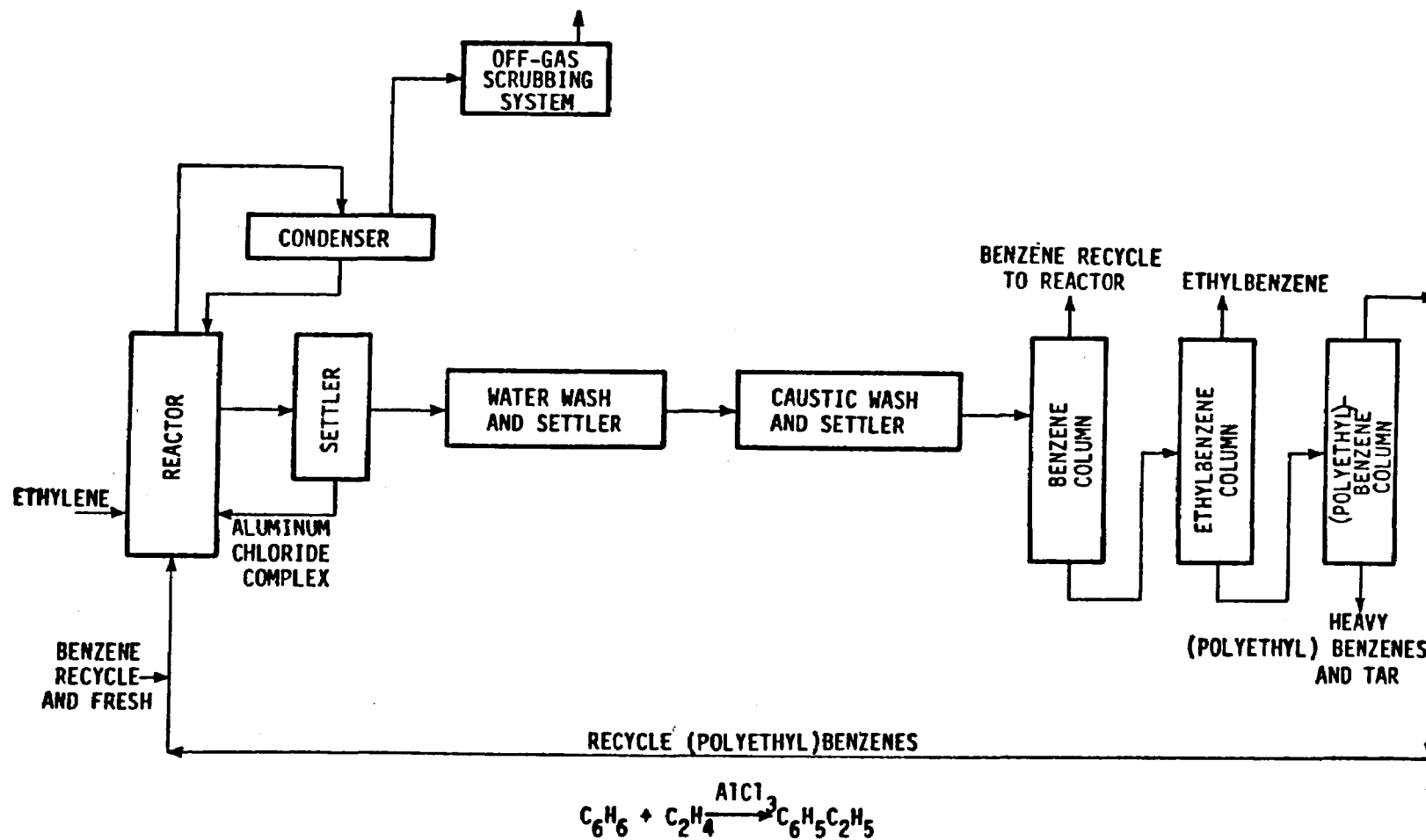
Source: PEDCo, 1977

FIGURE A-1. SCHEMATIC DIAGRAM OF BY-PRODUCT COKE OVEN SHOWING POSSIBLE ATMOSPHERIC EMISSION SOURCES FOR BENZENE



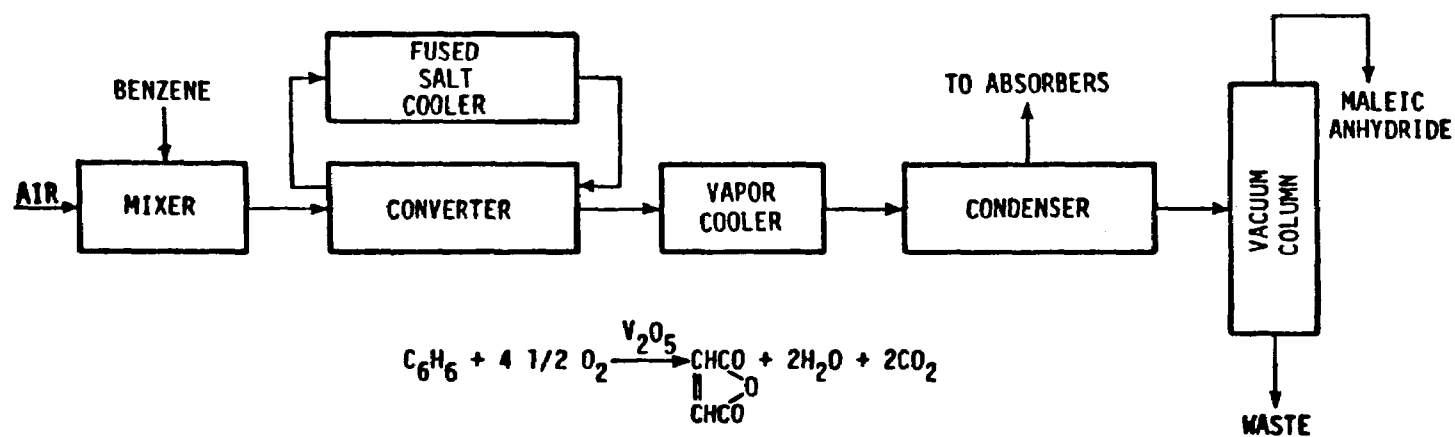
Source: PEDCo, 1977

FIGURE A-2. FLOW CHART FOR NITROBENZENE MANUFACTURE FROM BENZENE AND NITRIC ACID



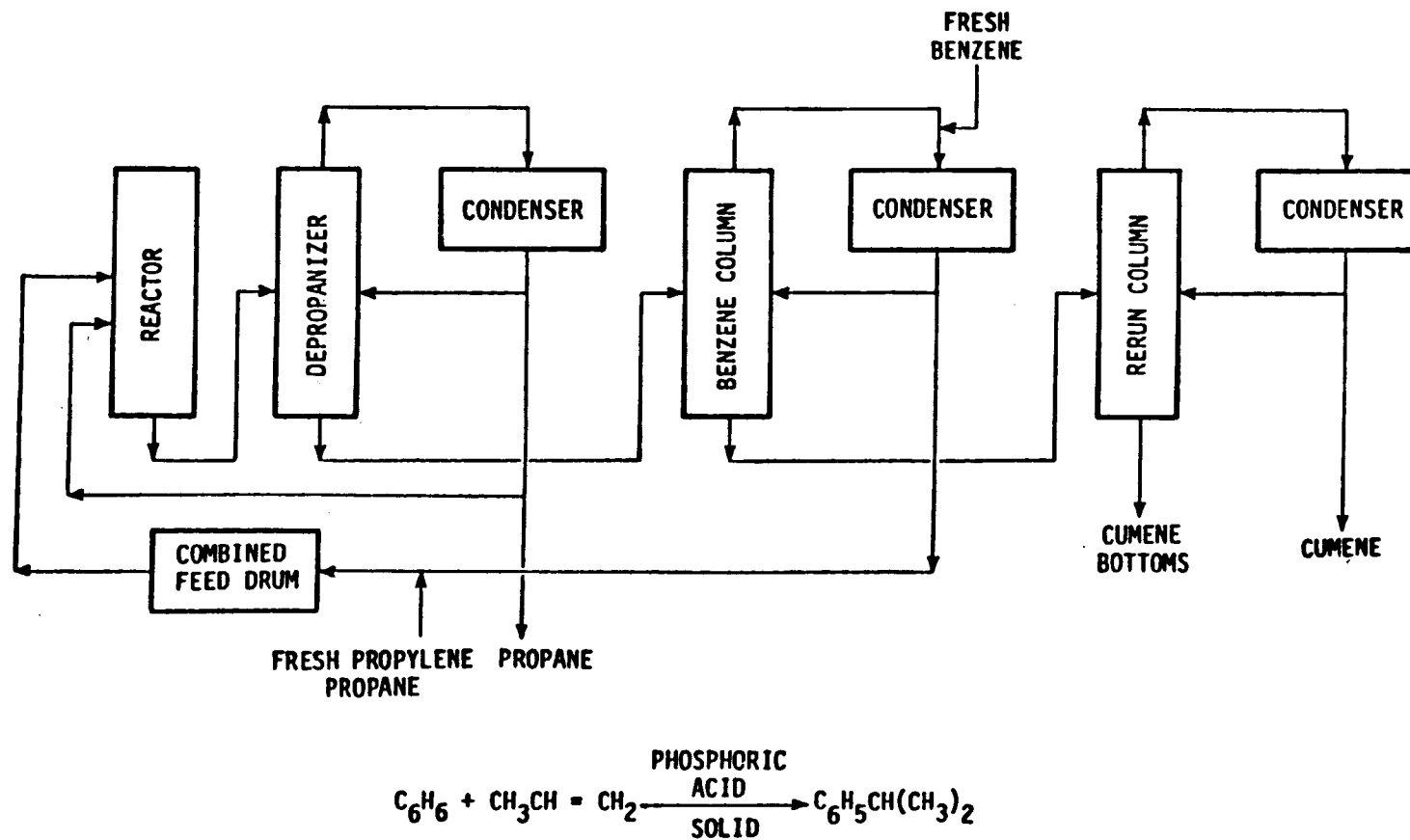
Source: PEDCo, 1977

FIGURE A-3. FLOW CHART FOR ETHYLBENZENE MANUFACTURE FROM BENZENE AND ETHYLENE



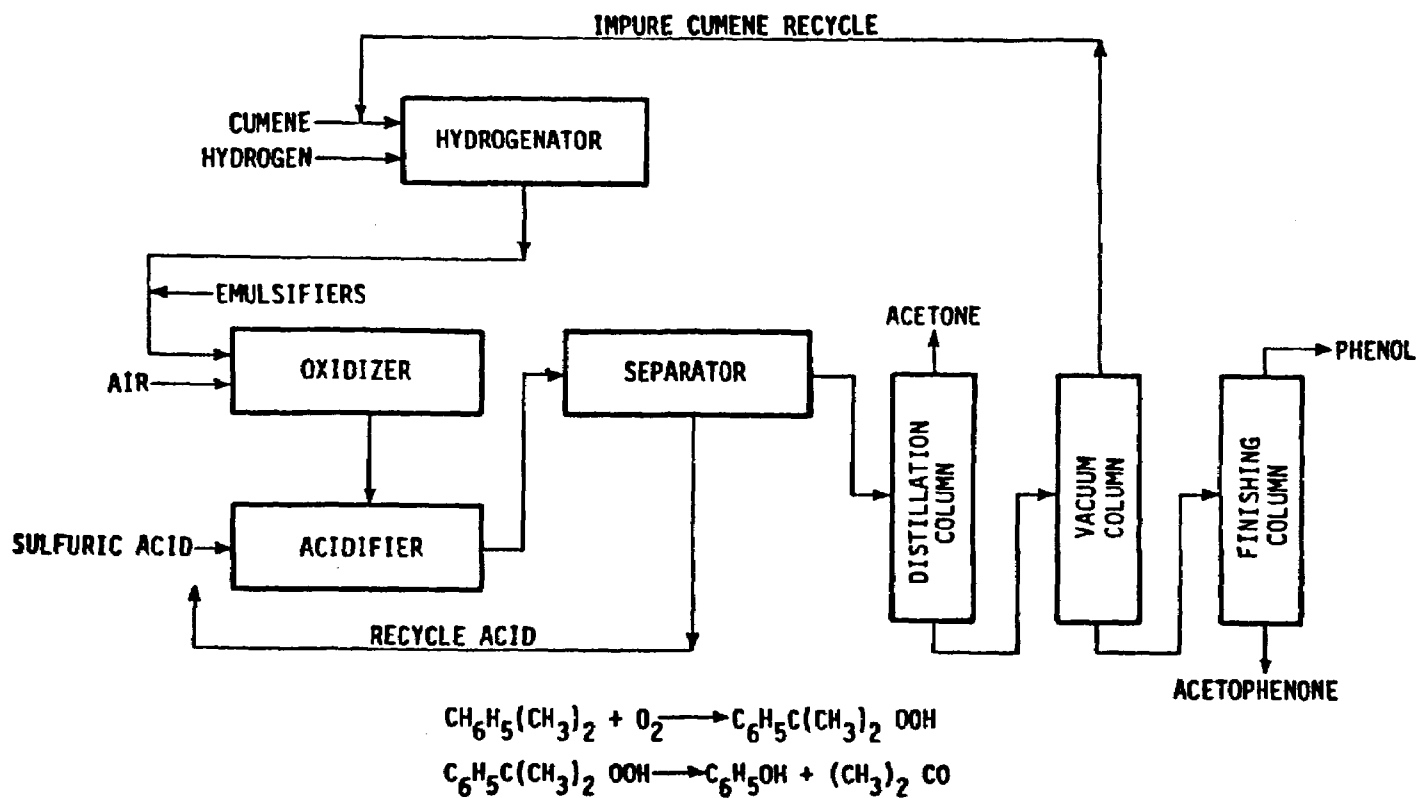
Source: PEDCo, 1977

FIGURE A-4. FLOW CHART FOR THE MANUFACTURE OF MALEIC ANHYDRIDE BY CATALYTIC VAPOR-PHASE OXIDATION OF BENZENE



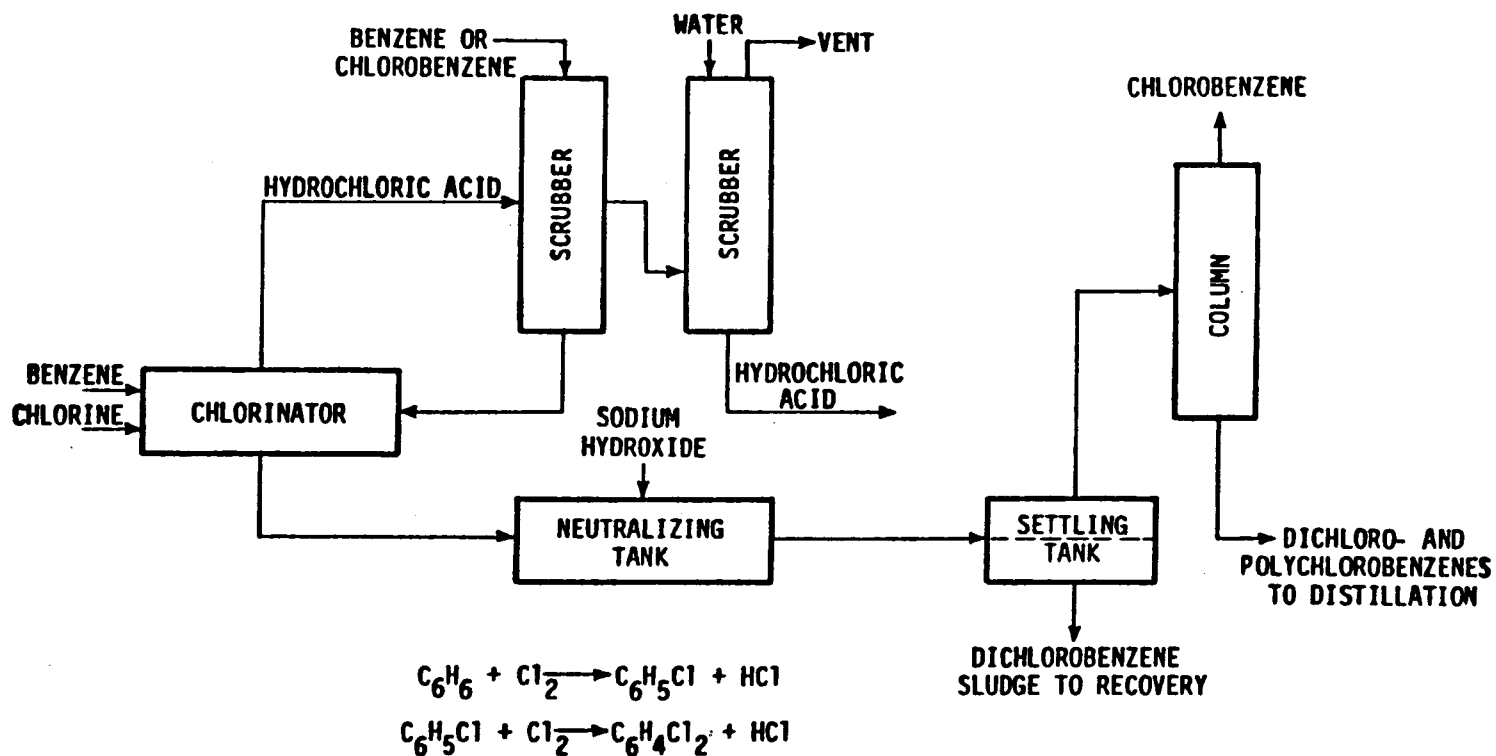
Source: PEDCo, 1977

FIGURE A-5. PROCESS FOR THE MANUFACTURE OF CUMENE



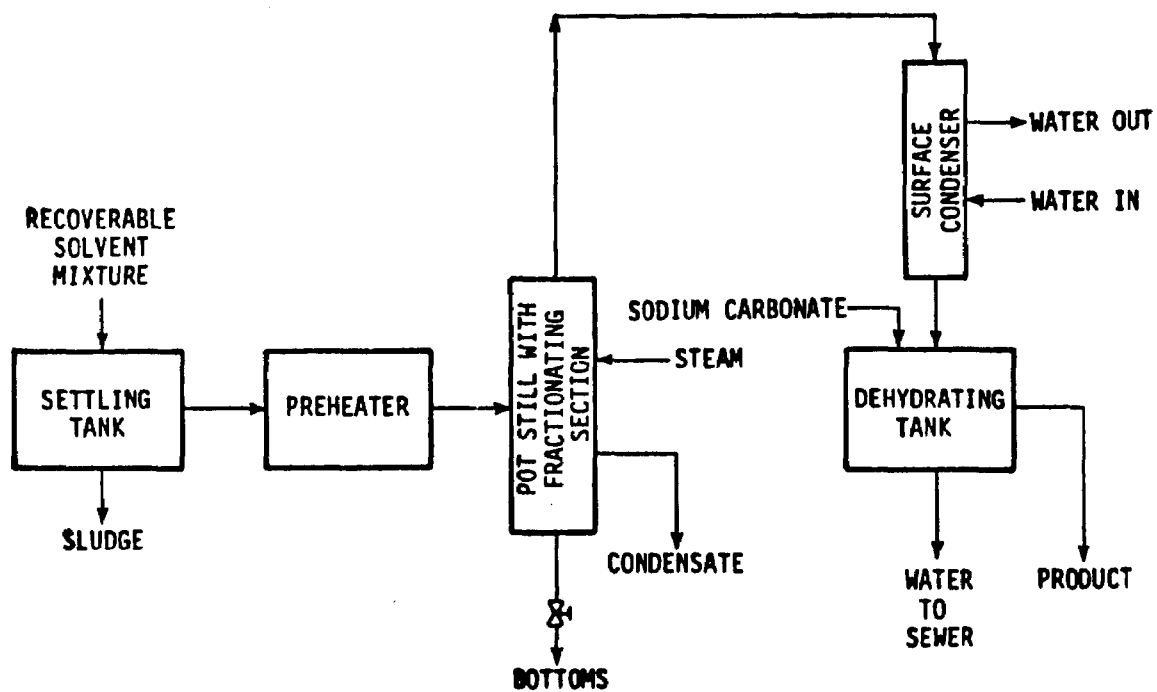
Source: PEDCo, 1977

FIGURE A-6. FLOW DIAGRAM FOR THE MANUFACTURE OF PHENOL BY THE CUMENE PEROXIDATION PROCESS



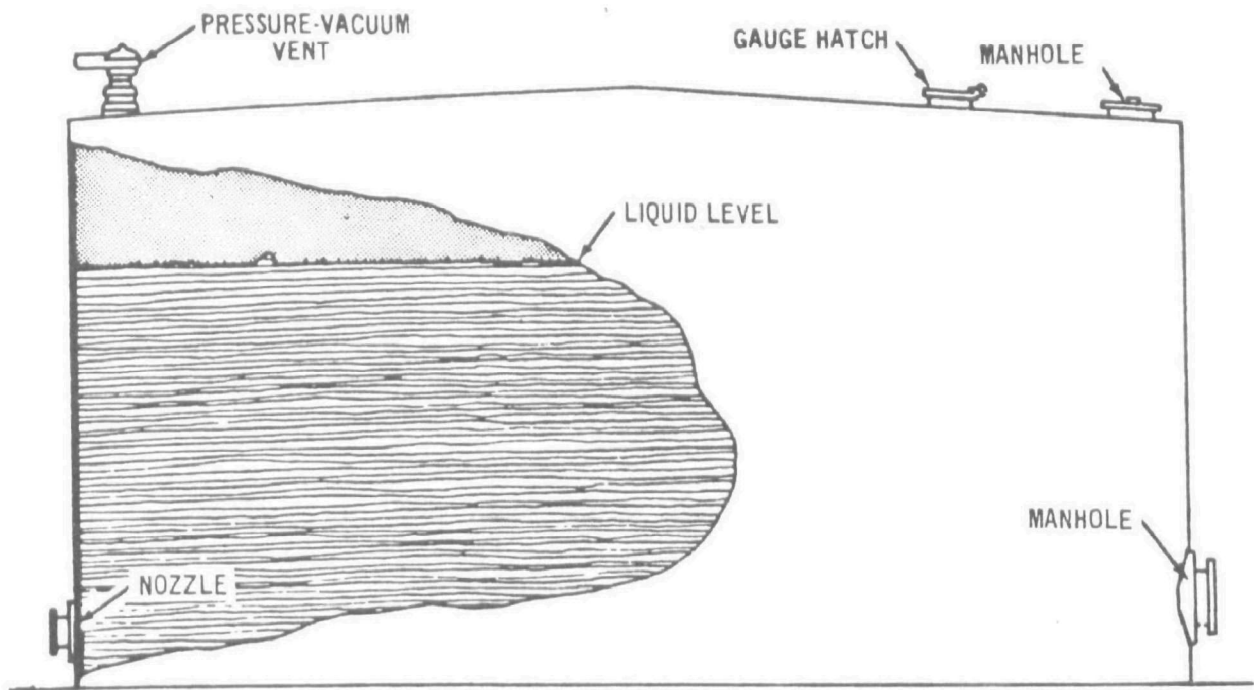
Source: PEDCo, 1977

FIGURE A-7. FLOW DIAGRAM FOR THE MANUFACTURE OF CHLOROBENZENE AND BY-PRODUCT DICHLOROBENZENES



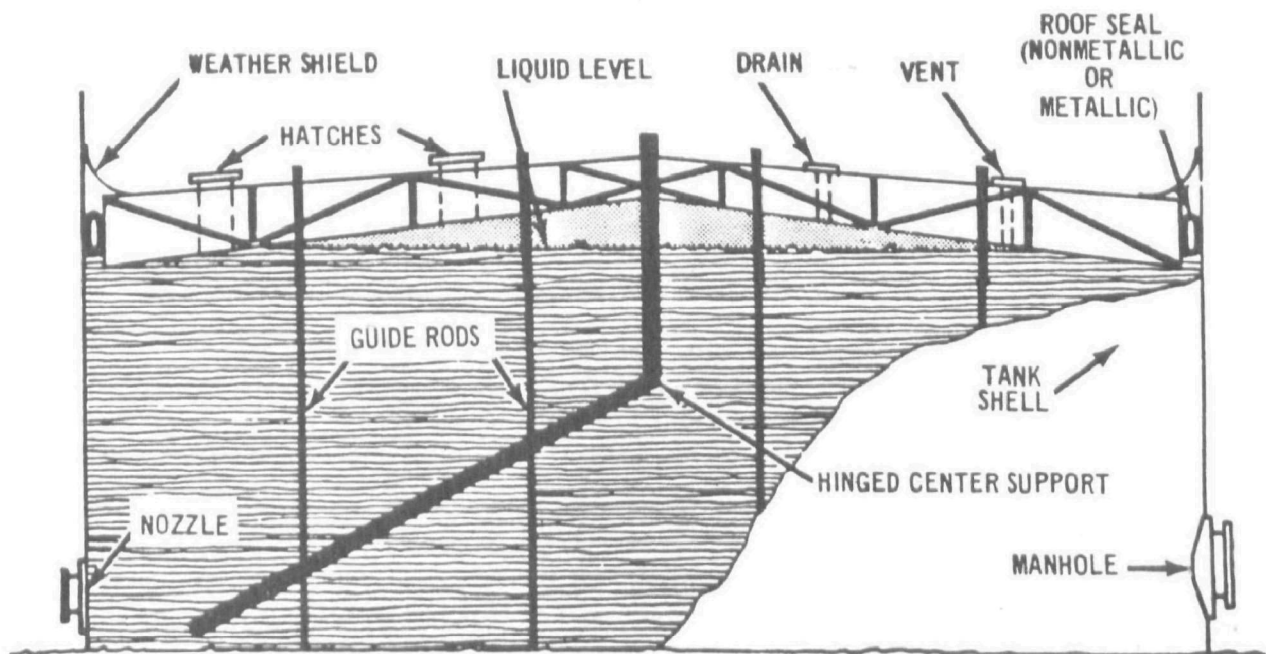
Source: PEDCo, 1977

FIGURE A-8. TYPICAL SOLVENT RE-REFINING INSTALLATION



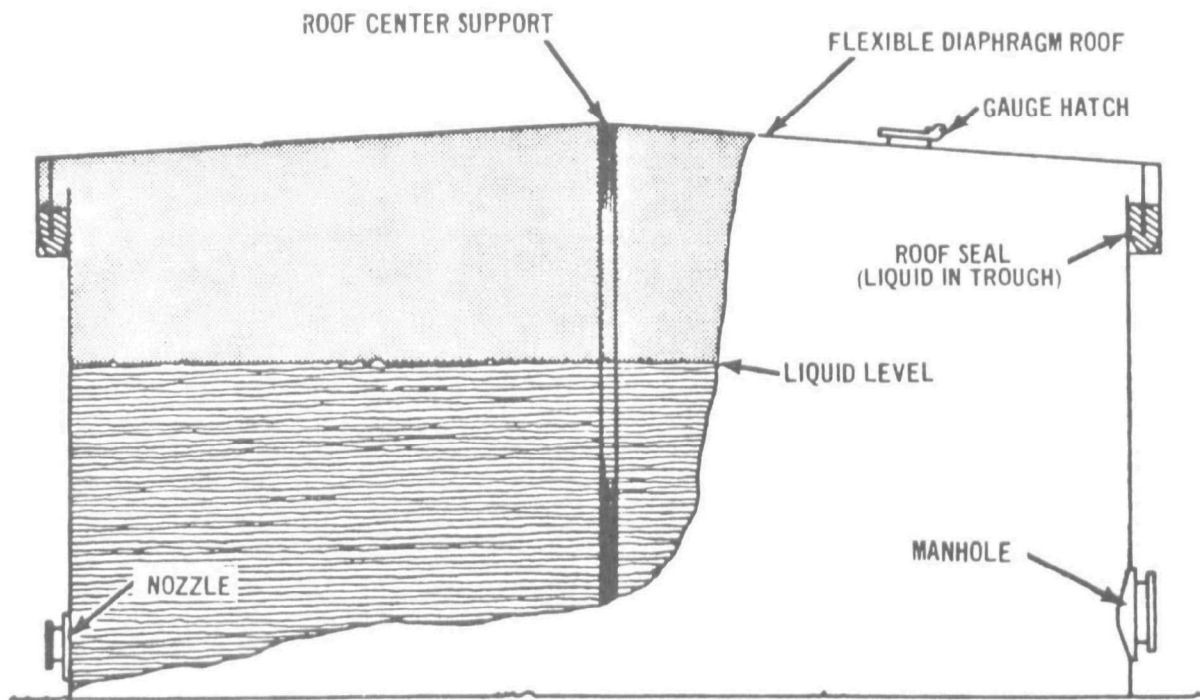
Source: PEDCo, 1977

FIGURE A-9. FIXED-ROOF STORAGE TANK



Source: PEDCo, 1977

FIGURE A-10. DOUBLE-DECK FLOATING-ROOF STORAGE TANK
(Nonmetallic Seal)



Source: PEDCo, 1977

FIGURE A-11. VARIABLE VAPOR SPACE STORAGE TANK
(Wet-Seal Lifter Type)

APPENDIX B

Emission Rates and Population Exposures from Chemical Manufacturing Facilities

Table B-1

EMISSION RATES FROM DIFFERENT CHEMICALS IN EACH PLANT USING BENZENE *

ESTIMATED EMISSION RATE, JANUARY 1, 1976 (millions of kg per year)

STATE	LOCATION	COMPANY	NITRO-BENZENE	ANILINE	ETHYL-BENZENE	STYRENE	MALEIC ANHYDRATE	CUMENE	PHENOL	MONO-CHLORO-BENZENE	DICHLORO-BENZENE (O- and P-)	CYCLO-HEXANE	DETERGENT ALKYLATE (Linear and Branch)	TOTAL EMISSION RATE
ALABAMA	TUSCALOOSA	REICHOLD CHEM., INC.							0.068					0.068
CALIFORNIA	CARSON	WITCO CHEM.											0.055	0.055
	EL SEGUNDO	STD. OIL CO. OF CALIF.						0.011						0.011
	IRWINDALE	SPECIALTY ORGANICS, INC.									0.080			0.080
	RICHMOND	STD. OIL CO. OF CALIF.							0.025				0.220	0.245
	SANTA FE SPRINGS	FERRO CORP.												
DELAWARE	DELAWARE CITY	STD. CHLORINE CHEM CO., INC.								0.119	0.232			0.351
GEORGIA	CARTERSVILLE	CHEM. PRODUCTS CORP.									0.086			0.086
ILLINOIS	BLUE ISLAND	CLARK OIL & REFINING						0.012	0.040					0.052
	CICERO	KOPPERS CO., INC.					0.483							0.483
	MORRIS	REICHOLD CHEM., INC.					2.610							2.610
	SAUGET	MONSANTO	0.031							0.182	0.111			0.324
KANSAS	EL DORADO	SKELLY OIL CO.						0.015	0.043					0.058
KENTUCKY	ASHLAND	ASHLAND OIL, INC.						0.040						0.040
LOUISIANA	BATON ROUGE	FOSTER GRANT CO.			0.272	0.558								0.830
	CORVILLE	COS-MAR, INC.			0.202	0.409								0.611
	CHALMETTE	TENNECO, INC.			0.070									0.070
	GEISMAR	RUBICON CHEM., INC.	0.238											0.238
	PLAQUEMINE	GEORGIA PACIFIC CORP.							0.120					0.120
	WELCOME	GULF OIL CORP.			0.155	0.357								0.512
MARYLAND	BALTIMORE	CONTINENTAL OIL CO.											0.215	0.215
MASSACHUSETTS	MALDEN	SOLVENT CHEM. CO., INC.									0.008			0.008
MICHIGAN	MIDLAND	DOW CHEMICAL			0.155	0.273		0.001	0.018	0.476	0.249			1.172
MISSISSIPPI	PASCAGOULA	FIRST MISSISSIPPI CORP.	0.427											0.427
MISSOURI	ST. LOUIS	MONSANTO					4.641							4.641
NEVADA	HENDERSON	MONTRON CHEM. CORP. OF CAL.								0.112				0.112
NEW JERSEY	BOUND BROOK	AMERICAN CYANAMID	0.266											0.266
	BOUND BROOK	UNION CARBIDE							0.068					0.068
	ELIZABETH	REICHOLD CHEM., INC.					1.353							1.353
	FORDS	TENNECO, INC.					1.160							1.160
	GIBBSTOWN	E. I. du PONT	0.637											0.637
	KEARNY	STD. CHLORINE CHEM. CO.									0.060			0.060
	WESTVILLE	TEXACO, INC.						0.029						0.029

Table B-1 (Continued)

STATE	LOCATION	COMPANY	NITRO- BENZENE	ANILINE	ETHYL- BENZENE	STYRENE	MALEIC ANHYDRATE	CUMENE	PHENOL	MONO- CHLORO- BENZENE	DICHLORO- BENZENE (O- and P-)	CYCLO- HEXANE	DETERGENT ALKYLATE (Linear and Branch)	TOTAL EMISSION RATE
NEW YORK	NIAGARA FALLS	ICC INDUSTRIES, INC.												
	NIAGARA FALLS	OCCIDENTAL PETROLEUM								0.024				0.024
	NIAGARA FALLS SYRACUSE	SOLVENT CHEM. CO. ALLIED CHEM. CORP.								0.038	0.077 0.077			0.070 0.115
OHIO	HAVERHILL	UNITED STATES STEEL							0.090					0.090
PENNSYLVANIA	BEAVER VALLEY	ARCO/POLYMERS, INC.				0.300								0.300
	BRIDGEVILLE	KOPPERS CO., INC.					1.450							1.450
	CLAIRTON	UNITED STATES STEEL												
	FRANKFORD	ALLIED CHEMICAL CORP.							0.250					0.250
	NEVILLE ISLAND PHILADELPHIA	UNITED STATES STEEL GULF OIL CORP.					1.740	0.051				0.274		1.740 0.325
PUERTO RICO	GUAYAMA	PHILLIPS PETROLEUM										0.585		0.585
	PENUELAS	COMMONWEALTH OIL			0.045							0.330		0.375
	PENUELAS	UNION CARBIDE CORP						0.072	0.090					0.162
TEXAS	BAYTOWN	EXXON CORP										0.330		0.330
	BEAUMONT	E. I. du PONT	0.987											0.987
	BEAUMONT	UNION OIL CO. OF CALIFORNIA										0.280		0.280
	BIG SPRING	AMERICAN PETROFINA			0.012	0.080						0.098		0.170
	BORGER	PHILLIPS PETROLEUM										0.330		0.330
	CHOCOLATE BAYOU	MONSANTO						0.073	0.227				0.224	0.524
	CORPUS CHRISTI	COASTAL STATES GAS						0.016						0.016
	CORPUS CHRISTI	SUN OIL CO.			0.026	0.054		0.028						0.108
	CORPUS CHRISTI	UNION PACIFIC CORP										0.182		0.182
	FREEPORT	DOW CHEMICAL			0.525	1.009								1.534
	HOUSTON	ARCO/POLYMERS, INC.			0.027	0.067								0.094
	HOUSTON	THE CHARTER CO.			0.009									0.009
	HOUSTON	JOE OIL, INC.												
	HOUSTON	THE MERICHEM CO.												
	HOUSTON	PETRO-TEX CHEM CORP.					2.224							2.224
	ODESSA	EL PASO NATURAL GAS			0.077	0.102								0.179
	OYSTER CREEK	DOW CHEMICAL							0.182					0.182
	PHILLIPS	PHILLIPS PETROLEUM CO.												
	PORT ARTHUR	ARCO/POLYMERS, INC.			0.124									0.124
	PORT ARTHUR	GULF OIL CORP						0.051						0.051
	PORT ARTHUR	TEXACO										0.060		0.060
	SEADRIFT	UNION CARBIDE CORP			0.086	0.204								0.300
	SWEENEY	PHILLIPS PETROLEUM CO.										0.703		0.703

Table B-1 (Concluded)

STATE	LOCATION	COMPANY	NITROGEN	ANILINE	ETHYL- BENZENE	STYRENE	MALEIC ANHYDRATE	CUMENE	PHENOL	MONO- CHLORO- BENZENE	DICHLORO- BENZENE (O- and P.)	CYCLO- HEXANE	DETERGENT ALKYLATE (Linear and Branch)	TOTAL EMISSION RATE
TEXAS	TEXAS CITY	MARATHON OIL CO.						0.021						0.021
	TEXAS CITY	MONSANTO			0.888	0.885								1.784
	TEXAS CITY	STANDARD OIL (INDIANA)			0.266	0.573		0.007						0.846
WEST VIRGINIA	CHARLESTON	UNION CARBIDE CORP.											0.149	0.149
	FOLLANSBEE	KOPPERS CO., INC.					0.261							0.436
	MOUNDSVILLE	ALLIED CHEM CORP.	0.175											0.436
	NATRIUM	PPG INDUSTRIES, INC.								0.143	0.197			0.340
	NEW MARTINSVILLE	MOBAY CHEM CORP.	0.427											0.427
	WILLOW ISLAND	AMERICAN CYANAMIDE	0.189											0.189
WASHINGTON	ANACORTES	STIMSON LUMBER CO.							N.A.					
	KALAMA	KALAMA CHEMICAL							0.025					0.025

N.A. - NOT AVAILABLE

* SOURCE SRI ESTIMATES

Table B-2

ESTIMATED ANNUAL AVERAGE EXPOSURES
FROM CHEMICAL MANUFACTURING FACILITIES

State	Location	Company	Total Benzene Emission Rate 10 ⁶ Kg/yr	Population** Exposed to Benzene (ppb)***					Total
				0.1-1.0	1.1-2.0	2.1-4.0	4.1-10.0	>10.0	
Alabama	Tuscaloosa	Reichhold Chem., Inc.	0.068	62,700	2,000	800	400	100*	66,000
California	Carson	Witco Chem.	0.055	10,700	4,300	1,700	800	300	17,800
	El Segundo	Std. Oil Co. of Calif.	0.011	14,900	400	200	100	††	15,600
	Irwindale	Specialty Organics	0.008	800	†	†	†	†	800
	Richmond	Std. Oil Co. of Calif.	0.245	78,200	11,800	4,600	2,100	900	97,600
	Santa Fe Springs	Ferro Corp.	N.A.						
Delaware	Delaware City	Std. Chlorine Chemical Co., Inc.	0.351	76,200	2,200	1,300	800	300	80,800
Georgia	Cartersville	Chem. Products Corp	0.086	10,900	700	300	100	100	12,100
Illinois	Blue Island	Clark Oil & Refining	0.052	12,500	400	100	100	††	13,100
	Cicero	Koppers Co., Inc.	0.483	84,300	2,400	29,600	24,900	10,200	151,400
	Morris	Reichhold Chem., Inc.	2.610	58,000*	23,400	9,200	6,400	5,200	102,200
	Sauget	Monsanto	0.324	49,200	1,400	500	300	100	51,500
Kansas	El Dorado	Skelly Oil Co.	0.058	11,800	400	200	100	††	12,500
Kentucky	Ashland	Ashland Oil, Inc.	0.040	26,800	1,500	600	300	100	29,300
Louisiana	Baton Rouge	Foster Grant Co.	0.830	50,100*	102,500	40,200	18,400	7,500	218,700
	Corville	Cos-Mar, Inc.	0.611	37,100*	1,300	500	400	700	40,000
	Chalmette	Tenneco, Inc.	0.07	18,700	500	200	100	††	19,500
	Geismar	Rubicon Chem. Inc.	0.238	13,200	400	100	100	††	13,800
	Plaquemine	Georgia Pacific Corp.	0.120	10,400	1,100	400	200	100	12,200
	Welcome	Gulf Oil Corp.	0.512	37,100	1,100	400	200	100	38,900
Maryland	Baltimore	Continental Oil Co.	0.215	800,400	46,500	18,200	8,300	3,400	876,800
Massachusetts	Malden	Solvent Chem. Co., Inc.	0.008	18,300	500	200	100	††	19,100
Michigan	Midland	Dow Chemical	1.172	65,400*	6,200	21,500	10,100	4,100	107,300
Mississippi	Pascagoula	First Mississippi Corp.	0.427	21,000	18,600	7,300	3,300	1,400	51,600
Missouri	St. Louis	Monsanto	4.641	4,400*	17,400	6,800	348,600	190,200	576,400
Nevada	Henderson	Montrose Chem. Corp. of California	0.112	18,000	1,000	400	200	100	19,700
New Jersey	Bound Brook†	American Cyanamid	0.266						
	Bound Brook	Union Carbide	0.068	245,300	7,000	2,700	1,200	500	256,700
	Elizabeth	Reichhold Chem.	1.353	386,100*	46,000	18,000	73,100	34,100	557,300
	Fords	Tenneco, Inc.	1.160	400,300*	37,400	14,700	6,700	2,700	461,800
	Gibbstown	E. I. du Pont	0.637	434,500*	16,600	6,500	3,000	1,200	461,800
	Kearny	Std. Chlorine Chem. Co.	0.060	48,200	2,900	1,100	500	200	52,900
	Westville	Texaco, Inc.	0.029	9,000	300	100	††	††	9,400
New York	Niagara Falls†	ICC Industries, Inc.	N.A.						
	Niagara Falls	Occidental Petroleum	0.024	80,500	8,400	3,300	1,500	600	94,300
	Niagara Falls	Solvent Chem. Co.	0.07						
	Syracuse	Allied Chem. Corp.	0.115	183,100	13,200	5,200	2,400	1,000	204,900
Ohio	Haverhill	United States Steel	0.09	11,400	300	100	100	††	11,900
Pennsylvania	Beaver Valley	Arco/Polymers, Inc.	0.300	58,300	1,700	600	300	100	61,000
	Bridgeville	Koppers Co., Inc.	1.450	104,100*	13,900	5,400	5,000	2,300	130,700
	Clairton	United States Steel	N.A.						
	Frankford	Allied Chemical Corp.	0.250	45,600	1,300	500	200	100	47,700
	Neville Island	United States Steel	1.740	97,700*	17,800	7,000	3,200	2,400	128,100
	Philadelphia	Gulf Oil Corp.	0.325	1,681,200	106,700	41,800	19,100	7,800	1,856,600

Table B-2 (Concluded)

State	Location	Company	Total Benzene Emission Rate 10 ⁶ Kg/yr	Population** Exposed to Benzene (ppb)***					Total
				0.1-1.0	1.1-2.0	2.1-4.0	4.1-10.0	>10.0	
Puerto Rico	Guayama	Phillips Petroleum	0.585	401,500	13,000	5,300	2,400	1,000	423,200
	Poncellas	Commonwealth Oil	0.375	404,000	12,000	4,700	2,100	900	423,700
	Poncellas	Union Carbide Corp	0.162	805,500	25,000	10,000	4,500	1,700	846,700
Texas	Baytown	Exxon Corp	0.330	10,900	300	100	100	††	11,400
	Beaumont	E. I. duPont	0.987	17,700*	69,200	28,400	13,000	5,300	133,600
	Beaumont	Union Oil Co. of Calif.	0.280	22,000	6,600	2,600	1,200	500	32,900
	Big Spring	American Petrofina	0.170	17,500	4,300	1,700	800	300	24,600
	Borger	Phillips Petroleum	0.330	19,900*	600	200	100	††	20,800
	Chocolate Bayou	Monsanto	0.524						
	Corpus Christi	Coastal States Gas	0.016						
	Corpus Christi	Sun Oil Co.	0.108	9,800	12,500	5,200	2,400	1,000	30,900
	Corpus Christi	Union Pacific Corp	0.182						
	Freeport	Dow Chemical	1.534	16,800*	2,500	2,800	6,200	2,500	30,800
	Houston	Arco/Polymers	0.094						
	Houston	The Charter Co.	0.009						
	Houston	Joe Oil, Inc.	N.A.	399,500*	285,600	111,900	51,200	20,900	1,369,100
	Houston	The Merichem Co.	N.A.						
	Houston	Petro-Tex Chemical	2.224						
	Odessa	El Paso Natural Gas	0.179	60,200	13,400	5,200	2,400	1,000	82,200
	Oyster Creek	Dow Chemical	0.182	4,900	100	100	††	††	5,100
	Phillips	Phillips Petroleum Co.	N.A.						
	Port Arthur	Arco/Polymers	0.124						
	Port Arthur	Gulf Oil Corp	0.051	48,600	5,100	2,000	900	400	57,000
	Port Arthur	Texaco	0.050						
	Seadrift	Union Carbide Corp	0.300	9,600	300	200	700	300	11,100
	Sweeney	Phillips Petroleum Co.	0.703	19,400*	900	500	2,100	900	23,800
	Texas City	Marathon Oil Co.	0.021						
	Texas City	Monsanto	1.784	12,400*	5,200	21,800	12,500	5,100	57,000
	Texas City	Standard Oil (Ind.)	0.846						
West Virginia	Charleston	Union Carbide Corp	0.149	61,400	6,400	2,500	1,200	500	72,000
	Follansbee	Koppers Co., Inc.	N.A.						
	Moundsville	Allied Chemical	0.436	29,400	6,300	2,500	1,100	500	39,800
	Naturum	PPG Industries, Inc.	0.340	19,000	500	200	100	††	19,800
	New Martinsville	Mobay Chemical	0.427	25,800	3,000	2,400	1,100	400	32,700
	Willow Island	American Cyanamide	0.189	8,600	200	100	††	††	8,900
Washington	Anacortes	Stimson Lumber Co.	N.A.						
	Kalama	Kalama Chemical	0.025	1,200	100	100	††	††	1,400
TOTAL				7,496,500	944,600	452,800	644,800	319,400	9,882,600

*Some population may be exposed to levels above 0.1 ppb beyond 20 km.

**Population and density information were obtained from the Statistical Abstract-1975 and the 1972 City and County Data Book, both published by the Bureau of Census.

***To convert to $\mu\text{g}/\text{m}^3$ multiply by 3.2.

*Estimated benzene concentration at the location with more than one plant; the estimated concentration is the sum of individual concentration estimated from each plant.

†Less than 50 people exposed.

Source: SRI estimates

APPENDIX C

Population Exposures from Coke Oven Operations by Location

COKE PLANT LOCATIONS, CAPACITIES, POPULATION, EMISSION RATE AND
AREA AVERAGE CONCENTRATION OF BENZENE

State, City	Plant Name	Company	Annual Coal Capacity (tons)	Emission Rate (g/sec)	Population Exposed to Benzene (ppb) ^{††}			
					0.1-1.0	1.1-2.0	2.1-4.0	4.1-10
<u>Alabama</u>								
1. Tarrant	Tarrant Plant	Alabama By-Products Co.	1,200,000	1.572	130,509	388		
2. Holt	Holt Plant	Empire Coke Co.	150,000	0.196				
3. Woodward	Woodward Plant	Koppers Company, Inc.	800,000	1.048	101,935			
4. Gadsden	Gadsden Plant	Republic Steel Corp.	820,000	1.074	56,954	478		
5. Thomas	Thomas Plant	Republic Steel Corp.	185,000	0.242	2,188			
6. Birmingham	Birmingham Plant	U.S. Pipe and Foundry Co.	1,175,000	1.539	153,888	975		
7. Fairfield	Fairfield Plant	U.S. Steel Corp.	2,500,000	3.275	377,213	22,105		
<u>California</u>								
8. Fontana	Fontana Plant	Kaiser Steel Corp.	2,336,000	3.060	222,300	1,416		
<u>Colorado</u>								
9. Pueblo	Pueblo Plant*	CF&I Steel Corp.	1,332,000	1.744				
<u>Illinois</u>								
10. Granite City	Granite City Steel Div.	National Steel Corp.	1,132,000	1.482	79,609			
11. Chicago	Chicago Plant	Interlake, Inc.	949,000	1.743	313,798	827		
12. Chicago	Wisconsin Steel Works	International Harvester Co., Wisconsin Steel Div.	991,000	1.298	2,828			
13. South Chicago	South Chicago Plant	Republic Steel Corp.	590,000	0.772	220,088			
<u>Indiana</u>								
14. Chesterton	Burns Harbor Plant	Bethlehem Steel Corp.	2,630,000	3.445	89,582			
15. Indianapolis	Prospect Street Plant	Citizens Gas & Coke Utility	675,000	0.884	287,163			
16. Terre Haute	Terre Haute Plant	Indiana Gas and Chemical Corp.	204,000	0.267 [†]	3,571			
17. E. Chicago	Plant No. 2	Inland Steel Co.	3,102,000	4.063 [†]	572,452	21,279	53	
18. East Chicago	Plant No. 3	Inland Steel Co.	1,642,000	2.151				
19. Gary	Gary Plant	U.S. Steel Corp.	3,700,000	4.847	388,319	26,829	33	
20. Indiana Harbor	Indiana Harbor Plant	Youngstown Sheet and Tube Co.	2,100,000	2.751	733,369	482	99	

Source: SRI estimates.

Table C-1 (Continued)

State, City	Plant Name	Company	Annual Coal Capacity (tons)	Emission Rate (g/sec)	Population Exposed to Benzene (ppb) ^{††}			
					0.1-1.0	1.1-2.0	2.1-4.0	4.1-10
36. Portsmouth	Empire	Detroit Steel Div. of Cyclops Corp.	600,000	0.786	39,419			
37. Toledo	Toledo Plant*	Interlake Inc.	438,000	0.573	25,191			
38. Cleveland	Cleveland Plant	Republic Steel Corp.	2,220,000	2.908	1,342,409	4,228	1,530	
39. Massillon	Massillon Plant	Republic Steel Corp.	250,000	0.327	17,734			
40. Warren	Warren Plant	Republic Steel Corp.	650,000	1.650	102,288			
41. Youngstown	Youngstown Plant	Republic Steel Corp.	1,500,000	1.965	193,005	1,986		
42. Lorain	Lorain Cuyahoga Works	U.S. Steel Corp.	2,700,000	3.537	1,238,831	72,578	2,871	
43. Campbell	Campbell Plant	Youngstown Sheet and Tube Co.	2,300,000	3.013	280,123	37,797		
<u>Pennsylvania</u>								
44. Swedeland	Alan Wood Plant	Alan Wood Steel Co.	803,000	1.051	136,971			
45. Bethlehem	Bethlehem Plant*	Bethlehem Steel Corp.	2,210,000	2.895	336,726	1,593	3,960	
46. Johnstown	Rosedale Div.	Bethlehem Steel Corp.	550,000	0.720 [†]	89,682	36,330	1,804	
47. Johnstown	Franklin Div.	Bethlehem Steel Corp.	1,680,000	2.200				
48. Midland	Alloy & Stainless Steel Div.	Crucible Inc., Div. Colt Industries	657,000	0.860	12,859			
49. Aliquippa	Aliquippa Plant*	Jones and Laughlin Steel Corp.	2,250,633	2.947	198,194			
50. Pittsburgh	Pittsburgh Plant	Jones and Laughlin Steel Corp.	2,587,404	3.389	1,144,922	125,482		
51. Erie	Erie Plant	Koppers Company, Inc.	290,000	0.379	68,912			
52. Philadelphia	Philadelphia Plant	Philadelphia Coke Division	715,400	0.937	648,240			
53. Pittsburgh	Neville Island Plant	Shenango Inc.	1,022,000	1.338	154,478			
54. Clairton	Clairton Plant*	U.S. Steel Corp.	9,670,000 ^{**}	12.667	407,475	83,779	16,819	2,389
55. Fairless Hills	Fairless Hills Plant	U.S. Steel Corp.	1,800,000	1.768	148,277	4,131		
56. Monessen	Wheeling	Pittsburgh Steel Corp.	750,000	0.982	66,820			
<u>Tennessee</u>								
57. Chattanooga	Chattanooga Plant	Chattanooga Coke and Chemicals Co.	204,400	0.267	6,668			
<u>Texas</u>								
58. Houston	Houston Plant	Armco Steel Corp.	584,000	0.765	4,866			
59. Lone Star	E. B. Germany Plant	Lone Star Steel Co.	498,000	0.652	1,046			
<u>Utah</u>								
60. Provo	Geneva Works*	U.S. Steel Corp.	2,000,000	2.620	104,054		19	

Table C-1 (Concluded)

State, City	Plant Name	Company	Annual Coal Capacity (tons)	Emission Rate (g/sec)	Population Exposed to Benzene (ppb) ^{††}			
					0.1-1.0	1.1-2.0	2.1-4.0	4.1-10
<u>West Virginia</u>								
61. Weirton	Weirton Mainland Plant	Weirton Steel Div., National Steel Corp.	2,500,000	3.275 [†]	12,168			
62. Weirton	Weirton's Brown's Island Plant	Weirton Steel Div., National Steel Corp.	1,825,000	2.390				
63. Fairmont	Fairmont Plant	Sharon Steel Corp.	300,000	0.393				
64. Follonsbee	East Steubenville Plant	Wheeling-Pittsburgh Steel Corp.	2,500,000	3.275	104,932	20,971	3	
<u>Wisconsin</u>								
65. Milwaukee	Milwaukee Solvay Coke Co.	A Division of Picklands Mather and Co.	347,000	0.656	267,400			
Total Exposed Population					15,457,770	521,148	49,719	2,400

[†]Coke oven operations producing benzene as a by-product (PEDCo., 1977).

^{††}Based on a 1973 emission inventory.

Operations in same city are assumed to be co-located and their emissions are summed.

To convert to $\mu\text{g}/\text{m}^3$, multiply concentrations by 3.2; to convert to 8-hour worst-case, multiply concentrations by 10.

Basic Data Source: Keystone Coal Industries Manual (1975) and Varga (1974), as cited in Suza (1977).

APPENDIX D

Population Exposures from Petroleum Refineries by Location

Table D-1

POPULATION EXPOSED TO BENZENE FROM PETROLEUM REFINERIES BY PLANT LOCATION

Location ¹	Total Capacity (10 ⁶ m ³) ¹	Total Emission (10 ⁶ g) ²	Emission Rate (g/sec) ²	Population Exposed ² to Benzene (ppb)*				
				0.1-1.0	1.1-2.0	2.1-4.0	4.1-10.0	> 10.0
ALABAMA								
Holt								
Warrior Asphalt Co. of Alabama, Inc.	.17	2.1	.07	0	0	0	0	0
Theodore								
Marion Oil Co.	1.04	13.5	.43	0	0	0	0	0
Tuscaloosa								
Hunt Oil Co.	<u>1.65</u>	<u>21.5</u>	.68	<u>101</u>	0	0	0	0
Total	<u>2.86</u>	<u>37.1</u>		<u>101</u>				
ALASKA								
Kenai								
Chevron USA Inc.	1.28	16.6	.53 ^a					
Tesoro Petro Corp.	2.21	28.7	.91	2	0	0	0	0
North Slope								
At-Rich Co.	<u>.75</u>	<u>9.8</u>	.31	<u>0</u>	0	0	0	0
Total	<u>4.24</u>	<u>55.1</u>		<u>2</u>				
ARIZONA								
Fredonia								
Arizona Fuels Corp.	<u>.23</u>	<u>3.0</u>	.10	0	0	0	0	0
Total	<u>.23</u>	<u>3.0</u>						
ARKANSAS								
El Dorado								
Lion Oil Co.	2.69	35.0	1.11	456	0	0	0	0

1. Source: Oil and Gas Journal, May 28, 1977.

2. Source: SRI estimates.

Table D-1 (Continued)

Location ¹	Total Capacity (10 ⁶ m ³) ¹	Total Emission (10 ⁶ g) ²	Emission Rate (g/sec) ²	Population Exposed ² to Benzene (ppb)*				
				0.1-1.0	1.1-2.0	2.1-4.0	4.1-10.0	> 10.0
ARKANSAS (Cont.)								
Norphlet								
MacMillan Ring-Free Oil Co., Inc.	.26	3.3	.11	0	0	0	0	0
Smackover								
Cross Oil & Refining Co. of Arkansas	.34	4.4	.14	0	0	0	0	0
Stephens								
Crystal Oil Co.	.22	2.9	.09	0	0	0	0	0
Total	3.51	45.6		456				
CALIFORNIA								
Bakersfield								
Chevron USA Inc.	1.51	19.6	.62 ^a					
Kern Co. Refinery Co.	.92	12.0	.38					
Lion Oil Co. (TOSCO)	2.21	28.7	.91					
Mohawk Petroleum Corp., Inc.	1.28	16.7	.53					
Road Oil Sales	.09	1.1	.04					
Sabre Refining Co.	.20	2.6	.08					
Sunland Refining Co.	.81	10.6	.34					
West Coast Oil Co.	.87	11.3	.36	52,833	6	0	0	0
Benicia								
Exxon Co.	5.12	66.4	2.11	473	0	0	0	0
Carson								
Atlantic-Richfield*	10.16	264.1	8.39 ^a					
Fletcher Oil and Refining Co.	1.11	14.5	.46	132,936 [†]	459	30	2	0

Table D-1 (Continued)

Location ¹	Total Capacity (10 ⁶ m ³) ¹	Total Emission (10 ⁶ g) ²	Emission Rate (g/sec) ²	Population Exposed ² to Benzene (ppb)*				
				0.1-1.0	1.1-2.0	2.1-4.0	4.1-10.0	> 10.0
CALIFORNIA (Cont.)								
El Segundo								
Chevron USA Inc.**	23.51	611.2	19.40	63,748 [†]	318	21	1	0
Hanford								
Beacon Oil Co.	.71	9.3	.29	0	0	0	0	0
Hercules								
Pacific Refining Co.	3.09	40.2	1.28	67	0	0	0	0
Long Beach								
Edgington Oil Co. Inc.	1.71	22.3	.71	369	0	0	0	0
Los Angeles								
Union Oil Co. - Calif.	6.27	81.5	2.59	48,447	5	0	0	0
Martinez								
Lion Oil Co. (TOSCO)	7.31	95.1	3.02 ^a					
Shell Oil Co.	5.80	75.4	2.40	19,080	2	0	0	0
Newhall								
Newhall Refining Co. Inc.	.63	8.2	.26	0	0	0	0	0
Oildale								
Golden Bear Div., Witco.								
Chemical Corp.	.61	7.9	.25 ^a					
San Joaquin Refining Co.	1.57	20.4	.65	17	0	0	0	0
Oxnard								
Oxnard Refinery	.15	1.9	.06	0	0	0	0	0
Paramount								
Douglas Oil Co.	2.70	35.1	1.11	0	0	0	0	0
Richmond								
Shell Oil Co.**	21.20	550.8	17.49	2,226	0	0	0	0
San Francisco								
Union Oil Co. - Calif	6.44	83.8	2.66	134,711 [†]	3,945	261	18	1

Table D-1 (Continued)

Location ¹	Total Capacity (10 ⁶ m ³) ¹	Total Emission (10 ⁶ g) ²	Emission Rate (g/sec) ²	Population Exposed ² to Benzene (ppb)*				
				0.1-1.0	1.1-2.0	2.1-4.0	4.1-10.0	> 10.0
CALIFORNIA (Cont.)								
Santa Fe Springs								
Gulf Oil Co.	2.99	38.9	1.23 ^a					
Powerline Oil Co.	2.56	33.3	1.06	651	0	0	0	0
Santa Maria								
Douglas Oil Co.	.55	7.2	.23	1	0	0	0	0
Signal Hill								
MacMillan Ring-Free Oil Co.	.67	8.7	.28	0	0	0	0	0
South Gate								
Lunday-Thagard Oil Co.	.49	6.4	.20	3	0	0	0	0
Torrance								
Mobile Oil Corp.	7.17	93.2	2.96	88,756	10	1	0	0
Ventura								
USA Petrochem Corp.	.87	11.3	.36	13	0	0	0	0
Wilmington								
Champlin Petroleum Co.	1.78	23.1	.73 ^a					
Shell Oil Co.	5.22	67.9	2.16					
Texaco Inc.	4.35	56.6	1.80	10,822	1	0	0	0
Total	132.63	2,437.3		555,203	4,746	267	21	1
COLORADO								
Commerce City								
Asamera Oil (U.S.) Inc.	1.31	17.0	.54	0	0	0	0	0
Denver								
Continental Oil Co.	1.89	24.5	.78	391	0	0	0	0
Fruita								
Gary Western Co.	.53	6.94	.22	0	0	0	0	0
Total	3.73	48.44		391				

Table D-1 (Continued)

Location ¹	Total Capacity (10 ⁶ m ³) ¹	Total Emission (10 ⁶ g) ²	Emission Rate (g/sec) ²	Population Exposed ² to Benzene (ppb)*				
				0.1-1.0	1.1-2.0	2.1-4.0	4.1-10.0	> 10.0
DELAWARE								
Delaware City								
Getty Oil Co. Inc.	8.13	105.6	3.35	6,355	$\frac{1}{1}$	0	0	0
Total	8.13	105.6		6,355	1			
FLORIDA								
St Marks								
Seminole Asphalt								
Refinery Co.	.33	4.3	.14	0	0	0	0	0
Total	.33	4.3		0				
GEORGIA								
Douglasville								
Young Refining Co.	.28	3.6	.12	0	0	0	0	0
Savannah								
Amoco Oil Co.	8.71	11.3	.36	0	0	0	0	0
Total	8.99	14.9		0				
HAWAII								
Barbers Point								
Chevron USA Inc.	2.32	30.2	.96	22	0	0	0	0
Ewa Beach								
Hawaii Independent								
Refinery Inc.	3.42	44.5	1.41	65	0	0	0	0
Total	5.74	74.7		67				

Table D-1 (Continued)

Location ¹	Total Capacity (10 ⁶ m ³) ¹	Total Emission (10 ⁶ g) ²	Emission Rate (g/sec) ²	Population Exposed ² to Benzene (ppb)*				
				0.1-1.0	1.1-2.0	2.1-4.0	4.1-10.0	> 10.0
ILLINOIS								
Blue Island								
Clark Oil and Refining Co.	3.86	50.1	1.59	235	0	0	0	0
Colmar								
Yetter Oil Co.	.06	.8	.02	0	0	0	0	0
Hartford								
Clark Oil and Refining Co.	3.03	39.4	1.25	92	0	0	0	0
Joliet								
Mobil Oil Corp.	10.45	135.8	4.31	87,063	32	2	0	0
Lawrenceville								
Texaco Inc.	4.88	63.4	2.01	590	0	0	0	0
Lemont								
Union Oil Co. of Calif.**	8.76	227.9	7.23	89,134	10	1	0	0
Lockport								
Texaco Inc.	4.18	54.3	1.72	320	0	0	0	0
Plymouth								
Wireback Oil Co. Inc.	.10	1.4	.04	0	0	0	0	0
Robinson								
Marathon Oil Co.	11.32	147.1	4.67	16,067	2	0	0	0
Wood River								
Amoco Oil Co.	5.51	71.7	2.28 ^a					
Shell Oil Co.**	16.43	427.1	13.56	96,529 ⁺	217	14	1	0
Total	68.58	1,287.58		290,020	261	17	1	

Table D-1 (Continued)

Location ¹	Total Capacity (10 ⁶ m ³) ¹	Total Emission (10 ⁶ g) ²	Emission Rate (g/sec) ²	Population Exposed ² to Benzene (ppb)*				
				0.1-1.0	1.1-2.0	2.1-4.0	4.1-10.0	> 10.0
INDIANA								
East Chicago Energy Coop. Inc.	7.31	95.1	3.02	46,312	0	0	0	0
Fort Wayne Gladieux Refinery Inc.	.71	9.2	.29	5	0	0	0	0
Indianapolis Rock Island Refining Corp.	2.53	32.9	1.04	439	0	0	0	0
Laketon Laketon Asphalt Refining Inc.	.47	6.1	.19	0	0	0	0	0
Mt Vernon Indiana Farm Bureau Coop. Association Inc.	.12	1.6	.05	0	0	0	0	0
Princeton Princeton Refinery Inc.	.27	3.5	.11	0	0	0	0	0
Whiting Amoco Oil Co.	21.19	275.4	8.74	71,612 [†]	16	1	0	0
Total	33.31	423.8		118,368	16	1		
KANSAS								
Arkansas City Apco Oil Co.	2.68	34.9	1.11	7	0	0	0	0
Augusta Mobil Oil Corp.	2.90	37.7	1.20	10	0	0	0	0
Chanute Mid Amer Refinery Co.	.18	2.3	.07	0	0	0	0	0
Coffeyville CRA Inc.	2.81	36.5	1.16	9	0	0	0	0

Table D-1 (Continued)

Location ¹	Total Capacity (10 ⁶ m ³) ¹	Total Emission (10 ⁶ g) ²	Emission Rate (g/sec) ²	Population Exposed ² to Benzene (ppb)*				
				0.1-1.0	1.1-2.0	2.1-4.0	4.1-10.0	> 10.0
KANSAS (Cont.)								
El Dorado								
Getty Oil Co.**	4.57	118.8	3.77 ^a					
Pester Refining Co.	1.31	17.0	.54	1,524	0	0	0	0
Kansas City								
Phillips Petr. Co.	5.22	67.9	2.16	11,620	1	0	0	0
McPherson								
Nat. Coop. Refinery Assoc.	3.14	40.9	1.30	14	0	0	0	0
Phillipsburg								
CRA Inc.	15.32	199.2	6.32	6,832	1	0	0	0
Shallow Water								
E-Z Serve	.55	7.2	.23	0	0	0	0	0
Wichita								
Derby Refining Co.	1.45	18.1	.60	83	0	0	0	0
Total	40.13	580.5		20,099	2			
KENTUCKY								
Betsy Layne								
Ky Oil & Refining Co. Inc.	.03	.04	.01	0	0	0	0	0
Catlettsburg								
Ashland Petr. Co.**	7.88	204.9	6.51	24,554	3	0	0	0
Louisville								
Louisville Refining Co.	1.46	19.0	.60	0	0	0	0	0
Somerset								
Somerset Refinery Inc.	.17	2.3	.07	0	0	0	0	0
Total	9.54	226.24		24,554	3			

Table D-1 (Continued)

Location ¹	Total Capacity (10 ⁶ m ³) ¹	Total Emission (10 ⁶ g) ²	Emission Rate (g/sec) ²	Population Exposed ² to Benzene (ppb)*				
				0.1-1.0	1.1-2.0	2.1-4.0	4.1-10.0	> 10.0
LOUISIANA								
Baton Rouge Exxon Co.	29.60	384.8	12.22	201,106 ⁺	1,613	107	7	0
Belle Chasse Gulf Oil Co., Alliance Refinery**	11.4	295.6	9.38	40,200 ⁺	12	1	0	0
Chalmette Tenneco Oil Co.**	4.93	128.3	4.07	3,895	0	0	0	0
Church Point Canal Refining Co.	.26	3.4	.11	0	0	0	0	0
Convent Texaco	8.13	105.6	3.35	1,816	0	0	0	0
Cotton Valley Kerr-McGee Refining Corp.	.64	8.30	.26	0	0	0	0	0
Garyville Marathon Oil Co.	11.61	150.9	4.79	7,376	1	0	0	0
Hosston Bayou St. Oil Corp.	.23	3.0	.10	0	0	0	0	0
Jennings Evangeline Refining Co. Inc.	.29	3.8	.12	0	0	0	0	0
Lake Charles Cities Service Oil Co.	15.56	202.2	6.42 ^a					
Continental Oil Co.	4.82	62.6	1.99	40,204 ⁺	8	0	0	0
Lisbon Claiborne Gasoline Co.	.38	4.9	.16	0	0	0	0	0
Meraux Murphy Oil Co.	5.37	69.8	2.22	362	0	0	0	0

Table D-1 (Continued)

Location ¹	Total Capacity (10 ⁶ m ³) ¹	Total Emission (10 ⁶ g) ²	Emission Rate (g/sec) ²	Population Exposed ² to Benzene (ppb)*				
				0.1-1.0	1.1-2.0	2.1-4.0	4.1-10.0	> 10.0
LOUISIANA (Cont.)								
Metairie								
Good Hope Refineries Inc.	3.86	50.2	1.59	98	0	0	0	0
Norco								
Shell Oil Co.	13.93	181.1	5.75	15,093	2	0	0	0
Port Allen								
Placid Refining Co.	1.99	25.8	.82	7	0	0	0	0
Princeton								
Calumet Refining Co.	.14	1.8	.06	0	0	0	0	0
Shreveport								
Atlas Production Co., Div. of Pennzoil**	2.61	67.9	2.16	12,555	1	0	0	0
St. James								
LaJet Inc.	.83	10.8	.34	0	0	0	0	0
Venice								
Gulf Oil Co.	1.67	21.7	.69	4	0	0	0	0
Total	118.25	1,782.5		322,716	1,637	108	7	
MARYLAND								
Baltimore								
Amoco Oil Co.	.87	11.3	.36 ^a					
Chevron USA Inc.	.78	10.2	.32	489	0	0	0	0
Total	1.65	21.5		489				
MICHIGAN								
Alma								
Total Petroleum Inc.	2.32	30.2	.96	26	0	0	0	0

Table D-1 (Continued)

Location ¹	Total Capacity (10 ⁶ m ³) ¹	Total Emission (10 ⁶ g) ²	Emission Rate (g/sec) ²	Population Exposed ² to Benzene (ppb)*				
				0.1-1.0	1.1-2.0	2.1-4.0	4.1-10.0	> 10.0
MICHIGAN (Cont.)								
Bay City								
Dow Chemical USA	1.21	15.8	.50	63	0	0	0	0
Carson City								
Crystal Refining Co.	.36	4.7	.15	0	0	0	0	0
Detroit								
Marathon Oil Co.	3.77	49.0	1.56	12,007	1	0	0	0
Kalamazoo								
Lakeside Refining Co.	.33	4.2	.13	0	0	0	0	0
West Branch								
Osceola Refinery Div.,								
Texas American Petrochemicals								
Inc.	.72	9.3	.30	0	0	0	0	0
Total	8.71	113.2		12,096	1			
MINNESOTA								
Rosemount								
Koch Refining Co.	7.39	96.1	3.05	746	0	0	0	0
St. Paul Park								
Northwest Refining Co., Div.								
of Ashland Oil Co.	3.83	49.8	1.58	57	0	0	0	0
Wrenshall								
Continental Oil Co.	1.36	17.7	.56	1	0	0	0	0
Total	12.58	163.6		804	0			

Table D-1 (Continued)

Location ¹	Total Capacity (10 ⁶ m ³) ¹	Total Emission (10 ⁶ g) ²	Emission Rate (g/sec) ²	Population Exposed ² to Benzene (ppb)*				
				0.1-1.0	1.1-2.0	2.1-4.0	4.1-10.0	> 10.0
MISSISSIPPI								
Lumberton								
Southland Oil Co.	.33	4.3	.14	0	0	0	0	0
Pascagoula								
Chevron USA Inc.**	16.3	422.5	13.41	49,501	1,032	68	5	0
Purvis								
Amerada-Hess Corp.	1.65	21.5	.68	2	0	0	0	0
Sandersville								
Southland Oil Co.	.60	7.85	.25	0	0	0	0	0
Yazoo City								
Southland Oil Co.	.23	3.0	.10	0	0	0	0	0
Total	19.11	459.2		49,503	1,032	68	5	
MISSOURI								
Sugar Creek								
Amoco Oil Co.	6.21	80.7	2.56	534	0	0	0	0
Total	6.21	80.7		534				
MONTANA								
Billings								
Continental Oil Co.	3.05	39.6	1.26 ^a					
Exxon Co.	2.61	34.0	1.08	22,492	3	0	0	0
Cut Bank								
Westco Refining Co.	.27	3.5	.11	0	0	0	0	0
Great Falls								
Phillips Petroleum Co.	.35	4.5	.14	0	0	0	0	0
Kevin								
Big West Oil Co.	.30	3.87	.12	0	0	0	0	0

Table D-1 (Continued)

Location ¹	Total Capacity (10 ⁶ m ³) ¹	Total Emission (10 ⁶ g) ²	Emission Rate (g/sec) ²	Population Exposed ² to Benzene (ppb)*				
				0.1-1.0	1.1-2.0	2.1-4.0	4.1-10.0	> 10.0
MONTANA (Cont.)								
Laurel								
Cenex	2.35	30.5	.97	1	0	0	0	0
Wolf Point								
Tesoro Petroleum Corp.	.15	1.9	.06	0	0	0	0	0
Total	9.08	117.87		22,493	3			
NEBRASKA								
Scottsbluff								
CRA Inc.	.29	3.8	.12	0	0	0	0	0
Total	.29	3.8		0				
NEW HAMPSHIRE								
Newington								
Atlantic Terminal Corp.	.75	9.8	.31	0	0	0	0	0
Total	.75	9.8		0				
NEW JERSEY								
Bayonne								
National Oil Recovery Corp.	.35	4.5	.14	0	0	0	0	0
Linden								
Exxon Co.	16.54	215.0	6.83	378,786	151	10	1	0
Paulsboro								
Mobil Oil Corp.	5.69	73.9	2.35	5,315	1	0	0	0
Perth Amboy								
Chevron USA Inc.	9.75	126.8	4.02	77,763	41	3	0	0
Westville								
Texaco, Inc.	5.42	66.4	2.12	3,549	0	0	0	0
Total	37.45	486.6		465,413	193	13	1	

Table D-1 (Continued)

Location ¹	Total Capacity (10 ⁶ m ³) ¹	Total Emission (10 ⁶ g) ²	Emission Rate (g/sec) ²	Population Exposed ² to Benzene (ppb)*				
				0.1-1.0	1.1-2.0	2.1-4.0	4.1-10.0	> 10.0
NEW MEXICO								
Artesia								
Novajo Refining Co.	1.74	22.6	.72	0	0	0	0	0
Bloomfield								
Plateau Inc.	.49	6.3	.20 ^a					
Thriftway Co.	.44	5.7	.18	0	0	0	0	0
Ciniza								
Shell Oil Co.	1.04	13.6	.43	0	0	0	0	0
Farmington								
Giant Refining Co. Inc.	.51	6.6	.21	0	0	0	0	0
Kirtland								
Caribou Four Corners Inc.	.17	2.2	.07	0	0	0	0	0
Lovington								
Southern Union Refining Co.	2.23	29.0	.92	1	0	0	0	0
Monument								
Southern Union Refining Co.	.30	3.9	.12	0	0	0	0	0
Total	6.92	96.82		1				
NEW YORK								
Buffalo								
Mobil Oil Corp.	2.50	32.4	1.03	2,412	0	0	0	0
N. Tonawanda								
Ashland Petroleum**	3.71	96.6	3.07	38,107	6	0	0	0
Total	6.21	129.0		40,519	6			

Table D-1 (Continued)

Location ¹	Total Capacity (10 ⁶ m ³) ¹	Total Emission (10 ⁶ g) ²	Emission Rate (g/sec) ²	Population Exposed ² to Benzene (ppb)*				
				0.1-1.0	1.1-2.0	2.1-4.0	4.1-10.0	> 10.0
NORTH DAKOTA								
Dickson								
Northland Oil & Refining Co.	.29	3.8	.12	0	0	0	0	0
Mandan								
Amoco Oil Co.	2.84	37.0	1.17	4	0	0	0	0
Williston								
Westland Oil Co.	.27	3.5	.11	0	0	0	0	0
Total	3.40	44.30		4				
OHIO								
Canton								
Ashland Petroleum Co.	3.71	48.3	1.53	5,877	1	0	0	0
Cleves								
Gulf Oil Co.	2.48	32.2	1.02	54	0	0	0	0
Findlay								
Ashland Petroleum Co.	1.16	15.1	.48	34	0	0	0	0
Lima								
Standard Oil Co. of Ohio	9.75	126.8	4.02	62,124	23	2	0	0
Toledo								
Gulf Oil Co.	2.92	38.0	1.20 ^a					
Standard Oil Co. of Ohio	6.96	90.5	2.87					
Sun Petroleum Prod. Co.	7.26	94.3	2.99	469,013	216	14	1	0
Total	34.24	445.2		537,102	240	16	1	
OKLAHOMA								
Ardmore								
Vickers Petroleum Corp.	3.56	46.2	1.47	34	0	0	0	0

Table D-1 (Continued)

Location ¹	Total Capacity (10 ⁶ m ³) ¹	Total Emission (10 ⁶ g) ²	Emission Rate (g/sec) ²	Population Exposed ² to Benzene (ppb)*				
				0.1-1.0	1.1-2.0	2.1-4.0	4.1-10.0	> 10.0
OKLAHOMA (Cont.)								
Arnett								
Tonkawa Refining Co.	.35	4.52	.14	0	0	0	0	0
Cushing								
Hudson Refining Co. Inc.	1.10	14.3	.46	0	0	0	0	0
Cyril								
Apco Oil Corp.	.81	10.6	.33	0	0	0	0	0
Duncan								
Sun Petroleum Products Inc.	2.81	36.6	1.16	13	0	0	0	0
Enid								
Champlin Petroleum Co.	3.12	40.6	1.29	992	0	0	0	0
Okmulgee								
OKC Refining Co.	1.45	18.9	.60	1	0	0	0	0
Ponca City								
Continental Oil Co.	7.31	95.1	3.02	20,292	2	0	0	0
Stroud								
Allied Materials Corp.	.03	3.6	.11	0	0	0	0	0
Tulsa								
Sun Petroleum Products Inc.**	5.14	133.6	4.24	105,882	12	1	0	0
West Tulsa								
Texaco Inc.	2.90	37.7	1.20	15	0	0	0	0
Wynnewood								
Kerr-McGee Corp.	2.90	37.7	1.20	15	0	0	0	0
Total	31.48	479.42		127,244	14	1		

Table D-1 (Continued)

Location ¹	Total Capacity (10 ⁶ m ³) ¹	Total Emission (10 ⁶ g) ²	Emission Rate (g/sec) ²	Population Exposed ² to Benzene (ppb)*				
				0.1-1.0	1.1-2.0	2.1-4.0	4.1-10.0	> 10.0
OREGON								
Portland								
Chevron USA Inc.	.81	10.6	.34	12	0	0	0	0
Total	.81	10.6		12				
PENNSYLVANIA								
Bradford								
Kendall-Amalie Div., Witco Chemical Co.	.52	6.8	.22	0	0	0	0	0
Emlenton								
Quaker State Oil Refining Corp.	.19	2.5	.98	47	0	0	0	0
Farmers Val								
Quaker State Oil Refining Corp.	.38	4.9	.16	0	0	0	0	0
Freedom								
Valvoline Oil Co. Div. of Ashland Oil Co.	.39	5.1	.16	0	0	0	0	0
Marcus Hook								
BP Oil Corp.	9.34	121.5	3.86 ^a					
Sun Petroleum Products Co.**	9.58	249.0	7.90	128,081 [†]	89	6	0	0
Philadelphia								
Atlantic-Richfield Co.**	10.74	279.2	8.86 ^a					
Gulf Oil Co.**	11.85	308.2	9.78	2,009,462	31,189	2,060	142	4
Reno								
Pennzoil Co. - Wolf's Head Div.	.12	1.6	.05	0	0	0	0	0

Table D-1 (Continued)

Location ¹	Total Capacity (10 ⁶ m ³) ¹	Total Emission (10 ⁶ g) ²	Emission Rate (g/sec) ²	Population Exposed ² to Benzene (ppb)*				
				0.1-1.0	1.1-2.0	2.1-4.0	4.1-10.0	> 10.0
PENNSYLVANIA (Cont.)								
Roseville								
Pennzoil Co. - Wolf's Head Div.	.58	7.5	.24	0	0	0	0	0
Warren								
United Refining Co.	3.02	39.2	1.25	121	0	0	0	0
Total	46.71	1,025.5		2,137,711	31,278	2,066	142	4
TENNESSEE								
Memphis								
Delta Refining Co.	2.55	2.3	1.05	665	0	0	0	0
Total	2.55	2.3		665				
TEXAS								
Abilene								
Pride Refining Co.	2.12	27.5	.87	133	0	0	0	0
Amarillo								
Texaco Inc.	1.16	15.1	.48	23	0	0	0	0
Baytown								
Exxon Co.	22.6	294.3	9.34	65,159 [†]	237	16	1	0
Beaumont								
Mobil Oil Corp.	18.86	245.2	7.78 ^a					
Union Oil Co. of Calif.	6.96	181.1	5.75	134,266	963	64	4	0
Big Spring								
Cosden Oil & Chemical Co.*	3.77	98.1	3.11	28,992	4	0	0	0
Borger								
Phillips Petroleum Co.	5.80	75.5	2.40	276	0	0	0	0
Carrizo Springs								
Tesoro Petroleum Corp.	1.51	19.7	.63	1	0	0	0	0

Table D-1 (Continued)

Location	Total Capacity (10 ⁶ m ³) ¹	Total Emission (10 ⁶ g) ²	Emission Rate (g/sec) ²	Population Exposed ² to Benzene (ppb)*				
				0.1-1.0	1.1-2.0	2.1-4.0	4.1-10.0	> 10.0
TEXAS (Continued)								
Corpus Christi								
Champlin Petroleum Corp.	7.26	188.6	5.99 ^a					
Coastal States Petrochemical Co.	10.7	279.2	8.86					
Howell Corp. **	1.23	31.9	1.01					
Quintana Refining Co. **	1.36	35.3	1.12					
Saber Refining Co.	.54	7.0	.22					
Southwestern Refining Co. Inc. *	6.96	181.1	5.75					
Sun Petroleum Products Co.	3.31	86.0	2.75	216,970 [†]	5,188	343	24	1
Deer Park								
Shell Oil Co. **	17.06	443.7	14.08	22,585	32	2	0	0
El Paso								
Chevron USA Inc. **	4.00	105.6	3.35					
Texaco Inc.	.99	12.8	.41	93,949	11	1	0	0
Eules								
Texas Asphalt Refining Co.	.35	4.5	.14	0	0	0	0	0
Ft. Worth								
Winston Refining Co.	1.16	15.1	.48	21	0	0	0	0
Hearne								
Mid-Tex Refinery	.17	2.3	.07	0	0	0	0	0
Houston								
Atlantic Richfield Co. **	17.76	461.8	14.66					
Charter International Oil Co.	3.77	49.0	1.56					
Crown Central Petroleum Co. **	5.80	150.9	4.79					
Eddy Refining Co.	.18	2.3	.73	1,170,743 [†]	131	9	1	0

Table D-1 (Continued)

Location	Total Capacity (10 ⁶ m ³) ¹	Total Emission (10 ⁶ g) ²	Emission Rate (g/sec) ²	Population Exposed ² to Benzene (ppb)*				
				0.1-1.0	1.1-2.0	2.1-4.0	4.1-10.0	> 10.0
TEXAS (Cont.)								
LaBlanca								
Crystal Oil Co.	.28	3.6	.11	0	0	0	0	0
Longview								
Crystal Oil Co.	.50	6.5	.20	1	0	0	0	0
Mt. Pleasant								
American Petrofina Inc.	1.51	19.6	.63	1	0	0	0	0
Nixon								
Pioneer Refining	.15	1.9	.06	0	0	0	0	0
Odessa								
Shell Oil Co.**	1.86	48.3	1.53	4,327	0	0	0	0
Port Arthur								
American Petrofina Inc.**	6.38	166.0	5.27 ^a					
Gulf Oil Co.**	18.11	471.0	15.0					
Texaco Inc.	23.56	306.3	9.72	60,839	15,798	1,044	72	2
Port Neches								
Texaco Inc.	2.73	35.5	1.13	14	0	0	0	0
Quitman								
Gulf St. Oil & Refining Co.	.24	3.1	.10	0	0	0	0	0
San Antonio								
Flint Chemical Co.	.07	0.9	.03 ^a					
Howell Corp.	.20	2.6	.08	0	0	0	0	0
Silsbee								
South Hampton Co.	1.05	13.7	.43	0	0	0	0	0
Sunray								
Diamond Shamrock Corp.	2.99	38.9	1.23	20	0	0	0	0
Sweeny								
Phillips Petroleum Co.	6.04	78.5	2.49	319	0	0	0	0

Table D-1 (Continued)

Location ¹	Total Capacity (10 ⁶ m ³) ¹	Total Emission (10 ⁶ g) ²	Emission Rate (g/sec) ²	Population Exposed ² to Benzene (ppb)*				
				0.1-1.0	1.1-2.0	2.1-4.0	4.1-10.0	> 10.0
TEXAS (Cont.)								
Texas City								
Amoco Oil Co.**	20.20	525.2	16.67 ^a					
Marathon Oil Co.**	3.83	99.6	3.16					
Texas City Refining Inc.	4.32	56.2	1.78	56,049	2,139	141	10	0
Three Rivers								
Sigmor Refining Co.	.59	7.7	.24	0	0	0	0	0
Tucker								
J&W Refining Inc.	.58	7.5	.24	0	0	0	0	0
Tyler								
LaGloria Oil & Gas Co.	1.70	22.1	.70	118	0	0	0	0
White Deer								
Dorchester Gas Products Co.	.06	.8	.02	0	0	0	0	0
Winnie								
Independent Refining Co.**	.77	19.9	.63	1	0	0	0	0
Young County								
Thriftway Inc.	.06	.8	.02	0	0	0	0	0
Total	243.22	4,949.8		1,854,807	24,503	1,620	112	3
UTAH								
Asphalt Ridge								
Arizona Fuels Corp.	.06	0.8	.02	0	0	0	0	0
North Salt Lake								
Husky Oil Co.	1.33	17.4	.55	0	0	0	0	0
Roosevelt								
Plateau Inc.	.46	6.0	.19	0	0	0	0	0
Salt Lake City								
Amoco Oil Co.	2.26	29.4	.93 ^a					
Chevron USA	2.61	34.0	1.08	10,212	1	0	0	0

Table D-1 (Continued)

Location ¹	Total Capacity (10 ⁶ m ³) ¹	Total Emission (10 ⁶ g) ²	Emission Rate (g/sec) ²	Population Exposed ² to Benzene (ppb)*				
				0.1-1.0	1.1-2.0	2.1-4.0	4.1-10.0	> 10.0
UTAH (Cont.)								
Woods Cross								
Caribou Four Corners Inc.	.41	5.4	.17 ^a					
Morrison Petroleum Co.	.15	1.9	.06					
Phillips Petroleum Co.	1.33	17.4	.55	3	0	0	0	0
Western Refining Co. Inc.	.57	7.4	.23					
Total	9.18	119.7		10,215	1			
VIRGINIA								
Yorktown								
Amoco Oil Co.	3.08	40.0	1.27	60	0	0	0	0
Total	3.08	40.0		60				
WASHINGTON								
Anacortes								
Shell Oil Co.	5.28	68.7	2.18 ^a					
Texaco Inc.	4.53	58.9	1.87	2,388	0	0	0	0
Ferndale								
Atlantic Richfield Co.	5.57	72.4	2.30 ^a					
Mobil Oil Corp.	4.15	53.9	1.71	2,297	0	0	0	0
Seattle								
Chevron USA	.26	3.4	.11	0	0	0	0	0
Tacoma								
Sound Refining Co.	.26	3.40	.11 ^a					
U.S. Oil and Refining Co.	1.24	16.1	.51	95	0	0	0	0
Total	21.29	276.8		4,780				

Table D-1 (Continued)

Location ¹	Total Capacity (10 ⁶ m ³) ¹	Total Emission (10 ⁶ g) ²	Emission Rate (g/sec) ²	Population Exposed ² to Benzene (ppb)*				
				0.1-1.0	1.1-2.0	2.1-4.0	4.1-10.0	> 10.0
WEST VIRGINIA								
Falling Rock Pennzoil Co., Elk Refining Div.	.28	3.7	.12	0	0	0	0	0
Newell Quaker State Oil Refining Corp.	.56	7.3	.23	0	0	0	0	0
St. Marys Quaker State Oil Refining Corp.	.28	3.7	.12	0	0	0	0	0
Total	1.12	14.7						
WISCONSIN								
Superior Murphy Oil Corp.	2.64	34.3	1.09	22	0	0	0	0
Total	2.64	34.3		22				
WYOMING								
Casper Amoco Oil Co.	2.50	32.4	1.03 ^a					
Little American Refining Co.	1.42	18.5	.59					
Texaco Inc.	1.22	15.8	.50	13,084	1	0	0	0
Cheyenne Husky Oil Co.	1.37	17.8	.57	75	0	0	0	0
Cody Husky Oil Co.	.63	8.1	.26	0	0	0	0	0

Table D-1 (Concluded)

Location	Total Capacity (10 ⁶ m ³) ¹	Total Emission (10 ⁶ g) ²	Emission Rate (g/sec) ²	Population Exposed ² to Benzene (ppb)*				
				0.1-1.0	1.1-2.0	2.1-4.0	4.1-10.0	> 10.0
WYOMING (Cont.)								
Cowley								
Sage Creek Refining Co.	.07	.86	.03	0	0	0	0	0
LaBarge								
Mountaineer Refining Co. Inc.	.02	.23	.007					
Southwestern Refining Co.	.03	.4	.01	0	0	0	0	0
Lusk								
C&H Refinery Inc.	.01	.14	.005	0	0	0	0	0
Newcastle								
Tesoro Petroleum Corp.	.61	7.92	.25	0	0	0	0	0
Osage								
Glacier Park Co.	.24	3.09	.10	0	0	0	0	0
Sinclair								
Sinclair Oil Corp.	2.84	37.0	1.17	2	0	0	0	0
Total	10.96	142.24		13,162	1			
Total Exposed Population				6,617,134	63,944	4,223	291	8

a - When more than one refinery is located in a city, it is assumed that they are in approximately the same area and the emission levels are summed.

*To convert to $\mu\text{g}/\text{m}^3$, multiply concentrations by 3.2; to convert to 8-hour worst case, multiply by 10.

**Refineries having catalytic reforming of benzene. Their emission rate is assumed to be twice that of refineries with no benzene production.

†Some population may be exposed to annual average concentrations >0.1 ppb beyond 20 km.