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## Evaluation of the Public Health Risks Associated with Former Manufactured Gas Plants

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Evaluation of the Public Health Risks Associated with Former Manufactured Gas Plants

by

Robin Brewer DeHate

A dissertation submitted in partial fulfillment  
of the requirements for the degree of  
Doctor of Philosophy  
Department of Environmental and Occupational Health  
College of Public Health  
University of South Florida

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Benzene, Inhalation Unit Risk, Cancer

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## Dedication

In loving memory of my father, William Jackson Brewer Sr.; “my life has been a poor attempt to imitate the man” (Dan Fogelberg). I love you Dad.

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First I thank God for the blessings He has given me in my life; the biggest of those being my family. Without the sacrifice, loving support and understanding of my wonderful husband Wade, and my children Alexis, Colin, and Corey, this work would not have been possible. I love you guys. Thanks Mom for always letting me know how much you love me and how proud you are of me. I love you too.

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## Table of Contents

List of Tables .....	iii
List of Figures .....	vii
List of Abbreviations .....	x
Abstract .....	xiii
Chapter One Introduction .....	1
Statement of the Problem.....	1
Chapter Two Health Effects Summary.....	6
Risk Assessment Guidelines.....	12
Integrated Risk Information System (IRIS).....	12
National Toxicology Program (NTP) .....	14
Agency for Toxic Substances and Disease Registry (ATSDR).....	14
International Agency for Research on Cancer (IARC).....	14
Benzene (Benzol, phenyl hydride, CAS #71-43-2) .....	15
Toluene (methylbenzene, toluol, CAS # 108-88-3).....	17
Ethylbenzene (Ethylbenzol, CAS # 100-41-4).....	18
Xylene Isomers (Xylenes, CAS # 1330-20-7, meta-Xylene, CAS # 108-38-3) (para-Xylene, CAS # 106-42-3)(ortho-Xylene, CAS # 95-47-6).....	20
Chapter Three Methods and Materials.....	25
Study Description.....	25
Risk Assessment .....	31
Chapter Four Results.....	34
Chapter Five Discussion and Conclusions.....	106

List of References .....	112
Bibliography .....	117
About the Author .....	End Page

## List of Tables

Table 1.	Carcinogens Associated with MGPs.....	7
Table 2.	Frequency of Detected Chemicals for No Vadose Zone .....	8
Table 3.	Frequency of Detected Chemicals for 0- 6 feet Vadose Zone .....	9
Table 4.	Frequency of Detected Chemicals for 6 – 25 feet Vadose Zone .....	11
Table 5.	Inhalation Reference Concentration (RfC) Summary.....	22
Table 6.	Inhalation Unit Risk (IUR) Summary.....	23
Table 7.	Weight of Evidence (WOE) Information Summary .....	24
Table 8.	EPA 2001 Building Assessment and Survey Evaluation (BASE) Background Concentrations for Indoor Air (ug/m <sup>3</sup> ).....	35
Table 9.	EPA 2001 Building Assessment and Survey Evaluation (BASE) Background Concentrations for Outdoor Air (ug/m <sup>3</sup> ) .....	35
Table 10.	NYSDOH 2003 Study of Volatile Organic Chemicals in Air of Fuel Oil Heated Homes (ug/m <sup>3</sup> ) – Indoor Air.....	36
Table 11.	NYSDOH 2003 Study of Volatile Organic Chemicals in Air of Fuel Oil Heated Homes (ug/m <sup>3</sup> ) – Outdoor Air.....	36
Table 12.	Maximum Concentrations of Benzene in Indoor Air versus Soil Vapor for Locations with No Vadose Zone.....	37
Table 13.	Maximum Concentrations of Benzene in Indoor Air versus Soil Vapor for Locations with 0 - 6 Feet Vadose Zone.....	40

Table 14. Maximum Concentrations of Benzene in Indoor Air versus Soil Vapor for Locations with 6 - 25 Feet Vadose Zone.....	42
Table 15. Maximum Concentrations of Toluene in Indoor Air versus Soil Vapor for Locations with No Vadose Zone.....	43
Table 16. Maximum Concentration of Toluene by Location with 0- 6 feet Vadose Zone .....	46
Table 17. Maximum Concentration of Toluene by Locations with 6 -25 feet Vadose Zone .....	48
Table 18. Maximum Concentration of Ethylbenzene by Location with No Vadose Zone .....	49
Table 19. Maximum Concentrations for Ethylbenzene by Location for Indoor Air vs Soil Vapor 0-6 Feet Vadose Zone.....	51
Table 20. Maximum Concentrations for Ethylbenzene by Location for Indoor Air vs Soil Vapor 6- 25 Feet Vadose Zone.....	53
Table 21. Maximum Concentrations for m,p-Xylene by Location for Indoor Air vs Soil Vapor No Vadose Zone .....	54
Table 22. Maximum Concentrations for m,p-Xylene by Location for Indoor Air vs Soil Vapor 0-6 Feet Vadose Zone .....	57
Table 23. Maximum Concentrations for m,p-Xylene by Location for Indoor Air vs Soil Vapor 6-25 Feet Vadose Zone .....	59
Table 24. Maximum Concentrations for o-Xylene by Location for Indoor Air vs Soil Vapor No Vadose Zone.....	60
Table 25. Maximum Concentrations for o-Xylene by Location for Indoor Air vs Soil Vapor 0-6 Feet Vadose Zone.....	62
Table 26. Maximum Concentrations for o-Xylene by Location for Indoor Air vs Soil Vapor 6-25 Feet Vadose Zone.....	63



Table 27. Minimum, Maximum and Mean Concentrations of Detected Chemicals in Outdoor Air by Thickness of Vadose Zone (ug/m <sup>3</sup> ).....	77
Table 28. Minimum and Maximum Concentrations of Detected Chemicals in Indoor Air by Thickness of Vadose Zone (ug/m <sup>3</sup> ).....	78
Table 29. Minimum and Maximum Concentrations of Detected Chemicals in Soil Vapor by Thickness of Vadose Zone (ug/m <sup>3</sup> ).....	79
Table 30. Summary Table of Minimum, Maximum and Mean Concentrations of Highest Frequency Chemicals in Outdoor Air by Thickness of Vadose Zone (ug/m <sup>3</sup> ).....	80
Table 31. Summary Table of Minimum, Maximum and Mean Concentrations of Highest Frequency Chemicals in Indoor Air by Thickness of Vadose Zone (ug/m <sup>3</sup> ).....	80
Table 32. Summary Table of Minimum, Maximum and Mean Concentrations of Highest Frequency Chemicals in Soil Vapor by Thickness of Vadose Zone (ug/m <sup>3</sup> ).....	80
Table 33. Hazard Indices for Mean Concentrations for Indoor Air by Vadose Zone .....	81
Table 34. Hazard Indices for Maximum Concentrations for Indoor Air by Vadose Zone .....	81
Table 35. Hazard Indices for Mean Concentrations for Soil Vapor by Vadose Zone .....	82
Table 36. Hazard Indices for Maximum Concentrations for Soil Vapor by Vadose Zone .....	83
Table 37. Hazard Indices for Mean Concentrations for Outdoor Air by Vadose Zone .....	83
Table 38. Hazard Indices for Maximum Concentrations for Outdoor Air by Vadose Zone .....	84

Table 39. Hazard Indices for DOH Background Maximum, Mean and 95 <sup>th</sup> Percentile Concentrations for Indoor Air.....	84
Table 40. Hazard Indices for DOH Background Maximum, Mean and 95 <sup>th</sup> Percentile Concentrations for Outdoor Air.....	85
Table 41. Hazard Indices for EPA Background Maximum, Mean and 95 <sup>th</sup> Percentile Concentrations for Indoor Air.....	85
Table 42. Hazard Indices for EPA Background Maximum, Mean and 95 <sup>th</sup> Percentile Concentrations for Outdoor Air.....	86
Table 43. Cancer Inhalation Risks for Benzene Mean Concentrations for Indoor Air from Study Results and EPA/DOH Background.....	93
Table 44. Cancer Inhalation for Benzene Maximum Concentrations for Indoor Air from Study Results and EPA/DOH Background.....	94
Table 45. Cancer Inhalation Risks for Benzene Mean Concentrations for Soil Vapor from Study Results and EPA/DOH Background.....	96
Table 46. Cancer Inhalation Risks for Benzene Maximum Concentrations for Soil Vapor from Study Results and EPA/DOH Background.....	97
Table 47. Cancer Inhalation Risks for Benzene Mean Concentrations for Outdoor Air from Study Results and EPA/DOH Background.....	98
Table 48. Cancer Inhalation Risks for Benzene Maximum Concentrations for Outdoor Air from Study Results and EPA/DOH Background.....	99

## List of Figures

Figure 1. Example of Collection of Indoor Air Samples using Summa® or equivalent canisters .....	28
Figure 2. Example of Collection of Soil Vapor Sample from a Temporary Soil Vapor Point using a Summa® or equivalent canister .....	29
Figure 3. Maximum Concentration of Benzene by Locations with No Vadose Zone .....	39
Figure 4. Maximum Concentration of Benzene by Locations with 0 – 6 feet Vadose Zone .....	41
Figure 5. Maximum Concentration of Benzene by Locations with 6 -25 feet Vadose Zone .....	42
Figure 6. Maximum Concentration of Toluene by Location with No Vadose Zone .....	45
Figure 7. Maximum Concentration of Toluene by Locations with 0- 6 feet Vadose Zone .....	47
Figure 8. Maximum Concentration of Toluene by Locations with 6 - 25 feet Vadose Zone .....	48
Figure 9. Maximum Concentration of Ethylbenzene by Locations with No Vadose Zone .....	50
Figure 10. Maximum Concentration of Ethylbenzene by Locations with 0- 6 feet Vadose Zone .....	52
Figure 11. Maximum Concentration of Ethylbenzene by Locations with .....	53
Figure 12. Maximum Concentration of m,p-Xylene by Location with No Vadose Zone .....	56

Figure 13. Maximum Concentration of m,p-Xylene by Location with 0-6 feet Vadose Zone .....	58
Figure 14. Maximum Concentration of m,p-Xylene by Locations with 6 - 25 feet Vadose Zone .....	59
Figure 15. Maximum Concentration of o-Xylene by Location with No Vadose Zone .....	61
Figure 16. Maximum Concentration of o-Xylene by Location with 0-6 feet Vadose Zone .....	63
Figure 17. Maximum Concentration of o-Xylene by Locations with 6 - 25 feet Vadose Zone .....	64
Figure 18. Difference in Frequency of Detections between Outdoor Air and Indoor Air with No Vadose Zone. ....	68
Figure 19. Difference in Frequency of Detections between Outdoor Air and Indoor Air with a 0-6 Foot Vadose Zone.....	69
Figure 20. Difference in Frequency of Detections between Outdoor Air and Indoor Air with a 6-25 Foot Vadose Zone.....	70
Figure 21. Difference in Frequency of Detections between Indoor Air and Soil Vapor with No Vadose Zone. ....	71
Figure 22. Difference in Frequency of Detections between Indoor Air and Soil Vapor with a 0-6 Foot Vadose Zone.....	72
Figure 23. Difference in Frequency of Detections between Indoor Air and Soil Vapor with a 6-25 foot Vadose Zone.....	73
Figure 24. Difference in Frequency of Detections between Outdoor Air and Soil Vapor with No Vadose Zone. ....	74
Figure 25. Difference in Frequency of Detections between Outdoor Air and Soil Vapor with a 0-6 foot Vadose Zone.....	75

Figure 26. Difference in Frequency of Detections between Outdoor Air and Soil Vapor with a 6-25 foot Vadose Zone.....	76
Figure 27. Hazard Index Comparison for Outdoor Air Mean Concentrations.....	87
Figure 28. Hazard Index Comparison for Outdoor Air Maximum Concentrations.....	88
Figure 29. Hazard Index Comparison for Indoor Air Mean Concentrations.....	89
Figure 30. Hazard Index Comparison for Indoor Air Maximum Concentrations.....	90
Figure 31. Hazard Index Comparison for Soil Vapor Mean Concentrations.....	91
Figure 32. Hazard Index Comparison for Soil Vapor Maximum Concentrations.....	92
Figure 33. Inhalation Cancer Risks for Benzene Indoor Air Mean Concentrations.....	100
Figure 34. Inhalation Cancer Risks for Benzene Indoor Air Maximum Concentrations.....	101
Figure 35. Inhalation Cancer Risks for Benzene Soil Vapor Mean Concentrations.....	102
Figure 36. Inhalation Cancer Risks for Benzene Soil Vapor Maximum Concentrations.....	103
Figure 37. Inhalation Cancer Risks for Benzene Outdoor Air Mean Concentrations.....	104
Figure 38. Inhalation Cancer Risks for Benzene Outdoor Air Maximum Concentrations.....	105

## List of Abbreviations

ATSDR	Agency for Toxic Substances and Disease Registry
BASE	Building Assessment and Survey Evaluation
BMCL	Benchmark Concentration Level
BTEX	Benzene, Toluene, Ethylbenzene, Xylene
BTX	Benzene, Toluene, Xylene
CAS(RN)	Chemical Abstract Service Registry Number
CNS	Central Nervous System
CWG	Carburetted Water Gas
DOH	New York State Department of Health
ECG	Electrocardiogram
ECD	Electron Capture Detector
EPA	United States Environmental Protection Agency
EPRI	Electric Power Research Institute
FID	Flame Ionization Detector
GC/MS	Gas Chromatography Mass Spectrophotometry
HEC	Human Equivalence Concentration
HI	Hazard Index
HQ	Hazard Quotient

IARC	International Agency for Research on Cancer
IAIR	Indoor Air
IUR	Inhalation Unit Risk
LCS	Laboratory Control Sample
MGP	Manufactured Gas Plant
MRL	Minimum Risk Level
MS	Matrix Spike
MSD	Matrix Spike Duplicate
NAPL	Non-aqueous Phase Liquid
ND	Non-detect
NIOSH	National Institute of Occupational Safety and Health
NLM	National Library of Medicine
NOAEL	No Observable Adverse Effects Level
NRC	National Research Council
NTP	National Toxicology Program
NV	No Vadose
NYSDOH	New York State Department of Health
OAIR	Outdoor Air
PAHs	Polycyclic Aromatic Hydrocarbons
PID	Photoionization Detector
POD	Point of Departure
RfC	Reference Concentration

RfD	Reference Dose
RoC	Report on Carcinogens
SV	Soil Vapor
SVI	Soil Vapor Intrusion
SVOCs	Semi-volatile Organic Compounds
USEPA	United States Environmental Protection Agency
US	United States of America
VOCs	Volatile Organic Compounds
WOE	Weight of Evidence



# Evaluation of the Public Health Risks Associated with Former Manufactured Gas Plants

Robin Brewer DeHate

## ABSTRACT

Regulatory agencies have recently focused on assessing the potential for soil vapor intrusion (SVI) and risk posed to occupants of residential and commercial properties overlying and surrounding former Manufactured Gas Plants (MGPs). This study evaluated the potential for SVI at 10 commercial buildings and 26 single family and multi-family residential properties overlying and/or adjacent to three former MGPs. The potential for SVI exposure was categorized into three groupings according to thickness of the vadose zones: no vadose zone; 0 - 6 feet thick, and 6 to 25 feet thick.

Indoor and outdoor air and soil vapor samples were collected and analyzed for VOCs by the USEPA Method TO-15. These findings were compared to federal and state regulatory background data sets. The results did not identify evidence of MGP-related soil vapor intrusion from any of the 36 sites regardless of depth to water table or proximity to MGP source tar or dissolved phase plumes.

In addition, comparative risks were calculated based on maximum and mean concentrations for benzene, toluene, ethylbenzene, and xylenes measured in ambient air samples, soil vapor, and indoor air. These chemicals were selected based on frequency of detection within the data sets. Hazard Indexes were calculated using the study results and

the mean, maximum and 95<sup>th</sup> percentile concentrations from regulatory data bases. Carcinogenic risks associated with benzene were calculated using both the measured mean and maximum study results and the mean, maximum and 95<sup>th</sup> percentile concentrations from state and federal data bases. The calculated Hazard Indexes were less than 1 or were comparable to the regulatory mean and maximum background levels. Calculated cancer risks for residential and occupational exposures ranged from  $9.75 \times 10^{-6}$  to  $4.52 \times 10^{-4}$ . However background benzene exposure not related to former MGP sites ranged from  $9.9 \times 10^{-6}$  to  $3.59 \times 10^{-3}$ .

Cancer risk and exposures to indoor air, soil vapor or ambient air concentrations were equivalent or less than a normal resident in the northeast United States. No increased public health risks were associated with occupied residential or commercial properties overlying or surrounding MGPs.

## Chapter One

### Introduction

#### *Statement of the Problem*

Manufactured Gas Plants (MGP) have historically been used for generating local supplies of coal gas for decades during the early part of the 20<sup>th</sup> century. Manufactured gas supplied lighting, refrigeration, and heating to cities and encouraged the growth and development of the United States (US). Although the coal gasification process generated a valuable product it also generated waste products that, ultimately, contaminated the soil and groundwater surrounding these sites. With the advent of natural gas many of these manufactured gas systems were either converted from the use of coal to natural gas or abandoned. As a result of these activities, there are over 1,500 abandoned MGP sites in the US that present potential public health risks today (EPRI, 2008). The cost of remediation of these MGP sites range from one million dollars to tens of millions of dollars (EPRI, 2008). Without knowledge of the potential contamination associated with these former MGP sites many of these abandoned sites and the properties immediately abutting or adjacent to them, were redeveloped for residential and/or commercial purposes.

Three processes were used to produce manufactured coal gas:

- Coal Carbonization
- Carbureted Water Gas (CWG)

- Oil Gas.

Coal carbonization, used exclusively until 1875, heated bituminous coal in closed retorts with limited air contact. The gas was collected, cooled, and purified for use, while the coke was removed and sold or used. The gas was then measured, stored, and delivered to customers via underground pipes (EPA, 2004).

The carbureted water gas process, introduced in the 1875, involved heating coal or coke in a generator into which steam was injected. Steam was fed through a bed of incandescent coke, producing a gas containing hydrogen and carbon monoxide. This gas (blue gas) then passed through two chambers containing hot firebrick, where oil was sprayed into the gas and cracked into gaseous hydrocarbons and tar (Harkins, et.al., 1986).

The most common oil gas process was patented in 1889. It is similar to the carbureted water gas process with a vaporizer replacing the carburetor. Oil was added to the reactor thereby generating more heat. The oil vapors were thermally cracked into gaseous hydrocarbons, tar, and carbon (lampblack) (Harkins, et.al., 1986).

All of these processes generated a dense, oily liquid by-product known as coal tar. While the coal tar was a valuable by-product with many industrial uses, routine leaks and spills occurred that contaminated surface soils, subsurface soils, and groundwater. From 1880 to 1950, MGPs produced approximately 15 trillion cubic feet of gas and approximately 11 billion gallons of tar as a by-product resulting in thousands of contaminated acres of land and millions of gallons of impacted water (Fischer et al, 1999).

These contaminated sites have been targeted by both federal and state environmental agencies for assessment and remediation. Previous assessments of these sites concentrated on the condition of the soil and groundwater at and surrounding these sites, however recent state and federal regulatory agencies have focused on the potential hazards associated with soil vapor. Soil vapor intrusion (SVI) assessments of volatile chemicals associated with manufactured gas are being routinely required by environmental regulatory agencies to evaluate the potential risks posed to residents and occupants of commercial properties overlying and surrounding former MGP sites.

The purpose of this research was to evaluate the potential public health risks associated with former MGP sites to the human population located in residences and businesses adjacent to or above these contaminated sites. Specifically, 1) What contaminants are present in the soil vapor, the indoor air, and the ambient outdoor air; 2) Is the presence of chemical contaminants in the indoor air of these residences and commercial buildings the result of soil vapor intrusion; 3) What are the potential public health risks posed by these contaminants; and 4) Is this adjacent human population at greater risk of adverse health effects than that of a normal resident in the northeastern US.

The goal of this risk assessment research is to evaluate whether there are complete exposure pathways from soil vapor to indoor air. In order for a complete exposure pathway to exist, vapors from MGP-related constituents would need to migrate through various pathways into residential or commercial buildings at concentrations that could result in an unacceptable human health risk.

This study evaluated a total of 10 commercial and 26 single family and multi-family residential properties that were potentially affected by SVI associated with the

three former MGPs. All of these properties had potable water from municipal water sources. Each of the sites included in this study were located in the northeastern US. This study evaluated the potential for SVI for properties overlying and immediately abutting MGP tar source material and properties overlying and adjacent to dissolved phased benzene, toluene, ethylbenzene and xylene (BTEX) and naphthalene plumes emanating from the MGPs.

Further evaluation of the potential for SVI exposure was conducted to evaluate whether depth to groundwater influenced the potential for SVI by categorizing each of the sites into three groupings according to depth to the water table: no vadose zone; water table within 6 feet of the building slab (0-6 Feet Vadose Zone); and water table between 6 and 25 feet of the building slab (6-25 Feet Vadose Zone). Vadose zone is defined by the Britannica Encyclopedia (2008) as the region of aeration above the water table. This zone includes the capillary fringe above the water table, the height of which will vary according to the grain size of the sediments.

In addition, comparative risk assessments were conducted on the five most frequently detected chemicals in the indoor air of the sampled buildings. These include benzene, toluene, ethylbenzene, m,p-xylene, and o-xylene. For benzene, a known human carcinogen (NTP, 2005), cancer risk calculations were computed for the mean and maximum concentrations of benzene detected in the sample groups. For the non-carcinogenic chemicals, toluene, ethylbenzene, m,p-xylene, and o-xylene, hazard indices were calculated for both the mean and maximum concentrations detected in the sample groups.

The hypothesis that was tested was: Indoor air levels of volatile organic compounds are influenced by soil vapor concentrations from former MGP sites resulting in an increased risk of adverse health effects for residents or occupants of buildings near or adjacent to these abandoned sites.

## Chapter Two

### Health Effects Summary

Manufactured gas plants provided a major source of fuel for heating and lighting in many communities prior to the introduction of interstate natural gas pipelines in the 1950s. 1,500 to 3,000 plants were in operation in the United States during the period from the early 1800s to the 1960s, (EPRI, 1999). According to the EPA 3,000 – 5,000 MGP formerly operated in the US (EPA, 1999a).

Coal tar and petroleum products derived from the coal gasification process contain both volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs). Many of these compounds, residuals from the manufacturing process, impacted the soils and groundwater of these former plants. The VOCs consist of a mixture of benzene, toluene, ethylbenzene, xylene isomers (BTEX), benzothiophene, carbon disulfide, n-decane, n-dodecane, 2-ethylthiophene, indan, indene, 2-methylthiophene, 3-methylthiophene, nonane, styrene, 1,2,4,5-tetramethylbenzene, thiophene, 1,2,3-trimethylbenzene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, and n-undecane.

The SVOCs consist of a mixture of acenaphthene, acenaphthylene, anthracene, benz(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, benzo(e)pyrene, benzo(g,h,i)perylene, chrysene, dibenz(a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3-cd)pyrene, 2-methyl naphthalene, naphthalene, phenanthrene, phenols, and pyrene. Of these SVOCs naphthalene and 2-methyl naphthalene are the



semi-volatile components of coal tar most likely to be associated with soil vapor intrusion due to their volatility.

These compounds can be present within sub-surface soils or as a dissolved phase groundwater plume. In some cases, these chemical components may be present in non-aqueous phase liquids (NAPL) such as fuels, oils, or tar.

The following table categorizes potentially MGP-related compounds as known, probable or possible carcinogens and the agencies that have classified them as such:

Table 1. Carcinogens Associated with MGPs

<b>Source:</b>	<b>NTP<sup>1</sup></b>	<b>EPA<sup>2</sup></b>	<b>IARC<sup>3</sup></b>
<b>Benzene</b>	X	X	X
Benz[a]anthracene	X	X	X
Benzo[a]pyrene	X	X	X
Benzo[b]fluoranthene	X	X	X
Benzo[k]fluoranthene	X	X	X
Chrysene		X	
Dibenz[a,h]anthracene	X	X	X
Indeno[1,2,3-cd]pyrene	X	X	X
Naphthalene	X	X	X
Styrene			X

**Bolding indicates known carcinogen**

<sup>1</sup>National Toxicology Program, 2005

<sup>2</sup> U.S. Environmental Agency, 2005

<sup>3</sup> International Agency for Research on Cancer, 2002

Of the above listed known, probable or possible carcinogens only benzene was detected at a high enough frequency in the sample groups to be considered for further evaluation. For the non-carcinogenic chemicals toluene, ethylbenzene, and the xylene isomers had the greatest frequency of detections in the sample groups.

The highest percentage of detections in the outdoor air in the No Vadose Zone sample set for chemicals were benzene, toluene, m,p-xylene, ethylbenzene, and o-xylene, respectively, as listed in Table 2. The highest percentage of detections in the indoor air in the No Vadose Zone sample set for chemicals were benzene, toluene, m,p-xylene, ethylbenzene, and o-xylene, respectively. The highest percentage of detections in soil vapor in the No Vadose Zone sample set for chemicals were toluene, benzene, n-undecane, m,p-xylene, and ethylbenzene, respectively.

Table 2. Frequency of Detected Chemicals for No Vadose Zone

	No Vadose Zone		
	Frequency of Detection	Frequency of Detection	Frequency of Detection
Chemical Name	Outdoor Air	Indoor Air	Soil Vapor
Benzene	24%	11%	10%
Benzothiophene	0%	0%	1%
Carbon disulfide	3%	2%	7%
Decane, n-	1%	6%	7%
Dodecane, n-	3%	5%	5%
Ethylbenzene	9%	9%	6%
Ethylthiophene, 2-	0%	0%	0%
Indan	0%	2%	2%
Indene	0%	0%	3%
Methylnaphthalene, 1-	0%	1%	1%
Methylnaphthalene, 2-	0%	1%	2%
Methylthiophene, 2-	0%	0%	0%
Methylthiophene, 3-	0%	0%	0%
Naphthalene	0%	2%	4%
Nonane	1%	5%	5%
Styrene	0%	3%	4%
Tetramethylbenzene 1,2,4,5-	0%	2%	2%

Table 2. (continued)

Thiophene	0%	0%	1%
Toluene	27%	12%	11%
Trimethylbenzene 1,2,3-	0%	3%	4%
Trimethylbenzene 1,2,4-	0%	5%	5%
Trimethylbenzene 1,3,5-	0%	3%	2%
Undecane, n-	3%	7%	7%
Xylene, m,p-	20%	11%	7%
Xylene, o-	7%	8%	5%

Summarized in Table 3, the highest percentage of detections in the outdoor air in the 0 – 6 feet thick Vadose Zone sample set for chemicals were toluene, m,p-xylene, benzene, ethylbenzene, and o-xylene, respectively. The highest percentage of detections in the indoor air in the 0 – 6 feet thick Vadose Zone sample set for chemicals were o-xylene, toluene, benzene, m,p-xylene, ethylbenzene, n-decane, and n-undecane respectively. The highest percentage of detections in soil vapor in the 0-6 feet thick Vadose Zone sample set for chemicals were toluene, benzene, carbon disulfide, n-decane, m,p-xylene, and n-undecane, respectively.

Table 3. Frequency of Detected Chemicals for 0- 6 feet Vadose Zone

	<b>0-6 feet Vadose Zone</b>		
	<b>Frequency of Detection</b>	<b>Frequency of Detection</b>	<b>Frequency of Detection</b>
<b>Chemical Name</b>	<b>Outdoor Air</b>	<b>Indoor Air</b>	<b>Soil Vapor</b>
Benzene	13%	8%	10%
Benzothiophene	0%	0%	1%

Table 3.(continued)

Carbon disulfide	1%	2%	7%
Decane, n-	6%	7%	7%
Dodecane, n-	6%	6%	5%
Ethylbenzene	7%	7%	6%
Ethylthiophene, 2-	0%	0%	0%
Indan	1%	2%	2%
Indene	0%	0%	3%
Methylnaphthalene,1-	0%	2%	1%
Methylnaphthalene,2-	1%	3%	2%
Methylthiophene, 2-	0%	0%	0%
Methylthiophene, 3-	0%	0%	0%
Naphthalene	1%	3%	4%
Nonane	4%	5%	5%
Styrene	1%	3%	4%
Tetramethylbenzene1,2,4,5-	0%	2%	2%
Thiophene	1%	0%	1%
Toluene	16%	10%	11%
Trimethylbenzene 1,2,3-	4%	3%	4%
Trimethylbenzene 1,2,4-	6%	6%	5%
Trimethylbenzene 1,3,5-	3%	3%	2%
Undecane, n-	4%	7%	7%
Xylene, m,p-	13%	10%	7%
Xylene, o-	7%	8%	5%

As summarized in Table 4 the highest percentage of detections in the outdoor air in the 6- 25 feet thick Vadose Zone sample set for chemicals were toluene, m,p-xylene, o-xylene, benzene, n-decane, 1,2,4-trimethylbenzene, and n-undecane respectively. The highest percentage of detections in the indoor air in the 6- 25 feet thick Vadose Zone sample set for chemicals were benzene, n-decane, n-dodecane, ethylbenzene, nonane, toluene, n-dodecane, m,p-xylene, and o-xylene, respectively. The highest percentage of

detections in soil vapor in the 6- 25 feet thick Vadose Zone sample set for chemicals were toluene, m,p-xylene, n-undecane, nonane, 1,2,4,5-tetramethylbenzene, ethylbenzene, n-decane, n-dodecane, and naphthalene respectively.

Table 4. Frequency of Detected Chemicals for 6 – 25 feet Vadose Zone

	6-25 feet Vadose Zone		
	Frequency of Detection	Frequency of Detection	Frequency of Detection
Chemical Name	Outdoor Air	Indoor Air	Soil Vapor
Benzene	9%	7%	5%
Benzothiophene	0%	0%	0%
Carbon disulfide	0%	1%	3%
Decane, n-	9%	7%	6%
Dodecane, n-	6%	7%	6%
Ethylbenzene	6%	7%	6%
Ethylthiophene, 2-	0%	0%	0%
Indan	0%	2%	4%
Indene	0%	0%	1%
Methylnaphthalene, 1-	0%	2%	3%
Methylnaphthalene, 2-	6%	3%	4%
Methylthiophene, 2-	0%	0%	0%
Methylthiophene, 3-	0%	0%	0%
Naphthalene	3%	5%	6%
Nonane	6%	7%	6%
Styrene	0%	4%	5%
Tetramethylbenzene 1,2,4,5-	0%	3%	6%
Thiophene	0%	0%	0%
Toluene	11%	7%	7%
Trimethylbenzene 1,2,3-	6%	5%	5%
Trimethylbenzene 1,2,4-	9%	6%	5%

Table 4.(continued)

Trimethylbenzene 1,3,5-	0%	2%	4%
Undecane, n-	9%	7%	6%
Xylene, m,p-	11%	7%	7%
Xylene, o-	11%	7%	5%

*Risk Assessment Guidelines*

The National Research Council defines risk assessment as the characterization of the potential adverse health effects of human exposures to environmental hazards (NRC, 1983). In addition risk assessment includes the potential for health effects based on an evaluation of results of epidemiologic, clinical, toxicologic, and environmental research; extrapolation from those results to predict the type and estimate the extent of health effects in humans under given conditions of exposures; judgments as to the number and characteristics of persons exposed at various intensities and durations; and summary judgments on the existence and overall magnitude of the public-health problem. Risk assessment also includes characterization of the uncertainties inherent in the process of inferring risk (NRC, 1983). The USEPA and other federal and state agencies have developed risk assessment guidelines consistent with those of the NRC.

Sources used for this risk assessment include the USEPA’s Integrated Risk Information System (IRIS), the National Toxicology program (NTP), the Agency for Toxic Substances and Disease Registry (ATSDR), and the International Agency for Cancer Research (IARC).

*Integrated Risk Information System (IRIS).* The Integrated Risk Information System (IRIS), prepared and maintained by the EPA’s National Center for Environmental

Assessment (NCEA), is an electronic database containing information on human health effects that may result from exposure to various substances in the environment (EPA, 2008). Originally designed for internal use by the U.S. EPA, IRIS is now a publicly available repository of health effects information on over 500 chemicals found in the environment (Persad et al., 2008). This information database contains descriptive and quantitative information for both non-cancer and cancer effects of substances. The term “substances” is used to include chemicals, and other forms of hazardous materials including radiation and biological agents. For non-cancer effects oral reference doses (RfDs) and inhalation reference concentrations (RfCs) are developed generally for the non-carcinogenic effects of substances. Both RfCs and RfDs are estimates of daily exposure that are likely to be without an appreciable risk of any adverse effect over a lifetime (Persad et al., 2008).

The USEPA developed weight-of-evidence (WOE) used to describe a substance’s potential to cause cancer in humans and the conditions under which the carcinogenic effects may be expressed. In the past the USEPA utilized categories A through E to describe carcinogenic risk of substances. Since 2005, the USEPA has utilized a narrative approach to characterize carcinogenicity. Five standard weight-of-evidence descriptors *Carcinogenic to Humans, Likely to Be Carcinogenic to Humans, Suggestive Evidence of Carcinogenic Potential, Inadequate Information to Assess Carcinogenic Potential, and Not Likely to Be Carcinogenic to Humans* are now used to characterize carcinogenicity (IRIS, 2008).

The USEPA has also developed cancer slope factors (ingestion) and unit risks (inhalation) used to estimate the risk of cancer associated with exposure to a carcinogenic

or potentially carcinogenic substance. The slope factor is an upper bound estimate, approximating a 95% confidence limit, on the increased cancer risk from a lifetime exposures to an agent by ingestion generally expressed in units of proportion (of a population) affected per mg of substance/kg body weight-day. A unit risk is an upper-bound excess lifetime cancer risk estimated to result from continuous exposure to an agent at a concentration of 1 µg/L in water or 1 µg/m<sup>3</sup> in air (IRIS, 2008).

*National Toxicology Program (NTP).* This federal agency, found in the National Institutes of Health (NIH) in the United States Department of Health and Human Services (DHHS), evaluates agents of public health concern and publishes a biennial report known as the Report on Carcinogens (RoC). This report contains a list of all known human carcinogens or reasonably be anticipated to be human carcinogens to which a significant number of persons residing in the United States are exposed. The RoC does not present quantitative assessment of the risks of cancer nor the exposure conditions associated with these substances (NTP, 2005).

*Agency for Toxic Substances and Disease Registry (ATSDR).* The ATSDR, another agency of the DHHS located in the Center for Disease Control and Registry, by congressional mandate, has specific functions concerning the effect on public health of hazardous substances in the environment. ATSDR publishes minimum risk levels (MRLs) for many hazardous substances. The MRLs are estimates of exposure levels for substances that are estimated to be without an appreciable risk of adverse health effects over a specified duration (ATSDR, 2008).

*International Agency for Research on Cancer (IARC).* A branch of the World Health Organization, IARC conducts research on environmental carcinogens and



established strength of evidence categories for them. This strength of evidence categories are: Group 1A *Carcinogenic to Humans (105 agents)*; Group 2A *Probably Carcinogenic to Humans (66 agents)*; Group 2B *Possibly Carcinogenic to Humans (248 agents)*; Group 3 *not classifiable as to its carcinogenicity to humans (515 agents)*; and Group 4 *probably not carcinogenic to humans (1 agent)* (IARC, 2008).

Based on the frequency of detection in the sample groups, the assessment of public health risks from potential soil vapor intrusion from former MGP sites will be conducted on the five chemicals with the highest level of detections: benzene, toluene, ethylbenzene, m,p-xylene, and o-xylene.

*Benzene (Benzol, phenyl hydride, CAS #71-43-2).* Benzene is a colorless to light-yellow liquid with an aromatic odor (NIOSH, 2003, 2005). It is used as a gasoline additive, and can be found in cigarette smoke, petroleum, and as a consequence of biomass combustion. It is also found to occur naturally in some foods (Harbison 1998).

Benzene is found in the air from emissions from burning coal and oil, gasoline service stations, and motor vehicle exhaust (EPA, 2000). Benzene was first discovered and isolated from coal tar in the 1800s but today, benzene is made mostly from petroleum. Because of its wide use, benzene ranks in the top 20 in production volume for chemicals produced in the United States (ATSDR, 2007). Natural sources of benzene, which include gas emissions from volcanoes and forest fires, also contribute to the presence of benzene in the environment (ATSDR, 2007).

Benzene is readily absorbed via inhalation with about 40-50% retained. It is taken up preferentially by fatty and nervous tissues, and about 30-50% is excreted unchanged via exhalation. Epidemiologic studies and case studies provide clear evidence of a causal

association between exposure to benzene and acute nonlymphocytic leukemia and also suggest evidence for chronic nonlymphocytic leukemia and chronic lymphocytic leukemia. Other neoplastic conditions that are associated with an increased risk in humans are hematologic neoplasms, blood disorders such as preleukemia and aplastic anemia, Hodgkin's lymphoma, and myelodysplastic syndrome (NLM, 2005). The majority of benzene metabolism occurs in the liver, but the bone marrow is the target organ where its toxicity is expressed with the greatest sensitivity (EPA, 2002).

Acute effects of benzene exposure include irritation of mucous membranes, restlessness, convulsions, excitement, depression and even death due to respiratory failure. The major toxic effect of benzene is its hematopoietic toxicity (Khan, 2007). Benzene has been shown to produce neurotoxic effects in experimental animals and humans after short-term exposures to relatively high concentrations of the compound. Benzene produces generalized symptoms such as dizziness, headache, and vertigo, leading to drowsiness, tremor, delirium, and loss of consciousness (EPA, 2002).

Benzene is characterized as a known human carcinogen for all routes of exposure based upon convincing human evidence as well as supporting evidence from animal studies (EPA, 2003). To date, only benzene, has utilized human data for derivation of all three quantitative risk estimates (i.e., RfC, RfD, and dose-response modeling for cancer assessment)(Persad et al., 2008). The RfC for established for benzene is  $3 \times 10^{-2} \text{ mg/m}^3$  (EPA, 2005). The unit risk factor, expressed as a range, is  $2.2 \times 10^{-6}$  to  $7.8 \times 10^{-6}$ , the increase in the lifetime risk of an individual who is exposed for a lifetime to  $1 \mu\text{g/m}^3$  benzene in air (EPA, 2000).

*Toluene (methylbenzene, toluol, CAS # 108-88-3).* Toluene is a clear, colorless liquid with a distinctive smell. Toluene occurs naturally in crude oil and in the tolu tree. It is also produced in the process of making gasoline and other fuels from crude oil and making coke from coal. Toluene is used in making paints, paint thinners, fingernail polish, lacquers, adhesives, and rubber and in some printing and leather tanning processes (ATSDR, 2008a).

Acute exposures to toluene may cause dizziness, headache, lethargy, inebriation, exhilaration, drowsiness, staggering gait, nausea, and CNS depression. Over 200 ppm, effects are more pronounced including dilated pupils, insomnia, and poor light accommodation. High concentrations lead to collapse, coma, and death (Harbison, 1998). Observed effects include reversible neurological symptoms from acute exposure progressing from fatigue, headache, and decreased manual dexterity to narcosis with increasing exposure level, degenerative changes in white matter in chronic solvent abusers, and subtle changes in neurological functions including cognitive and neuromuscular performance, hearing, and color discrimination in chronically exposed workers (ATSDR, 2000). In humans, respiratory tract irritation is experienced from exposure to toluene. Cardiac arrhythmia is a cause of death that has been associated with some solvent abuse fatalities. However, studies in laboratory animals do not provide convincing support for a direct effect of toluene on the cardiovascular system (ATSDR, 2000). No studies examining the chronic or subchronic effects of oral exposure to toluene in humans are available (EPA, 2005).

Eleven human epidemiology studies were located that assessed toluene exposure as a possible risk factor for cancer. Cancers of most sites were not significantly

associated with toluene exposure in any study and there was weak consistency in the findings of those studies that did find association of a particular cancer type with toluene exposure. Eleven human epidemiology studies were located that assessed toluene exposure as a possible risk factor (ATSDR, 2000). Under the *Guidelines for Carcinogen Risk Assessment* (EPA, 2005), *there is inadequate information to assess the carcinogenic potential* of toluene because studies of humans chronically exposed to toluene are inconclusive, toluene was not carcinogenic in adequate inhalation cancer bioassays of rats and mice exposed for life for cancer (EPA, 2005) Cancers of most sites were not significantly associated with toluene exposure in any study and there was weak consistency in the findings of those studies that did find association of a particular cancer type with toluene exposure(ATSDR, 2000). The RfC established for toluene is 5 mg/m<sup>3</sup> (EPA, 2005).

*Ethylbenzene (Ethylbenzol, CAS # 100-41-4)*. Ethylbenzene is a colorless liquid with an aromatic odor. Ethylbenzene is an aromatic hydrocarbon that occurs naturally in petroleum and is a component of aviation and automotive fuels. Ethylbenzene is widely distributed in the environment. It is primarily used for the production of styrene, which is the monomeric unit for polystyrene materials. Ethylbenzene is also used as a solvent and in the manufacture of several organic compounds other than styrene; however, these uses are very minor in comparison to the amounts used for styrene production (ATSDR, 2007a).

Routine human activities, such as driving automobiles, boats, or aircraft, or using gasoline powered tools and equipment, release ethylbenzene to the environment. Environmental and background levels of ethylbenzene are generally small and therefore,

have minimal impact on public health. Trace levels of ethylbenzene are found in internal combustion engine exhaust, food, soil, water, and tobacco smoke, but usually at levels well below those that have been shown to exhibit toxic effects in laboratory animals or human exposure studies (ATSDR, 2007a). Ethylbenzene in air is broken down in less than 3 days with the aid of sunlight (EPA, 1991).

The production volume of ethylbenzene is typically among the highest of all chemicals manufactured in the United States. In 2005, nearly 12 billion pounds of ethylbenzene were produced domestically, with historical levels ranging anywhere from approximately 7 to 13 billion pounds annually (ATSDR, 2007a).

There are currently 3,558 facilities that produce, process, or use ethylbenzene in the United States (ATSDR, 2007). Unfractionated crude oil contains 1–2.5% by weight of C6–C8 aromatics, mainly toluene, the xylenes and ethylbenzene, and oil refining therefore is also likely to result in exposures. Ethylbenzene has been detected in bitumen fumes during road paving. Another source of occupational exposure to ethylbenzene is the production and handling of gasoline and other fuels in which it is a component (IARC, 2000).

Exposure to high levels of ethylbenzene in the air for short periods can cause eye and throat irritation. Exposure to higher levels can result in vertigo and dizziness. Ethylbenzene is primarily an irritant to the skin and mucous membranes and possesses narcotic properties at high concentrations (Fishbein, 1985a). No studies were located regarding lethality in humans following inhalation exposure to ethylbenzene (ATSDR, 2007a). Long-term biomonitoring of occupational ethylbenzene exposures, carried out in the past 20 years in some 200 ethylbenzene-production workers, revealed this substance

to pose little hazard to human health (Bardoděj, et al, 1988). The RfC established for ethylbenzene is 1 mg/m<sup>3</sup> (EPA, 1991). Ethylbenzene is considered *not classifiable as to human carcinogenicity* (EPA, 1991).

*Xylene Isomers (Xylenes, CAS # 1330-20-7, meta-Xylene, CAS # 108-38-3) (para-Xylene, CAS # 106-42-3)(ortho-Xylene, CAS # 95-47-6).* Xylene isomers are clear, colorless liquids with a sweet aroma. Commercial or mixed xylene generally contains about 40–65% *m*-xylene and up to 20% each of *o*-xylene, *p*-xylene, and ethylbenzene (ATSDR, 2007b). It is produced in very large quantities and is extensively employed in a broad spectrum of applications, primarily as a solvent for which its use is increasing as a "safe" replacement for benzene, and in gasoline as part of the BTX component (benzene-toluene-xylene); xylenes are also frequently used in the rubber industry with other solvents such as toluene and benzene (Fishbein, 1985). Xylene is a common ingredient in paints with some containing greater than 50% xylenes (Harbison, 1998). U.S. manufacturers had an estimated annual production capacity of 18 billion pounds of mixed xylene in 2006 (SRI 2006). According to data collected under the Toxic Substances Control Act Inventory Update Rule, the total production volume of mixed xylene reported by U.S. manufacturers has remained above 1 billion pounds during each reporting year (ATSDR, 2007b).

As individual isomers they are extensively employed in the synthesis of synthetic agents, for example phthalic acid, isophthalic acid, terephthalic acid and dimethylterephthalate, which have very broad applications in the further preparation of phthalate ester plasticizers and components of polyester fiber, film and fabricated items. There is a broad potential for exposure both to industrial workers in the production and

use of the xylenes and to the general public (via vehicle exhausts, consumer products, etc) (Fishbein, 1985). Approximately 70% of mixed xylene is used in the production of ethylbenzene and the *m*-, *o*-, and *p*-isomers. The remaining mixed xylene is used as a solvent, in products such as paints and coatings, or blended into gasoline (ATSDR, 2007b).

Xylene vapor is absorbed rapidly from the lungs, and xylene liquid and vapor are absorbed slowly through the skin (Langman, 1994). High levels of xylene exposure can cause polyuric renal failure, respiratory failure, hemorrhages, and necrosis in the brain, liver kidneys, and heart (Harbison, 1998). Xylene in high concentrations acts as a narcotic, inducing neuropsychological and neurophysiological dysfunction. Respiratory tract symptoms are also frequent. More chronic, occupational exposure has been associated with anemia, thrombocytopenia, leukopenia, chest pain with ECG abnormalities, dyspnea and cyanosis, in addition to CNS symptoms (Langman, 1994).

Chronic occupational exposure of workers to an unspecified concentration of vapors of mixed xylene has also been associated with labored breathing and impaired pulmonary function (ATSDR, 2007b). A cross-sectional study performed in shipyard painters exposed to with solvent-based paints containing > 50% xylene found decreased peripheral nerve function (Ruijten, et al., 1994).

The RfC for non-carcinogenic health effects established for xylenes 0.1 mg/m<sup>3</sup> (EPA, 2003a). Xylenes refer to mixtures of all three xylene isomers and ethylbenzene. The inhalation RfC for xylenes is based on a principal study in which rats were exposed by inhalation to *m*-xylene. There was some uncertainty associated with selecting a principal study for xylenes that involved exposure to *m*-xylene alone, but this isomer is

generally predominant in commercial mixtures (EPA, 2003a). IRIS classifies xylenes as *data are inadequate for an assessment of the carcinogenic potential*. Adequate human data on the carcinogenicity of xylenes are not available, and the available animal data are inconclusive as to the ability of xylenes to cause a carcinogenic response. Evaluations of the genotoxic effects of xylenes have consistently given negative results (EPA, 2003a).

The RfCs, unit risk factors, and weight of evidence, as listed by EPA’s IRIS, for each chemical discussed above are summarized on Tables 5 through 7. The term “*point of departure*” (POD) used in Table 5 marks the beginning of extrapolation to lower doses. The POD is an estimated dose (usually expressed in human-equivalent terms) near the lower end of the observed range, without significant extrapolation to lower doses (EPA, 2005a).

Table 5. Inhalation Reference Concentration (RfC) Summary

<b>Inhalation Reference Concentrations</b>					
<b>Substance</b>	<b>CASRN</b>	<b>Critical Effects</b>	<b>Inhalation RfC</b>	<b>Point of Departure*</b>	<b>Overall Confidence</b>
<b>Benzene</b>	71-43-2	Decreased lymphocyte count	3x10 <sup>-2</sup> mg/m <sup>3</sup>	BMCL : 8.2 mg/m <sup>3</sup>	Medium
<b>Ethylbenzene</b>	100-41-4	Developmental toxicity	1 mg/m <sup>3</sup>	NOAEL (HEC): 434 mg/m <sup>3</sup>	Low
<b>Toluene</b>	108-88-3	Neurological effects in occupationally-exposed workers (other effect: )	5 mg/m <sup>3</sup>	NOAEL (ADJ): 46 mg/m <sup>3</sup>	High



Table 5. (continued)

<b>Xylenes</b>	1330-20-7	Impaired motor coordination (decreased rotarod performance)	0.1 mg/m <sup>3</sup>	NOAEL (HEC): 39 mg/m <sup>3</sup>	Medium
Source: IRIS, 2008.					
<p>*The Point of Departure listed serves as a basis from which the Inhalation RfC was derived.  CASRN – Chemical Abstract Service Registry Number  BMCL- Benchmark Concentration Level  HEC – Human Equivalence Concentration  NOAEL- No Observable Adverse Effects Level</p>					

Table 6. Inhalation Unit Risk (IUR) Summary

Inhalation Unit Risks					
Substance	CASRN	Precursor Effect/ Tumor Type	Extrapolation Method	Inhalation Unit Risks	Study Route
<b>Benzene</b>	71-43-2	Leukemia	Low-dose linearity utilizing maximum likelihood estimates	2.2x10 <sup>-6</sup> per ug/m <sup>3</sup> <sup>1</sup>	Inhalation
			Low-dose linearity utilizing maximum likelihood estimates	7.8x10 <sup>-6</sup> per ug/m <sup>3</sup> <sup>1</sup>	
<b>Ethylbenzene</b>	100-41-4	<b>Not Assessed under the IRIS program.</b>			
<b>Toluene</b>	108-88-3	<b>Not Assessed under the IRIS program.</b>			
<b>Xylenes</b>	1330-20-7	<b>Not Assessed under the IRIS program.</b>			

CASRN – Chemical Abstract Service Registry Number

Table 7. Weight of Evidence (WOE) Information Summary

<b>Weight-of-Evidence Characterizations</b>			
<b>Substance</b>	<b>CASRN</b>	<b>WOE 86 Guidelines</b>	<b>WOE Narrative</b>
<b>Benzene</b>	71-43-2	A, Human Carcinogen	Under the proposed revised Carcinogen Risk Assessment Guidelines (U.S. EPA, 1996), benzene is characterized as a known human carcinogen for all routes of exposure based upon convincing human evidence as well as supporting evidence from animal studies. (U.S. EPA, 1979, 1985, 1998; ATSDR, 1997).
<b>Ethylbenzene</b>	100-41-4	D, Not classifiable as to human carcinogenicity	Nonclassifiable due to lack of animal bioassays and human studies.
<b>Toluene</b>	108-88-3	D, Not classifiable as to human carcinogenicity	No human data and inadequate animal data. Toluene did not produce positive results in the majority of genotoxic assays.
<b>Xylenes</b>	1330-20-7	NA, Not applicable. This substance was not assessed using the 1986 cancer guidelines (U.S. EPA, 1986).	Under the Draft Revised Guidelines for Carcinogen Risk Assessment (U.S. EPA, 1999), data are inadequate for an assessment of the carcinogenic potential of xylenes. Adequate human data on the carcinogenicity of xylenes are not available, and the available animal data are inconclusive as to the ability of xylenes to cause a carcinogenic response. Evaluations of the genotoxic effects of xylenes have consistently given negative results.

## Chapter Three Methods and Materials

### *Study Description*

This study evaluated the potential for SVI for properties overlying and immediately abutting MGP tar source material and properties overlying and adjacent to dissolved phased benzene, toluene, ethylbenzene and xylene (BTEX) and naphthalene plumes emanating from the MGPs. A total of 10 commercial and 26 single family and multi-family residential properties associated with the three former MGPs were evaluated for potential SVI of MGP-related chemicals. Each of the sites included in this study were located in the northeastern US.

Further evaluation of the potential for SVI exposure was conducted to evaluate whether depth to groundwater influenced the potential for SVI by categorizing each of the sites into three groupings according to depth to the water table: no vadose zone; water table within 6 feet of the building slab; and water table between 6 and 25 feet of the building slab.

In addition, comparative risk assessments were conducted on the five chemicals with the highest frequency of detection in the indoor air and soil vapor of the sampled buildings, and the outdoor air near these structures. The chemicals with the highest frequency of detection were benzene, toluene, ethylbenzene, m,p-xylene, and o-xylene (See Tables 2 through 4). For benzene, a known human carcinogen (NTP, 2005), cancer

risk calculations were computed for the mean and maximum concentrations of benzene detected in the sample groups. For the non-carcinogenic chemicals, toluene, ethylbenzene, m,p-xylene, and o-xylene, hazard indices were calculated for both the mean and maximum concentrations detected in the sample groups. HQs were also calculated for benzene.

Vapor Intrusion is the migration of volatile chemicals from the subsurface into overlying buildings (EPA, 2002a). Prior to conducting a soil vapor intrusion assessment for a private property, an analysis of the factors contributing to the migration of soil vapor to indoor air was conducted.

Factors that could influence the results of the soil vapor assessment included environmental factors and building factors. Environmental factors included site specific conditions in the subsurface and aboveground surface that may affect the rate and direction at which soil vapor may migrate. Evaluation of the potential for SVI exposure was conducted to evaluate whether depth to groundwater influenced the potential for SVI by categorizing each of the former MGP sites into three groupings according to depth to the water table: no vadose zone; water table within 6 feet of the building slab; and water table between 6 and 25 feet of the building slab. Building factors included the physical characteristics, such as structure, floor layout, air flow and physical conditions.

The soil and groundwater conditions between the contamination and the residential/ commercial building were evaluated to identify the potential for man-made or natural preferential pathways for vapor migration in the vadose zone and/or for groundwater migration. Additional environmental factors evaluated included the depth to groundwater and the direction of groundwater flow from the contaminant source to the

residential or commercial building; the location, depth, extent and concentration of potential MGP-related constituents in unsaturated soil and groundwater on the property; the presence of an overlying water bearing zone not containing MGP impacts; and if present, the location, depth, and extent of potential “smear zones” (residual NAPL present at depths over which the water table fluctuates).

Building factors that could influence indoor air quality include the use or storage of petroleum-based household chemical products or those containing volatile organic compounds (VOCs); the use of home heating oil storage tanks, underground storage tanks (USTs) or kerosene heaters; and recent renovations to the building such as new paint or new carpet. The use or presence of these chemicals or products could be a confounder in the evaluation of potential MGP impacts on indoor air quality.

According to the EPA, a complicating factor in evaluating the potential chronic risk from vapor intrusion is the potential presence of some of the same chemicals at or above background concentrations (from the ambient outdoor air and/or emission sources in the building e.g., household solvents, gasoline, cleaners) that may pose separately or in combination with vapor intrusion, a significant human health risk (EPA, 2002a). The mere presence of a chemical in both the subsurface and indoor air is in general insufficient to establish that linkage, given the high potential for other above-ground and indoor sources of many volatile organic chemicals of interest (Johnson, et al., 2002). To this end, a pre-assessment building survey and chemical inventory was conducted to identify and record the presence of these factors.

In addition to the use of products that could influence air quality, an assessment of the building foundation construction characteristics (basement, footers, crawl spaces, etc)

was conducted to identify potential preferential vapor intrusion pathways such as foundations cracks and utility penetrations. Heating systems, including fireplaces and clothes dryers, were identified since their use could create a pressure differential between the structure and the outside environment, causing an increase of migration of soil vapor into the building.

For each property evaluated indoor air samples and outdoor ambient air samples were collected with Summa® or equivalent canisters. In property settings where a vadose zone was present beneath the building slab, sub-slab soil vapor samples were collected. Where the water table was present above a buildings basement slab, soil vapor samples were collected beneath a surrogate cap (patio, driveway, etc.) at an elevation above the basement slab; and in the property settings where no vadose zone was present (water table within 6-inches of the land surface) only indoor air samples were collected.

For quality assurance purposes, a helium tracer gas was utilized to evaluate the integrity of the soil vapor probe seal and assess the potential for introduction of outside air into the soil vapor sample.



Figure 1. Example of Collection of Indoor Air Samples using Summa® or equivalent canisters



Figure 2. Example of Collection of Soil Vapor Sample from a Temporary Soil Vapor Point using a Summa® or equivalent canister

The samples were collected in accordance with federal and state regulatory recommended sampling procedures. An approved laboratory was utilized to analyze all air samples, including the sub-slab or soil vapor samples. All samples were analyzed for VOCs by the United States Environmental Protection Agency (USEPA) Method TO-15 plus naphthalene. The vapor intrusion assessments focused on those volatile chemicals that are potentially MGP related, however the TO-15 analytical method used to assess indoor air quality included many chemicals that are not MGP-related but are commonly evaluated when assessing indoor air quality.

To analyze an air sample using Method TO-15, a known volume of sample is directed from the canister through a solid multisorbent concentrator. A portion of the water vapor in the sample breaks through the concentrator during sampling, to a degree depending on the multisorbent composition, duration of sampling, and other factors. Water content of the sample can be further reduced by dry purging the concentrator with helium while retaining target compounds. After the concentration and drying steps are completed, the VOCs are thermally desorbed, entrained in a carrier gas stream, and then

focused in a small volume by trapping on a reduced temperature trap or small volume multisorbent trap. The sample is then released by thermal desorption and carried onto a gas chromatographic column for separation. The analytical strategy for Compendium Method TO-15 involves using a high resolution gas chromatograph (GC) coupled to a mass spectrometer. Mass spectrometry is considered a more definitive identification technique than single specific detectors such as flame ionization detector (FID), electron capture detector (ECD), photoionization detector (PID), or a multidetector arrangement of these (EPA, 1999).

An independent data reviewer was used to perform data validation on all laboratory analytical results. The data validation was based on the USEPA Contract Laboratory Program National Functional Guidelines for Organic Data Review, January 2005 (EPA, 2005b). The organic data were evaluated based on the following parameters:

- Data Completeness
- Holding Times and Sample Preservation
- Gas Chromatography/Mass Spectrometry (GC/MS) Tunes
- Initial and Continuing Calibrations
- Surrogate Recoveries
- Matrix Spike/Matrix Spike Duplicate (MS/MSD) Results
- Internal Standards
- Laboratory Control Sample (LCS) Results
- Quantitation Limits and Data Assessment
- Sample Quantitation and Compound Identification



### *Risk Assessment*

This risk assessment followed the guidelines outlined in EPA's *Risk Assessment Guidance for Superfund* (EPA, 1989). There are four steps to the risk assessment process: data collection and analysis; exposure assessment; toxicity assessment; and risk characterization. Data collection and analysis involves gathering and evaluating site data that will be the focus of the risk assessment. Indoor air, outdoor air, and soil vapor samples were collected from residents and buildings and analyzed for VOCs and SVOCs. This study identified five chemicals to be used in the risk assessment based on the frequency of detection in indoor air, outdoor air, and soil vapor.

Exposure assessment estimates the magnitude, frequency, duration, and the potential pathways of exposure. This study focused on the potential pathway of soil vapor intrusion of chemicals into the indoor air of residents and buildings and the potential risks associated with inhalation of these chemicals. Toxicity assessment considers potential adverse health effects associated with chemical exposures; the relationship between magnitude of exposure and adverse effects; and the uncertainties such as the weight of evidence data. The health effects considered in this study are outlined in the previous section. Risk characterization summarizes and combines the data collected and used in the exposure assessment with the results of the toxicity assessment to characterize baseline risk to the occupants of buildings or residences adjacent to former MGP sites.

Occupants of buildings and residences adjacent to the former MGP sites were evaluated in this risk assessment. This population included adults and children. Comparisons of the indoor air, soil vapor, and outdoor air maximum and mean results

categorized by vadose zone were made to the 95<sup>th</sup> percentile regulatory background concentrations for indoor and outdoor air. No data base is available for comparison of soil vapor concentrations; however it is generally acceptable practice to compare soil vapor data to indoor air background levels if the soil vapor data is being evaluated for intrusion into the indoor air of a building structure.

In addition, concentrations detected in the indoor air were compared to concentrations detected in soil vapor for each location. If soil vapor intrusion was occurring the concentration of chemicals in the soil vapor would be higher than those detected in the indoor air. Also, indoor air concentrations were compared to outdoor air concentrations to evaluate whether indoor air quality was influenced by chemicals detected in the outdoor air.

To assess the overall potential for non-carcinogenic effects posed by more than one chemical, a hazard index (HI) approach was utilized (EPA, 1989). The HI approach presumes that simultaneous sub-threshold exposures to several chemicals could result in an adverse health effect. HIs are sums of a non-cancer hazard quotient that assumes there is a level of exposure (i.e., RfC) below which it is unlikely for even sensitive populations to experience adverse health effects. Hazard quotients (HQs) were calculated by dividing the exposure concentration by the reference concentration. There may be a concern for potential non-carcinogenic effects if the HI is greater than 1 (EPA, 1989).

Hazard Quotients (HQs) were calculated using the study results and the mean, maximum, and 95<sup>th</sup> percentile concentrations from regulatory data bases. HQs were calculated by dividing the mean, maximum and 95<sup>th</sup> percentile concentrations found in

indoor air, outdoor air, and soil vapor by the RfC. HIs were then calculated by summing the totals of the HQs for each chemical by media (i.e. indoor air, outdoor air, soil vapor).

Carcinogenic risks associated with exposure to benzene were calculated using both the measured mean and maximum study results and the mean, maximum and 95<sup>th</sup> percentile concentrations from state and federal data bases. The IUR for benzene is  $2.2 \times 10^{-6}$  to  $7.8 \times 10^{-6}$  (EPA, 2003). The IUR is based on a 70 kg adult breathing 20 m<sup>3</sup> of air per day. Based on this IUR an individual exposed to 1 µg/m<sup>3</sup> benzene in air has an increased lifetime risk or IUR of  $2.2 \times 10^{-6}$  to  $7.8 \times 10^{-6}$  of developing leukemia. Cancer risks from inhalation of benzene were calculated by multiplying the concentrations in indoor air, outdoor air, and soil vapor by benzene's inhalation unit risk range. The EPA expresses the likelihood of cancer as a probability, such as  $1 \times 10^{-6}$  or 1 in a 1,000,000 chance. This expression of probability means that for every 1,000,000 people, one excess cancer case may occur as a result of an exposure to a chemical. This one cancer case is in excess of the normal cancer cases expected from all other causes. This is an upper bound estimate of risk and the true risk could actually be zero. A generally acceptable range for cumulative excess cancer risk of  $10^{-6}$  to  $10^{-4}$  for protecting human health has been established by the EPA.

## Chapter Four

### Results

Data was categorized into three groupings according to depth to the water table: no vadose zone; water table within 6 feet of the building slab; water table between 6 and 25 feet of the building slab. Frequency of detection was determined for each compound analyzed and the five compounds with the highest frequency of detection identified (Tables 2-4). Benzene, toluene, ethylbenzene, m,p-xylene, and o-xylene had the highest frequency of detections of the study results. Analytical results of the soil vapor intrusion assessments were directly compared to US federal and state background concentrations.

The two comparative data bases used in this study as background values were the United States Environmental Protection Agency *Building Assessment and Survey Evaluation* (BASE 1994-1998) and the New York State Department of Health (NYSDOH) *Guidance for Evaluating Soil Vapor Intrusion in the State of New York* (2006). The USEPA BASE study included measurement of VOCs, radon, formaldehyde, carbon monoxide, carbon dioxide, and particulates in indoor air (Table 8) and outdoor air (Table 9) at 100 randomly selected public and commercial office buildings across the United States (EPA, 2001). Tables 8 and 9 summarize EPA background concentrations for benzene, toluene, ethylbenzene, m,p-xylene, and o-xylene.

Table 8. EPA 2001 Building Assessment and Survey Evaluation (BASE) Background Concentrations for Indoor Air (ug/m<sup>3</sup>)

<b>Indoor Air</b>									
<b>Compound</b>	<b>Mean*</b>	<b>Min</b>	<b>25th</b>	<b>Median</b>	<b>75th</b>	<b>90th</b>	<b>95th</b>	<b>99th</b>	<b>Max</b>
Benzene	4.5	<0.8	2.1	3.4	5.1	9.4	12.5	25.0	63.0
Ethylbenzene	2.8	<0.9	<1.6	1.4	3.4	5.7	7.6	18.5	73.6
Toluene	25.1	3.5	10.7	15.7	25.9	43.0	70.8	348.9	390.3
m,p-Xylene	10.8	<1.5	4.1	6.9	12.2	22.2	28.5	67.6	260.8
o-Xylene	3.8	<0.7	<2.4	2.4	4.4	7.9	11.2	20.1	90.5

Min - Minimum concentration detected

25<sup>th</sup> - 25<sup>th</sup> percentile

75<sup>th</sup> - 75<sup>th</sup> percentile

90<sup>th</sup> - 90<sup>th</sup> percentile

95<sup>th</sup> - 95<sup>th</sup> percentile

99<sup>th</sup> - 99<sup>th</sup> percentile

Max - Maximum concentration detected

Table 9. EPA 2001 Building Assessment and Survey Evaluation (BASE) Background Concentrations for Outdoor Air (ug/m<sup>3</sup>)

<b>Outdoor Air</b>									
<b>Compound</b>	<b>Mean*</b>	<b>Min</b>	<b>25th</b>	<b>Median</b>	<b>75th</b>	<b>90th</b>	<b>95th</b>	<b>99th</b>	<b>Max</b>
Benzene	3.2	<1.2	1.2	2.7	3.7	6.6	9.6	12.6	13.0
Ethylbenzene	1.4	<0.8	<1.4	<1.8	1.6	3.5	4.3	7.6	7.8
Toluene	15.4	2.1	5.9	9.6	16.3	33.7	49.2	86.5	93.1
m,p-Xylene	5.6	<1.4	<3.6	4.4	7.3	12.8	16.1	24.8	26.8
o-Xylene	2.0	<0.6	<1.4	1.4	2.6	4.6	6.0	9.6	11.1

Min - Minimum concentration detected

25<sup>th</sup> - 25<sup>th</sup> percentile

75<sup>th</sup> - 75<sup>th</sup> percentile

90<sup>th</sup> - 90<sup>th</sup> percentile

95<sup>th</sup> - 95<sup>th</sup> percentile

99<sup>th</sup> - 99<sup>th</sup> percentile

Max - Maximum concentration detected

The NYSDOH conducted a study of the occurrence of VOCs in the indoor air of homes that heat with fuel oil. The purpose of the study was to characterize the indoor environment of fuel oil heated homes as a means of evaluating post clean-up conditions in residences affected by petroleum spills. The summary report was used to help characterize concentrations and establish “background” concentrations of 69 compounds commonly found in the indoor and outdoor air of residential settings heated with fuel oil (NYSDOH, 2006). Tables 10 and 11 summarize NYSDOH background concentrations for benzene, toluene, ethylbenzene, m,p-xylene, and o-xylene.

Table 10. NYSDOH 2003 Study of Volatile Organic Chemicals in Air of Fuel Oil Heated Homes (ug/m<sup>3</sup>) – Indoor Air

INDOOR AIR										
Compound	Mean*	Min	25th	Median	75th	90th	95th	99th	Max	Upper Fence
Benzene	8.3	<0.25	1.1	2.1	5.9	15	29	120	460	13
Ethylbenzene	3.7	<0.25	0.4	1	2.8	7.3	13	26	340	6.4
Toluene	26	<0.25	3.5	9.6	25	58	110	300	510	57
m,p-Xylene	5.9	<0.25	0.5	1.5	4.6	12	21	46	550	11
o-Xylene	3.8	<0.25	0.4	1.1	3.1	7.6	13	32	310	7.1

Min- Minimum concentration detected

25<sup>th</sup> – 25<sup>th</sup> percentile

75<sup>th</sup> – 75<sup>th</sup> percentile

90<sup>th</sup> – 90<sup>th</sup> percentile

95<sup>th</sup> - 95<sup>th</sup> percentile

99<sup>th</sup> - 99<sup>th</sup> percentile

Max – Maximum concentration detected

Table 11. NYSDOH 2003 Study of Volatile Organic Chemicals in Air of Fuel Oil Heated Homes (ug/m<sup>3</sup>) – Outdoor Air

OUTDOOR AIR										
Compound	Mean*	Min	25th	Median	75th	90th	95th	99th	Max	Upper Fence
Benzene	1.9	<0.25	0.6	1.3	2.2	4.3	5.8	13	17	4.8

Table 11. (continued)

Ethylbenzene	0.8	<0.25	<0.25	<0.25	0.5	1.1	1.9	19	21	1.0
Toluene	11	<0.25	0.6	1.3	2.4	5.9	21	350	640	5.1
m,p-Xylene	0.8	<0.25	<0.25	<0.25	0.5	1.4	3.1	17	20	1.0
o-Xylene	0.7	<0.25	<0.25	<0.25	0.6	1.7	2.5	8.9	10	1.2

Min- Minimum concentration detected  
 25<sup>th</sup> – 25<sup>th</sup> percentile                      75<sup>th</sup> – 75<sup>th</sup> percentile  
 90<sup>th</sup> – 90<sup>th</sup> percentile                      95<sup>th</sup>- 95<sup>th</sup> percentile  
 99<sup>th</sup>- 99<sup>th</sup> percentile                      Max – Maximum concentration detected

The soil vapor data for each location was categorized by thickness of the vadose zone and maximum indoor air and soil vapor concentrations. Table 12 displays the maximum concentration for benzene in the indoor air as compared to soil vapor at each location with no vadose zone. Soil vapor samples were not collected at seven of the locations due to groundwater in contact with the building slab. Twelve of the locations had higher concentrations of benzene in the soil vapor than in indoor air. Locations 15, 20, 3, and 14 exceeded the EPA 95<sup>th</sup> percentile background concentration for benzene but were below DOH background. All of these locations had benzene in the indoor air well below background. The soil vapor concentration of benzene at Location 2 exceeded both the EPA and NYSDOH 95<sup>th</sup> percentiles for background indoor air; however the concentration of benzene in the indoor air for this location was well below background.

Table 12. Maximum Concentrations of Benzene in Indoor Air versus Soil Vapor for Locations with No Vadose Zone

<b>Maximum Concentrations of Benzene by Location for Indoor Air vs Soil Vapor (No Vadose Zone) (ug/m<sup>3</sup>)</b>		
<b>Location</b>	<b>Indoor Air</b>	<b>Soil Gas</b>
Location 8	0.61	

Table 12. (continued)

Location 5	0.77	
Location 4	0.79	
Location 16	0.8	
Location 19	0.8	
Location 1	0.93	
Location 12	1	
Location 10	1.1	0.96
Location 7	0.58	1.2
Location 21	4.4	1.3
Location 9	0.69	1.8
Location 11	1.31	1.92
Location 6	0.64	2.6
Location 17	1.2	3
Location 13	1.69	3.14
Location 18	0.64	3.2
Location 15	1.1	14
Location 20	0.74	15
Location 3	1.2	18
Location 14	0.89	19
Location 2	0.7	58



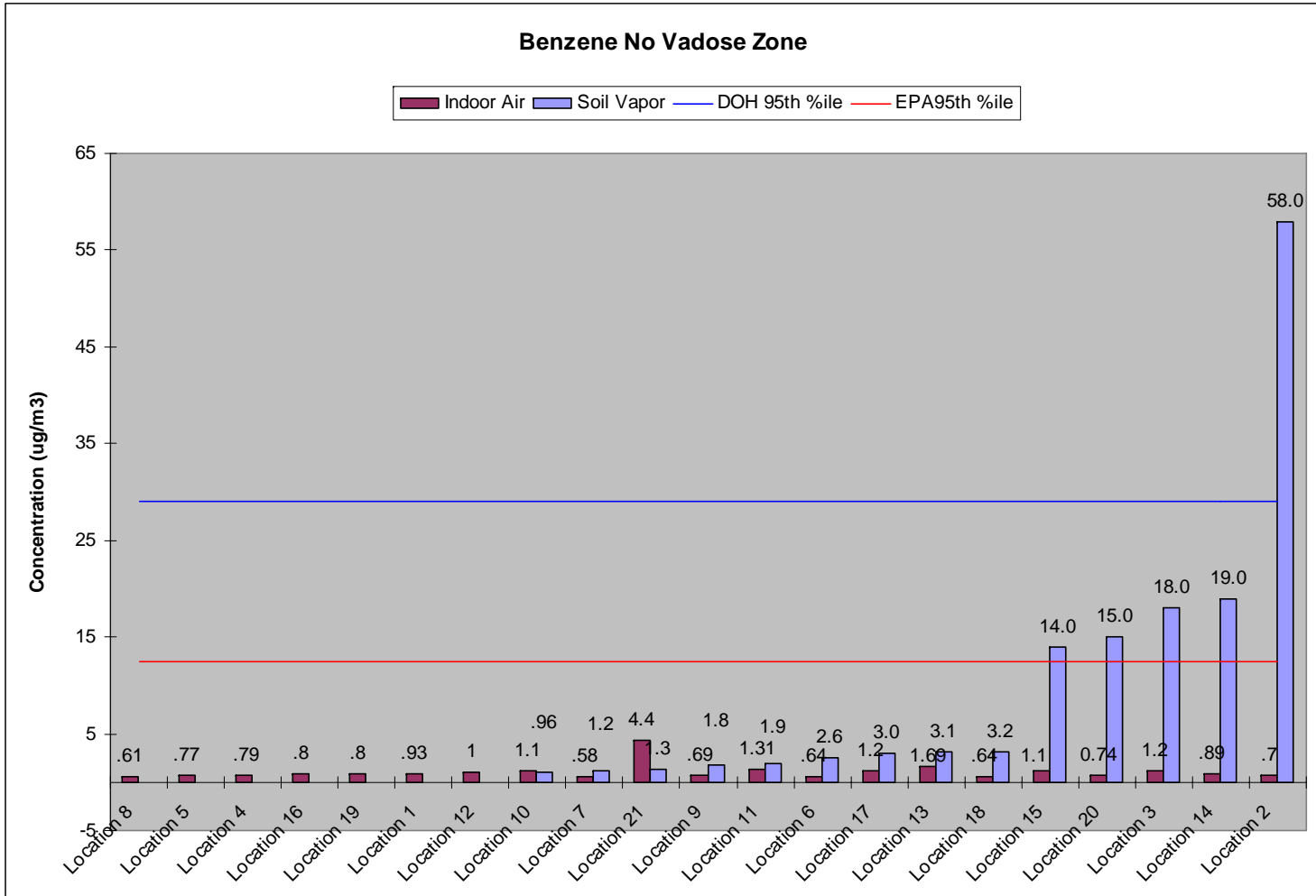


Figure 3. Maximum Concentration of Benzene by Locations with No Vadose Zone

DOH 95<sup>th</sup> %ile – NYSDOH Background 95<sup>th</sup> Percentile for Indoor Air, 2003  
 EPA 95<sup>th</sup> %ile- - USEPA BASE Background 95<sup>th</sup> Percentile for Indoor Air, 2001

Table 13 displays the maximum concentration for benzene in the indoor air as compared to soil vapor at each location with a 0 – 6 feet thick vadose zone. A soil vapor sample was not collected for Location 24. Only one out of 10 locations had a higher concentration of benzene in the indoor air than in the soil vapor. As seen in Figure 4 all of the indoor air and soil vapor concentrations for benzene were well below both the EPA and NYSDOH 95<sup>th</sup> percentiles for background indoor air.

Table 13. Maximum Concentrations of Benzene in Indoor Air versus Soil Vapor for Locations with 0 - 6 Feet Vadose Zone

<b>Maximum Concentrations of Benzene by Location for Indoor Air vs Soil Vapor (0- 6 feet Vadose Zone)(ug/m<sup>3</sup>)</b>		
Location	Indoor Air	Soil Vapor
Location 26	0.8	0.94
Location 22	2.1	1.1
Location 23	0.85	1.1
Location 27	0.76	1.2
Location 29	0.64	1.6
Location 32	0.69	2.2
Location 28	1.8	2.9
Location 31	2.3	5.9
Location 25	1.1	6.1
Location 30	1.3	8.2
Location 24	4.72	

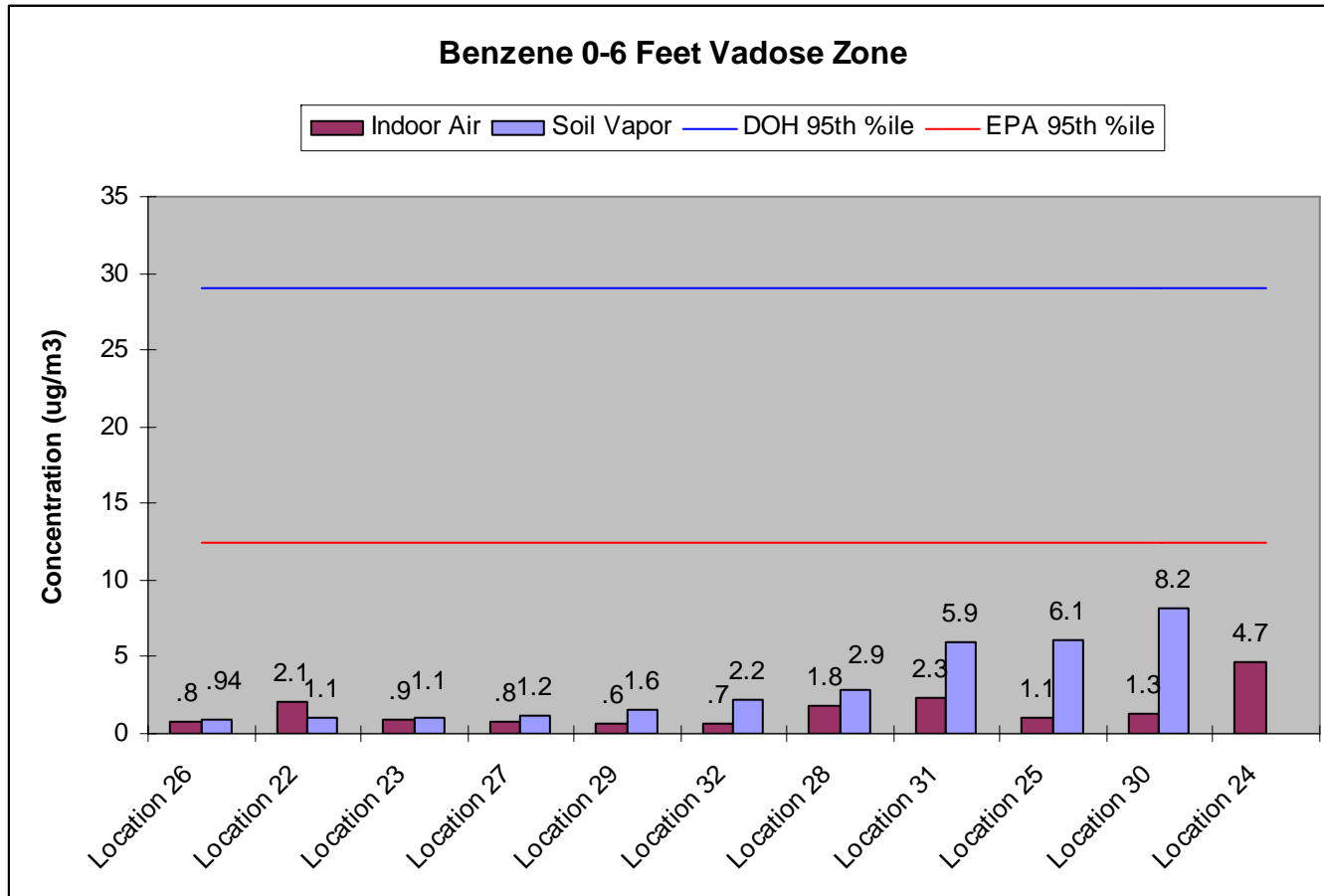


Figure 4. Maximum Concentration of Benzene by Locations with 0 – 6 feet Vadose Zone

DOH 95<sup>th</sup> %ile – NYSDOH Background 95<sup>th</sup> Percentile for Indoor Air, 2003

EPA 95<sup>th</sup> %ile- - USEPA BASE Background 95<sup>th</sup> Percentile for Indoor Air, 2001

Table 14 displays the maximum concentration for benzene in the indoor air as compared to soil vapor at each location with a 6 – 25 feet thick vadose zone. Three out of the 4 locations had higher concentrations of benzene in the soil vapor than in indoor air. As seen in Figure 5 all of the indoor air and soil vapor concentrations for benzene were well below both the EPA and NYSDOH 95<sup>th</sup> percentiles for background indoor air.

Table 14. Maximum Concentrations of Benzene in Indoor Air versus Soil Vapor for Locations with 6 - 25 Feet Vadose Zone

Maximum Concentrations of Benzene by Location for Indoor Air vs Soil Vapor (6- 25 feet) (ug/m <sup>3</sup> )		
Location	Indoor Air	Soil Vapor
Location 34	2.8	0.99
Location 35	0.99	3.1
Location 36	2.8	3.2
Location 33	1.6	6.6

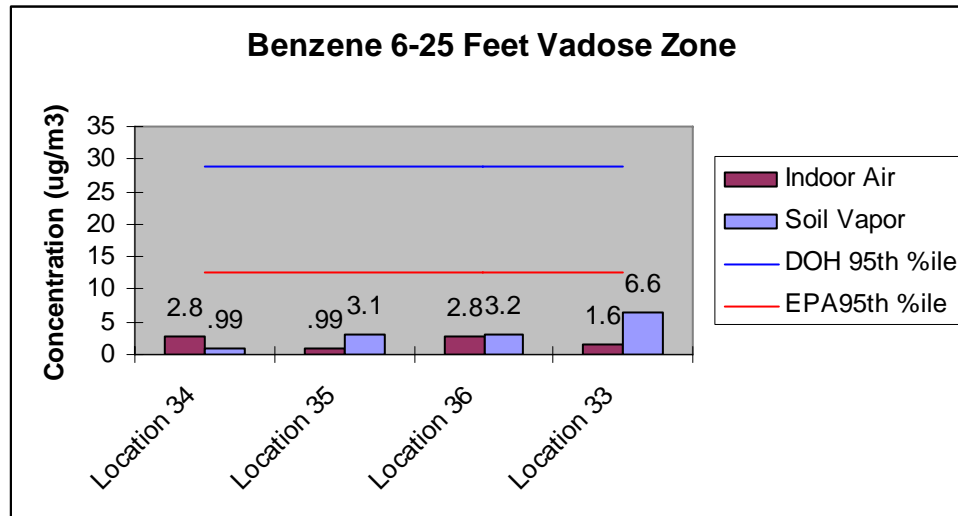


Figure 5. Maximum Concentration of Benzene by Locations with 6 -25 feet Vadose Zone

DOH 95<sup>th</sup> % ile – NYSDOH Background 95<sup>th</sup> Percentile for Indoor Air, 2003  
 EPA 95<sup>th</sup> %ile- - USEPA BASE Background 95<sup>th</sup> Percentile for Indoor Air, 2001

Table 15 displays the maximum concentration for toluene in the indoor air as compared to soil vapor at each location with no vadose zone. Soil vapor samples were not collected at seven of the locations due to groundwater in contact with the building slab. Seven of the locations had higher concentrations of toluene in the indoor air than in the soil vapor. One location had equal concentrations of toluene in the indoor air and soil vapor. Six of the locations had higher concentrations of toluene in the soil vapor than in indoor air. As seen in Figure 6 three locations, 15, 9, and 4, had toluene concentrations above the EPA 95<sup>th</sup> percentile for background indoor air. Locations 9 and 4 exceeded both 95<sup>th</sup> percentile background concentrations for toluene in indoor air. According to the questionnaire conducted at the time of sampling Location 9 had recently painted and Location 4 recently used solvents.

In addition, groundwater monitoring information was researched to determine the potential source of toluene in the soil vapor at Location 9. Toluene was either non-detect or at very low concentrations in the groundwater near this location and therefore could not be the source of toluene. It was concluded the recent painting activities accounted for the high concentrations of toluene.

Table 15. Maximum Concentrations of Toluene in Indoor Air versus Soil Vapor for Locations with No Vadose Zone

<b>Maximum Concentrations of Toluene by Location for Indoor Air vs Soil Vapor (No Vadose Zone) (ug/m<sup>3</sup>)</b>		
Location	Indoor Air	Soil Vapor
Location 10	6.2	0.92

Table 15.(continued)

Location 18	2.5	1.2
Location 7	2.2	1.3
Location 6	2.1	1.5
Location 17	3.7	2.6
Location 21	4.2	6.6
Location 3	13	6.7
Location 15	100	7.2
Location 20	7.8	7.8
Location 14	3.4	8.4
Location 11	4.63	9.49
Location 13	5.72	14
Location 2	10	15
Location 9	220	430
Location 1	37	
Location 4	190	
Location 5	1.8	
Location 8	3.7	
Location 12	4.6	
Location 16	3.8	
Location 19	2.8	

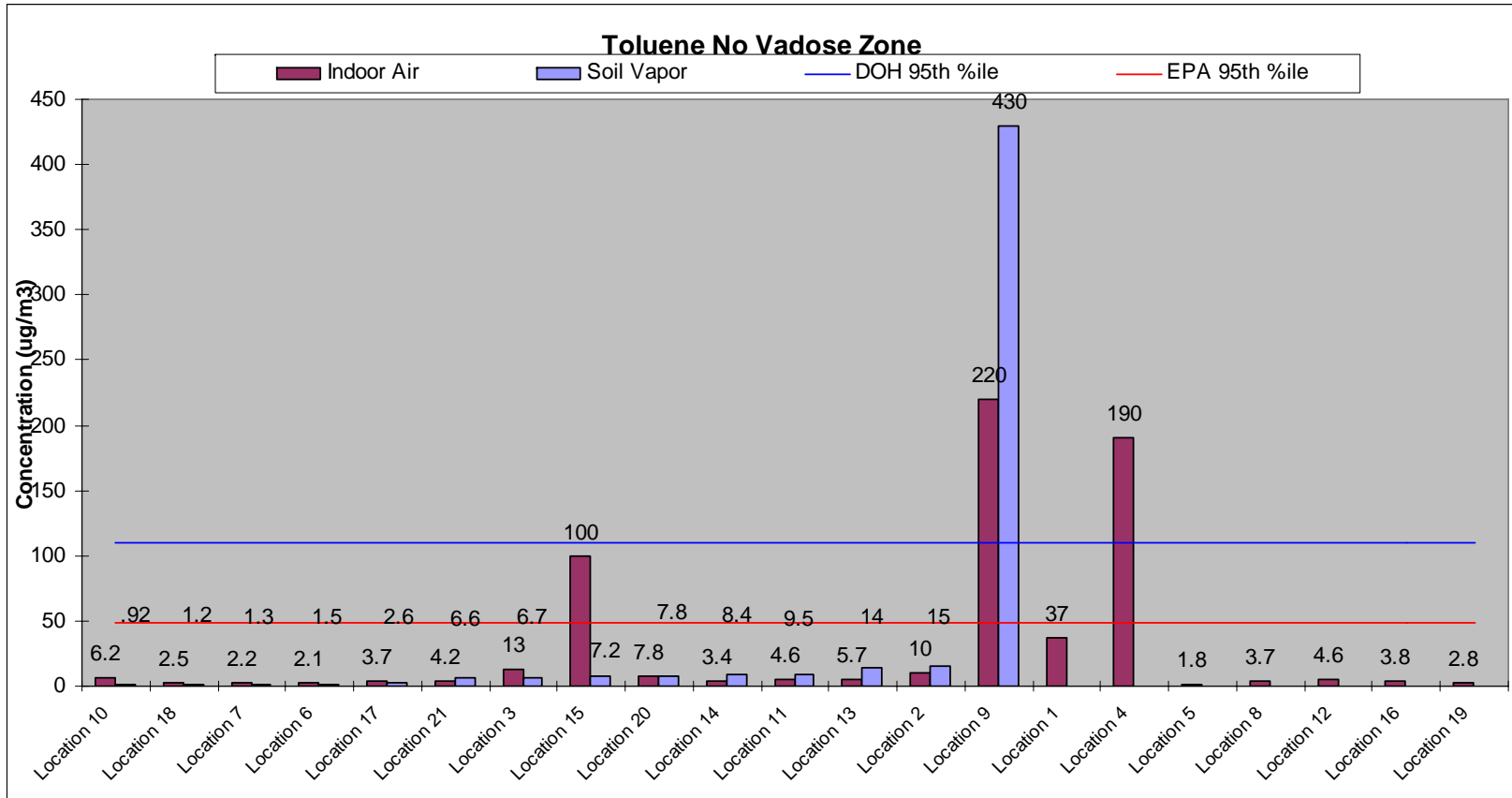


Figure 6. Maximum Concentration of Toluene by Location with No Vadose Zone

DOH 95<sup>th</sup> % ile – NYSDOH Background 95<sup>th</sup> Percentile for Indoor Air, 2003  
 EPA 95<sup>th</sup> %ile- - USEPA BASE Background 95<sup>th</sup> Percentile for Indoor Air, 2001

Table 16 displays the maximum concentration for toluene in the indoor air as compared to soil vapor at each location with 0-6 feet thick vadose zone. A soil vapor sample was not collected for Location 24. Ten locations had higher concentrations of toluene in the indoor air than in soil vapor. As seen in Figure 7 none of the locations with 0-6 feet thick vadose zones exceeded either the EPA or NYSDOH 95<sup>th</sup> percentiles for background indoor air for toluene.

Table 16. Maximum Concentration of Toluene by Location with 0- 6 feet Vadose Zone

<b>Maximum Concentrations of Toluene by Location for Indoor Air vs Soil Vapor (0 -6 feet)(ug/m<sup>3</sup>)</b>		
Location	Indoor Air	Soil Vapor
Location 23	2.6	0.86
Location 29	9.8	1.2
Location 27	2.7	1.3
Location 26	2.6	1.9
Location 32	5.7	1.9
Location 25	9.2	3.3
Location 22	12	4.6
Location 31	7.7	5.2
Location 30	8.3	6
Location 28	7.4	6.3
Location 24	10.7	



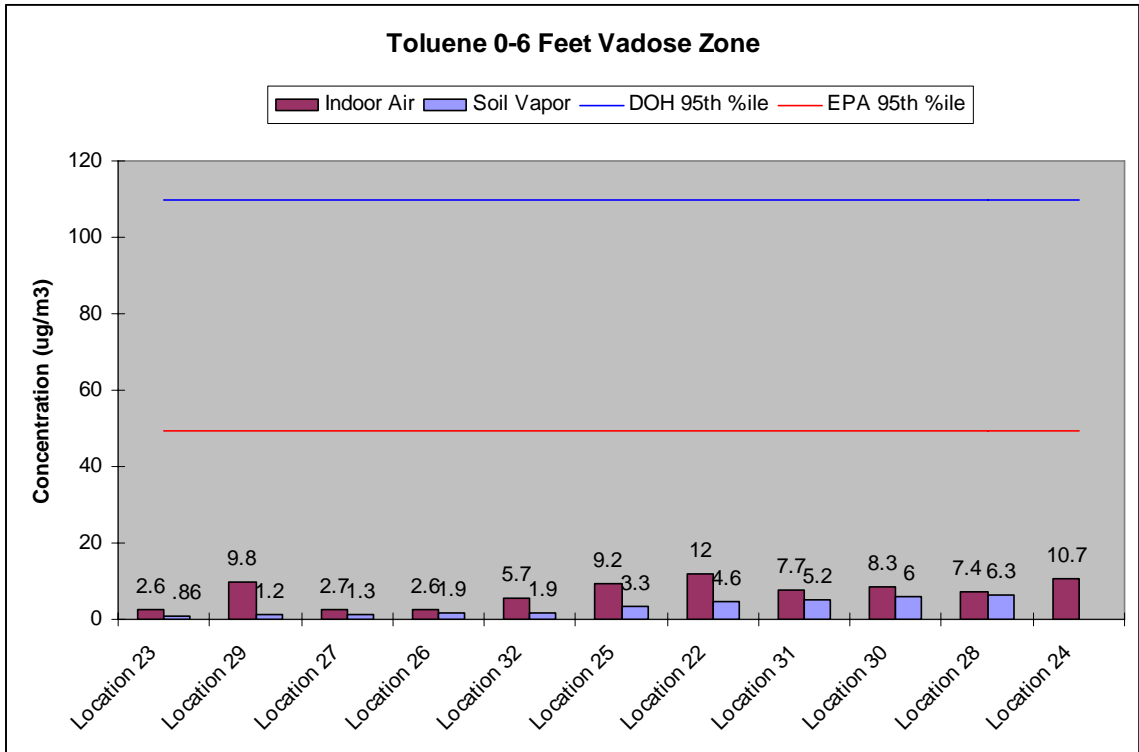


Figure 7. Maximum Concentration of Toluene by Locations with 0- 6 feet Vadose Zone

DOH 95<sup>th</sup> %ile – NYSDOH Background 95<sup>th</sup> Percentile for Indoor Air, 2003  
 EPA 95<sup>th</sup> %ile- - USEPA BASE Background 95<sup>th</sup> Percentile for Indoor Air, 2001

Table 17 displays the maximum concentration for toluene in the indoor air as compared to soil vapor at each location with a 6-25 feet thick vadose zone. Three out of the 4 locations had higher concentrations of toluene in the indoor air than in soil vapor. As seen in Figure 8 all of the indoor air concentrations for toluene were well below both the EPA and NYSDOH 95<sup>th</sup> percentiles for background indoor air.

Table 17. Maximum Concentration of Toluene by Locations with 6 -25 feet Vadose Zone

Maximum Concentrations of Toluene by Location for Indoor Air vs Soil Vapor (6 - 25 feet) (ug/m <sup>3</sup> )		
Location	Indoor Air	Soil Vapor
Location 34	6.7	1.8
Location 35	9	9.6
Location 36	31	10
Location 33	7.9	12.9

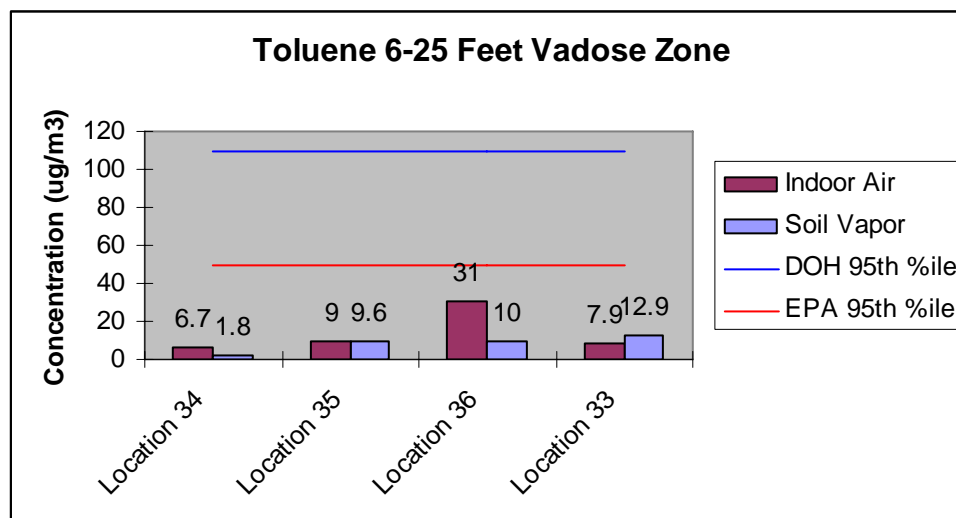


Figure 8. Maximum Concentration of Toluene by Locations with 6 - 25 feet Vadose Zone

DOH 95<sup>th</sup> %ile – NYSDOH Background 95<sup>th</sup> Percentile for Indoor Air, 2003  
 EPA 95<sup>th</sup> %ile- - USEPA BASE Background 95<sup>th</sup> Percentile for Indoor Air, 2001

Table 18 displays the maximum concentration for ethylbenzene in the indoor air as compared to soil vapor at each location with no vadose zone. Soil vapor samples were not collected at seven of the locations due to groundwater in contact with the building slab. Only one of the locations had higher concentrations of ethylbenzene in the indoor air than in the soil vapor. As seen in Figure 9 two locations, 15 and 9 had ethylbenzene

concentrations above the EPA 95th percentile for background indoor air but were below DOH background concentrations.

Table 18. Maximum Concentration of Ethylbenzene by Location with No Vadose Zone

<b>Maximum Concentrations of Ethylbenzene by Location for Indoor Air vs Soil Vapor (No Vadose Zone) (ug/m<sup>3</sup>)</b>		
Location	Indoor Air	Soil Vapor
Location 3	1.3	1.1
Location 2	0.87	1.4
Location 14	0.87	1.4
Location 6	0.87	1.7
Location 7	0.87	1.7
Location 10	0.51	1.7
Location 15	5.7	1.7
Location 17	0.87	1.7
Location 18	0.7	1.7
Location 21	0.87	1.8
Location 20	1.3	2.1
Location 11	0.651	2.52
Location 13	0.521	3.25
Location 9	1.6	9.3
Location 1	1.3	
Location 4	1.3	
Location 5	0.87	
Location 8	0.87	
Location 12	0.88	
Location 16	0.87	
Location 19	0.87	

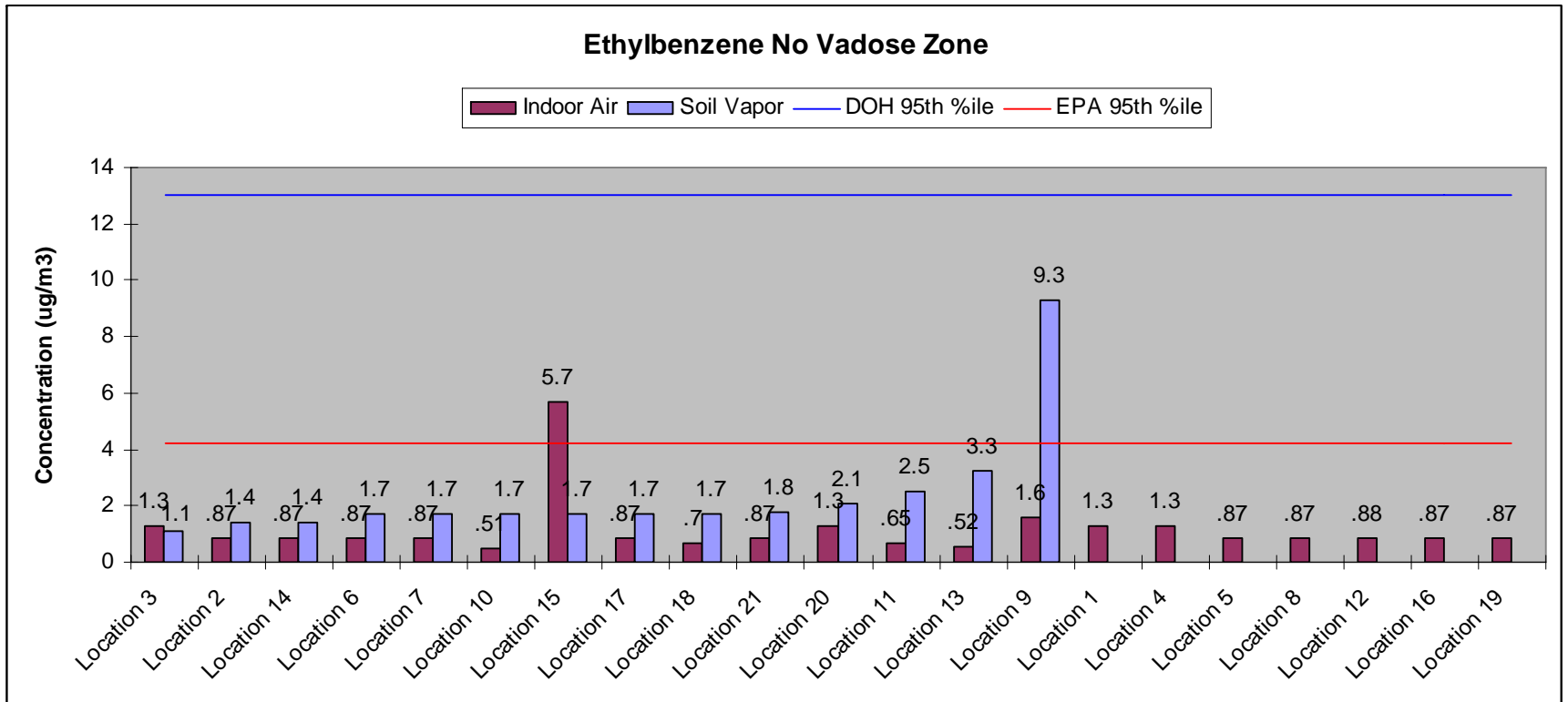


Figure 9. Maximum Concentration of Ethylbenzene by Locations with No Vadose Zone

DOH 95<sup>th</sup> % ile – NYSDOH Background 95<sup>th</sup> Percentile for Indoor Air, 2003

EPA 95<sup>th</sup> %ile- - USEPA BASE Background 95<sup>th</sup> Percentile for Indoor Air, 2001

Table 19 displays the maximum concentration for ethylbenzene in the indoor air as compared to soil vapor at each location with 0-6 feet thick vadose zones. A soil vapor sample was not collected for Location 24. Three of the locations had higher concentrations of ethylbenzene in the indoor air than in the soil vapor. As seen in Figure 10 one location, 24, had ethylbenzene at a concentration above the EPA 95th percentile for background indoor air but was below DOH background concentrations.

Table 19. Maximum Concentrations for Ethylbenzene by Location for Indoor Air vs Soil Vapor 0-6 Feet Vadose Zone

<b>Maximum Concentrations of Ethylbenzene by Location for Indoor Air vs Soil Vapor (0 - 6 feet) (ug/m<sup>3</sup>)</b>		
Location	Indoor Air	Soil Vapor
Location 28	1.3	0.61
Location 22	1.9	0.78
Location 30	0.87	1.2
Location 31	0.99	1.2
Location 25	0.87	1.6
Location 26	0.87	1.7
Location 29	0.87	1.7
Location 32	1.3	1.7
Location 23	0.87	1.8
Location 27	0.87	1.9
Location 24	5.34	

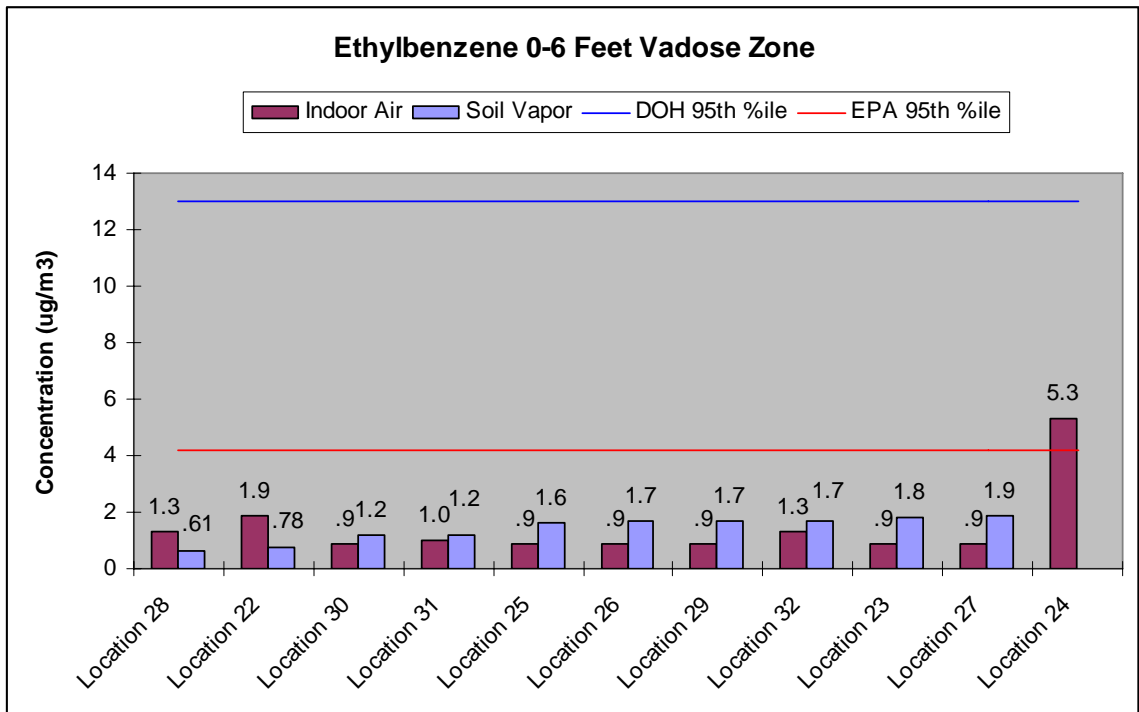


Figure 10. Maximum Concentration of Ethylbenzene by Locations with 0- 6 feet Vadose Zone

DOH 95<sup>th</sup> %ile – NYSDOH Background 95<sup>th</sup> Percentile for Indoor Air, 2003  
 EPA 95<sup>th</sup> %ile- - USEPA BASE Background 95<sup>th</sup> Percentile for Indoor Air, 2001

Table 20 displays the maximum concentration for ethylbenzene in the indoor air as compared to soil vapor at each location with 6-25 feet thick vadose zones. Two out of the 4 locations had higher concentrations of ethylbenzene in the indoor air than in the soil vapor. As seen in Figure 11 two locations, 36 and 33, had ethylbenzene at concentrations above the EPA 95<sup>th</sup> percentile for background indoor air but were below DOH background concentrations.

Table 20. Maximum Concentrations for Ethylbenzene by Location for Indoor Air vs Soil Vapor 6- 25 Feet Vadose Zone

Maximum Concentrations for Ethylbenzene by Location for Indoor Air vs Soil Vapor (6-25 Feet)(ug/m <sup>3</sup> )		
Location	Indoor Air	Soil Vapor
Location 34	0.95	0.35
Location 36	5.6	1.2
Location 35	0.47	2.4
Location 33	3.9	8.9

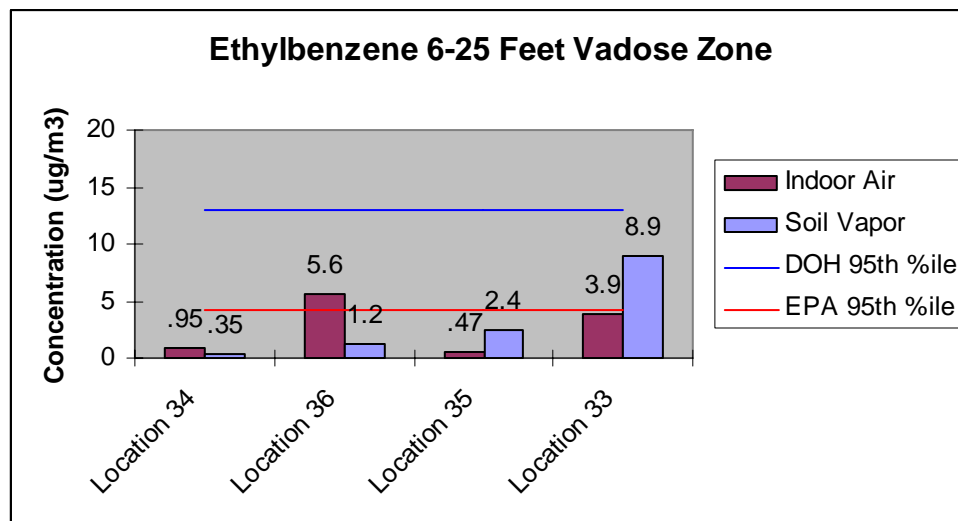


Figure 11. Maximum Concentration of Ethylbenzene by Locations with 6 - 25 feet Vadose Zone

DOH 95<sup>th</sup> % ile – NYSDOH Background 95<sup>th</sup> Percentile for Indoor Air, 2003  
 EPA 95<sup>th</sup> %ile- - USEPA BASE Background 95<sup>th</sup> Percentile for Indoor Air, 2001

Table 21 displays the maximum concentration for m,p-xylene in the indoor air as compared to soil vapor at each location with no vadose zone. Soil vapor samples were not collected at seven of the locations due to groundwater in contact with the building slab. Five of the locations had higher concentrations of m,p-xylene in the indoor air than in the soil vapor. As seen in Figure 12 one Location 9 had m,p-xylene concentrations in soil vapor above both the EPA and DOH 95th percentile for background indoor air.

Table 21. Maximum Concentrations for m,p-Xylene by Location for Indoor Air vs Soil Vapor No Vadose Zone

<b>Maximum Concentrations of m, p- Xylene by Location for Indoor Air vs Soil Vapor (No Vadose Zone) (ug/m<sup>3</sup>)</b>		
Location	Indoor Air	Soil Vapor
Location 17	1	0.44
Location 7	0.96	0.47
Location 20	3.5	1.7
Location 14	1.7	2.2
Location 15	12	2.9
Location 2	1.6	3.3
Location 6	0.46	3.4
Location 10	1.2	3.4
Location 18	1.7	3.4
Location 21	2	3.5
Location 3	6.6	3.7
Location 11	1.69	4.16
Location 13	1.17	5.85
Location 9	4.6	28
Location 1	3.9	
Location 4	3.7	
Location 5	0.52	
Location 8	0.69	



Table 21. (continued)

Location 12	2	
Location 16	1.7	
Location 19	1.7	

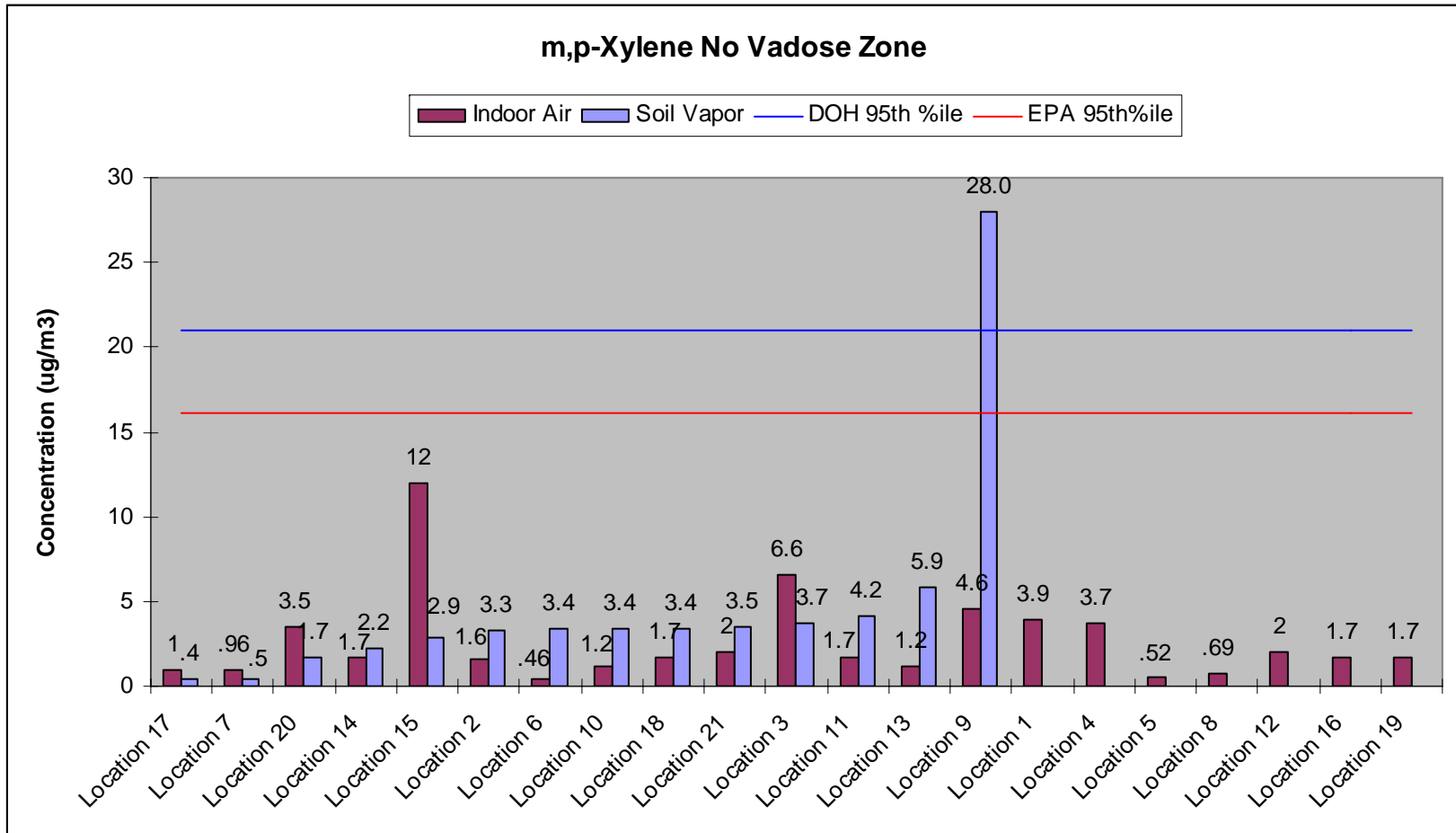


Figure 12. Maximum Concentration of m,p-Xylene by Location with No Vadose Zone

DOH 95<sup>th</sup> % ile – NYSDOH Background 95<sup>th</sup> Percentile for Indoor Air, 2003

EPA 95<sup>th</sup> %ile- - USEPA BASE Background 95<sup>th</sup> Percentile for Indoor Air, 2001

Table 22 displays the maximum concentration for m,p-xylene in the indoor air as compared to soil vapor at each location with 0-6 feet thick vadose zones. A soil vapor sample was not collected for Location 24. Four of the locations had higher concentrations of m,p-xylene in the indoor air than in the soil vapor. As seen in Figure 13 none of the locations had m,p-xylene concentrations above either the EPA or DOH 95<sup>th</sup> percentile for background indoor air.

Table 22. Maximum Concentrations for m,p-Xylene by Location for Indoor Air vs Soil Vapor 0-6 Feet Vadose Zone

<b>Maximum Concentrations of m, p- Xylene by Location for Indoor Air vs Soil Vapor (0 -6 feet) (ug/m<sup>3</sup>)</b>		
Location	Indoor Air	Soil Vapor
Location 28	2.9	1.1
Location 32	2.8	1.5
Location 31	2.4	1.8
Location 22	6.4	2.7
Location 25	2.3	3.3
Location 30	1.4	3.3
Location 26	1.2	3.4
Location 29	1.7	3.4
Location 23	1.6	3.6
Location 27	2.5	3.8
Location 24	13.4	

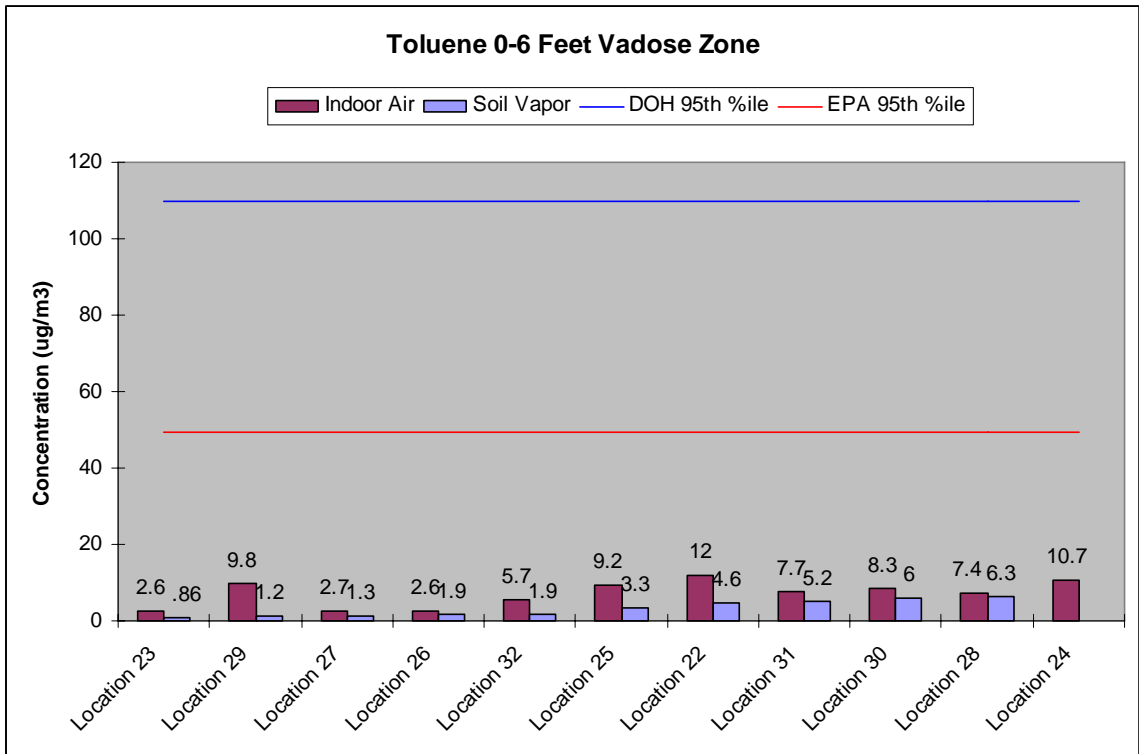


Figure 13. Maximum Concentration of m,p-Xylene by Location with 0-6 feet Vadose Zone

DOH 95<sup>th</sup> %ile – NYSDOH Background 95<sup>th</sup> Percentile for Indoor Air, 2003  
 EPA 95<sup>th</sup> %ile- - USEPA BASE Background 95<sup>th</sup> Percentile for Indoor Air, 2001

Table 23 displays the maximum concentration for m,p-xylene in the indoor air as compared to soil vapor at each location with 6-25 feet thick vadose zones. Three out of the 4 locations had higher concentrations of m,p-xylene in the indoor air than in the soil vapor. As seen in Figure 14, Location 36 exceeded the EPA 95<sup>th</sup> percentile m,p-xylene in background indoor air.

Table 23. Maximum Concentrations for m,p-Xylene by Location for Indoor Air vs Soil Vapor 6-25 Feet Vadose Zone

Maximum Concentrations of m, p- Xylene by Location for Indoor Air vs Soil Vapor (6 - 25 feet) (ug/m <sup>3</sup> )		
Location	Indoor Air	Soil Vapor
Location 34	2.2	0.88
Location 36	20	1.9
Location 33	13	4.8
Location 35	1.3	6.6

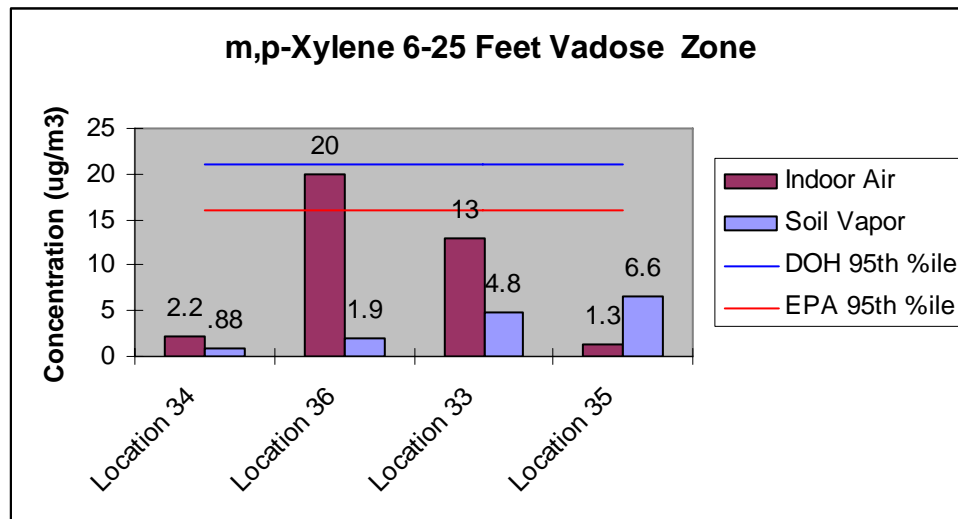


Figure 14. Maximum Concentration of m,p-Xylene by Locations with 6 - 25 feet Vadose Zone

DOH 95<sup>th</sup> % ile – NYSDOH Background 95<sup>th</sup> Percentile for Indoor Air, 2003  
 EPA 95<sup>th</sup> %ile- - USEPA BASE Background 95<sup>th</sup> Percentile for Indoor Air, 2001

Table 24 displays the maximum concentration for o-xylene in the indoor air as compared to soil vapor at each location with no vadose zone. Soil vapor samples were not collected at seven of the locations due to groundwater in contact with the building slab. Five of the locations had higher concentrations of o-xylene in the indoor air than in the

soil vapor. As seen in Figure 15 one Location 9 had o-xylene concentrations above both the EPA and DOH 95th percentile for background indoor air.

Table 24. Maximum Concentrations for o-Xylene by Location for Indoor Air vs Soil Vapor No Vadose Zone

<b>Maximum Concentrations of o-Xylene by Location for Indoor Air vs Soil Vapor (No Vadose Zone)(ug/m<sup>3</sup>)</b>		
Location	Indoor Air	Soil Vapor
Location 20	1.4	1.3
Location 3	3.6	1.4
Location 14	0.87	1.4
Location 15	4.4	1.5
Location 2	0.87	1.6
Location 6	0.87	1.7
Location 7	0.87	1.7
Location 10	0.93	1.7
Location 17	1	1.7
Location 18	0.87	1.7
Location 21	0.87	1.8
Location 11	0.607	1.82
Location 13	0.521	2.14
Location 9	1.5	9.7
Location 1	1.7	
Location 4	1.5	
Location 5	0.87	
Location 8	0.35	
Location 12	0.82	
Location 16	0.87	
Location 19	0.87	

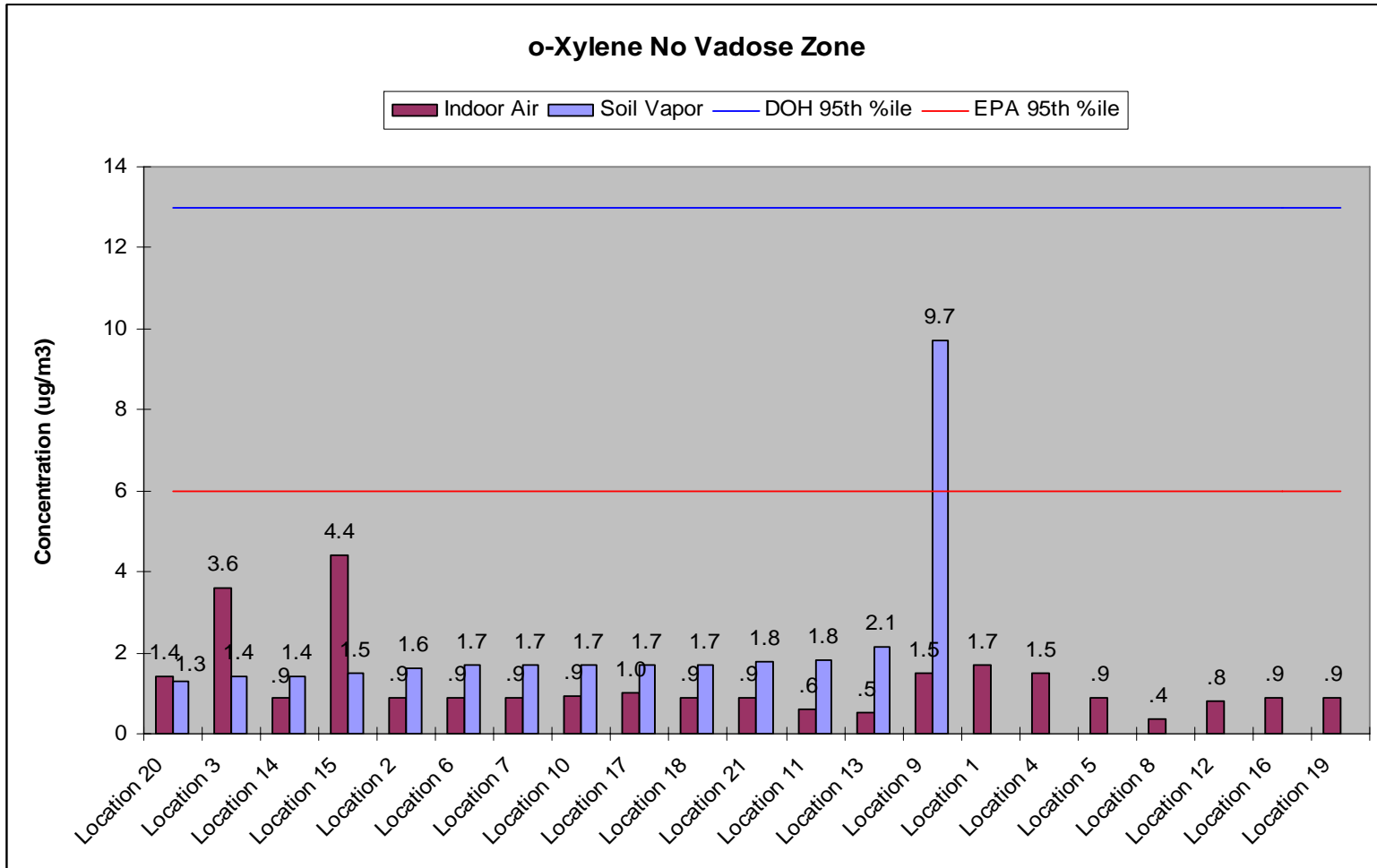


Figure 15. Maximum Concentration of o-Xylene by Location with No Vadose Zone

DOH 95<sup>th</sup> %ile – NYSDOH Background 95<sup>th</sup> Percentile for Indoor Air, 2003

EPA 95<sup>th</sup> %ile- - USEPA BASE Background 95<sup>th</sup> Percentile for Indoor Air, 2001

Table 25 displays the maximum concentration for o-xylene in the indoor air as compared to soil vapor at each location with 0-6 feet thick vadose zones. A soil vapor sample was not collected for Location 24. Two of the locations had higher concentrations of o-xylene in the indoor air than in the soil vapor. As seen in Figure 16 one no locations exceeded the EPA or DOH 95<sup>th</sup> percentile for background indoor air for o-xylene.

Table 25. Maximum Concentrations for o-Xylene by Location for Indoor Air vs Soil Vapor 0-6 Feet Vadose Zone

<b>Maximum Concentrations of o- Xylene by Location for Indoor Air vs Soil Vapor (0 -6 feet) (ug/m<sup>3</sup>)</b>		
Location	Indoor Air	Soil Vapor
Location 22	2	0.97
Location 31	0.82	1
Location 25	0.66	1.6
Location 26	0.87	1.7
Location 29	0.87	1.7
Location 30	0.87	1.7
Location 32	1.1	1.7
Location 23	0.72	1.8
Location 27	2	1.9
Location 28	1.2	2
Location 24	7.46	



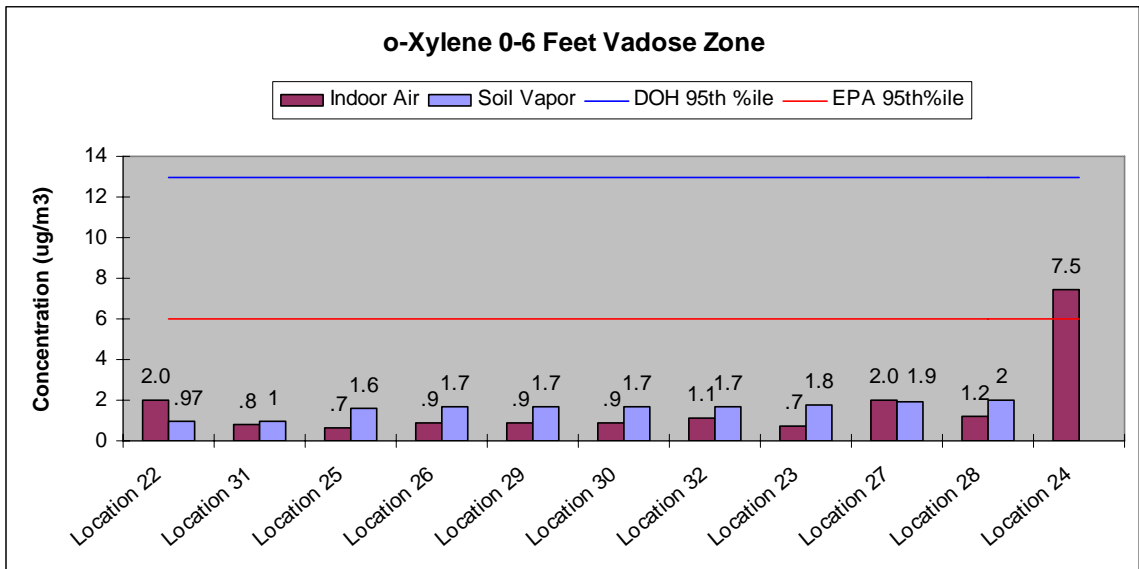


Figure 16. Maximum Concentration of o-Xylene by Location with 0-6 feet Vadose Zone

DOH 95<sup>th</sup> % ile – NYSDOH Background 95<sup>th</sup> Percentile for Indoor Air, 2003  
 EPA 95<sup>th</sup> %ile- - USEPA BASE Background 95<sup>th</sup> Percentile for Indoor Air, 2001

Table 26 displays the maximum concentration for o-xylene in the indoor air as compared to soil vapor at each location with 6 - 25 feet thick vadose zones. Two out of the 4 locations had higher concentrations of o-xylene in the indoor air than in the soil vapor. As seen in Figure 17, Locations 36 and 33 had o-xylene concentrations above the EPA 95th percentile for background indoor air.

Table 26. Maximum Concentrations for o-Xylene by Location for Indoor Air vs Soil Vapor 6-25 Feet Vadose Zone

Maximum Concentrations of o- Xylene by Location for Indoor Air vs Soil Vapor (6 -25 feet)(ug/m <sup>3</sup> )		
Location	Indoor Air	Soil Vapor
Location 34	0.74	0.41

Table 26.(continued)

Location 36	6.4	1.2
Location 35	0.51	3.5
Location 33	2.9	8.9

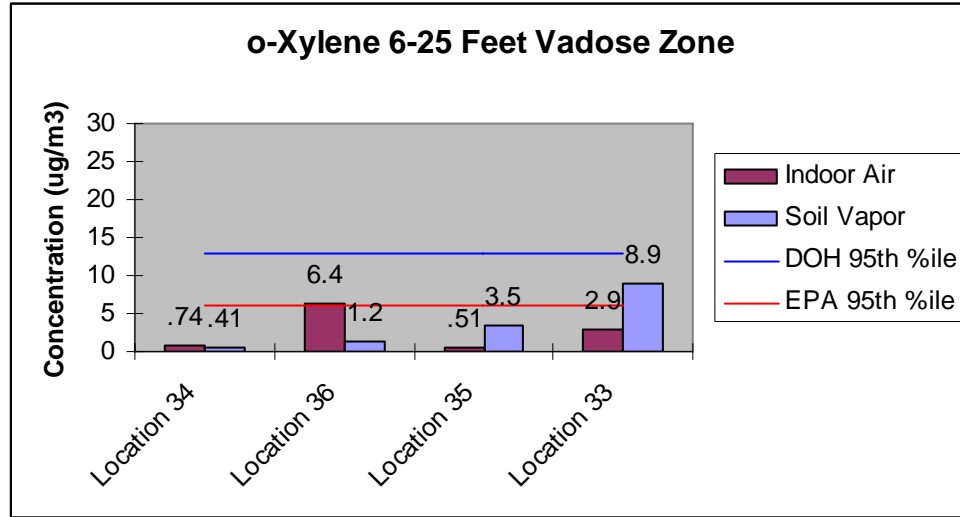


Figure 17. Maximum Concentration of o-Xylene by Locations with 6 - 25 feet Vadose Zone

DOH 95<sup>th</sup> % ile – NYSDOH Background 95<sup>th</sup> Percentile for Indoor Air, 2003  
 EPA 95<sup>th</sup> %ile- - USEPA BASE Background 95<sup>th</sup> Percentile for Indoor Air, 2001

Based on the results of the assessment conducted for the 36 properties included in this study, no evidence of soil vapor intrusion was found regardless of the thickness of vadose zone. Even at locations where indoor air concentrations exceeded background these concentrations were an order of magnitude below reference concentrations. The highest concentration of benzene in indoor air was detected at Location 24 at 4.72 ug/m<sup>3</sup>. The RfC for benzene is 3x10<sup>-2</sup> mg/m<sup>3</sup>. The highest concentration for toluene in indoor air was detected at Location 9 at 220 ug/m<sup>3</sup>. The RfC for toluene is 5 mg/m<sup>3</sup>.

The highest concentration for ethylbenzene in indoor air was detected at Location 15 at  $5.7 \text{ ug/m}^3$ . The RfC for ethylbenzene is  $1 \text{ mg/m}^3$ . The highest concentration for m,p-xylene in indoor air was detected at Location 15 at  $12 \text{ ug/m}^3$ . The RfC for xylenes is  $0.1 \text{ mg/m}^3$ . The highest concentration for o-xylene in indoor air was detected at Location 24 at  $7.46 \text{ ug/m}^3$ . The RfC for xylenes is  $0.1 \text{ mg/m}^3$ .

The following figures (18-26) depict difference in frequency of detections between outdoor air, indoor air, and soil vapor categorized by vadose zones. Figure 18 depicts the difference in the frequency of detection for chemicals detected in the outdoor air versus the indoor air of buildings with no vadose zones. The positive values represent more detections for benzene, carbon disulfide, toluene, and m,p-xylene in the outdoor air than in the indoor air. Carbon disulfide is a natural product of anaerobic biodegradation; benzene, toluene, and m,p-xylene are all petroleum-related chemicals. The presence of these chemicals in the outdoor air could account for some proportion of their concentrations found in indoor air.

Figure 19 depicts the difference in the frequency of detection for chemicals detected in the outdoor air versus the indoor air of buildings with 0-6 feet thick vadose zones. The positive values represent more detections for benzene, thiophene, toluene, 1,2,3-trimethylbenzene, and m,p-xylene in the outdoor air than in the indoor air. All of these chemicals are petroleum-related. The presence of these chemicals in the outdoor air could account for some proportion of their concentrations found in indoor air.

Figure 20 depicts the difference in the frequency of detection for chemicals detected in the outdoor air versus the indoor air of buildings with 6-25 feet thick vadose zones. The positive values represent more detections for benzene, n-decane,

2-methylnaphthalene, toluene, 1,2,3-trimethylbenzene, 1,2,4-trimethylbenzene, n-undecane, m,p-xylene, and o-xylene in the outdoor air than in the indoor air. All of these chemicals are present in petroleum-related compounds. The presence of these chemicals in the outdoor air could account for some proportion of their concentrations found in indoor air.

Figure 21 depicts the difference in the frequency of detection for chemicals detected in the indoor air versus soil vapor of buildings with no vadose zones. The positive values represent more detections for benzene, ethylbenzene, indan, 1-methylnaphthalene, nonane, toluene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, m,p-xylene and o-xylene in the indoor air than in soil vapor. All of these chemicals are petroleum-related.

Figure 22 depicts the difference in the frequency of detection for chemicals detected in the indoor air versus soil vapor of buildings with 0-6 feet thick vadose zones. The positive values represent more detections for n-decane, ethylbenzene, indan, 1-methylnaphthalene, 2-methylnaphthalene, 2-methylthiophene, 3-methylthiophene, nonane, 1,2,4,5-tetramethylbenzene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, n-undecane, m,p-xylene and o-xylene in the indoor air than in soil vapor. All of these chemicals are petroleum-related.

Figure 23 depicts the difference in the frequency of detection for chemicals detected in the indoor air versus soil vapor of buildings with 6-25 feet thick vadose zones. The positive values represent more detections for benzene, benzothiophene, n-decane, n-dodecane, ethylbenzene, nonane, thiophene, toluene, 1,2,3-trimethylbenzene,

1,2,4-trimethylbenzene, n-undecane, m,p-xylene and o-xylene in the indoor air than in soil vapor. All of these chemicals are petroleum-related.

Figure 24 depicts the difference in the frequency of detection for chemicals detected in the outdoor air versus soil vapor of buildings with no vadose zones. The positive values represent more detections for benzene, ethylbenzene, toluene, m,p-xylene and o-xylene in the outdoor air than in soil vapor. All of these chemicals are petroleum-related.

Figure 25 depicts the difference in the frequency of detection for chemicals detected in the outdoor air versus soil vapor of buildings with 0-6 feet thick vadose zones. The positive values represent more detections for benzene, n-dodecane, ethylbenzene, thiophene, toluene, 1,2,3-trimethylbenzene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, m,p-xylene and o-xylene in the outdoor air than in soil vapor. All of these chemicals are petroleum-related.

Figure 26 depicts the difference in the frequency of detection for chemicals detected in the outdoor air versus soil vapor of buildings with 6-25 feet thick vadose zones. The positive values represent more detections for benzene, n-decane, 2-methylnaphthalene, toluene, 1,2,3-trimethylbenzene, 1,2,4-trimethylbenzene, n-undecane, m,p-xylene and o-xylene in the outdoor air than in soil vapor. All of these chemicals are petroleum-related.

Based on the analyses of this data the five chemicals with highest frequency of detection in the study results, benzene, toluene, ethylbenzene, m,p-xylene, and o-xylene, were more frequent in outdoor air than in indoor air and soil vapor.

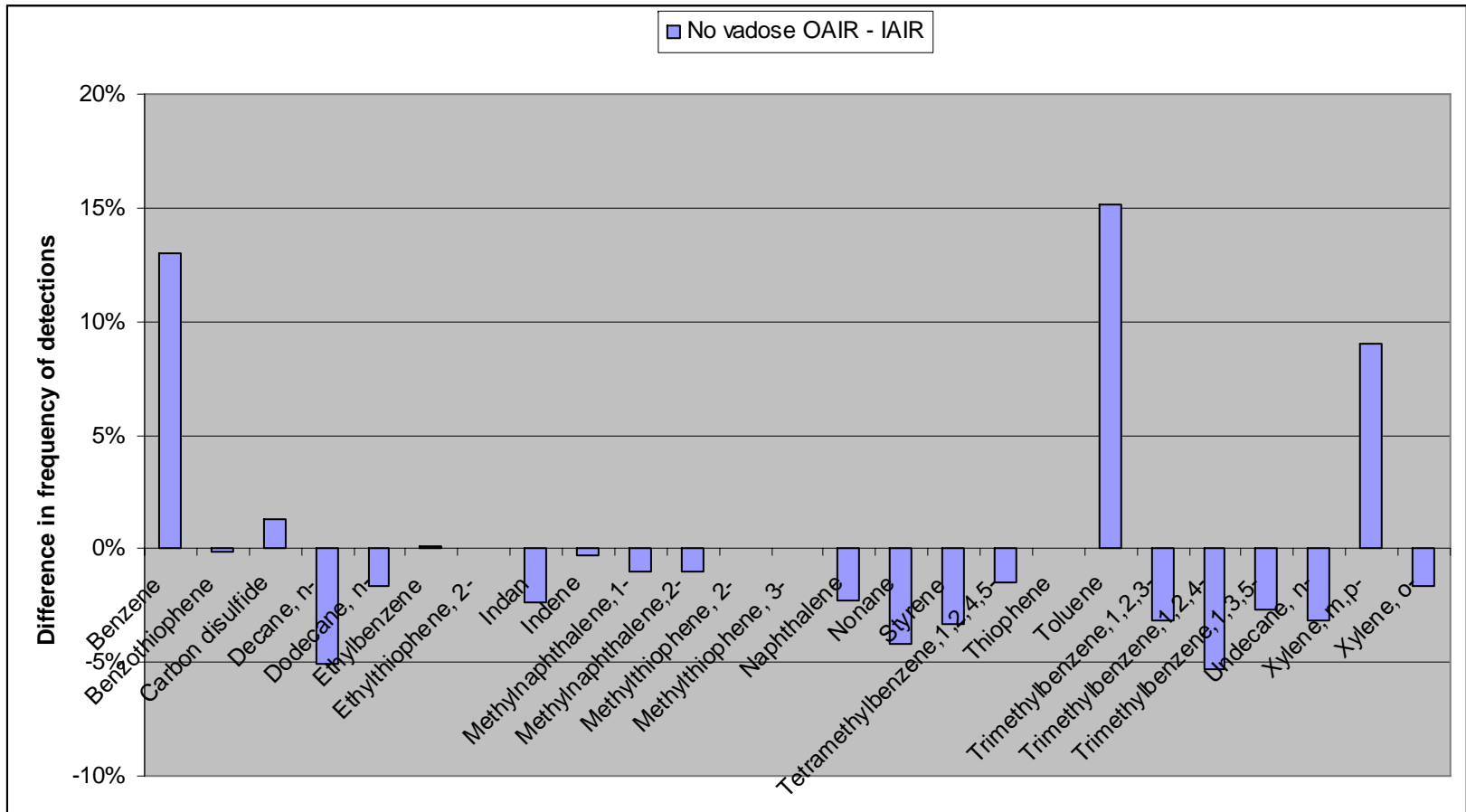


Figure 18. Difference in Frequency of Detections between Outdoor Air and Indoor Air with No Vadose Zone.

A positive value represents more detections found in outdoor air.

OAIR – Outdoor Air

IAIR – Indoor Air

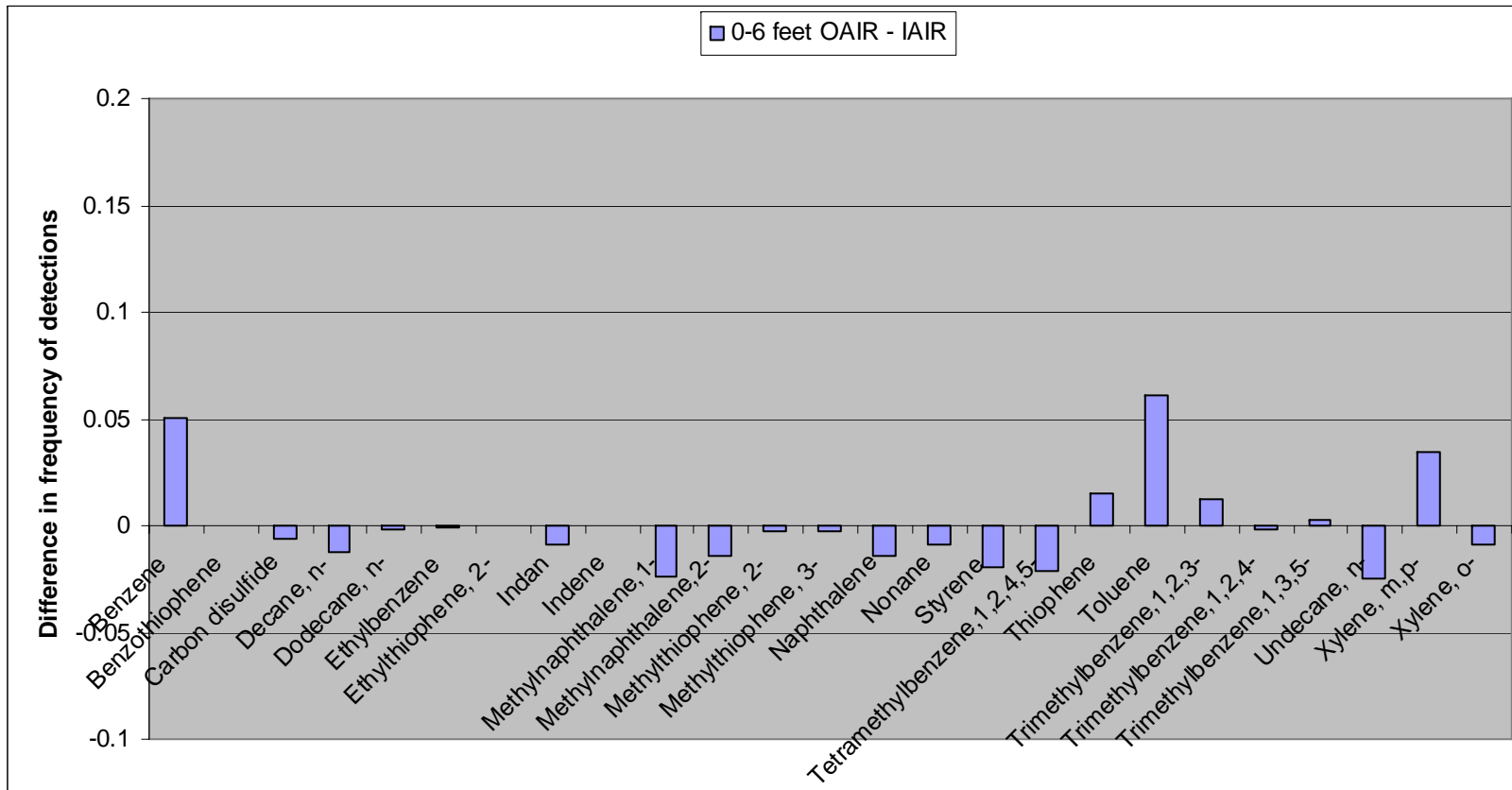


Figure 19. Difference in Frequency of Detections between Outdoor Air and Indoor Air with a 0-6 Foot Vadose Zone.

A positive value represents more detections found in outdoor air.

OAIR – Outdoor Air

IAIR – Indoor Air

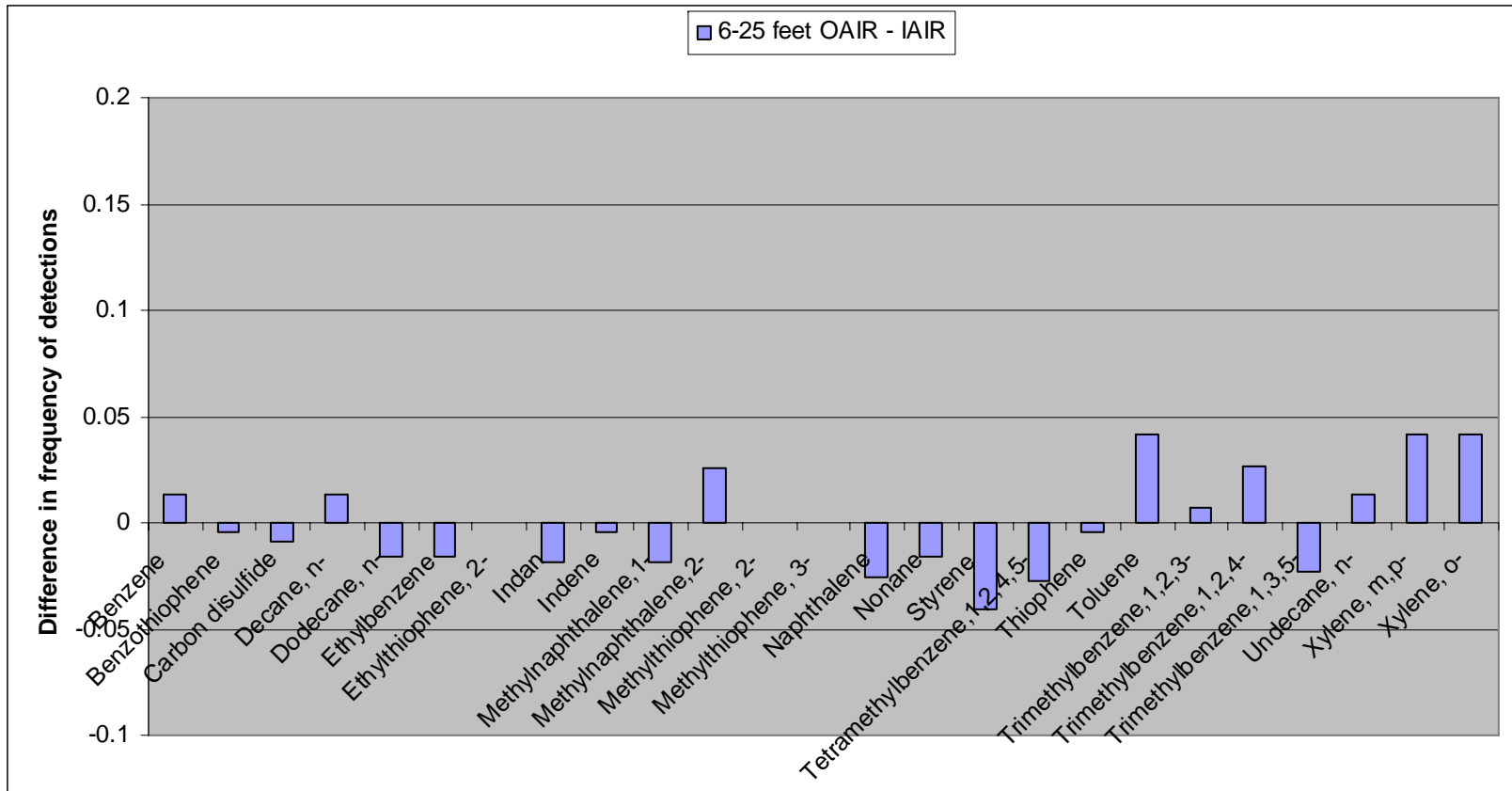


Figure 20. Difference in Frequency of Detections between Outdoor Air and Indoor Air with a 6-25 Foot Vadose Zone.

A positive value represents more detections found in outdoor air.

OAIR – Outdoor Air

IAIR – Indoor Air



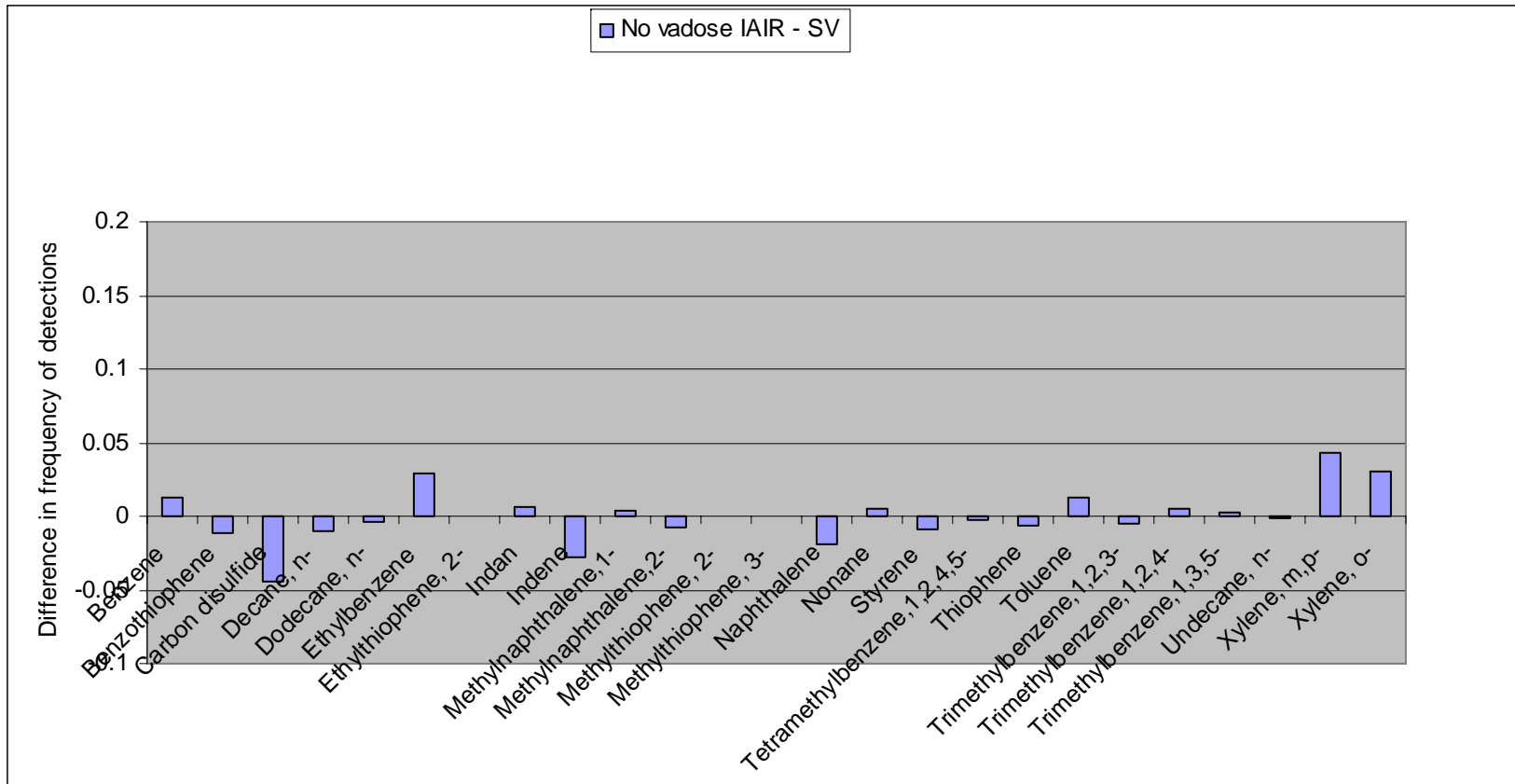


Figure 21. Difference in Frequency of Detections between Indoor Air and Soil Vapor with No Vadose Zone.

A positive value represents more detections found in indoor air

IAIR – Indoor Air

SV – Soil Vapor

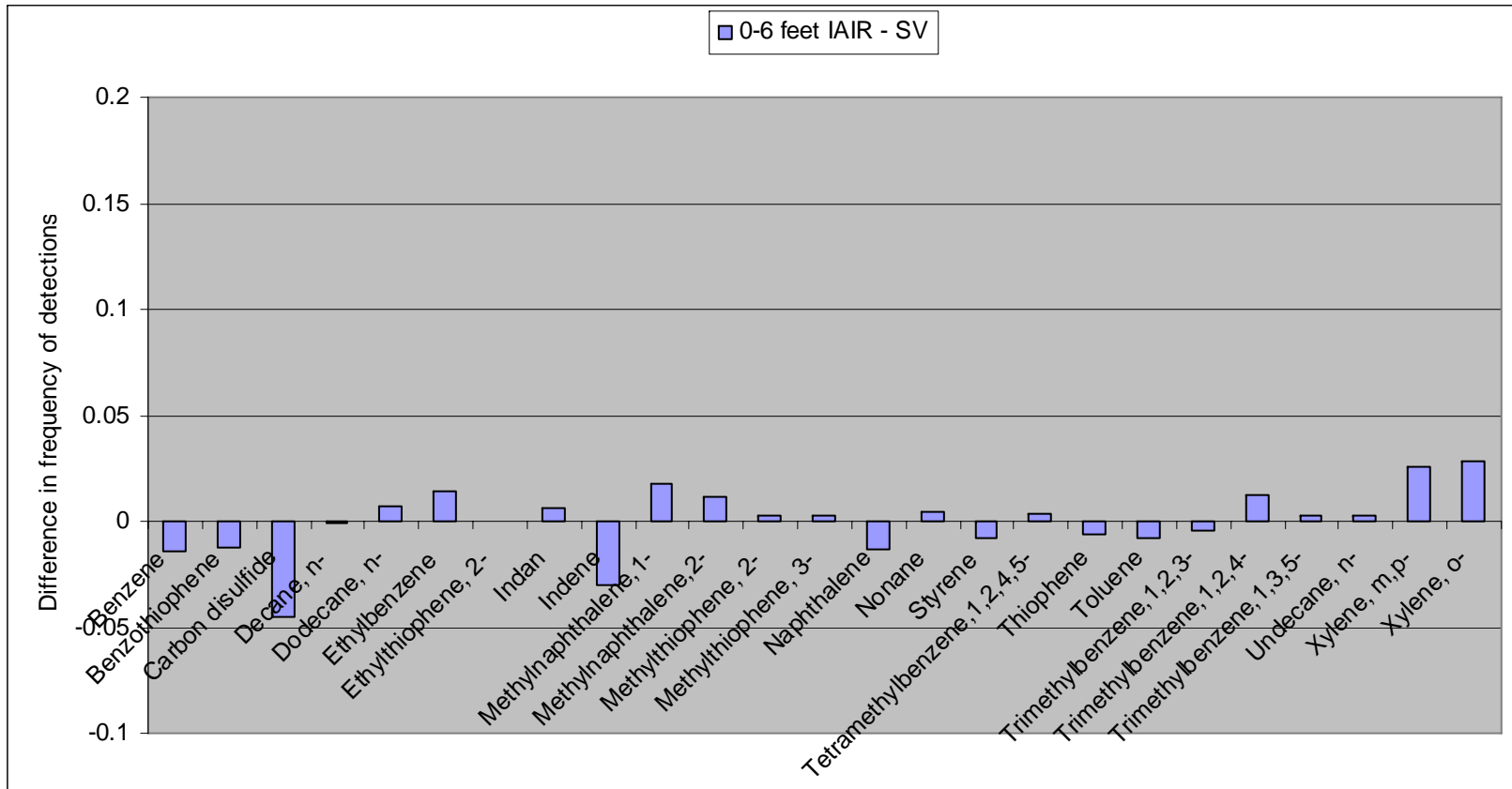


Figure 22. Difference in Frequency of Detections between Indoor Air and Soil Vapor with a 0-6 Foot Vadose Zone.

A positive value represents more detections found in indoor air

IAIR – Indoor Air

SV – Soil Vapor

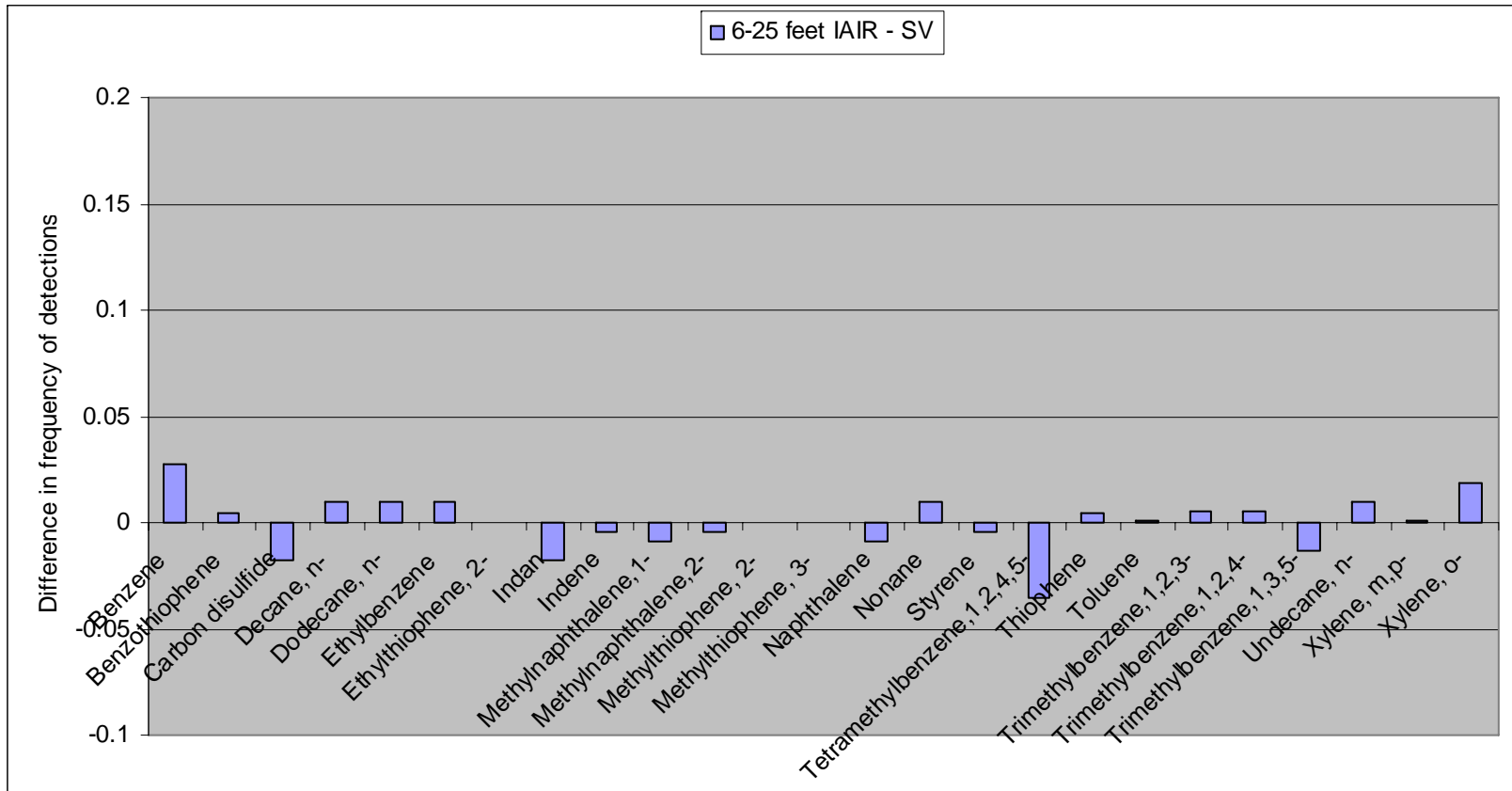


Figure 23. Difference in Frequency of Detections between Indoor Air and Soil Vapor with a 6-25 foot Vadose Zone.

A positive value represents more detections found in indoor air.

IAIR – Indoor Air

SV – Soil Vapor

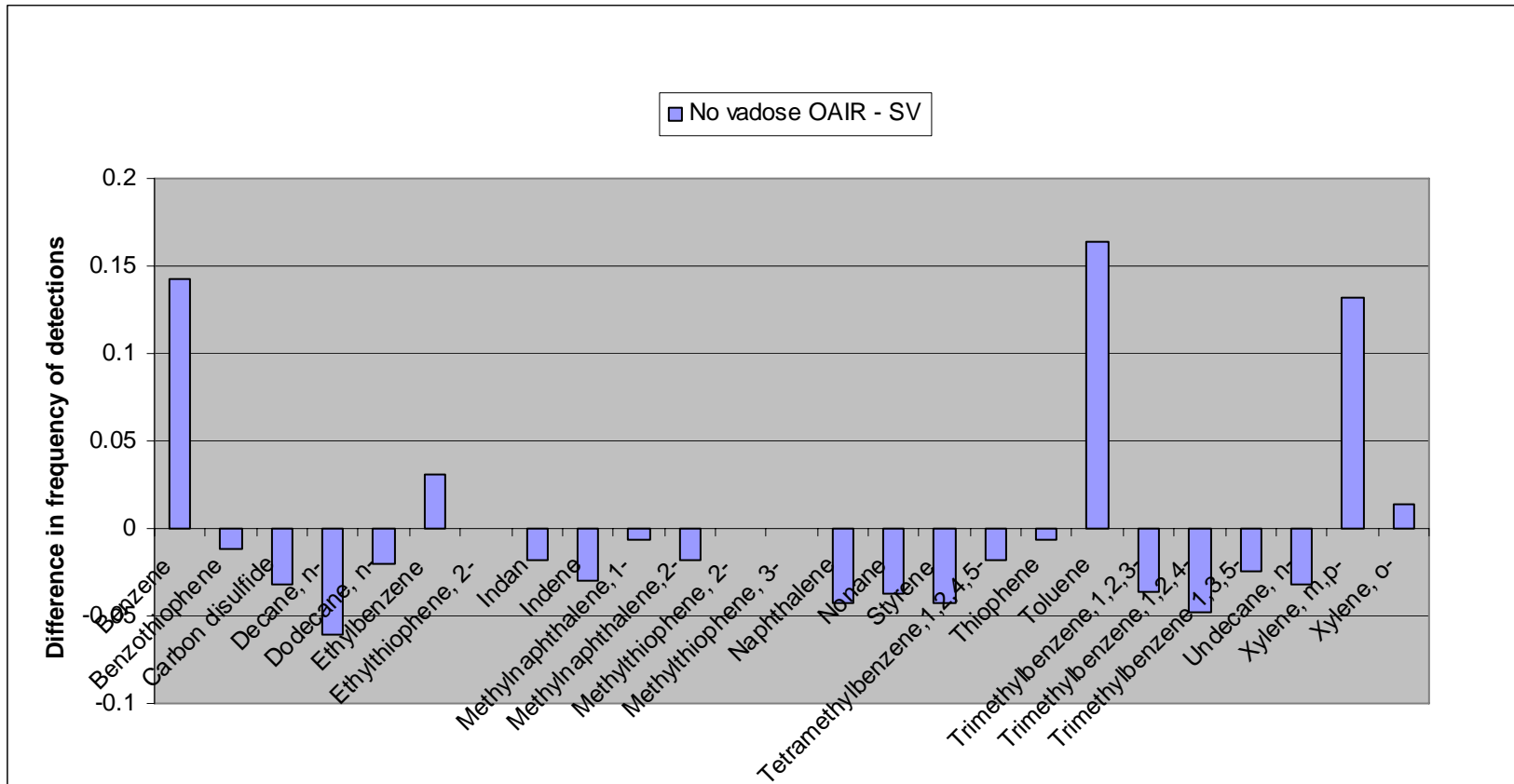


Figure 24. Difference in Frequency of Detections between Outdoor Air and Soil Vapor with No Vadose Zone.

A positive value represents more detections found in outdoor air

OAIR – Outdoor Air

SV – Soil Vapor

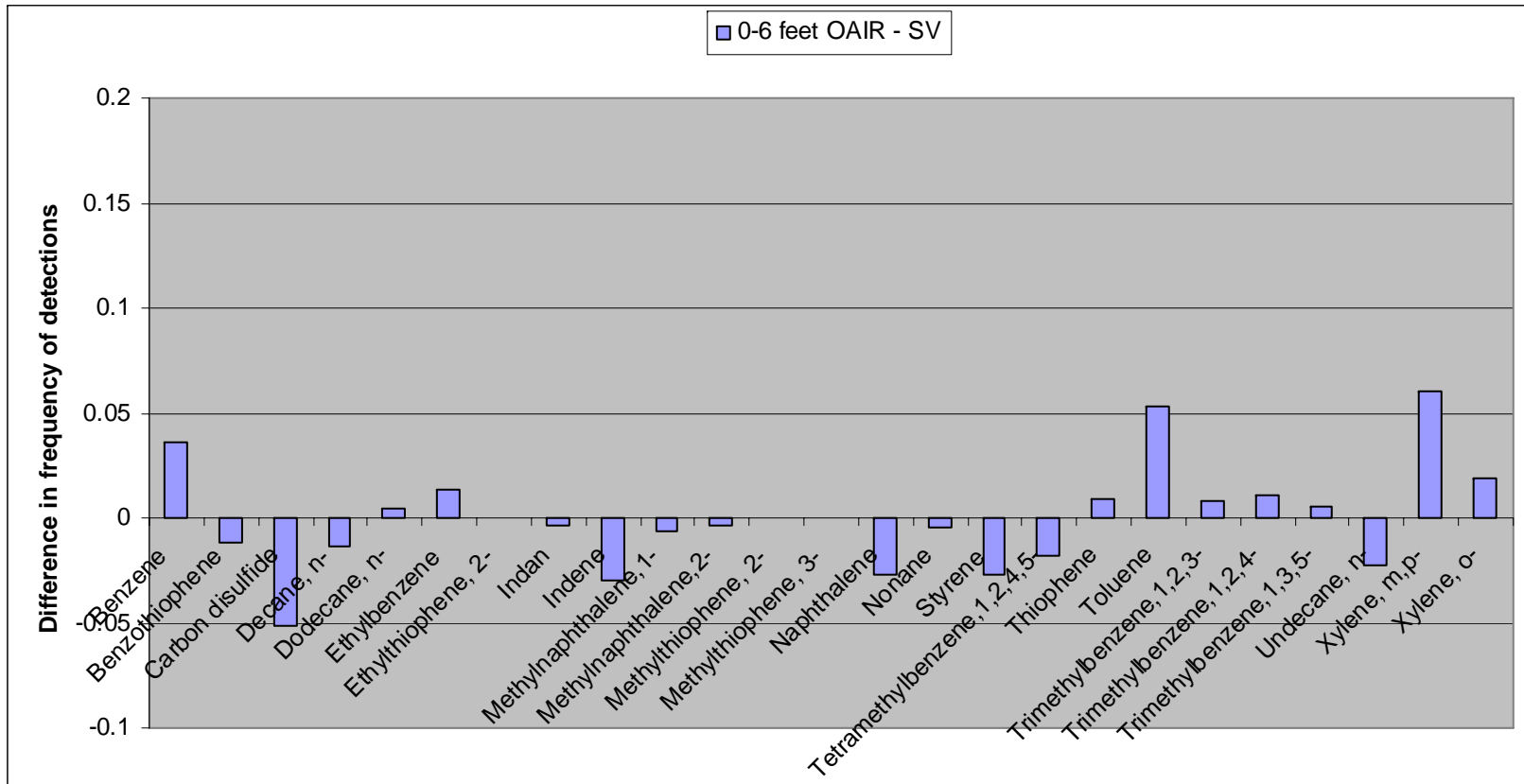


Figure 25. Difference in Frequency of Detections between Outdoor Air and Soil Vapor with a 0-6 foot Vadose Zone.

A positive value represents more detections found in outdoor air  
 OAIR – Outdoor Air  
 SV – Soil Vapor

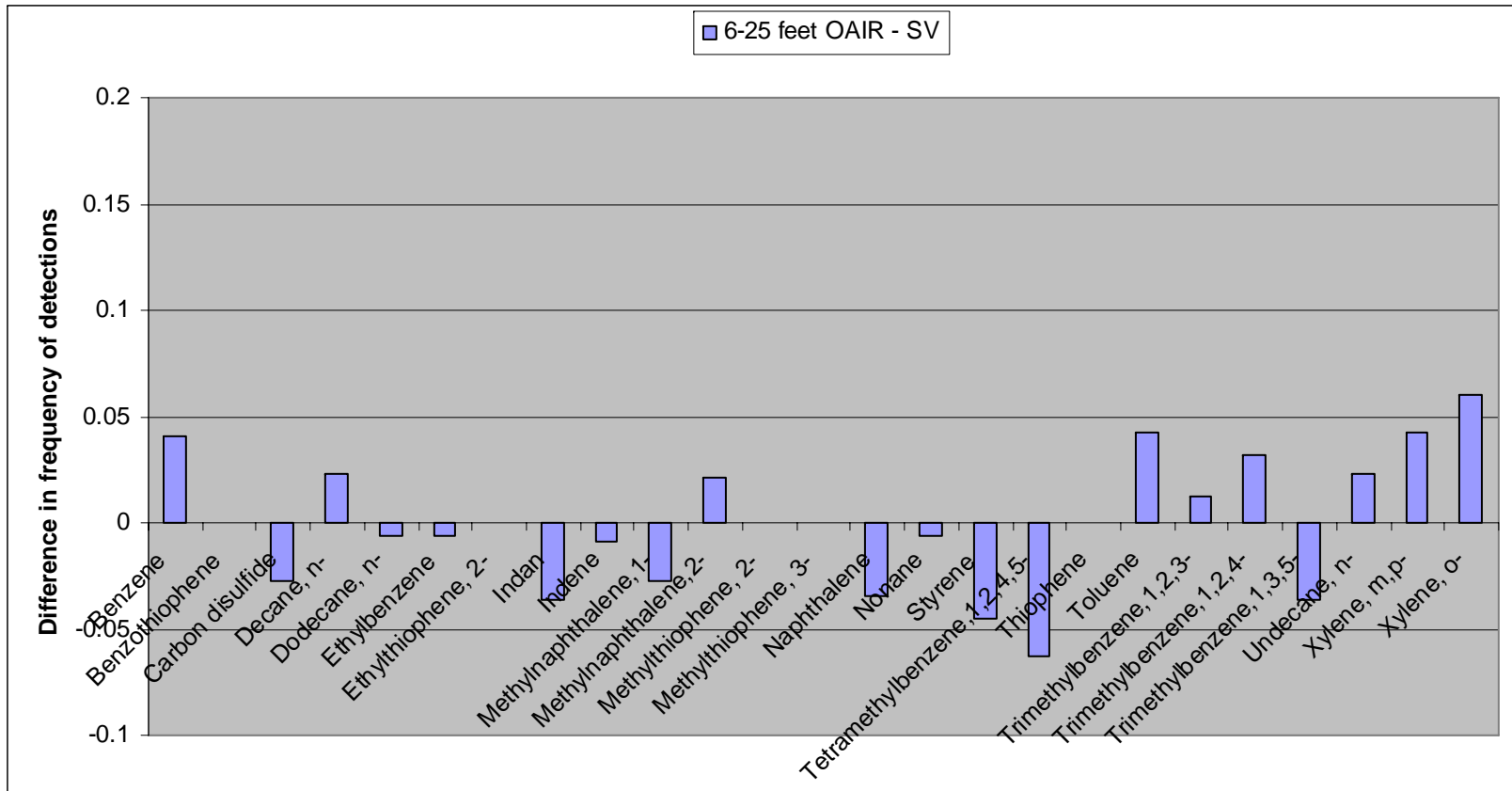


Figure 26. Difference in Frequency of Detections between Outdoor Air and Soil Vapor with a 6-25 foot Vadose Zone.

A positive value represents more detections found in outdoor air

OAIR – Outdoor Air

SV – Soil Vapor

Comparative risk analyses were conducted for mean and maximum concentrations detected in indoor and outdoor air and soil vapor to determine potential carcinogenic and non-carcinogenic health risks. Table 27 summarizes the minimum, mean, and maximum concentrations found in the study results for outdoor air categorized by vadose zone.

Table 27. Minimum, Maximum and Mean Concentrations of Detected Chemicals in Outdoor Air by Thickness of Vadose Zone (ug/m<sup>3</sup>)

Outdoor Air									
Chemical	No vadose zone			0-6 feet			6-25 feet		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Benzene	0.22	2.65	0.79	0.66	2.5	1.14	0.54	1.2	0.79
Carbon disulfide	0.19	0.38	0.30	0.35	0.35	0.35			
Decane, n-	0.62	0.62	0.62	0.41	1.7	0.97	0.29	0.87	0.62
Dodecane, n-	0.35	0.96	0.59	0.96	2.4	1.82	0.42	0.63	0.53
Ethylbenzene	0.24	0.83	0.44	0.26	1.3	0.76	1.1	1.4	1.25
Indan				0.4	0.4	0.40			
2-Methylphthalene				0.34	0.34	0.34	0.35	0.35	0.35
Naphthalene				0.35	0.35	0.35	0.26	0.26	0.26
Nonane	0.52	0.52	0.52	0.42	0.47	0.44	0.63	0.73	0.68
Styrene				0.84	0.84	0.84			
Thiophene				0.4	0.4	0.40			
Toluene	0.26	6.4	1.74	0.76	8.5	3.49	1	9.9	4.23
1,2,3-Trimethylbenzene				0.34	2.6	1.09	0.29	0.34	0.32
1,2,4-Trimethylbenzene				0.65	2.6	1.24	0.25	0.74	0.54
1,3,5-Trimethylbenzene				0.29	0.93	0.61			
Undecane, n-	0.38	2.6	1.46	0.45	2.5	1.25	0.32	0.89	0.66
Xylene, m,p-	0.33	2.5	0.81	0.44	2.7	1.31	0.59	4.1	2.23
Xylene, o-	0.23	0.39	0.31	0.26	1.1	0.73	0.22	1.1	0.61

Table 28 summarizes the minimum, mean, and maximum concentrations found in the study results for indoor air categorized by vadose zone.

Table 28. Minimum and Maximum Concentrations of Detected Chemicals in Indoor Air by Thickness of Vadose Zone (ug/m<sup>3</sup>)

Indoor Air									
Chemical	No vadose zone			0-6 feet			6-25 feet		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Benzene	0.31	4.4	0.88	0.58	4.72	1.36	0.7	2.8	1.29
Benzothiophene	0.346	0.346	0.35				0.274	0.274	0.27
Carbon disulfide	0.23	3.1	0.81	0.63	42.9	7.23	0.44	0.44	0.44
Decane, n-	0.29	50	3.93	0.52	8.32	1.81	0.63	2.7	1.22
Dodecane, n-	0.35	36	4.25	0.42	16	3.04	0.56	2.1	1.21
Ethylbenzene	0.24	5.7	0.91	0.44	5.34	1.12	0.27	5.6	1.33
Indan	0.3	1.4	0.69	0.28	0.961	0.61	0.111	1.1	0.47
Indene	0.237	0.42	0.33				0.119	0.119	0.12
1-Methylphthalene	0.46	4.4	1.72	0.29	1.9	0.66	0.29	1.15	0.60
2-Methylphthalene	0.453	5.6	2.64	0.41	8.7	1.64	0.29	2.24	0.71
2-Methylthiophene				0.26	0.26	0.26			
3-Methylthiophene				0.26	0.26	0.26			
Naphthalene	0.29	2.5	1.03	0.4	12.9	2.58	0.26	0.84	0.41
Nonane	0.27	4	1.50	0.38	4.5	1.39	0.28	2.6	0.92
Styrene	0.25	19	3.62	0.3	6.09	1.16	0.132	0.98	0.45
1,2,4,5-Tetramethylbenzene	0.44	4.8	1.18	0.33	15	5.55	0.055	1.3	0.48
Thiophene							0.41	0.41	0.41
Toluene	0.82	220	16.46	0.91	12	5.62	2.6	31	7.05
1,2,3-Trimethylbenzene	0.295	20	4.57	0.39	5.26	2.09	0.28	1.8	0.49
1,2,4-Trimethylbenzene	0.26	20	3.51	0.77	11.3	1.95	0.39	5	0.98
1,3,5-Trimethylbenzene	0.44	6.6	2.12	0.45	8.55	1.47	0.226	1.2	0.45
Undecane, n-	0.35	140	8.22	0.38	12	2.57	0.51	7.7	1.62
Xylene, m,p-	0.27	12	1.92	0.43	13.4	2.47	0.67	20	4.20
Xylene, o-	0.217	4.4	0.98	0.43	7.46	1.19	0.3	6.4	1.22



Table 29 summarizes the minimum, mean, and maximum concentrations found in the study results for soil vapor categorized by vadose zone.

Table 29. Minimum and Maximum Concentrations of Detected Chemicals in Soil Vapor by Thickness of Vadose Zone (ug/m<sup>3</sup>)

Soil Vapor									
	No vadose zone			0-6 feet			6-25 feet		
Chemical	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Benzene	0.48	58	9.55	0.62	8.2	2.90	0.96	3.2	1.98
Benzothiophene	1.1	1.4	1.25						
Carbon disulfide	0.666	12	4.08	1.5	5.1	3.37	6.7	16	10.13
Decane, n-	0.73	10	3.36	0.94	1.7	1.36	3.8	18.3	7.47
Dodecane, n-	1.11	100	15.78	0.93	9.1	3.63	3.8	383	108.40
Ethylbenzene	0.48	9.3	2.43	0.61	1.2	0.95	0.35	2.4	1.32
Indan	1.3	6.6	3.17	0.55	0.55	0.55	0.239	0.79	0.58
Indene	0.53	1.8	0.84				0.89	0.89	0.89
1-Methylphthalene	6	6	6.00	0.73	0.8	0.77	7.5	340	162.50
2-Methylphthalene	0.93	14	6.01	2	2.1	2.05	0.38	512	185.47
Naphthalene	0.55	33	5.93	0.59	0.94	0.79	0.4	11.9	3.22
Nonane	0.897	3.9	1.92	0.82	1.8	1.23	0.58	7.3	2.74
Styrene	0.3	2.6	1.23	0.56	2.1	1.30	0.43	1.6	0.78
1,2,4,5-Tetramethylbenzene	0.38	26	9.01	3.1	3.1	3.10	0.55	6.8	2.26
Thiophene	0.81	0.81	0.81	0.72	0.72	0.72			
Toluene	0.92	430	29.33	0.77	6.3	2.86	1.8	12.9	7.88
1,2,3-Trimethylbenzene	0.44	3.9	1.97	1.3	1.3	1.30	0.73	3	1.53
1,2,4-Trimethylbenzene	0.55	3.68	1.89	1.3	1.6	1.43	1.1	5.3	2.50
1,3,5-Trimethylbenzene	0.39	2.2	1.15				0.496	3.6	1.50
Undecane, n-	0.738	29	4.32	1.2	3.9	2.10	3.2	77.2	19.54
Xylene, m,p-	0.44	28	4.48	1.1	3.3	1.93	0.62	6.6	3.64
Xylene, o-	0.61	9.7	2.29	0.97	1.7	1.22	0.41	3.5	1.87

Tables 30 through 33 summarize the minimum, maximum and mean concentrations for benzene, toluene, ethylbenzene, m,p-xylene, and o-xylene, the chemicals with the highest frequency of detection from the study results in indoor and outdoor air, and soil vapor.

Table 30. Summary Table of Minimum, Maximum and Mean Concentrations of Highest Frequency Chemicals in Outdoor Air by Thickness of Vadose Zone (ug/m<sup>3</sup>)

Outdoor Air									
	No vadose zone			0-6 feet			6-25 feet		
Chemical	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Benzene	0.22	2.65	0.79	0.66	2.5	1.14	0.54	1.2	0.79
Ethylbenzene	0.24	0.83	0.44	0.26	1.3	0.76	1.1	1.4	1.25
Toluene	0.26	6.4	1.74	0.76	8.5	3.49	1	9.9	4.23
Xylene, m,p-	0.33	2.5	0.81	0.44	2.7	1.31	0.59	4.1	2.23
Xylene, o-	0.23	0.39	0.31	0.26	1.1	0.73	0.22	1.1	0.61

Table 31. Summary Table of Minimum, Maximum and Mean Concentrations of Highest Frequency Chemicals in Indoor Air by Thickness of Vadose Zone (ug/m<sup>3</sup>)

Indoor Air									
	No vadose zone			0-6 feet			6-25 feet		
Chemical	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Benzene	0.31	4.4	0.88	0.58	4.72	1.36	0.7	2.8	1.29
Ethylbenzene	0.24	5.7	0.91	0.44	5.34	1.12	0.27	5.6	1.33
Toluene	0.82	220	16.46	0.91	12	5.62	2.6	31	7.05
Xylene, m,p-	0.27	12	1.92	0.43	13.4	2.47	0.67	20	4.20
Xylene, o-	0.217	4.4	0.98	0.43	7.46	1.19	0.3	6.4	1.22

Table 32. Summary Table of Minimum, Maximum and Mean Concentrations of Highest Frequency Chemicals in Soil Vapor by Thickness of Vadose Zone (ug/m<sup>3</sup>)

Soil Vapor									
	No vadose zone			0-6 feet			6-25 feet		
Chemical	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Benzene	0.48	58	9.55	0.62	8.2	2.90	0.96	3.2	1.98
Ethylbenzene	0.48	9.3	2.43	0.61	1.2	0.95	0.35	2.4	1.32
Toluene	0.92	430	29.33	0.77	6.3	2.86	1.8	12.9	7.88
Xylene, m,p-	0.44	28	4.48	1.1	3.3	1.93	0.62	6.6	3.64
Xylene, o-	0.61	9.7	2.29	0.97	1.7	1.22	0.41	3.5	1.87

To determine the potential risk of non-carcinogenic health effects the concentrations summarized in Tables 30 through 32 were used to calculate hazard quotients (HQ) for each chemical by media and vadose zones. The HQs were used to obtain Hazard Indices (HIs) to assess the overall potential for non-carcinogenic effects posed by chemicals by vadose zone. To calculate HQs the concentrations from the study

results were divided by the individual chemicals' RfCs. These HQs were then summed to obtain the HIs. HIs of 1 or less are considered to not pose chronic non-carcinogenic health hazards to the public.

Table 33 summarizes the HQs and HIs for the mean concentrations of the study results for indoor air. HIs for the chemicals in the no vadose zone, the 0-6 feet thick vadose zone, and the 6-25 feet thick vadose zone were all below 1.

Table 33. Hazard Indices for Mean Concentrations for Indoor Air by Vadose Zone

<b>Hazard Index (HI) for Mean Concentrations for Indoor Air</b>			
<b>Chemical</b>	<b>No Vadose</b>	<b>0-6 Ft Vadose</b>	<b>6-25 Ft Vadose</b>
Benzene	0.029167	0.045204301	0.0429125
Ethylbenzene	0.0009146	0.001116429	0.001332063
Toluene	0.003291	0.001124789	0.00141025
Xylene, m,p-	0.019153	0.0247	0.042
Xylene, o-	0.098173	0.01186129	0.0122275
<b>Hazard Index</b>	<b>0.05</b>	<b>0.07</b>	<b>0.09</b>

Table 34 summarizes the HQs and HIs for the maximum concentrations of the study results for indoor air. HIs for the chemicals in the no vadose zone, the 0-6 feet thick vadose zone, and the 6-25 feet thick vadose zone were all below 1.

Table 34. Hazard Indices for Maximum Concentrations for Indoor Air by Vadose Zone

<b>Hazard Index (HI) for Maximum Concentrations for Indoor Air</b>			
<b>Chemical</b>	<b>No Vadose</b>	<b>0-6 Ft Vadose</b>	<b>6-25 Ft Vadose</b>
Benzene	0.146667	0.1573333	0.093333
Ethylbenzene	0.0057	0.00534	0.0056

Table 34. (continued)

Toluene	0.044	0.0024	0.0062
Xylene, m,p-	0.12	0.134	0.2
Xylene, o-	0.044	0.0746	0.064
<b>Hazard Index</b>	<b>0.32</b>	<b>0.30</b>	<b>0.31</b>

Table 35 summarizes the HQs and HIs for the mean concentrations of the study results for soil vapor. HIs for the chemicals in the no vadose zone, the 0-6 feet thick vadose zone, and the 6-25 feet thick vadose zone were all below 1.

Table 35. Hazard Indices for Mean Concentrations for Soil Vapor by Vadose Zone

<b>Hazard Quotient (HQ) for Mean Concentrations for Soil Vapor</b>			
<b>Chemical</b>	<b>No Vadose</b>	<b>0-6 Ft Vadose</b>	<b>6-25 Ft Vadose</b>
Benzene	0.318	0.09655	0.06613
Ethylbenzene	0.0024	0.00095	0.00132
Toluene	0.00587	0.00057	0.00158
Xylene, m,p-	0.0447	0.01933	0.03638
Xylene, o-	0.02291	0.01223	0.01873
<b>Hazard Index</b>	<b>0.37</b>	<b>0.12</b>	<b>0.11</b>

Table 36 summarizes the HQs and HIs for the maximum concentrations of the study results for soil vapor. HIs for the chemicals in the 0-6 feet thick vadose zone, and the 6-25 feet thick vadose zone were below 1, however the HI for the no vadose zone was above 1.

Table 36. Hazard Indices for Maximum Concentrations for Soil Vapor by Vadose Zone

<b>Hazard Quotient (HQ) for Maximum Concentrations for Soil Vapor</b>			
<b>Chemical</b>	<b>No Vadose</b>	<b>0-6 Ft Vadose</b>	<b>6-25 Ft Vadose</b>
Benzene	1.93	0.318333333	0.1067
Ethylbenzene	0.01	0.0012	0.0024
Toluene	0.09	0.00024	0.0005
Xylene, m,p-	0.28	0.033	0.0660
Xylene, o-	0.10	0.017	0.0350
<b>Hazard Index</b>	<b>2.31</b>	<b>0.35</b>	<b>0.18</b>

Table 37 summarizes the HQs and HIs for the mean concentrations of the study results for outdoor air. HIs for the chemicals in the no vadose zone, the 0-6 feet thick vadose zone, and the 6-25 feet thick vadose zone were all below 1.

Table 37. Hazard Indices for Mean Concentrations for Outdoor Air by Vadose Zone

<b>Hazard Quotients (HQ) for Mean Concentrations for Outdoor Air</b>			
<b>Chemical</b>	<b>No Vadose</b>	<b>0-6 Ft Vadose</b>	<b>6-25 Ft Vadose</b>
Benzene	0.02638095	0.037925926	0.04
Ethylbenzene	0.00044063	0.00076	0.00125
Toluene	0.00034867	0.000698909	0.000845
Xylene, m,p-	0.00805611	0.013112222	0.02225
Xylene, o-	0.00314	0.00728	0.006125
<b>Hazard Index</b>	<b>0.04</b>	<b>0.06</b>	<b>0.07</b>

Table 38 summarizes the HQs and HIs for the maximum concentrations of the study results for outdoor air. HIs for the chemicals in the no vadose zone, the 0-6 feet thick vadose zone, and the 6-25 feet thick vadose zone were all below 1.

Table 38. Hazard Indices for Maximum Concentrations for Outdoor Air by Vadose Zone

<b>Hazard Quotients (HQ) for Maximum Concentrations for Outdoor Air</b>			
<b>Chemical</b>	<b>No Vadose</b>	<b>0-6 Ft Vadose</b>	<b>6-25 Ft Vadose</b>
Benzene	0.08833333	0.08333333	0.04
Ethylbenzene	0.00083	0.0013	0.0014
Toluene	0.00128	0.0017	0.00198
Xylene, m,p-	0.025	0.027	0.041
Xylene, o-	0.0039	0.011	0.011
<b>Hazard Index</b>	<b>0.12</b>	<b>0.12</b>	<b>0.10</b>

For comparative purposes HQs and HIs were calculated for the mean, maximum and 95<sup>th</sup> percentile concentrations from both the EPA and the NYSDOH background studies. Table 39 summarizes the HQs and HIs for the maximum, mean and 95<sup>th</sup> percentile concentrations from the DOH background study for indoor air. The HIs for the mean and 95<sup>th</sup> percentile concentrations were below 1, however the HI for the maximum concentrations was 24.37533333, well above 1. As with the study results for soil vapor with no vadose zone, the driver for this risk calculation was benzene.

Table 39. Hazard Indices for DOH Background Maximum, Mean and 95<sup>th</sup> Percentile Concentrations for Indoor Air

<b>Hazard Quotient (HQ) for DOH Background Concentrations for Indoor Air</b>			
<b>Chemical</b>	<b>Maximum</b>	<b>Mean</b>	<b>95th Percentile</b>
Benzene	15.33333333	0.276666667	0.966666667
Ethylbenzene	0.34	0.0037	0.013
Toluene	0.102	0.0052	0.022
Xylene, m,p-	5.5	0.059	0.21
Xylene, o-	3.1	0.038	0.13
<b>Hazard Index</b>	<b>24.38</b>	<b>0.38</b>	<b>1.34</b>

Table 40 summarizes the HQs and HIs for the maximum, mean and 95<sup>th</sup> percentile concentrations from the DOH background study for outdoor air. HIs for these concentrations were all below 1.

Table 40. Hazard Indices for DOH Background Maximum, Mean and 95<sup>th</sup> Percentile Concentrations for Outdoor Air

<b>Hazard Quotient (HQ) for DOH Background Concentrations for Outdoor Air</b>			
<b>Chemical</b>	<b>Maximum</b>	<b>Mean</b>	<b>95th Percentile</b>
Benzene	0.146667	0.063333333	0.093333
Ethylbenzene	0.0057	0.0008	0.0056
Toluene	0.044	0.0022	0.0062
Xylene, m,p-	0.12	0.008	0.2
Xylene, o-	0.044	0.007	0.064
<b>Hazard Index</b>	<b>0.32</b>	<b>0.08</b>	<b>0.31</b>

Table 41 summarizes the HQs and HIs for the maximum, mean and 95<sup>th</sup> percentile concentrations from the EPA background study for indoor air. The HIs for the mean and 95<sup>th</sup> percentile concentrations were below 1, however the HI for the maximum concentrations was 5.76466, well above 1. As with the HI for the maximum concentration in the DOH study, the driver for this risk calculation was benzene.

Table 41. Hazard Indices for EPA Background Maximum, Mean and 95<sup>th</sup> Percentile Concentrations for Indoor Air

<b>Hazard Quotient (HQ) for EPA Background Concentrations for Indoor Air</b>			
<b>Chemical</b>	<b>Maximum</b>	<b>Mean</b>	<b>95th Percentile</b>
Benzene	2.1	0.15	0.416666667
Ethylbenzene	0.0736	0.0028	0.0076
Toluene	0.07806	0.00502	0.01416

Table 41. (continued)

Xylene, m,p-	2.608	0.108	0.285
Xylene, o-	0.905	0.038	0.112
<b>Hazard Index</b>	<b>5.76</b>	<b>0.30</b>	<b>0.84</b>

Table 42 summarizes the HQs and HIs for the maximum, mean and 95<sup>th</sup> percentile concentrations from the EPA background study for outdoor air. HIs for these concentrations were all below 1.

Table 42. Hazard Indices for EPA Background Maximum, Mean and 95<sup>th</sup> Percentile Concentrations for Outdoor Air

<b>Hazard Quotient (HQ) for EPA Background Concentrations for Outdoor Air</b>			
<b>Chemical</b>	<b>Maximum</b>	<b>Mean</b>	<b>95th Percentile</b>
Benzene	0.433333333	0.106666667	0.32
Ethylbenzene	0.0078	0.0014	0.0043
Toluene	0.01862	0.00308	0.00984
Xylene, m,p-	0.268	0.056	0.161
Xylene, o-	0.111	0.02	0.06
<b>Hazard Index</b>	<b>0.84</b>	<b>0.19</b>	<b>0.56</b>

Figures 27 through 32 compare the calculated Hazard Indices from the study results to the EPA and NYSDOH background studies calculated Hazard Indices. As these figures demonstrate, the HIs from study results are below the HIs calculated from regulatory background concentrations.



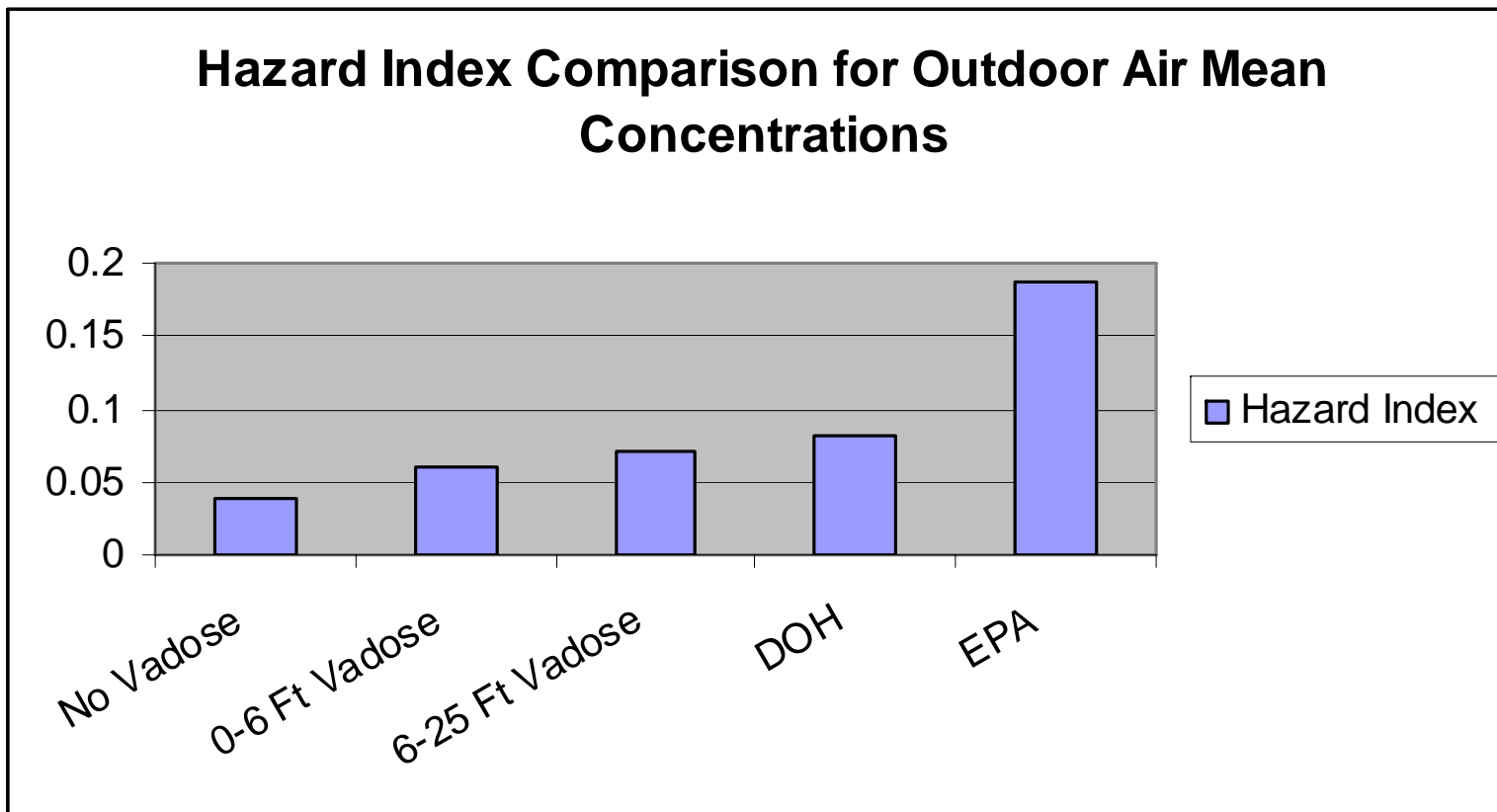


Figure 27. Hazard Index Comparison for Outdoor Air Mean Concentrations

NYSDOH Background Outdoor Air Mean Concentrations, 2003

USEPA Background Outdoor Air Mean Concentrations, 2001

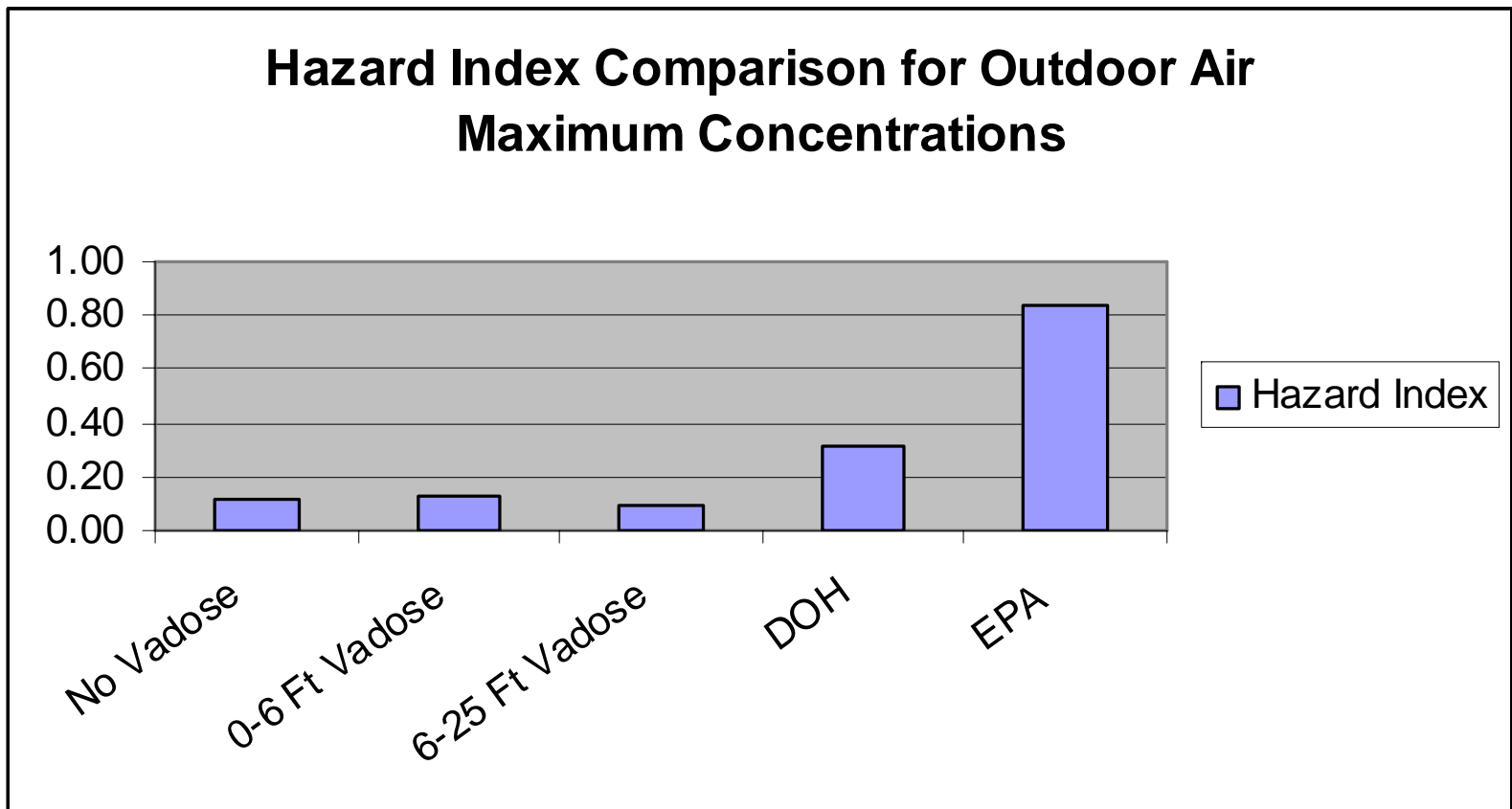


Figure 28. Hazard Index Comparison for Outdoor Air Maximum Concentrations

NYSDOH Background Outdoor Air Maximum Concentrations, 2003  
 USEPA Background Outdoor Air Maximum Concentrations, 2001

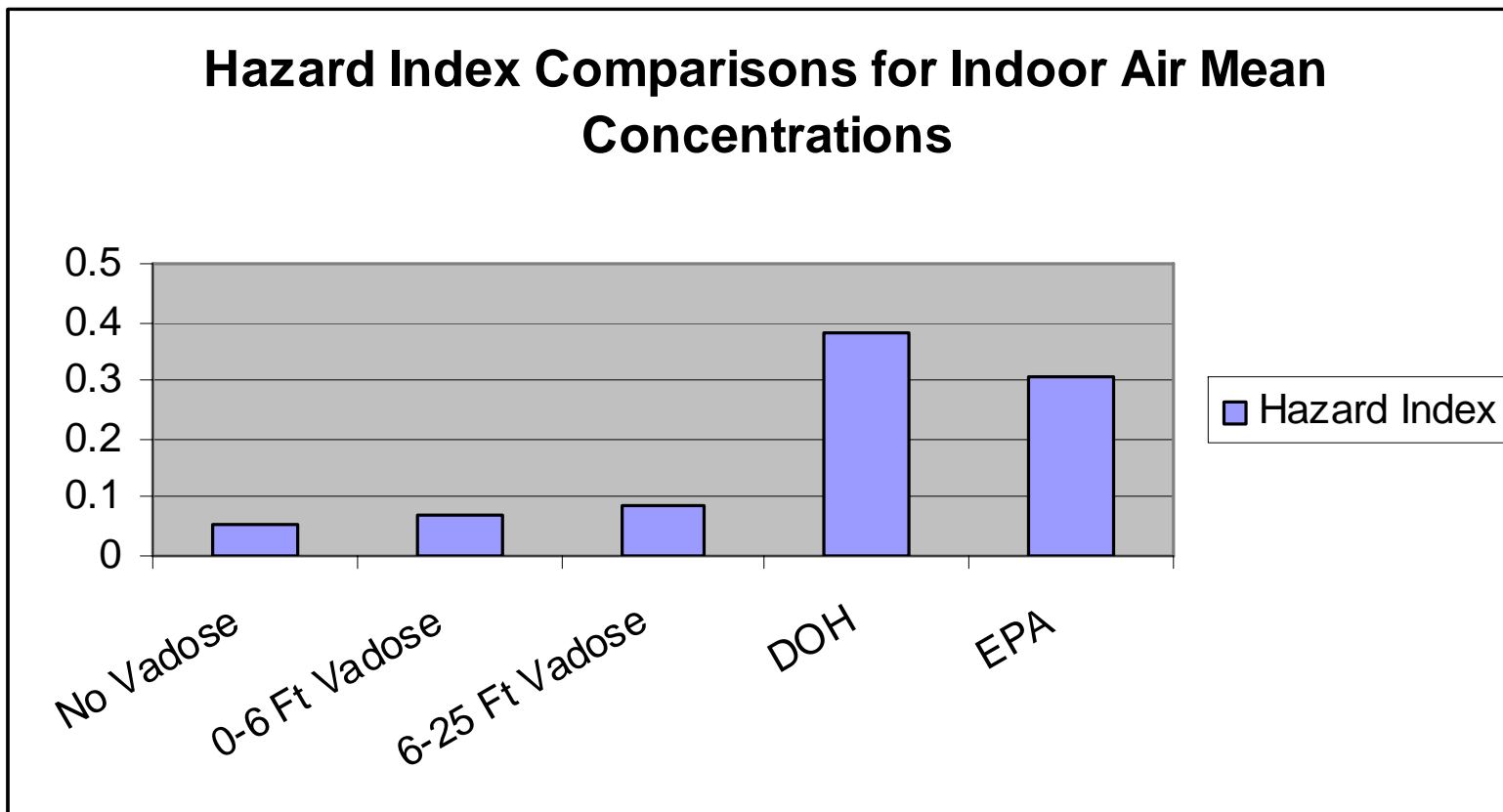


Figure 29. Hazard Index Comparison for Indoor Air Mean Concentrations

NYSDOH Background Indoor Air Mean Concentrations, 2003  
 USEPA Background Indoor Air Mean Concentrations, 2001

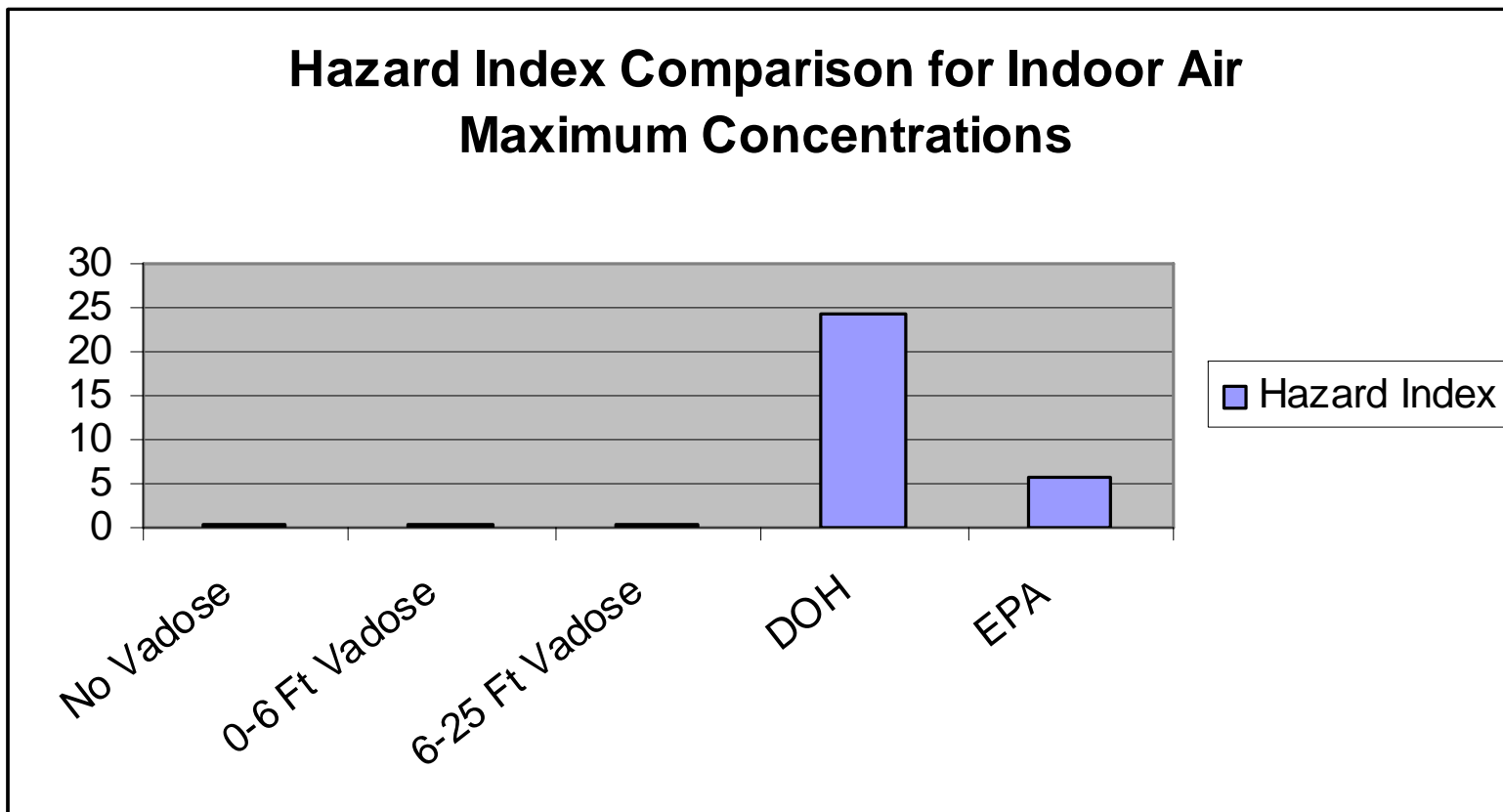


Figure 30. Hazard Index Comparison for Indoor Air Maximum Concentrations

NYSDOH Background Indoor Air Maximum Concentrations, 2003  
 USEPA Background Indoor Air Maximum Concentrations, 2001

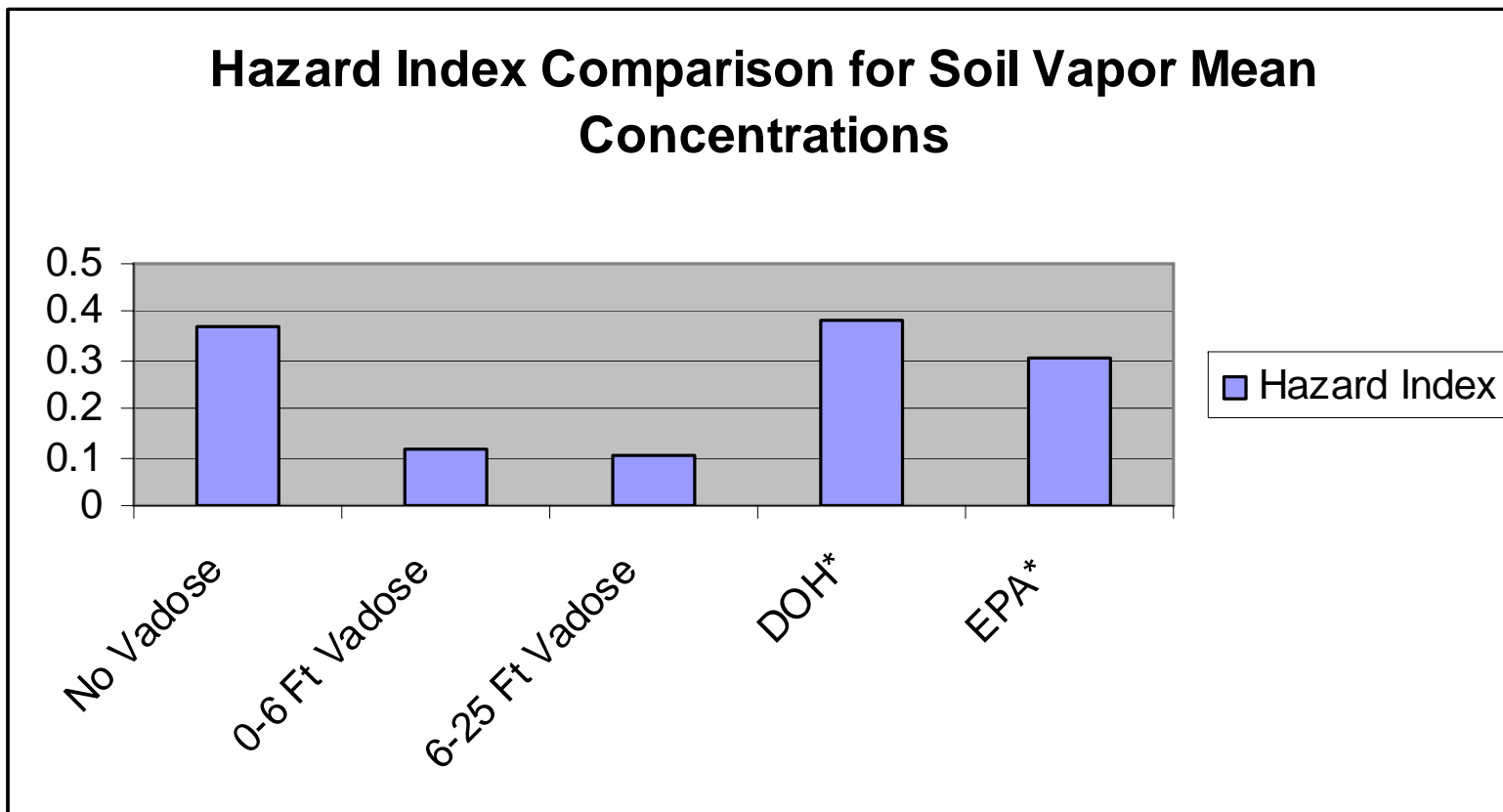


Figure 31. Hazard Index Comparison for Soil Vapor Mean Concentrations

\*NYSDOH Background Indoor Air Mean Concentrations, 2003

\*USEPA Background Indoor Air Mean Concentrations, 2001

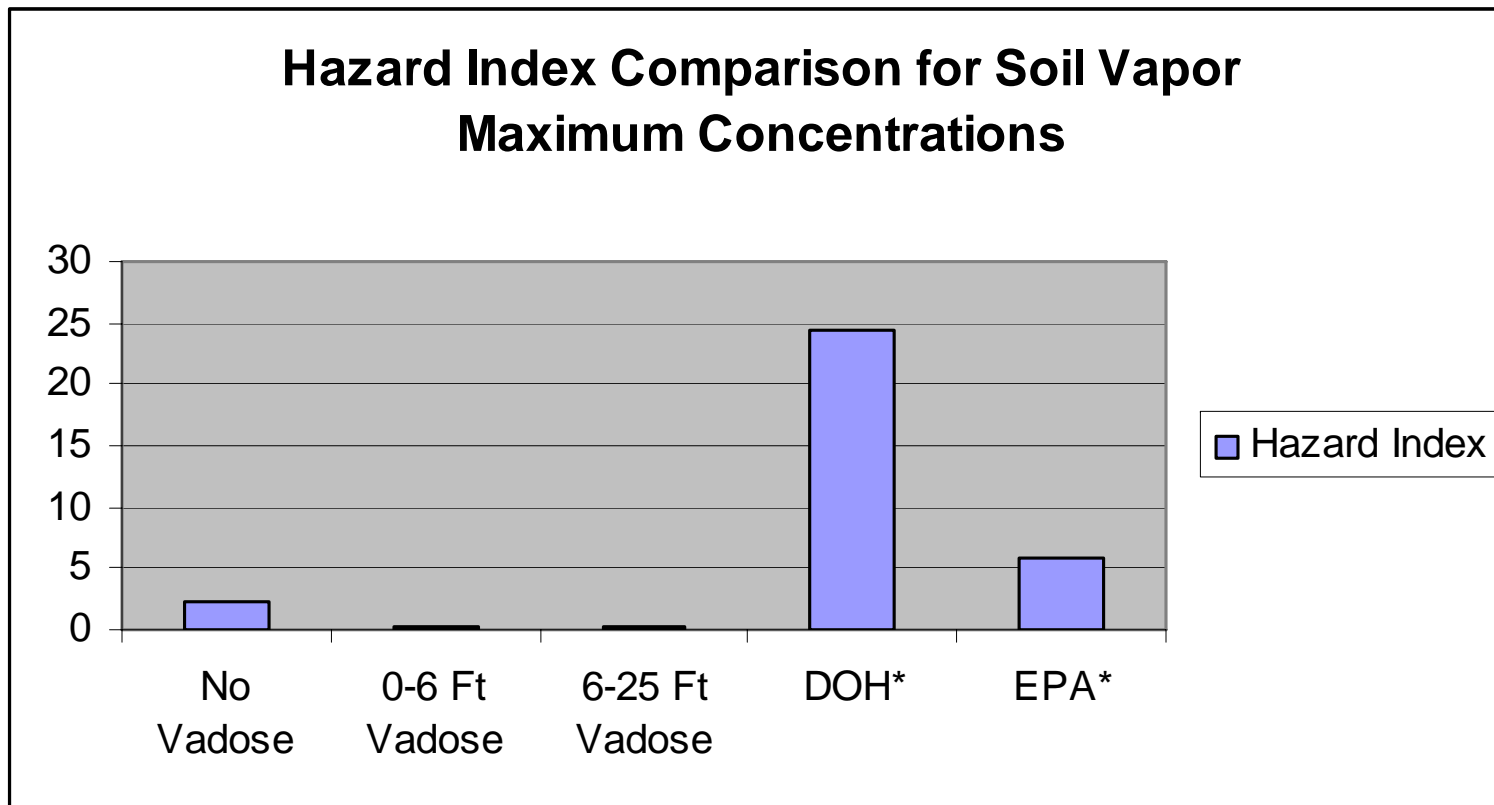


Figure 32. Hazard Index Comparison for Soil Vapor Maximum Concentrations

\*NYSDOH Background Indoor Air Maximum Concentrations, 2003

\*USEPA Background Indoor Air Maximum Concentrations, 2001

Benzene, a known human carcinogen, was the chemical with the highest frequency of detection in the study results. Inhalation is the only route of exposure that this study considered. Cancer risks from inhalation of benzene were calculated by multiplying the mean and maximum concentrations in indoor air, outdoor air, and soil vapor by the inhalation unit risk (IUR) range of  $2.2 \times 10^{-6}$  and  $7.8 \times 10^{-6}$ . Based on this IUR, exposure to  $1 \mu\text{g}/\text{m}^3$  benzene in air results in an increased lifetime risk or IUR of  $2.2 \times 10^{-6}$  to  $7.8 \times 10^{-6}$  of developing leukemia. A generally acceptable range for cumulative excess lifetime cancer risk of  $10^{-6}$  to  $10^{-4}$  for protecting human health has been established by the EPA.

Table 43 summarizes the cancer inhalation risk calculations for the mean concentrations of benzene in indoor air from the study results and the mean and 95<sup>th</sup> percentile concentrations from the EPA and NYSDOH background studies. Study results ranged from  $6.83 \times 10^{-6}$  to  $1 \times 10^{-5}$ . This range falls within EPA's acceptable risk range for excess lifetime cancer risk. Regulatory background results calculations ranged from  $9.9 \times 10^{-6}$  to  $2.26 \times 10^{-4}$ . The cancer risk for the population in the study exposed to the mean concentration of benzene in indoor air was below the risk calculated for the mean and the 95<sup>th</sup> percentile concentrations of benzene in the regulatory background studies.

Table 43. Cancer Inhalation Risks for Benzene Mean Concentrations for Indoor Air from Study Results and EPA/DOH Background

<b>Indoor Air Mean Concentrations</b>		
<b>Benzene</b>		
	<b>Inhalation Unit Risk</b>	
	<b><math>2.2 \times 10^{-6}</math></b>	<b><math>7.8 \times 10^{-6}</math></b>
No Vadose Mean	1.93E-06	6.83E-06

Table 43.(continued)

0-6 feet Mean	2.98E-06	1.06E-05
6-25 feet Mean	2.83E-06	1.00E-05
DOH Mean	1.83E-05	1.48E-05
EPA Mean	9.90E-06	3.51E-05
DOH 95th	6.38E-05	2.26E-04
EPA 95th	2.75E-05	9.75E-05

Table 44 summarizes the cancer risk calculations for the maximum concentrations of benzene in indoor air from the study results and the maximum and 95<sup>th</sup> percentile concentrations from the EPA and NYSDOH background studies. Study results ranged from  $9.68 \times 10^{-6}$  to  $1.04 \times 10^{-5}$ . This range falls within EPA's acceptable risk range for excess lifetime cancer risk. Regulatory background results calculations ranged from  $9.75 \times 10^{-5}$  to  $1.01 \times 10^{-3}$ . The cancer risk for the population in the study exposed to the maximum concentration of benzene in indoor air was below the risk calculated for the maximum and 95<sup>th</sup> percentile concentrations of benzene in the regulatory background studies.

Table 44. Cancer Inhalation for Benzene Maximum Concentrations for Indoor Air from Study Results and EPA/DOH Background

<b>Indoor Air Maximum Concentrations</b>		
<b>Benzene</b>		
	<b>Inhalation Unit Risk</b>	
	<b><math>2.2 \times 10^{-6}</math></b>	<b><math>7.8 \times 10^{-6}</math></b>
No Vadose Max	9.68E-06	3.43E-05
0-6 feet Max	1.04E-05	3.68E-05
6-25 feet Max	6.16E-06	2.18E-05
DOH Max	1.01E-03	3.59E-03



Table 44. (continued)

EPA Max	1.39E-04	4.91E-04
DOH 95th	6.38E-05	2.26E-04
EPA 95th	2.75E-05	9.75E-05

Table 45 summarizes the cancer risk calculations for the mean concentrations of benzene in soil vapor from the study results and the mean and 95<sup>th</sup> percentile concentrations in indoor air from the EPA and NYSDOH background studies. These calculations are based on a worse-case scenario for soil vapor. The concentrations of benzene in soil vapor used for these calculations assume that the concentration of benzene in soil vapor are the same as would be found in the indoor air of a building or residence. Acceptable practice when screening soil vapor is to apply an attenuation factor of 0.1 to a concentration of a chemical detected in soil vapor to estimate the potential concentration of that same chemical in the indoor air. The concentrations used to calculate the cancer risk for benzene from soil vapor does not use an attenuation factor.

Study results ranged from  $6.37 \times 10^{-6}$  to  $1.55 \times 10^{-5}$ . This range falls within EPA's acceptable risk range for excess lifetime cancer risk. Regulatory background results calculations ranged from  $9.9 \times 10^{-6}$  to  $2.26 \times 10^{-4}$ . The cancer risk for the population in the study exposed to the mean concentration of benzene in soil vapor was below the risk calculated for the mean and 95<sup>th</sup> percentile concentrations of benzene in the regulatory background studies.

Table 45. Cancer Inhalation Risks for Benzene Mean Concentrations for Soil Vapor from Study Results and EPA/DOH Background

<b>Soil Vapor Mean Concentrations</b>		
<b>Benzene</b>		
	<b>Inhalation Unit Risk</b>	
	<b>2.2x10<sup>-6</sup></b>	<b>7.8x10<sup>-6</sup></b>
No Vadose Mean	2.10E-05	7.45E-05
0-6 feet Mean	6.37E-06	2.26E-05
6-25 feet Mean	4.36E-06	1.55E-05
DOH Mean*	1.83E-05	1.48E-05
EPA Mean*	9.90E-06	3.51E-05
DOH 95th*	6.38E-05	2.26E-04
EPA 95th*	2.75E-05	9.75E-05

Table 46 summarizes the cancer risk calculations for the maximum concentrations of benzene in soil vapor from the study results and the maximum and 95<sup>th</sup> percentile concentrations in indoor air from the EPA and NYSDOH background studies. As previously mentioned, these calculations do not consider an attenuation factor. Study results ranged from 7.04x10<sup>-6</sup> to 4.52x10<sup>-4</sup>. The cancer risk calculated for the No Vadose maximum concentration is above the acceptable range for excess lifetime cancer risk; however this risk calculation is still below that of the background regulatory results. Regulatory background calculation results ranged from 9.75x10<sup>-5</sup> to 1.01x10<sup>-3</sup>. The cancer risk for the population in the study exposed to the maximum concentration of benzene in soil vapor was below the risk calculated for the maximum and 95<sup>th</sup> percentile concentrations of benzene in indoor air in the regulatory background studies.

Table 46. Cancer Inhalation Risks for Benzene Maximum Concentrations for Soil Vapor from Study Results and EPA/DOH Background

<b>Soil Vapor Maximum Concentrations</b>		
<b>Benzene</b>		
	<b>Inhalation Unit Risk</b>	
	<b>2.2x10<sup>-6</sup></b>	<b>7.8x10<sup>-6</sup></b>
No Vadose Max	1.28E-04	4.52E-04
0-6 feet Max	1.80E-05	6.40E-05
6-25 feet Max	7.04E-06	2.50E-05
DOH Max*	1.01E-03	3.59E-03
EPA Max*	1.39E-04	4.91E-04
DOH 95th*	6.38E-05	2.26E-04
EPA 95th*	2.75E-05	9.75E-05

Table 47 summarizes the cancer risk calculations for the mean concentrations of benzene in outdoor air from the study results and the mean and 95<sup>th</sup> percentile concentrations in outdoor air from the EPA and NYSDOH background studies. Study results ranged from 9.36x10<sup>-6</sup> to 1.74x10<sup>-6</sup>. This range falls within EPA's acceptable risk range for excess lifetime cancer risk. Regulatory background results calculations ranged from 7.04x10<sup>-6</sup> to 1.28x10<sup>-5</sup>. The cancer risk for the population in the study exposed to the mean concentration of benzene in outdoor air was similar to the risk calculated for the mean and 95<sup>th</sup> percentile concentrations of benzene in the regulatory background studies.

Table 47. Cancer Inhalation Risks for Benzene Mean Concentrations for Outdoor Air from Study Results and EPA/DOH Background

<b>Outdoor Air Mean Concentrations</b>		
<b>Benzene</b>		
	<b>Inhalation Unit Risk</b>	
	<b>2.2x10<sup>-6</sup></b>	<b>7.8x10<sup>-6</sup></b>
No Vadose Mean	1.74E-06	6.17E-06
0-6 feet Mean	2.50E-06	8.87E-06
6-25 feet Mean	2.64E-06	9.36E-06
DOH Mean	4.18E-06	1.48E-05
EPA Mean	7.04E-06	2.50E-05
DOH 95th	1.28E-05	4.52E-05
EPA 95th	2.11E-05	7.49E-05

Table 48 summarizes the cancer risk calculations for the maximum concentrations of benzene in outdoor air from the study results and the maximum and 95<sup>th</sup> percentile concentrations in outdoor air from the EPA and NYSDOH background studies. Study results ranged from 9.36x10<sup>-6</sup> to 1.95x10<sup>-5</sup>. This range falls within EPA's acceptable risk range for excess lifetime cancer risk. Regulatory background results calculations ranged from 4.52x10<sup>-5</sup> to 1.01x10<sup>-4</sup>. The cancer risk for the population in the study exposed to the maximum concentration of benzene in outdoor air was similar to the risk calculated for the maximum and 95<sup>th</sup> percentile concentrations of benzene in the regulatory background studies.

Table 48. Cancer Inhalation Risks for Benzene Maximum Concentrations for Outdoor Air from Study Results and EPA/DOH Background

<b>Outdoor Air Maximum Concentrations</b>		
<b>Benzene</b>		
	<b>Inhalation Unit Risk</b>	
	<b>2.2x10<sup>-6</sup></b>	<b>7.8x10<sup>-6</sup></b>
No Vadose Max	5.83E-06	2.07E-05
0-6 feet Max	5.50E-06	1.95E-05
6-25 feet Max	2.64E-06	9.36E-06
DOH Max	3.74E-05	1.33E-04
EPA Max	2.86E-05	1.01E-04
DOH 95th	1.28E-05	4.52E-05
EPA 95th	2.11E-05	7.49E-05

Figures 33 through 38 compare the calculated cancer risks for benzene mean and maximum concentrations from the study results to the calculated cancer risks for benzene for the mean, maximum, and 95<sup>th</sup> percentile concentrations in the EPA and NYSDOH background studies. As these figures demonstrate, the cancer risks for benzene concentrations from study results are below or similar to those calculated from regulatory background concentrations.

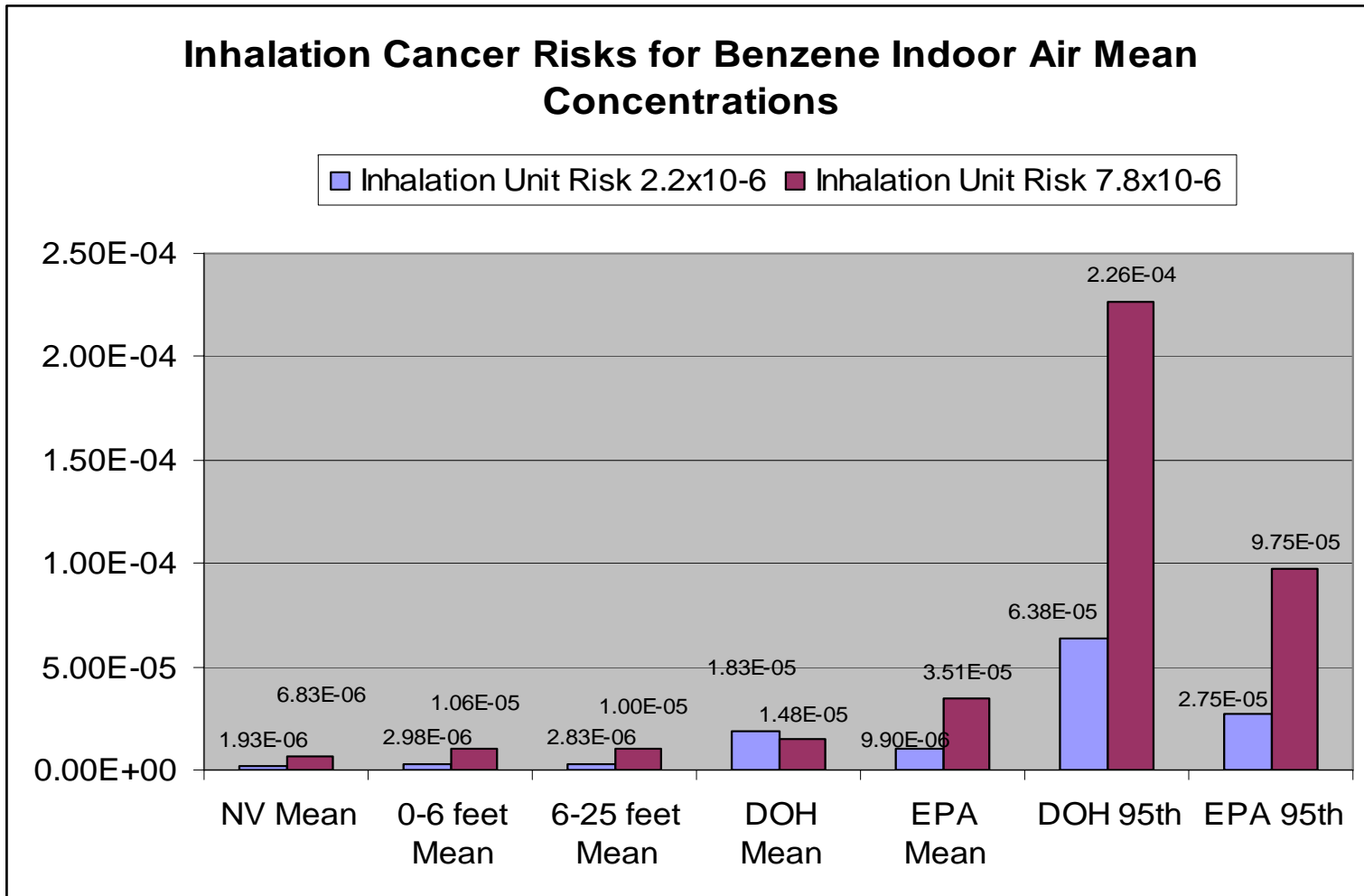


Figure 33. Inhalation Cancer Risks for Benzene Indoor Air Mean Concentrations

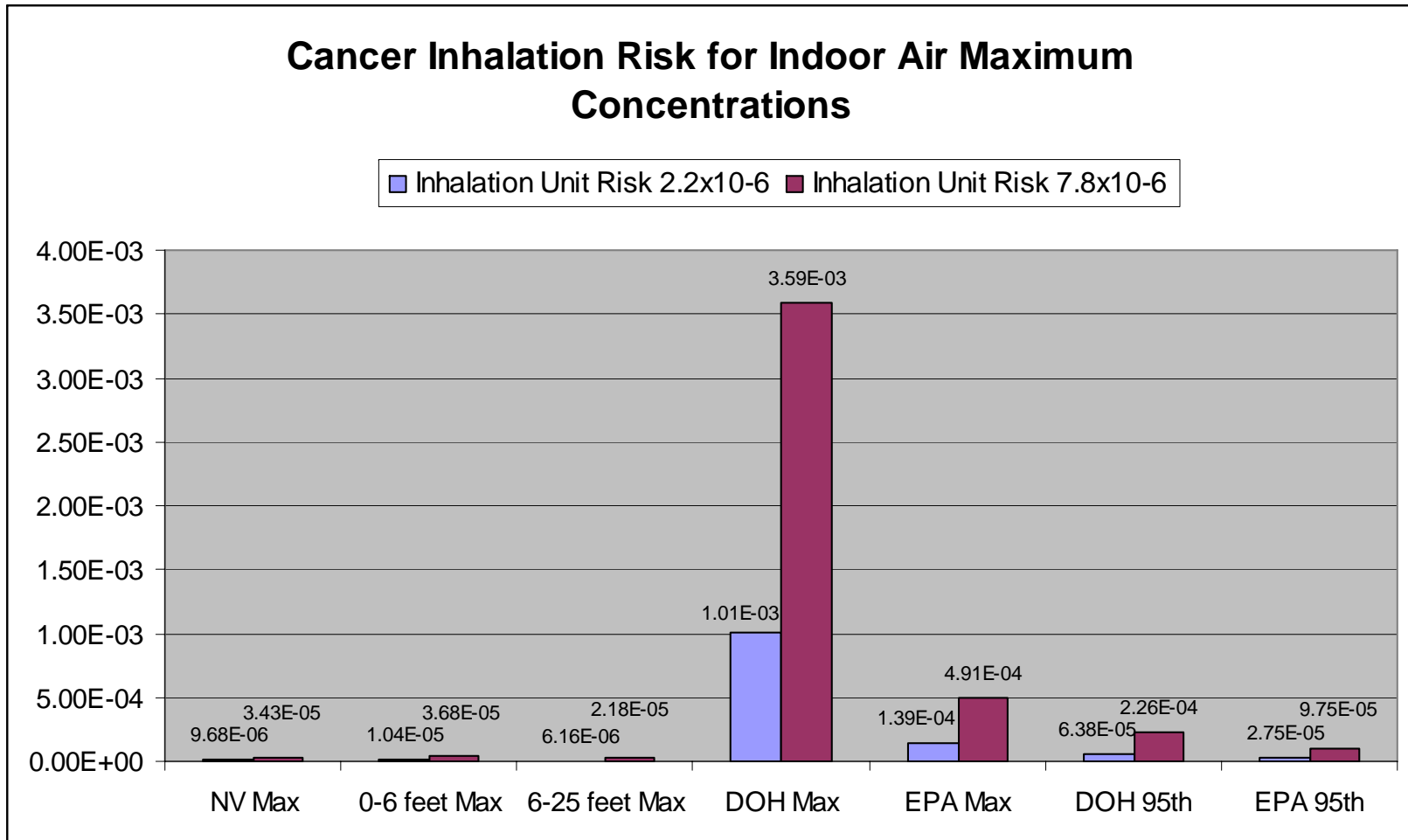


Figure 34. Inhalation Cancer Risks for Benzene Indoor Air Maximum Concentrations

## Cancer Inhalation Risks for Soil Vapor Mean Concentrations

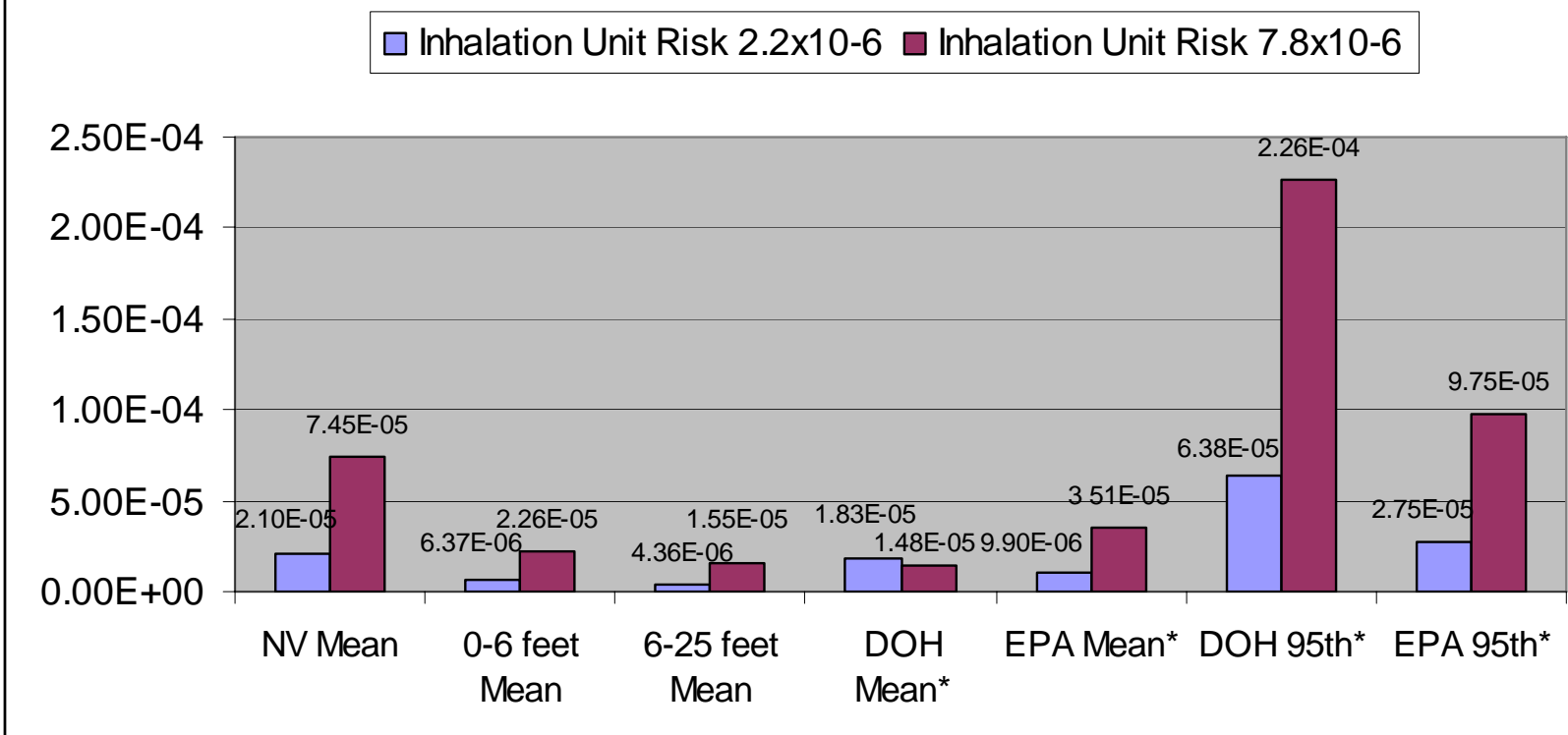


Figure 35. Inhalation Cancer Risks for Benzene Soil Vapor Mean Concentrations

\*Comparison made to regulatory indoor air background concentrations



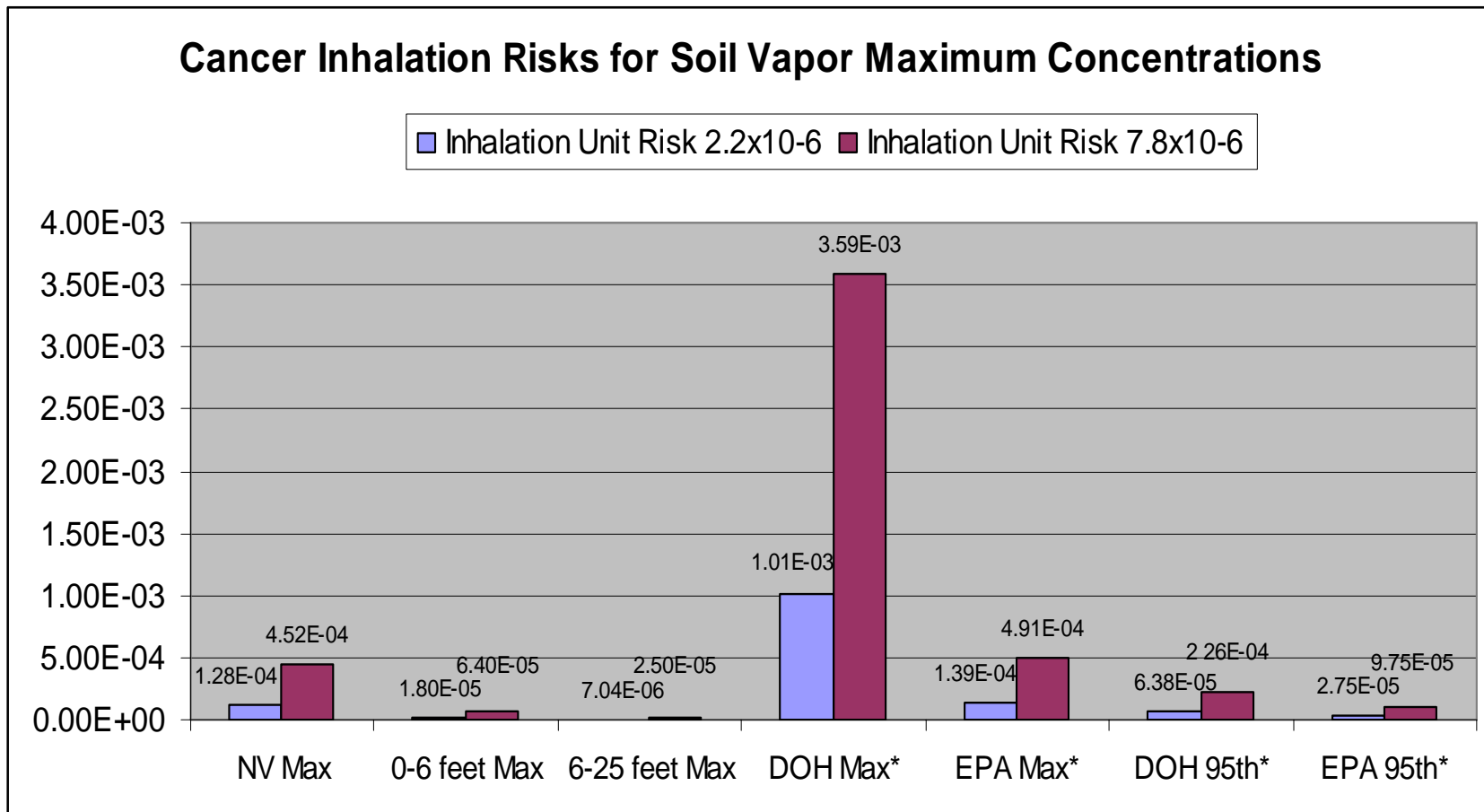


Figure 36. Inhalation Cancer Risks for Benzene Soil Vapor Maximum Concentrations

\*Comparison made to regulatory indoor air background concentrations

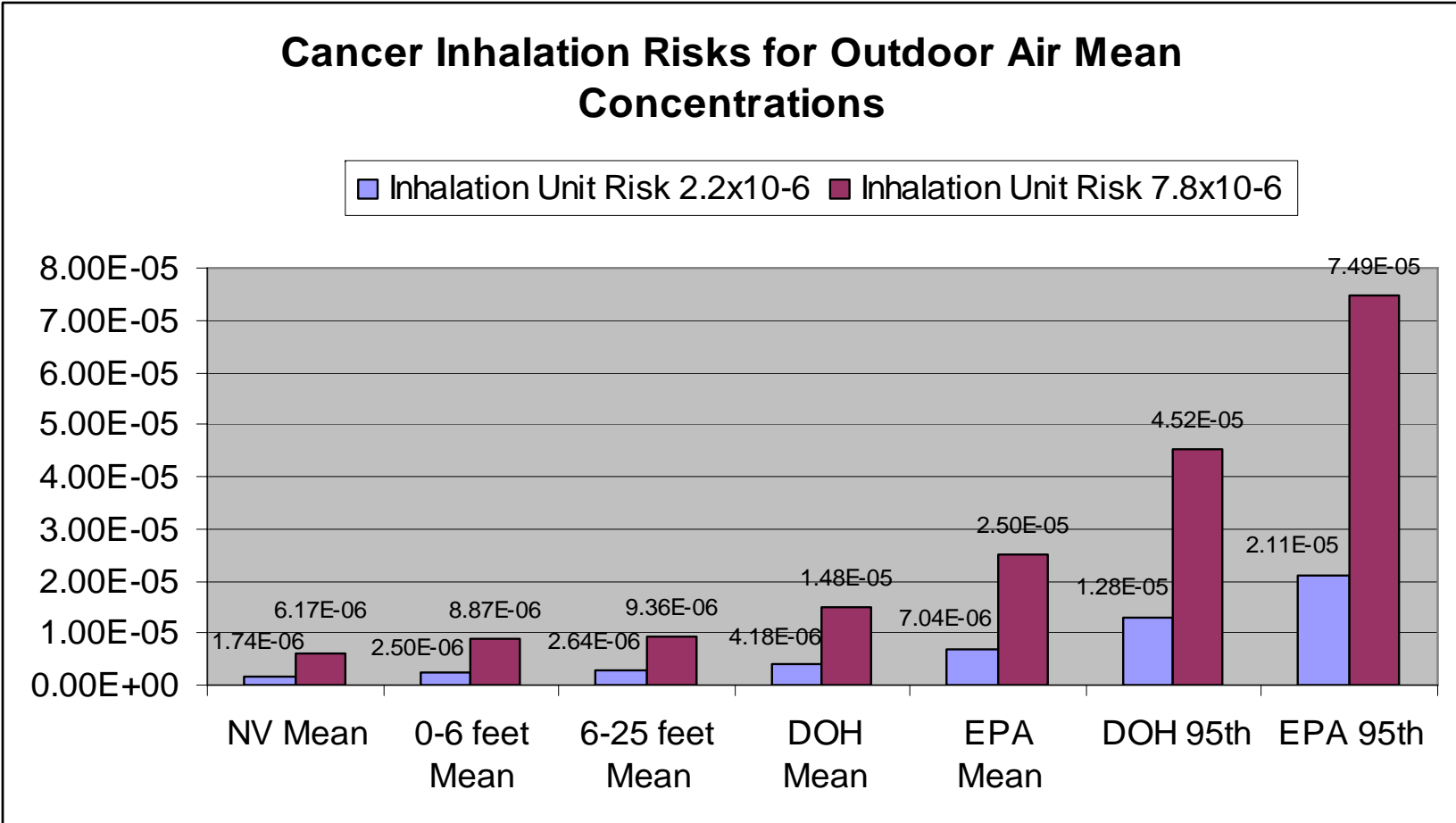


Figure 37. Inhalation Cancer Risks for Benzene Outdoor Air Mean Concentrations

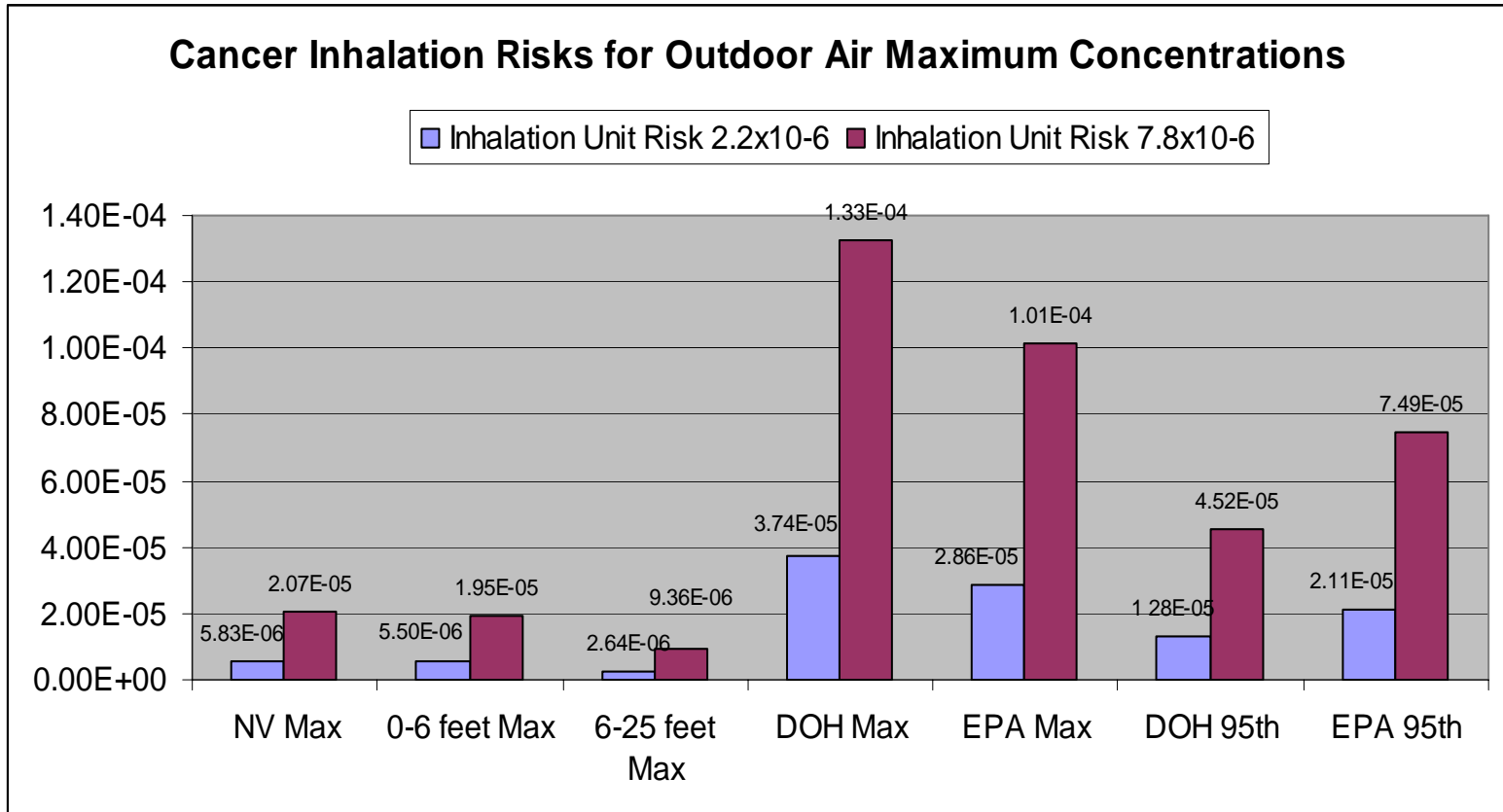


Figure 38. Inhalation Cancer Risks for Benzene Outdoor Air Maximum Concentrations

## Chapter Five

### Discussion and Conclusions

The purpose of this research was to evaluate the potential public health risks associated with former MGP sites to the human population located in residences and businesses adjacent to or overlying these contaminated sites. This study identified the contaminants present in the soil vapor, the indoor air, and the ambient outdoor air of residences and commercial buildings and evaluated whether the presence of these chemical contaminants in the indoor air were the result of soil vapor intrusion.

In addition this research identified the potential public health risks posed by these contaminants and evaluated whether the human population adjacent to the former MGPs was at greater risk of adverse health effects than that of a normal resident in the northeastern US.

Analysis of the data collected to evaluate the potential for soil vapor intrusion of MGP-related chemicals concluded that no intrusion had occurred. Concentrations of chemicals detected in indoor air were an order of magnitude below published reference concentrations. Based on the analyses of this data the five chemicals with highest frequency of detection in the study results, benzene, toluene, ethylbenzene, m,p-xylene, and o-xylene, were more frequent in outdoor air than in indoor air and soil vapor.

A confounding factor in the determination of soil vapor intrusion is that many of the chemicals associated with MGPs are petroleum-related, and are ubiquitous in the

environment and present in many common household products. This is true with any soil vapor intrusion assessment. On the other hand, soil vapor intrusion could be masked by the use of household products that contain the same chemical composition of the contaminant source. Based on the information uncovered in the pre-assessment interview and questionnaire, product inventory, and field observations, the risk assessor often has to determine whether what is being observed in indoor air is a result of soil vapor intrusion or from products that are in use in the building or from ambient outdoor sources.

As previously mentioned, the presence of chemicals in soil vapor does not, by default, mean that these chemicals will intrude into indoor air. Often chemical concentrations in the building are higher than those in soil vapor indicating that soil vapor intrusion has not occurred. In fact the opposite might be true that indoor air quality has affected soil vapor.

In addition, soil vapor intrusion does not occur preferentially, meaning one chemical will move into the building when others do not. Assessment of intrusion is holistic; the risk assessor must evaluate the movement of multiple volatile organic chemicals into indoor air from soil vapor to conclude vapor intrusion.

Federal and state regulatory agencies have conducted studies to establish background data for indoor air and outdoor air, yet while industry is spending millions of dollars in investigating and mitigating soil vapor intrusion, no background numbers exist for soil vapor. While EPA recommends the application of attenuation factors to soil vapor concentrations determine potential concentrations in indoor air, many regulatory agencies are reluctant to accept these attenuated numbers and require indoor air sampling. As this

study reports, money is spent to investigate and potentially remediate concentrations which are below background regulatory concentrations.

The majority of the buildings and residences in this study were built in the late 1950s to early 1960s; however some of these buildings were over 100 years old. Most of the structures had concrete floors in the basements, but some only had dirt floors or crawlspaces. Although the age and type of construction of these structures would seem to increase the risk factors for soil vapor intrusion, this was not observed. A number of issues played a potential role in preventing soil vapor intrusion. First, a clean layer of groundwater existed between the buildings and the contaminant plumes. Second, natural attenuation occurs for volatile organic chemicals, especially the BTEX compounds, and some of the semi-volatile chemicals. Many bacteria use contaminants as the sole source of carbon and energy (Vivaldi, 2001). And third, the construction of the structures was not air-tight, and although this could increase the chance for soil vapor intrusion, it also may play a role in dilution of indoor air.

As we have seen in this study a number of the chemicals detected in indoor air were attributed to the household or commercial products used in the buildings.

Risk assessment methodologies were used to evaluate whether residents and occupants of commercial buildings adjacent to or overlying former MGP sites were at greater risk of adverse health effects than that of a normal resident in the northeastern US. This assessment found exposures to the study population were less than or similar to background.

Hazard Indices were calculated to estimate the risk of non-carcinogenic health effects. EPA's Risk Assessment Guidelines (1989) state:

Another limitation with the hazard index approach is that the assumption of dose additivity is most properly applied to compounds that induce the same effect by the same mechanism of action. Consequently, application of the hazard index equation to a number of compounds that are not expected to induce the same type of effects or that do not act by the same mechanism could overestimate the potential for effects, although such an approach is appropriate at a screening level. This possibility is generally not of concern if only one or two substances are responsible for driving the HI above unity. If the HI is greater than unity as a consequence of summing several hazard quotients of similar value, it would be appropriate to segregate the compounds by effect and by mechanism of action and to derive separate hazard indices for each group .

With these limitations in mind the calculated HIs for the study group were less than the HIs calculated with regulatory background concentrations.

Calculations to determine the potential for non-carcinogenic health risks to the occupants of residents and commercial buildings found HIs below 1 for the mean and maximum concentrations of the study results for indoor air and outdoor air regardless of the thickness of the vadose zone (depth to groundwater). Benzene was the largest contributor to non-carcinogenic hazards for both the study results and the regulatory results.

The HIs for the mean concentrations soil vapor and the maximum concentrations for soil vapor for the 0-6 feet and 6-25 feet thick vadose zones were below 1. Only the maximum concentration for soil vapor with no vadose zone was above 1 with a calculated HI of 2.41. Benzene, with a HQ of 1.93, was the driver for this HI, however

this exceedance was not seen in either no vadose zone mean or maximum indoor air HIs indicating soil vapor was not intruding into indoor air. The calculated HIs for the study results were similar to the HIs calculated for the EPA and DOH background studies.

Use of health protective risk assessment procedures as described in the cancer guidelines means that estimates, while uncertain, are more likely to overstate than understate hazard and/or risk (EPA, 2005). Still using this risk assessment methodology the cancer risk calculations for inhalation of benzene for the study concentrations were below or similar to regulatory background cancer risks. As the results show exposure to benzene from the study results were below levels protective of human health.

Calculations to determine the potential for carcinogenic health risks from benzene to the occupants of residents and commercial buildings ranged from  $9.75 \times 10^{-6}$  to  $4.52 \times 10^{-4}$ . However background benzene exposure not related to former MGP sites ranged from  $9.9 \times 10^{-6}$  to  $3.59 \times 10^{-3}$ . The highest cancer risk in the study results was  $4.52 \times 10^{-4}$  for the maximum concentration of benzene in soil vapor with no vadose zone. This calculation is based on the assumption that the benzene concentration would be directly inhaled by the occupant. If an attenuation factor of 0.1 was applied to the maximum concentration of benzene in soil vapor the actual concentration used for the cancer calculation would be  $0.82 \text{ ug/m}^3$ . This attenuated concentration would result in a cancer risk range of  $6.4 \times 10^{-6}$  to  $1.8 \times 10^{-6}$ , well within EPA's acceptable risk range for excess lifetime cancer risk.

In conclusion, cancer risk and exposures to indoor air, soil vapor or ambient air concentrations were equivalent or less than a normal resident in the northeast United States. No increased public health risks were associated with occupied residential or



commercial properties overlying or surrounding MGPs.

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