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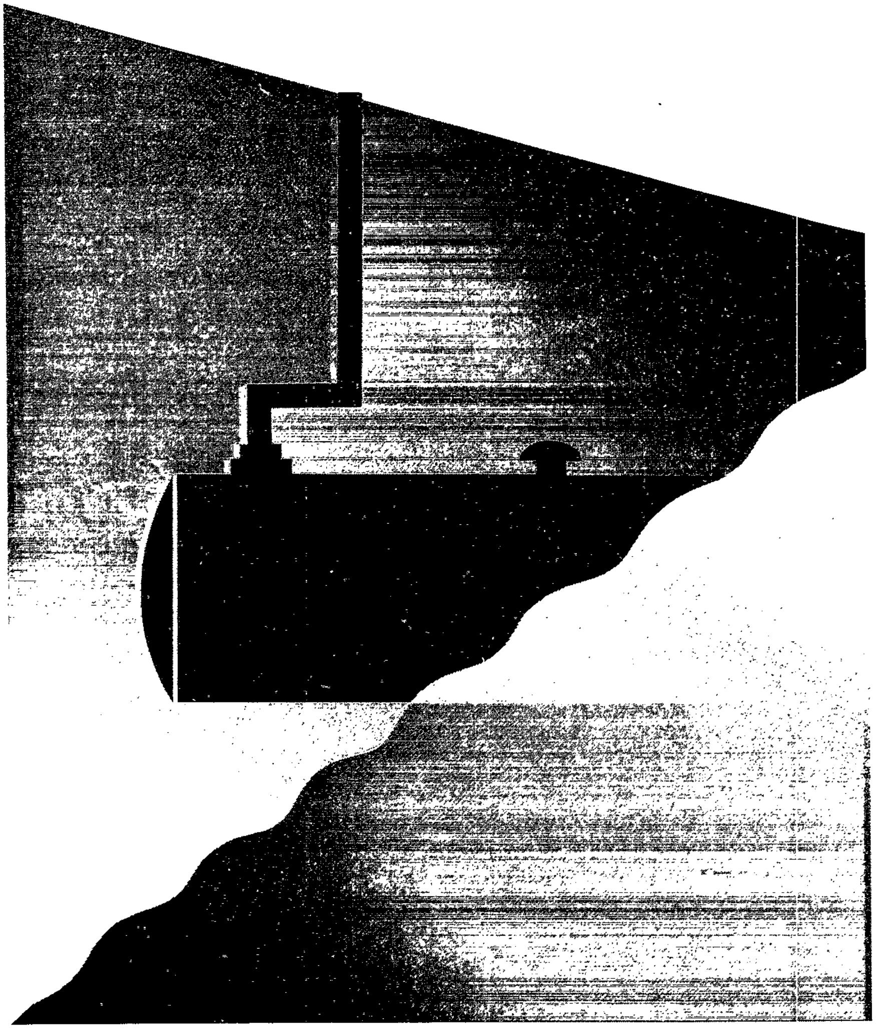
Leaking Underground Storage Tanks and Health

Understanding Health Risks From Petroleum Contamination



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LEAKING UNDERGROUND STORAGE TANKS and HEALTH

Understanding Health Risks From Petroleum Contamination

U.S. Environmental Protection Agency
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INTRODUCTION

This document summarizes the potential health effects associated with exposure to gasoline (as a whole product), with particular focus on its benzene constituent. A complete understanding of the potential health effects from exposure to gasoline requires the consideration of other gasoline constituents as well, such as ethylbenzene, toluene, and xylene.

Many State and local underground storage tank (UST) programs rely heavily on support from local and State health departments for assistance in protecting public health during the investigation and cleanup of releases from USTs. Because neither this nor any other single document will enable field staff to function as industrial hygienists or toxicologists, field staff are encouraged to consult health experts on a site-specific basis.

The purpose of this document is to present clearly the health effects of benzene exposure and what experts deem to be adequate levels of protection. This document is intended to help UST field staff: (1) understand the potential hazards associated with gasoline and benzene exposure and (2) communicate them more effectively to the public and health officials.

It is useful to remember that "risk" is based on the statistical concept of probability (i.e., that risk is a statement of likelihood, not absolute certainty). The statistical evaluation of risk depends on the existence of many data samples. Because the data base for the health effects of gasoline contamination is small, this document generalizes from a limited number of samples. Readers must understand that this document is NOT intended as a formal risk-assessment instrument. It is NOT a "predictor" of adverse health effects.

Whether or not adverse health effects occur following exposure to a substance depends upon the concentration and toxicity of the substance; the type, extent, and duration of the exposure; and the susceptibility of the individual being exposed. Understanding the potential for adverse health effects from exposure to gasoline requires the following four steps:

1. Identifying and researching which contaminants are involved;

2. Determining how much of the chemical is present;

3. Identifying who may be exposed to the chemical and how to consider the type, route, and duration of exposure; and,

4. Assessing the potential health effects associated with exposure.

Each of these steps is discussed in this document.

The first step in understanding potential health risks associated with the release of gasoline from an underground storage tank (UST) is determining the types of contamination that exist. Gasoline is a complex mixture of hydrocarbons composed of over 200 different compounds, some of which remain unidentified. The composition of different batches of gasoline varies widely as a result of chemical differences in naturally occurring crude stocks and differences in refining techniques.

Although each batch of gasoline differs, many of the constituents of gasoline recur in the batches time after time. The physical and chemical properties of the constituents can be used to predict how they will be transported in the environment. Some of the constituents are volatile; some are water soluble. Most constituents are less dense than water and, therefore, float on top of it. Following a release from an UST, gasoline components can be found: (1) as vapors, (2) solubilized in water, (3) adsorbed to soil, or (4) floating on water. The composition of a gasoline release, therefore, depends not only on differences among batches of refined gasoline but also on where and when you look at the release.

GASOLINE CONSTITUENTS

Generally, the constituents of gasoline can be divided into three categories: paraffins, aromatics, and olefins. Paraffins, which are the largest class of compounds and often comprise about 66 percent of the gasoline, are composed of chains of carbons that are singly-bonded to atoms of hydrogen (i.e., saturated hydrocarbons). Aromatics are those compounds whose structure includes a benzene ring. Aromatics often comprise approximately 25 percent of gasoline and are believed to be among its most toxic constituents. (See Figure 1.) The commonly recognized aromatic compounds--benzene, toluene, ethylbenzene, and xylenes--are often referred to as BTEX. Olefins are usually the smallest group of constituents, consisting of hydrocarbon chains that contain double or triple bonds (i.e.,unsaturated hydrocarbons).

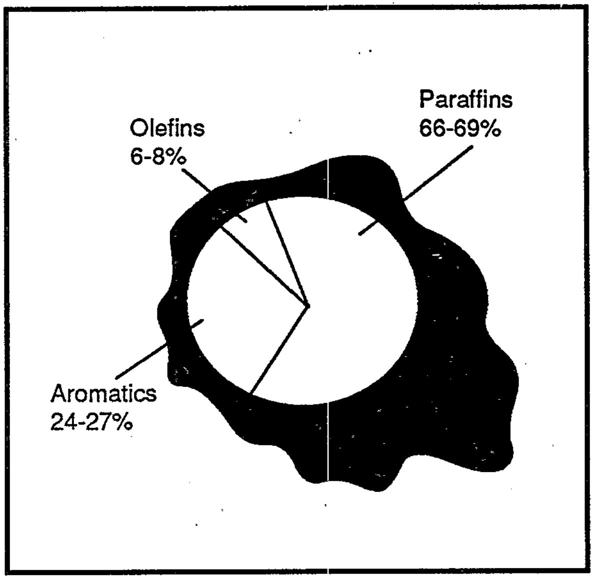


Figure 1. Free Product

FATE AND TRANSPORT

The fate and transport of gasoline and its constituents following a release from an UST are summarized in Figure 2. After a release, gasoline tends to flow downward through the soil toward the groundwater table. Soil characteristics and the depth to groundwater determine how quickly gasoline and its constituents reach groundwater. Porous soil allows the gasoline to be transported quickly; dense soil slows the transport. Once the gasoline reaches the water table, it tends to accumulate on top of it, because it is less dense than water and is virtually insoluble in it. If the soil has a high resistance to lateral flow, accumulations of free product (i.e., that petroleum product that would move through the soil matrix under gravity) several feet deep can occur.

The physical properties of the constituents along with environmental conditions affect the rate at which the free product separates into different components. Most of the paraffin constituents in gasoline are volatile and readily vaporize into the air.

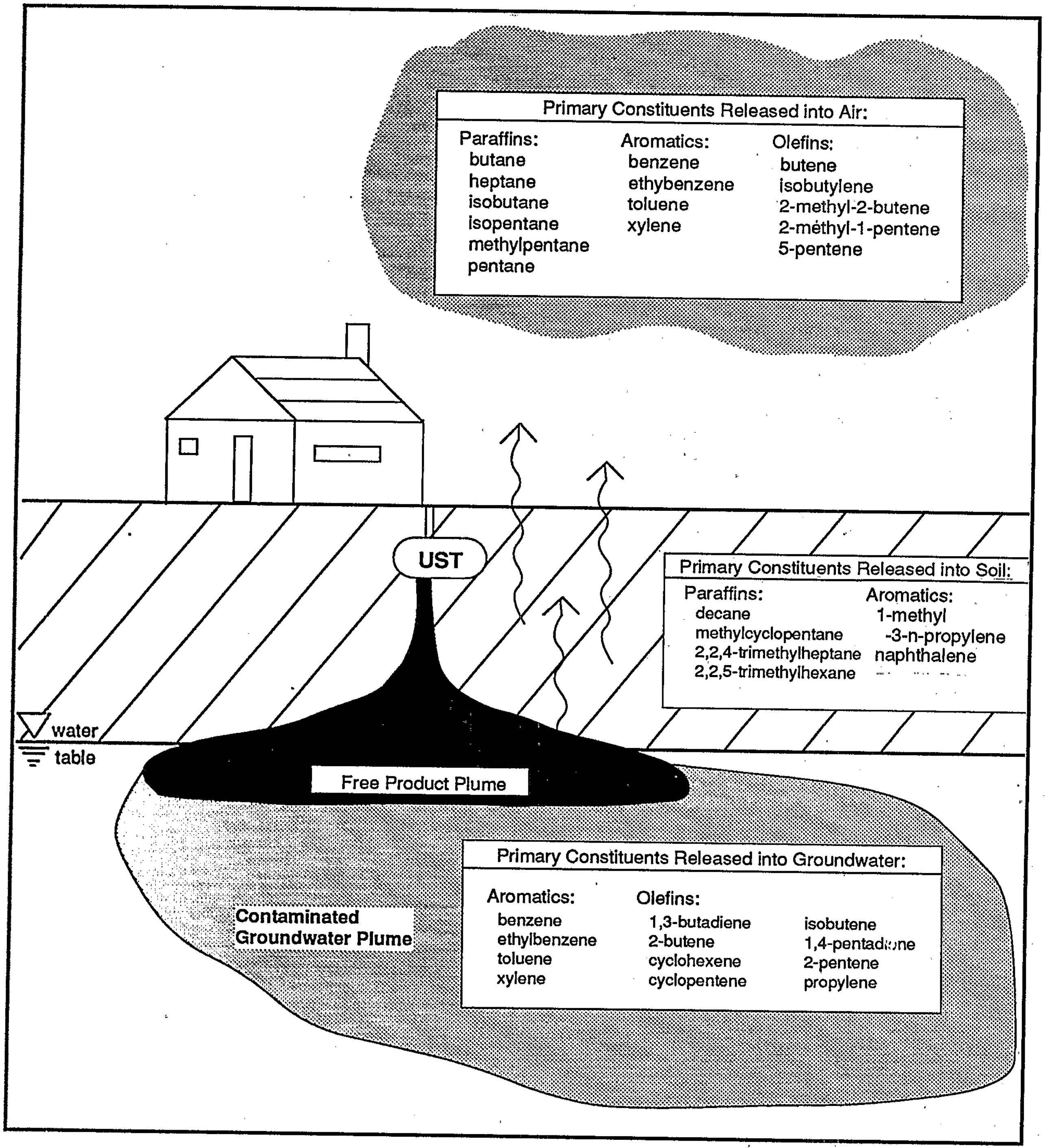


Figure 2. Fate and Transport of Selected Gasoline Constituents

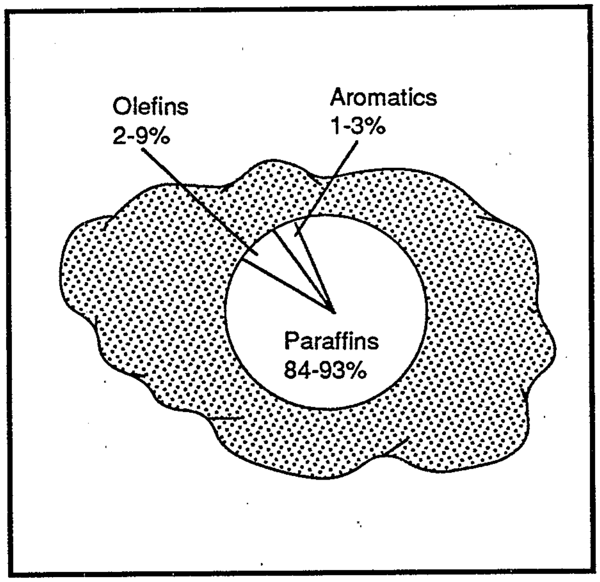


Figure 3. Vapor Fraction

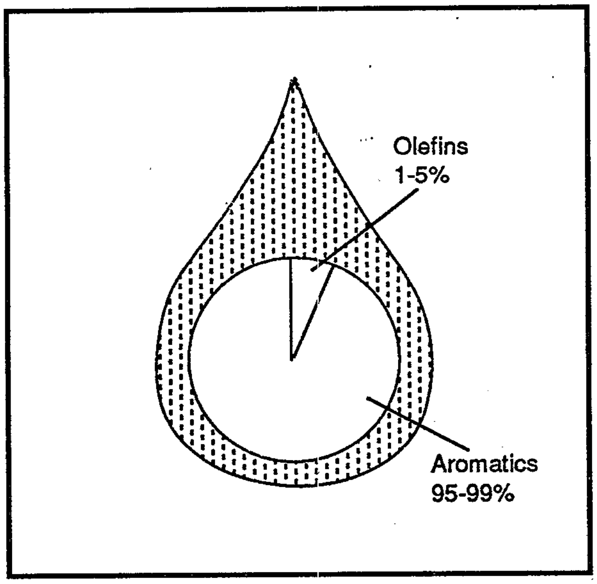


Figure 4. Water Soluble Fraction

A smaller fraction of the olefins and aromatics are volatile. Consequently, they make up a smaller percentage of the vapors in UST leaks than they do in free product. Overall, gasoline vapors tend to be heavier than air and are able to move laterally in soils to enter basements of nearby structures. See Figure 3.

The aromatic compounds are the most water soluble constituents of gasoline. As a result, the composition of the dissolved ground-water contaminants is heavily dominated by aromatics, such as BTEX. Percolation of rain through the soil matrix or fluctuations in the water table tend to dissolve and carry these constituents, increasing the rate at which they move downward through the soil and contaminate groundwater. See Figure 4.

As free product is transported through the soil matrix, it coats and attaches to soil particles. Residual contamination results from the constituents that remain after other constituents have vaporized or dissolved. Residual contamination tends to be composed of the heavier, longer-chained paraffins.

CHANGES OVER TIME

Because of volatilization, dissolution, and naturally occurring biodegradation, the composition of constituents at a particular site varies with the passage of time. For example, at the site of an older release, constituents such as BTEX may be absent from the contaminated soil but present in the groundwater. In fact, over time, the residual soil contamination from a gasoline spill may resemble constituents from a fuel oil spill. Older spills in nonporous soils can, however, retain unweathered pockets of free product. In these cases, constituents such as BTEX may be present at concentrations similar to those found at a new spill.

Measuring the presence of contamination is an important step in understanding the potential health effects resulting from gasoline exposure. Because toxicological research is usually performed on one chemical at a time to establish a discernible cause-and-effect relationship, little is known about the health effects from exposure to gasoline (a mixture of chemicals). However, the health effects of benzene exposure have been widely studied.

A gap exists between health effects information, which is typically based on one component of gasoline (benzene), and exposure data, which is commonly generated by field methods that measure groups of compounds, not individual compounds. This problem can be solved by either sampling for benzene or making assumptions about the relative fraction of benzene in the total measured compounds. Some common methods for measuring gasoline and selected gasoline constituents are mentioned below. Their expected uses and limitations for understanding health effects associated with vapor or water contamination are also discussed.

MEASURING GROUPS OF COMPOUNDS

Because gasoline is made up of hundreds of different hydrocarbon components, sampling and analyzing for each of the compounds is impractical. One common approach is to sample for groups of petroleum hydrocarbons such as total organic vapors (TOVs). Tests which measure TOVs are sensitive to the part per million (ppm) level and are useful for identifying contamination. If hydrocarbons are detected in a vapor or water sample, contamination is present. However, false negative readings are possible with these tests; if nothing is detected, contamination could still be present in significant concentrations. If low levels of contamination are suspected but not detected in a TOV reading, then instruments that can measure individual compounds should be used.

In one situation, a test that measures groups of constituents may give a positive reading even though contamination is not present: this occurs when the test detects methane and not TOVs. Methane can come from a variety of sources such as sewer lines, septic fields, and decaying organic materials. If methane is detected, petroleum contamination may or may not be present. (Biodegration of hydrocarbons also produces high concentrations of methane.) Other sensors not sensitive to methane or filters that remove the methane can be used where methane is suspected to be causing false positive test results.

Instruments such as the flame ionization detector (FID), photo ionization detector (PID), and a TOV colorimetric tube are widely used to detect organic vapors in basements. These methods can also be used above a confined headspace to measure contamination in water. The Hanby method also measures contamination in water. The description and performance of each of these instruments is described in detail in Field Measurements: Dependable Data When You Need It (EPA/530/UST-901003). Minimum concentrations detected with these instruments are a function of soil, water, compounds originally present, holding time, etc. Although readings from these instruments are sometimes expressed as benzene equivalents, measurements of groups of compounds have no direct correlation with the actual benzene concentration.

ESTIMATING BENZENE AMOUNT IN A TOV READING

Volatile compounds are among the most mobile and toxic constituents of gasoline. Therefore, they are monitored frequently around an UST release site. It is possible to roughly estimate the amount of benzene present in a TOV reading in air or water from the total concentration reading.

Benzene is generally less than 0.1 percent of the total amount of vapors present in a fresh gasoline release. As the spill ages, the benzene fraction of the vapor drops. If benzene-specific vapor measurements are unavailable, then the 0.1 percent fraction can be used as an upper bound of the benzene concentration.

When measuring water samples, the benzene fraction is more variable (i.e., from 5 to 100 percent). However, if hydrocarbons are detected by any of the methods that measure groups of compounds, the water is likely to have benzene concentrations above acceptable health protective levels. In these cases, use of the water should be suspended until benzene-specific tests can be conducted.

MEASURING SPECIFIC COMPOUNDS

When you know or suspect people are being exposed to low levels of contamination, specific compounds such as benzene should be measured. For example, testing for specific compounds should be undertaken when an old spill is discovered to have contaminated drinking water supplies or free product is under buildings emitting vapors. Specific measurements are also critical in determining when people may safely re-enter buildings or re-use drinking water supplies that were previously contaminated.

The portable gas chromatograph (GC) and compound-specific colorimetric tubes are two common field instruments that can measure benzene and other gasoline constituents. Other agencies and programs may use other compound-specific devices, but they will not be discussed in this document. More information about the GC and colorimetric tubes can also be found in Field Measurements: Dependable Data When You Need It.

DETECTION LIMITS

It is important to know the detection limits that you can achieve with a given sampling approach. Detection limits for an analytical test method indicate the smallest amount of constituents that can be measured using that technique. Because human health can be affected by low levels of contamination, the analytical methods used for determining when a site does not present a health risk must be capable of measuring the level that can be harmful.

Instruments that measure groups of petroleum hydrocarbons cannot detect the low levels of benzene considered to pose a health risk. Low levels of benzene cannot be measured with these instruments even if benzene vapors are the only vapors present. On the other hand, if contamination is detected with a group-measurement instrument, it is likely that benzene is present. Analytical methods for measuring groups of compounds and individual compounds are listed in Exhibit 1.

The Lower Detection Limits (LDLs) are presented for each analytical method listed in Exhibit 1. LDLs for individual testers, laboratories, and analysts may vary from those presented in Exhibit 1 for a variety of reasons: (1) the presence of other contaminants may interfere with the testing method; (2) the LDLs often vary among different instrument manufacturers; (3) the skill of the technician conducting the test is variable; and, (4) the efficiency of the equipment (e.g., a purge and trap apparatus) can affect the detection limits. Sample holding times and preservation techniques also dramatically influence the ability of a technique to detect low levels of contaminants.

Exhibit 1. Methods for Measuring Gasoline Constituents

PROCEDURE *	Measuring Device	Lower Detection Limits (LDLs) For Gasoline		Compounds Measured
		Water	Vapor	
Headspace Analysis Methods	PID	10 - 100 ppm	▨	BTEX
	FID	Variable	▨	TOVs
	Colorimetric Tube	Variable	▨	Benzene
	GC w/ VOA bottle	3 ppb	▨	Benzene
Drager Liquid Extraction	Colorimetric Tube	0.5 ppm	▨	Benzene or groups
Hanby Method	▨	0.1 ppm	▨	Total Aromatics
Vapor Analyses	PID	▨	1-10 ppm	TOVs
	FID	▨	1-10 ppm	TOVs
	Colorimetric Tube	▨	.5 ppm	Benzene
	GC TO - 14	▨	.3 ppb	Benzene
Laboratory Analyses	EPA 418.1	1-50 ppm	▨	Total Petroleum Hydrocarbons
	EPA 8020	2-250 ppb	▨	Benzene
	EPA 8240	5-625 ppb	▨	Benzene
	EPA 624 & 1624	5 ppb	▨	Benzene
	EPA 602	2 ppb	▨	Benzene
	Thin Layer Chromatography	10 - 100 ppm	▨	Total Petroleum Hydrocarbons

* For explanation of field procedures see EPA's Field Measurements: Dependable Data When You Need It.

▨ = Not Applicable

Understanding the potential health effects associated with exposure to a contaminant involves discovering who may be exposed, how they may be exposed, and how long the exposures may last. Individuals react differently to chemical exposures depending on their age and health. In addition, different effects may occur depending on whether a chemical is ingested or inhaled and the duration of exposure.

In only a very few cases are the factors affecting exposure (i.e., who is exposed, the exposure frequency and duration, and the concentration of chemicals at the point where the person is exposed) well understood. More often than not, the assessment of exposure involves estimating many, if not all, of these factors. The closer the actual exposure agrees with the predicted exposure, the better an expert can predict if exposed individuals are at risk. Greater reliability and accuracy in the exposure estimates will allow more reliable and accurate health risk estimates.

For simplicity, exposures are usually assessed separately for each chemical and for each exposure route. In reality, however, people may be exposed to more than one chemical at a time. To estimate health effects from multiple exposures, risks from carcinogens are generally considered additive; noncarcinogenic health effects from chemicals exerting similar types of effects are also considered additive.

EXPOSED INDIVIDUALS

In identifying "populations at risk," one needs to consider not only the location of the population relative to the spill but also the activity patterns of its members. Although people who live or work closest to a spill are likely to be exposed to the highest contaminant concentrations, people farther from a spill may experience more cumulative exposure over longer periods of time because they cannot detect contamination through taste or smell. Also, it is important to know the age and health status of the exposed individuals. Children, because of their body weight, are often at higher risk than adults. The sick and the elderly are also sensitive populations.

ROUTES OF EXPOSURE

The primary ways that people may be exposed are obvious for the most part. At the site, people may come in direct contact with contaminated soil or water or may inhale the volatile substances emitted from the petroleum product. People may inhale vapors that have entered a nearby building, ingest contaminants in contaminated drinking water, or inhale volatile components released from contaminated water during showering. Unlikely as it seems, exposures during showering are often equivalent to those associated with drinking the water.

MULTIPLE EXPOSURES

It is important to consider all of the ways people may be exposed. For example, a person at a business may be exposed only by drinking contaminated water. In contrast, a person at a residence may be drinking the water, inhaling contaminants that volatilize from the water while showering, and inhaling product vapors that have directly entered the building. Therefore, the overall exposure to the resident in this case is likely to be much higher. Field staff should also be aware of other sources of benzene in the home. For example, tobacco smoke, paints, adhesives, and lingering automotive exhaust from an attached garage can contribute to the total benzene loading.

DURATION OF EXPOSURE

In estimating exposures, it is also important to determine how long the exposure is expected to last. For example, if vapors have entered a structure, it is important to consider whether the people inside will be exposed for 8 hours a day for 5 days of the week (40 hours per week) or, as in the case of young children at home, exposed for possibly 24 hours a day for 7 days a week (168 hours a week)--a greater than four-fold increase in exposure. Whether the structure is a year-round residence (exposure for 52 weeks per year) or a vacation rental (exposure for 2 weeks per year)--a difference of 26 times--should also be considered.

The health effects information presented later in this document is accompanied by indicators of exposure time. Considering the duration of exposure is critical when evaluating the likely adverse health effects associated with a particular contaminant concentration. For evaluating exposures to carcinogenic substances, it is important to remember that any additional exposure to the substance increases the likelihood of developing cancer. In contrast, when evaluating exposures to noncarcinogenic substances, it may be possible to tolerate higher concentrations of the substance in some cases if the exposure is for a shorter period of time.

Site-specific constituent and exposure information can be combined with an estimate of a chemical's toxicity to evaluate the potential health effects of exposure. The types of health effects associated with exposure to gasoline and one of its constituents, benzene, are summarized in Exhibits 2, 3, and 4. These exhibits are designed to be used along with specific information collected for a site regarding contaminant concentrations, potentially exposed persons, and anticipated types and lengths of exposure.

Exhibit 2 presents the health effects associated with the inhalation of gasoline vapors. Exhibits 3 and 4 present the health effects associated with ingesting benzene in water and inhaling benzene vapors, respectively. A comparable exhibit for gasoline in drinking water is not provided because there is little available information on the health effects of gasoline as a whole product in drinking water. Information about dermal exposures is also not provided because the extent of these exposures is generally less than exposures by the other routes and is difficult to determine.

INFORMATION IN THE EXHIBITS

The exhibits provide:

A summary of the concentrations and durations at which carcinogenic and noncarcinogenic effects have been observed, or are predicted to occur, as a result of exposure;

Legally enforceable occupational exposure limits published by the Occupational Safety and Health Administration (OSHA);

Drinking water standards published by EPA's Office of Drinking Water;

Detection limits for various methods of detecting and measuring benzene in air and water; and

Risk estimates associated with exposures to other sources of benzene.

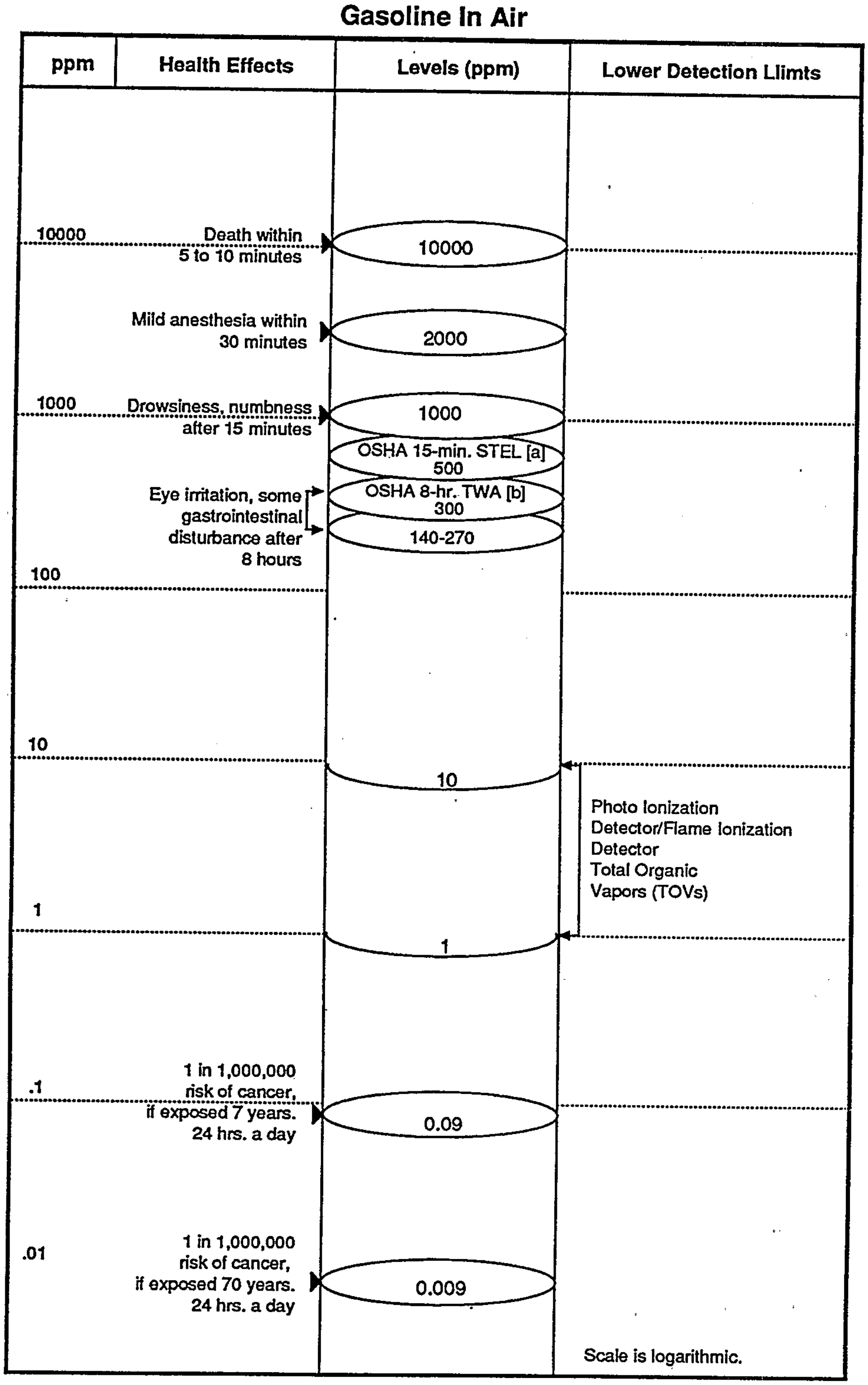
Also please note that the information in the exhibits has been plotted on a logarithmic scale. Although the scale increments on the exhibits are equidistant from one another, each scale increment is ten times greater than the one below it. Consequently, extrapolation between points on the scale cannot be accomplished in the same manner as extrapolation on a linear scale. Further explanation of some of the information in the exhibits is presented below.

Cancer and noncancer health effects. The information regarding noncancer health effects was gathered from studies conducted on laboratory animals and, occasionally, from observations on humans exposed to the chemicals in the workplace or by accident. Potential cancer risks were calculated based on EPA risk assessment information and standard assumptions (i.e., adults weigh 70 kilograms, drink 2 liters of water/day, and breathe 20 cubic meters of air/day). The more the behavior of the population being evaluated differs from these assumptions, the more the actual risk of adverse health effects will differ from the predicted risk. The assumptions used in the development of the risk levels presented in the exhibits are for adults; children may be three to seven times more sensitive than adults.

OSHA occupational exposure standards. OSHA exposure standards are designed to protect workers against excessive exposures in the workplace. OSHA standards are based on both health and economic considerations and may be inappropriate for evaluating exposures to the general public. These values are designed for use with a healthy population of working age to protect against adverse health effects due to exposures during an individual's working life (i.e., 40 hours per week for 45 years).

Drinking water standards. Drinking water standards, also called Maximum Contaminant Levels or MCLs, are legally enforceable levels of a chemical allowed in drinking water. They are provided in the exhibits as additional information, but, like OSHA standards, MCLs are not based

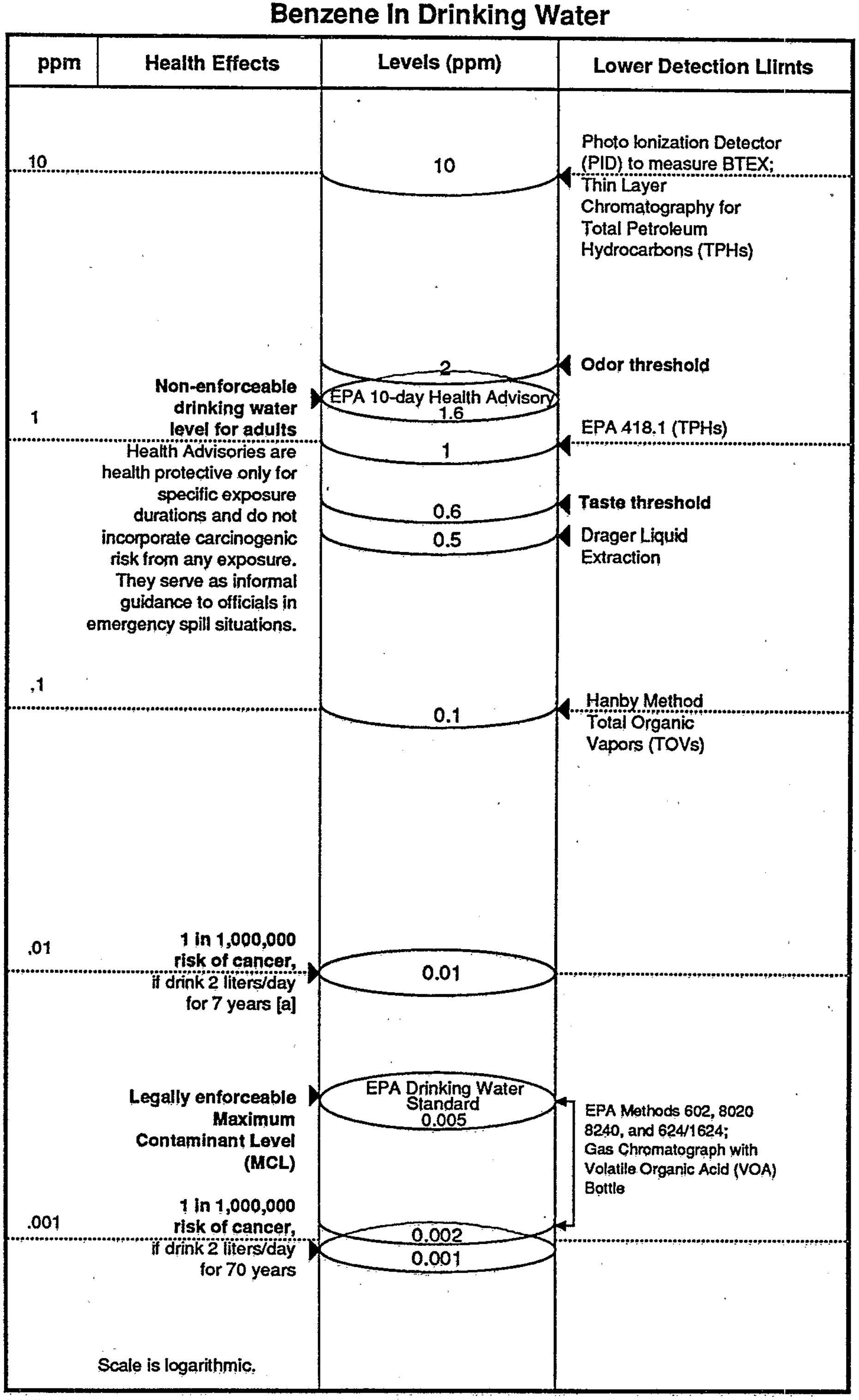
Exhibit 2. Health Effects Associated with Inhaling Gasoline Vapors



Gasoline In Air

[a] Short Term Exposure Limit (STEL) - 15 time-weighted average exposure not to exceed 500 ppm.
[b] Time Weighted Average (TWA) - not to exceed an average of 300 ppm over an 8 - hour day.
Average concentration for workday to which nearly all workers may be exposed without adverse effects.

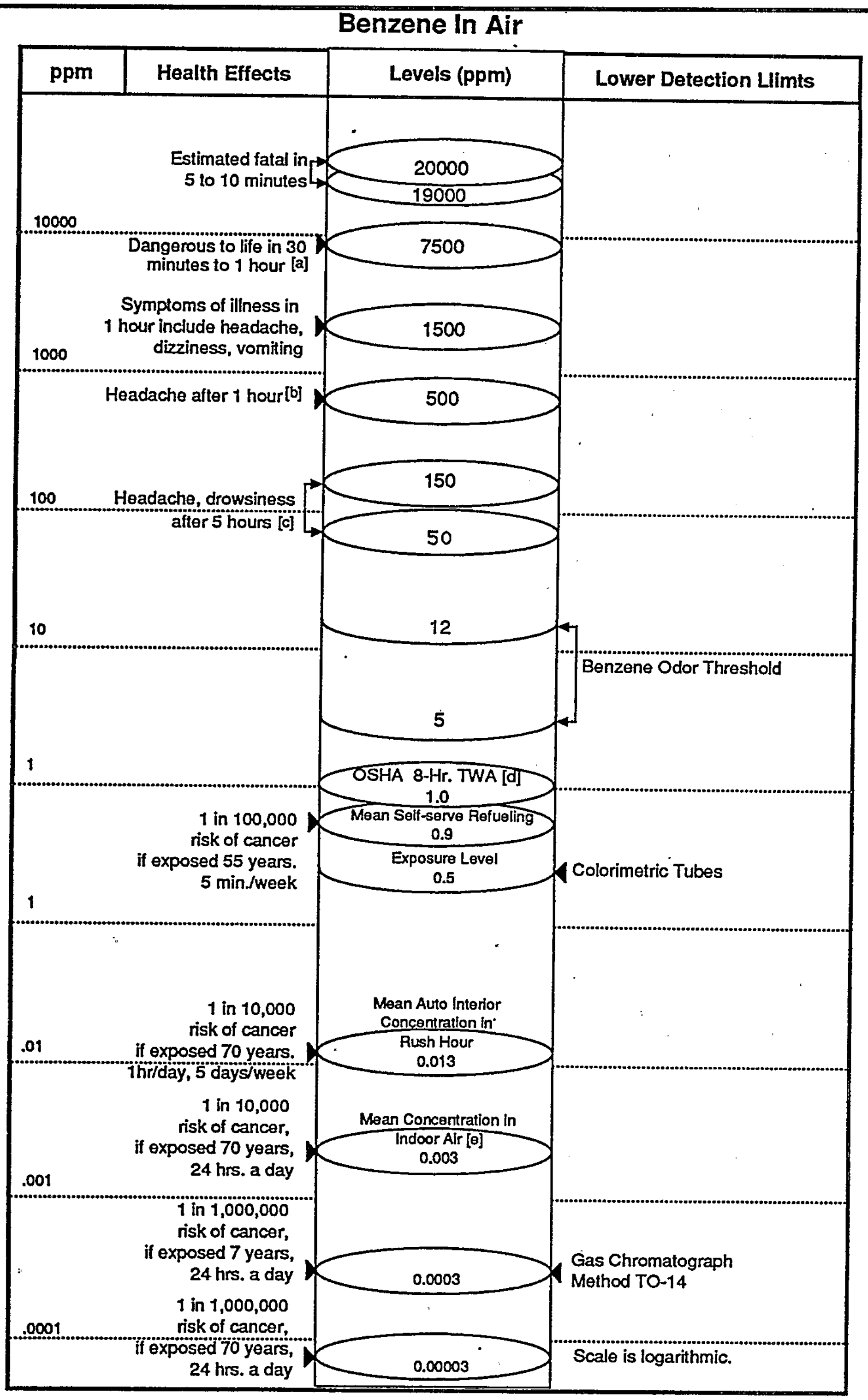
Exhibit 3. Health Effects Associated with Ingesting Benzene in Water



Benzene In Drinking Water

[a] The risk calculated for drinking 2 liters of water per day are roughly equivalent to those calculated for showering 15 min./day with water at 113F. If one is both drinking and showering with contaminated water, the Protection Advisories must be divided by two.

Exhibit 4. Health Effects Associated with Inhaling Benzene Vapors



[a] Signs of toxicity include drowsiness, vertigo, delirium, loss of consciousness.
[b] Long term exposure (generally 14 days or longer) has been associated with leukemia.
[c] Long term exposure (generally 14 days or longer) has been associated with effects on blood-forming organs.
[d] Time Weighted Average (TWA) - not to exceed an average of 1ppm over an 8 hour day.
[e] In homes or buildings with smokers this average will be 1 ppb higher.

solely on health-related information. Some MCLs, such as the one adopted for benzene, take into account the technical feasibility of removing the chemical from the water.

Taste and odor thresholds. Taste and odor thresholds for benzene in air and water are presented in the exhibits either as a single number or a threshold range, because odor and taste thresholds are highly variable due to differences in individual sensitivities. In addition, it should be noted that some gasoline compounds can be tasted and smelled at much lower concentrations than benzene. Although gasoline vapors and product tend to have a readily distinguishable odor and taste, there are no published gasoline odor or taste thresholds, because thresholds are measured for individual chemicals and not for a mixture of chemicals such as gasoline.

Comparative risk information. Some everyday exposures to benzene are presented in Exhibit 4 -- Benzene in Air -- to put some perspective on the extremely low levels that EPA considers safe for a lifetime exposure. The comparative risks are not meant to minimize the risk of benzene from USTs but to give some perspective on how pervasive benzene exposure is in our society. The reader is advised to use caution when interpreting these comparative risk numbers because the sample sizes were small in most studies. Furthermore, the indoor air concentration is not a formal EPA advisory. As of September 1991, EPA had not issued guidance concerning benzene in indoor air.

USING THE EXHIBITS

It is important to remember that the health effects summarized in the exhibits are based on particular exposed populations and particular exposure durations. Other populations, or even the same population exposed for other lengths of time, are likely to react differently.

It should be noted that the exhibits display the health effects associated only with the single route of exposure indicated on the exhibit. That is, effects for ingestion assume that the person is only being exposed by this route. If a person is being exposed by more than one route, it is important to decrease the allowable concentrations to account for the multiple exposures. Exposures from showering are often equivalent to those associated with drinking the water. Thus, if exposure is suspected by both drinking and showering, the allowable benzene concentrations should be divided by two.

Since the cancer-causing mechanism is still a mystery, EPA takes the conservative position that any exposure to a carcinogen (such as benzene) carries with it a corresponding risk (albeit very small) of developing cancer. The risks EPA predicts are upper bound values; the real risks are probably much smaller. Typically, EPA considers cancer risks greater than 1 in 10,000 unacceptable. A risk level between 1 in 10,000 and 1 in 1,000,000 is typically selected as the acceptable limit for cancer risks, depending upon the circumstances.

Carcinogenic effects usually occur from exposure to lower doses over longer periods of time relative to noncarcinogenic effects. Consequently, exposure levels developed to protect against carcinogenic effects are usually protective against the noncarcinogenic effects as well.

HEALTH EFFECTS OF GASOLINE EXPOSURE

Gasoline is a suspected human carcinogen because it contains benzene, a known carcinogen. Exposure, even at low levels, may result in the development of cancer. As exposure concentrations increase, it is also possible that effects other than cancer can occur, even if exposure duration is short. These noncancer effects include headache; nausea; drowsiness; skin, eye, and throat irritation; loss of reflexes; and liver and kidney damage. Inhalation of extremely high concentrations of gasoline can cause loss of consciousness, coma, and even sudden death. Over a number of years, inhalation of vapors can lead to severe blood damage (hemorrhaging and low blood cell levels), chromosomal alterations, or cerebral abnormalities.

HEALTH EFFECTS OF BENZENE EXPOSURE

Benzene is a known human carcinogen, capable of causing cancer at low levels of exposure for long periods of time. Benzene can enter the body through ingestion of contaminated water, inhalation of contaminated vapor, or through the skin. Noncancer effects include dizziness, headache, nausea, vomiting, skin irritation, and central nervous system effects. Exposure over a longer period of time may result in severe damage to blood-forming organs, leukemia, nerve damage, or paralysis. Studies have indicated that benzene adversely affects the immune system.

UNCERTAINTIES IN ASSESSING HEALTH EFFECTS

Using toxicological information gathered from laboratory animal studies and epidemiological studies for predicting the potential health effects likely to occur in humans as a result of future exposure involves uncertainty and requires professional judgment. Health-related guidance and exposure standards developed by EPA and other government agencies, such as the Department of Labor, are based on professional interpretation of the available toxicity data. Many times the guidelines developed by differing agencies are in agreement, but occasionally they are not. Some of the differences in the guidelines are based on differences in the purpose and assumptions used in their development. Other differences are the result of differing professional judgments regarding uncertain information.

COMPOSITION OF PETROLEUM PRODUCTS

Hari, R.V.; C.J. Dupuy; and D.R. Brown, Action Level for Methyl Tertiary Butyl Ether (MTBE) in Drinking Water. Connecticut Department of Health Services, Hartford, CT.

U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response. 1989. *UST Inspectors Safety and Health Manual.* Washington, D.C.: U.S. Government Printing Office.

MEASURING CONSTITUENTS

U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response. 1986. *Test Methods for Evaluating Solid Waste*, Vol 1A. Washington, D.C.: U.S. Government Printing Office.

U.S. Environmental Protection Agency, Office of Underground Storage Tanks. 1990. *Field Measurements: Dependable Data When You Need It.* Washington, D.C.: U.S. Government Printing Office.

Wallace, L. 1990. Major sources of exposure to benzene and other volatile organic chemicals, *Risk Analysis* 10: 59-64.

ASSESSING POTENTIAL HEALTH EFFECTS

U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response. 1989. *UST Inspectors Safety and Health Manual.* Washington, D.C.: U.S. Government Printing Office.

U.S. Environmental Protection Agency, Office of Emergency and Remedial Response. 1989. Risk Assessment Guidance for Superfund 1: *Human Health Evaluation Manual.*

HEALTH EFFECTS ASSOCIATED WITH EXPOSURE

Northeast States for Coordinated Air Use Management. 1989. *Evaluation of the Health Effects from Exposure to Gasoline and Gasoline Vapors.* Final Report.

U.S. Environmental Protection Agency, Strategies and Air Standards Division. 1978. *Assessment of Gasoline Toxicity.*

U.S. Environmental Protection Agency, Environmental Criteria and Assessment Office. 1984. *Health Effects Assessment for Benzene*, EPA 540/1-86-037. Cincinnati, Ohio.

U.S. Environmental Protection Agency, Office of Drinking Water. 1985. *Drinking Water Criteria Document for Benzene* (Final Draft).

U.S. Public Health Service. Agency for Toxic Substances and Disease Registry. 1989. *Toxicological Profile for Benzene.* ATSDR/TP-8803.