

**HUMAN HEALTH
RISK ASSESSMENT**

**FORMER OIL RECYCLING SITE
4200 ALAMEDA AVENUE
OAKLAND, CALIFORNIA**

D R A F T

**30 September 1996
(EKI 930040.05)**

HUMAN HEALTH RISK ASSESSMENT

4200 Alameda Avenue, Oakland, California
(EKI 930040.05)

TABLE OF CONTENTS

1.0 EXECUTIVE SUMMARY 1

2.0 INTRODUCTION..... 2

 2.1 SITE DESCRIPTION..... 2

 2.2 HUMAN HEALTH RISK ASSESSMENT OBJECTIVES
 AND APPROACH..... 3

3.0 EVALUATION OF SOIL AND GROUNDWATER ANALYTICAL DATA 4

 3.1 SUMMARY OF ANALYTICAL DATA..... 4

 3.2 REPRESENTATIVE CONCENTRATIONS
 OF CHEMICALS OF CONCERN 5

4.0 HUMAN HEALTH RISK ASSESSMENT..... 6

 4.1 TOXICITY CRITERIA 6

 4.1.1 Non-Carcinogenic Toxicity Criteria..... 6

 4.1.2 Carcinogenic Toxicity Criteria..... 7

 4.1.3 Compounds with No Toxicity Criteria..... 8

 4.2 EXPOSURE ASSESSMENT..... 9

 4.2.1 Identification of Potentially Exposed Populations 9

 4.2.2 Identification of Relevant Exposure Pathways 9

 4.2.3 Estimation of Exposure Point Concentrations..... 10

 4.2.4 Exposure Assumptions..... 10

 4.3 RISK CHARACTERIZATION..... 11

 4.3.1 Carcinogenic Effects 11

 4.3.2 Non-Carcinogenic Effects 12

 4.3.3 Risks Due to Lead Exposure 12

5.0 UNCERTAINTY ASSOCIATED WITH THE RISK ASSESSMENT..... 14

6.0 REFERENCES..... 15

TABLES

FIGURES

APPENDICES

1.0 EXECUTIVE SUMMARY

Erler & Kalinowski, Inc. has performed a human health risk assessment ("RA") for the 4200 Alameda Avenue property ("Site"), Oakland, California (Figure 1) to assess the potential human health risks associated with future uses of the Site after it is redeveloped. The objective of this RA is to provide upper-bound, health-conservative estimates of the risks to all future on-site populations.

The Site is fenced and completely covered with asphalt paving. The Site currently presents no significant human health risk because there are no potentially exposed populations. The primary chemicals of concern ("COCs") at the Site are constituents of petroleum hydrocarbon mixtures (e.g., waste oils) and volatile organic compounds that may have become commingled with such mixtures.

This risk assessment contemplates that the Site will be redeveloped for commercial uses. Such uses may include but are not limited to restaurants, convenience stores, or retail outlets. It is assumed that the entire Site will be covered with buildings, asphalt parking lots, or planter strips with imported soil. The two future potentially exposed populations consist of commercial building occupants and future maintenance personnel.

The estimated risks for these populations are within the risk range determined to be acceptable by U.S. EPA. The total non-carcinogenic hazard index for exposure to COCs in soil and groundwater is 0.03 for future commercial building occupants and 0.02 for future maintenance workers. Both of these values are significantly below the threshold at which non-carcinogenic effects may occur (i.e., one). The total estimated lifetime incremental carcinogenic risk for exposure to COCs in soil and groundwater is 9×10^{-6} for future commercial building occupants and 2×10^{-6} for future maintenance workers, which is within the acceptable range of incremental carcinogenic risks of 10^{-4} to 10^{-6} specified by U.S. EPA.

D R A F T

2.0 INTRODUCTION

Erler & Kalinowski, Inc. ("EKI") has performed a human health risk assessment ("RA") for the 4200 Alameda Avenue property ("Site"), California (Figure 1) to assess the potential human health risks associated with future uses of the Site after it is redeveloped. The objective of this RA is to provide upper-bound, health-conservative estimates of the risks to all future on-site populations.

Soil and groundwater investigations have been performed at the Site as well as removal actions consisting of the demolition of above grade buildings and tanks and below grade structures (e.g., pipe lines, an oil/water separator, sumps). These investigative and removal actions are discussed in detail in the following reports:

- EKI, *Demolition and Excavation Report*, Former Oil Recycling Site, 4200 Alameda Avenue, Oakland, California, 12 August 1996.
- EKI, *Groundwater Sampling Results for June 1996*, 4200 Alameda Avenue, Oakland, California, 12 August 1996.
- EKI, *Preliminary Investigation Report*, Former Oil Recycling Site, 4200 Alameda Avenue, Oakland, California, September 1995.

Presented below are a brief site description and the discussion of the objectives and approach of the RA.

2.1 SITE DESCRIPTION

As shown on Figure 1, the site is located at 4200 Alameda Avenue in Oakland, California. Oil recycling took place on the site from approximately 1925 to 1981. It has been known by various names including "Bonus International, Inc.", "Bayside Oil Company", "Fabian Oil Refining Company", "Economy Refining & Service Company", "Economy Byproducts & Economy Service Company", and "Ekotek Lube, Inc." No activities have occurred on the site since oil recycling was discontinued. Waste oil received by the facility primarily consisted of oils from automobiles, railroad locomotives, aircraft, and electrical transformers. Stoddard solvent was also reportedly recycled at the facility until approximately 1978.

The site is a small, triangular-shaped property that encompasses less than 35,000 ft² or 0.8 acres. The site is bounded by Alameda Avenue along its western side, East 8th Street along its east-southeastern side, and the former American National Can Company ("ANCC") site along its northern side. The Site is fenced and completely covered with

asphalt paving. The Site currently presents no significant human health risk because there are no potentially exposed populations or complete exposure pathways.

2.2 HUMAN HEALTH RISK ASSESSMENT OBJECTIVES AND APPROACH

The objectives of this human health risk assessment are to provide quantitative estimates of the potential human health impacts attributable to the chemicals detected in soil and groundwater (based upon available site-specific data) and in the air (based upon the results of volatilization from soil or groundwater). The RA utilizes the following risk assessment guidelines published by the State of California Environmental Protection Agency ("Cal-EPA") Department of Toxic Substances and Control ("DTSC"), the United States Environmental Protection Agency ("U.S. EPA"), and the American Society for Testing and Materials ("ASTM"):

- Cal-EPA, DTSC. *Preliminary Endangerment Assessment Guidance Manual*. January 1994
- U.S. EPA. *Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual (Part A)*. December 1989.
- ASTM. *Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites ("RBCA")*. 1995.

Although all three guidances were relied upon to perform this RA, exposure point concentrations ("EPCs") and attendant potential risks are estimated primarily through the use of transport models and risk equations provided in RBCA. A copy of RBCA is included as Appendix B. Potential risks posed by lead in soil at the Site were assessed through application of Cal-EPA, DTSC Lead Spreadsheet Version 6.0.

3.0 EVALUATION OF SOIL AND GROUNDWATER ANALYTICAL DATA

This section identifies the chemicals of concern ("COCs") at the Site based on analytical data obtained during previous soil and groundwater investigations at the Site. Soil and groundwater data compiled for the Site are presented in tables included as Appendix A. Soil and groundwater sampling locations at the Site are shown on Figure 2.

Because historical operations consisted of the recycling of waste motor and other lubricating oils, the primary COCs at the Site are constituents of petroleum hydrocarbons mixtures and volatile organic compounds ("VOCs") that may have been commingled with such mixtures. Besides VOCs, polychlorinated biphenyls ("PCBs") and metals such as lead, total chromium, and zinc have been identified in petroleum hydrocarbons released at the Site.

3.1 SUMMARY OF ANALYTICAL DATA

Available data indicate that petroleum hydrocarbons are present in soil and groundwater at the Site. Halogenated VOCs, benzene, toluene, ethyl benzene, total xylenes ("BTEX"), and semivolatile organic compounds ("SVOCs") were detected only at low concentrations in soil. Detected concentrations of halogenated VOCs and BTEX in groundwater are believed to be associated with free-phase petroleum hydrocarbons as opposed to being dissolved in groundwater itself. No appreciable migration of these compounds, and only minimal migration of petroleum hydrocarbons, have been observed in groundwater from the Site.

Petroleum hydrocarbons in soil and groundwater at the Site are characteristic of motor oil and are predominantly high molecular weight (with carbon chain lengths between C₁₆ and C₃₆). ASTM (1995) states that petroleum hydrocarbons of this type are "relatively viscous and insoluble in groundwater and relatively immobile in the subsurface." This statement is supported by available data that shows a lack of petroleum hydrocarbon migration in groundwater at the Site.

Metals detected in soil or groundwater at the Site include arsenic, total chromium, lead, cadmium, nickel, and zinc. Representative concentrations ("RCs") of total chromium, lead, nickel, and zinc appear to be above background concentrations reported for soil in the San Francisco Bay Area (Scott, 1995). Arsenic and cadmium were retained in the RA despite the fact that their RCs appear to be within the range of background levels reported for these metals. The following table presents the RCs for metals at Site and their respective background concentrations.

Metal	Site Representative Concentration (mg/kg)	San Francisco Bay Background Level (mg/kg); (a)
Arsenic	5.1	0.2-5.5
Cadmium	1.6	(b)
Total Chromium	75	30.5-72
Lead	89	6.8-16.1
Nickel	110	46.4-101
Zinc	450	47.7-82.8

Notes:

- (a) Background metal concentrations obtained from C. M. Scott, 1995. Range is based on the mean plus and minus one standard deviation, or a 68 percent confidence interval.
- (b) Statistical data for this metal are not available.

3.2 REPRESENTATIVE CONCENTRATIONS OF CHEMICALS OF CONCERN

Summarized in Tables 1A and 1B are the RCs of COCs in soil and groundwater at the Site. RCs of potential COCs were established as the lesser of the maximum concentration detected or the 95% upper confidence limit ("UCL") of the average concentration, assuming a lognormal distribution (U.S. EPA, 1992; DTSC, 1992). The data were assumed to be lognormally distributed.

The concentrations of petroleum hydrocarbons in some samples caused the laboratory reporting limits for specific compounds (e.g., VOCs) to be raised. Consistent with U.S. EPA guidance (1989), such samples were excluded when estimating RCs if the raised reporting limits were greater than the maximum detected chemical concentrations and the raised reporting limits significantly biased the RCs of chemicals at the Site.

4.0 HUMAN HEALTH RISK ASSESSMENT

This section presents toxicity information for each of the potential COCs, the assumptions used in the risk screening evaluation, and the results of the risk screening evaluation. This RA uses a reasonable maximum exposure ("RME") methodology as recommended by Cal-EPA and U.S. EPA (Cal-EPA, 1992; U.S. EPA, 1989a). The RME scenario provides a health-conservative methodology for developing RCs that tends to overestimate environmental concentrations of the detected chemicals for chronic exposures. Using RCs, exposure point concentrations ("EPCs"), chronic daily intakes ("CDIs"), and risk/hazard index estimates are derived for the RME scenarios.

4.1 TOXICITY CRITERIA

The toxicity criteria section provides quantitative estimates of the toxic effects associated with the potential COCs included in the RA. The two broad categories of adverse human health effects recognized in the assessment of health risks are non-carcinogenic and carcinogenic effects. Health criteria for each of these effects are presented separately, where data allow.

The toxicity criteria developed by both the California Environmental Protection Agency ("Cal-EPA") and U.S. EPA are derived primarily for two exposure routes, ingestion and inhalation. Toxicity criteria typically are not derived for dermal absorption exposures. Following U.S. EPA recommendations, the health risk estimates via dermal absorption of soil-bound chemicals are estimated using toxicity criteria developed for the ingestion exposure route (U.S. EPA, 1989), following estimates of the likelihood of absorption.

4.1.1 Non-Carcinogenic Toxicity Criteria

Non-carcinogenic effects encompass adverse, chronic human health effects that do not result in the production of tumors, but which include both developmental and reproductive effects. When the chemical dose levels for non-carcinogens exceed the chemical-specific threshold doses, the potentially exposed populations may exhibit adverse health effects. Dose levels less than the threshold level are assumed not to produce adverse health effects in exposed individuals.

Threshold levels for non-carcinogenic effects are expressed as reference doses ("RfDs"). An RfD, published in units of mg/kg-day, reflects the maximum chemical dose level that must be exceeded before adverse effects would be expected to occur, but generally incorporates a safety or uncertainty factor of two or more orders of magnitude. A low RfD indicates a low threshold dose level, and therefore a high chemical toxicity.

Conversely, a chemical with a higher RfD value is less toxic than chemicals with lower RfDs.

The following hierarchy for selecting RfD values is used in the risk screening evaluation. The preferred source for reference doses is the Integrated Risk Information System ("IRIS") database (U.S. EPA, 1995a). The toxicity values available in IRIS are updated monthly and have undergone agency review and verification by work groups comprising staff from several U.S. EPA program offices. In the absence of toxicity data from IRIS, the FY-1995 edition of U.S. EPA's Health Effects Assessment Summary Tables ("HEAST") is used (U.S. EPA, 1995b). These tables are updated annually and contain work group-verified or interim toxicity values based on the toxicological literature. The final source of toxicity information is the U.S. EPA Environmental Criteria Assessment Office ("ECAO") in Cincinnati, Ohio. The values obtained from ECAO are based on a variety of U.S. EPA reports and the toxicological literature, but are not work group verified.

As recommended in agency guidelines, the non-carcinogenic effects of the potential human carcinogens are also considered in the risk screening evaluation, where data allow (U.S. EPA, 1989; DTSC, 1992, 1994). This strategy provides for a more thorough evaluation of the potential non-carcinogenic effects posed by the potential COCs.

Inhalation and ingestion toxicity information for potential COCs in soil and groundwater is summarized in Tables 2 and 3, respectively.

4.1.2 Carcinogenic Toxicity Criteria

The toxicity criteria that indicate the potential carcinogenicity of chemicals are called slope factors ("SFs"). U.S. EPA defines an SF as the "plausible upper-bound estimates of the probability of a carcinogenic response per unit of chemical intake over a lifetime" (U.S. EPA, 1989). SFs are developed using mathematical models and are expressed in reciprocal units of exposure, $(\text{mg}/\text{kg}\text{-day})^{-1}$. Chemicals having a higher SF are believed to be inherently more carcinogenic, i.e., potent, than those with a lower SF.

The International Agency for Research on Carcinogenic ("IARC") and U.S. EPA have also developed systems to categorize chemicals that are potentially carcinogenic according to the strength of the existing experimental evidence (human and animal studies). The U.S. EPA Human Health Assessment Group ranks chemicals from Group A (known human carcinogen) to Group E (evidence of non-carcinogenicity for humans). Group A designation is assigned to those chemicals known to be carcinogenic to humans as substantiated by positive epidemiological evidence. Chemicals not known to be human carcinogens are classified into other categories based on the strength of the available human and animal toxicological data. The U.S. EPA carcinogen ranking classification is presented for each potential human carcinogen included in the risk screening evaluation.

DTSC's recommended hierarchy is used to select health criteria for the carcinogens included in the risk screening evaluation (DTSC, 1994). The preferred source for carcinogenic slope factors is the list of SFs published by the Cal-EPA Standards and Criteria Work Group, dated 1 November 1994 (Office of Environmental Health Hazard Assessment, 1994). The secondary source of SFs is the IRIS database (U.S. EPA, 1995a). The third source of SFs is the FY-1995 edition of the U.S. EPA's HEAST (U.S. EPA, 1995b).

Inhalation and ingestion toxicity information for carcinogenic COCs in soil is summarized in Tables 2 and 3, respectively.

4.1.3 Compounds with No Toxicity Criteria

COCs identified at the Site that lack U.S. EPA or DTSC-derived health criteria are petroleum hydrocarbons, n-butylbenzene, sec-butylbenzene, isopropylbenzene, p-isopropyltoluene, n-propylbenzene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, and 2-methylnaphthalene. Regarding quantitation of petroleum hydrocarbons, ASTM (1995) states:

Various chemical analysis methods commonly referred to as total petroleum hydrocarbons (TPHs) are often used in site assessments. These methods usually determine the total amount of hydrocarbons present as a single number and given no information on the types of hydrocarbons present. The TPHs should not be used for risk assessment because the general measure of TPH provides insufficient information about the amounts of individual chemical(s) of concern present.

Consequently, EKI followed the "individual constituent" approach advocated in RBCA to assess the potential risks associated with petroleum hydrocarbons. In this approach, the toxicity of each individual constituent is separately assessed and the toxicity of the mixture is assumed to be the sum of the individual toxicity using a hazard index approach. Individual constituents in petroleum hydrocarbons at the Site were identified by analyzing soil and groundwater samples for VOCs, SVOCs, PCBs, and selected metals.

Toxicity values were assigned to n-butylbenzene, sec-butylbenzene, isopropylbenzene, p-isopropyltoluene, n-propylbenzene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, and 2-methylnaphthalene by assuming their toxicity would be equivalent to compounds with similar chemical structures for which toxicity criteria are available. Toxicity criteria for n-butylbenzene, sec-butylbenzene, isopropylbenzene, and n-propylbenzene are assumed to be equivalent to ethylbenzene. Toxicity criteria for p-isopropyltoluene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene are assumed to be equivalent to total xylenes. Toxicity criteria for 2-methylnaphthalene are assumed to be equivalent to naphthalene.

4.2 EXPOSURE ASSESSMENT

The exposure assessment provides estimates of the levels of chemical exposures in hypothetical on-site populations that may come in contact with the potential COCs. This exposure assessment follows the RBCA Guidance.

4.2.1 Identification of Potentially Exposed Populations

This risk assessment contemplates that the Site will be redeveloped for commercial uses. Such uses may include but are not limited to restaurants, convenience stores, or retail outlets. It is assumed that the entire Site will be covered with buildings, asphalt parking lots, or planter strips with imported soil. People working at the Site can be divided into two main populations:

- Future commercial building occupants
- Future maintenance personnel

Table 4 summarizes the potentially exposed populations and their relevant exposure pathways. Any future customers would have exposures significantly lower than workers because they would spend significantly less time at the Site.

4.2.2 Identification of Relevant Exposure Pathways

Exposure pathways by which future populations may be exposed to COCs are discussed below.

4.2.2.1 Future Commercial Building Occupants

Since the Site will be covered with buildings, concrete, asphalt, and clean soil upon redevelopment of the Site, the only potential risk for future commercial building occupants is inhalation of volatilized chemicals from soil or groundwater into indoor air through floor cracks.

4.2.2.2 Future Maintenance Personnel

Future maintenance personnel include populations who may be exposed to contaminated soil while installing new utility hookups for tenants or repairing broken utility lines. The potential exposure pathways consist of the following:

- Incidental ingestion of soil
- Dermal contact with soil

- Inhalation of fugitive dust containing non-volatile COCs
- Inhalation of volatilized VOCs from either groundwater or soil exposed during digging at the Site

4.2.3 Estimation of Exposure Point Concentrations

Exposure point concentrations ('EPCs') are the chemical concentrations at the specific points of potential human contact. The RA provides estimated EPCs for each media that coincide with the RME scenarios.

4.2.3.1 Soil EPCs

Analytical results of the soil samples collected on the Site are used to estimate the soil EPCs. Soil EPCs for both commercial building occupants and maintenance personnel are based on the RCs presented in Table 1A.

4.2.3.2 Air EPCs

Exposures to COCs in air are estimated for volatilization of chemicals from both soil and groundwater into the breathing zone. Volatilized chemicals have the potential to move upward through interconnected air-filled soil pores in the unsaturated zone and impact the breathing zone of individuals standing outdoors on paved surfaces or within buildings constructed on top of such soils.

Emission fluxes of chemicals volatilizing from soil and groundwater were estimated from transport models in RBCA. Emission fluxes from soil and groundwater were not added because this would result in overestimation of overall emission fluxes into the breathing zone. For example, when considering emission fluxes from groundwater, it is assumed that the unsaturated soil is not contaminated. In actuality, the soil does contain chemicals and emission fluxes from soil would serve to lower emission fluxes from groundwater by reducing the concentration gradient or driving force in the air-filled soil pores.

In conducting the RA, EKI estimated and compared the EPCs for each COC arising from volatilization from soil only and groundwater only. The greater of these two EPCs was retained for each COC. This approach will provide upper-bound estimates of exposure and potential human health risk for individuals who may occupy the Site in the future.

4.2.4 Exposure Assumptions

Exposure assumptions are based on (1) default assumptions recommended by the U.S. EPA (U.S. EPA, 1989, 1991, 1992) and the DTSC (DTSC, 1992) and (2) best

professional judgment for conditions unique to the Site. Exposure assumptions for each exposure pathway are summarized in Table 5. Soil parameters are based on measured values for the ANCC site (SOMA, 1994). Table 6 lists soil parameters taken from the ANCC site and other assumptions used in RBCA exposure models. Tables 7A and 7B list physical and chemical properties for COCs in soil and groundwater, respectively.

4.3 RISK CHARACTERIZATION

For each hypothetical future population, risk estimates for each exposure medium (i.e., soil, groundwater, or air) are calculated for each potential COC and are added to derive the estimated hypothetical risk for each exposure medium. The risk estimates are added to obtain the total estimated lifetime risk for all complete exposure pathways affecting the potentially exposed populations.

Results of the risk screening evaluation are presented in Tables 8 through 10 and are discussed in more detail below.

4.3.1 Carcinogenic Effects

Risk characterization for carcinogens includes estimating the incremental probability of developing carcinogenic over a lifetime of 70 years due to a 30-year exposure to the potential human carcinogens. Except for those chemicals for which scientific information supporting a carcinogenic threshold exists, a carcinogen is considered to be a non-threshold agent, such that any exposure to a carcinogen is expected to increase the probability of developing carcinogenic over an individual's lifetime. Incremental carcinogenic risk is calculated as the product of the estimated dose from exposure to the potentials COCs and the carcinogenic slope factor. The PEA Guidance considers risks greater than 10^{-6} to be potentially significant, whereas the U.S. EPA's acceptable range of incremental carcinogenic risk is 10^{-4} to 10^{-6} (U.S. EPA, 1989).

The incremental lifetime carcinogenic risk via each complete exposure pathway is calculated by adding the risk estimates from all of the chemicals impacting that pathway. Risk across each pathway are then added to derive the total estimated incremental lifetime carcinogenic risk for the potentially exposed population. Such summation is a health-conservative screening step because it does not differentiate between target organs, i.e., chemical-specific carcinogenic health effects are not all the same.

Estimated incremental lifetime carcinogenic risks for all exposed populations and all applicable exposure pathways are included in Tables 8 and 9. The total lifetime incremental carcinogenic risks for each hypothetically exposed population are summarized in Table 10.

As summarized in Table 10, the total estimated incremental lifetime carcinogenic risks for the potentially exposed populations are as follows:

- 9×10^{-6} for future commercial building occupants;
- 2×10^{-6} for future maintenance personnel.

U.S. EPA specifies an acceptable range of incremental carcinogenic risks of 10^{-4} to 10^{-6} .

4.3.2 Non-Carcinogenic Effects

The non-carcinogenic risk characterization represents the relationship between the chemical doses estimated for the populations of concern and the toxicity of the individual non-carcinogenic COCs, including possible non-carcinogenic end points for carcinogenic chemicals where data allow. The calculated Hazard Index ("HI") is a ratio of the estimated dose from exposure to the potentials COCs and the RfD, which represents the "safe" dosage level. If an HI exceeds unity (one), the intake of the COC is greater than the "safe" dosage level represented by the RfD, and therefore adverse health effects may occur in the potentially exposed population. When the HI is less than unity, adverse health effects are not expected to occur in the exposed population.

Calculated HI values for all exposed populations and all applicable exposure pathways are included in Tables 8 and 9. The total non-carcinogenic HI for each hypothetically exposed population is summarized in Table 10.

As summarized in Table 10, the total non-carcinogenic HI values for the potentially exposed populations are as follows:

- 0.03 for future building occupants;
- 0.02 for future maintenance personnel.

Both of these values are significantly below the threshold at which non-carcinogenic effects may occur (i.e., one).

4.3.3 Risks Due to Lead Exposure

Adverse effects due to lead exposure are assessed in terms of the lead concentration in blood, rather than in terms of non-carcinogenic and carcinogenic risks. Therefore, the risks due to lead exposure are discussed here separately from other COCs.

The concentration of concern for lead in the blood is 10 micrograms per deciliter ("ug/dl") at the 99th percentile (DTSC, 1992). Lead concentration in the blood was calculated

using the DTSC Lead Spreadsheet Version 6.0, the equations for which are described in DTSC, 1992. The blood lead concentrations calculated as the sum of exposure to: (1) background levels of lead in air, (2) background levels of lead in drinking water, (3) background levels of lead in food, and (4) lead in soil at the Site. The representative concentration of lead in soil was 89 mg/kg (Table 1A). Potential risks posed by lead are discussed in the sections below for the future populations.

4.3.3.1 Future Commercial Building Occupants

No potential risk has been identified for future commercial building occupants due to lead-containing soil. The absence of risk results from the fact that a complete exposure pathway to lead-containing soil has not been identified for this population. As discussed earlier, the soil will be capped with buildings, concrete, asphalt, and clean cover upon redevelopment of the Site. Buildings and cover (e.g., asphalt parking lots, planter strips) materials over the Site will render conventional exposure pathways (i.e., ingestion of soil, inhalation of fugitive dust, dermal contact with soil) incomplete.

4.3.3.2 Future Maintenance Personnel

The risk due to exposure to lead-containing soil was evaluated for hypothetical future maintenance personnel and was below the level above which adverse effects due to lead exposure are believed to occur.

The exposure assumptions for the hypothetical future maintenance personnel are based on (1) default assumptions recommended by U.S. EPA (U.S. EPA 1989, 1991, 1992) and the DTSC (DTSC, 1992), and (2) best professional judgment for conditions unique to the Site. The assumptions used are summarized in Table 11. The source of each exposure assumption is referenced in Table 11.

The calculated lead concentration in blood for hypothetical future maintenance personnel is 3.9 ug/dl at the 99th percentile, which is significantly less than the level of concern of 10 ug/dl. Most of the calculated blood lead concentration for the hypothetical future maintenance personnel is due to background levels of lead in air, water, and food. Lead in soil at the Site only accounts for 0.1 percent of the blood lead concentration. Therefore, exposure of hypothetical future maintenance personnel to lead-containing soil at the Site should not result in blood lead concentrations in excess of the level of concern.

5.0. UNCERTAINTY ASSOCIATED WITH THE RISK ASSESSMENT

The hypothetical risks calculated and presented in Sections 4.3.1 and 4.3.2 are upper-bound, health-conservative estimates of risks for RME pathways.

Factors that contribute to the uncertainty or conservatism in this RA include the following:

- Chemical data for soil was retained in the risk screening evaluation, regardless of the soil sampling depth, which implies that hypothetical exposure to surface soil is the same as that from depth (e.g., 5 feet below ground surface).
- Risks from COCs in soil and groundwater were estimated without considering the effects of petroleum hydrocarbons on the volatilization of COCs. The volatility of halogenated VOCs and BTEX is likely to be reduced due to the enhanced solubility of these compounds in waste oil. Accordingly, EPCs are likely to be less than those assumed in this RA.

Potential risks may be significantly lower than those presented in Tables 7 through 9 if the RA were to account for the above factors.

6.0 REFERENCES

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Table 1A
 Representative Concentrations of Chemicals of Concern Detected in Soil

4200 Alameda Avenue
 Oakland, California
 (EKI 930040.05)

Compound	Frequency of Detection		Summary of Detected Concentration (mg/kg)				Representative Concentration (mg/kg) (e)
	Number of Times Detected	Number of Analyses Performed	Minimum (a)	Maximum (b)	Arithmetic Mean (c)	95% Upper Confidence Limit (lognormal); (d)	
TPHg (f)	34	40	2	4,100	600	(i)	4,100
TPHd (g)	40	40	1.5	11,000	1,800	(i)	11,000
TPHm (h)	38	40	21	15,000	3,500	(i)	15,000
Benzene	9	36	0.018	1.5	0.14	1.2	1.2
Chlorobenzene	5	32	0.0072	0.5	0.093	0.37	0.37
2-chlorotoluene	4	10	0.53	22	4.5	(i)	22
1,2-Dichlorobenzene	17	40	0.0058	11	0.66	8.8	8.8
1,1-Dichloroethane	2	17	0.012	0.023	0.0047	(i)	0.023
1,2-Dichloroethane	2	17	0.018	0.028	0.0054	(i)	0.028
cis-1,2-Dichloroethene	5	40	0.014	8.5	0.48	4.2	4.2
trans-1,2-Dichloroethene	1	17	0.033	0.033	0.0047	(i)	0.033
Ethylbenzene	31	40	0.007	34.5	3.5	(i)	34.5
Freon113	1	25	0.83	0.83	0.073	0.61	0.61
n-Butylbenzene	8	10	0.58	19	5.3	(i)	19
sec-Butylbenzene	4	7	0.66	3.4	1.0	(i)	3.4
Isopropylbenzene	3	7	0.53	3.2	0.87	(i)	3.2
p-Isopropyltoluene	8	10	0.5	8.4	2.6	(i)	8.4
n-Propylbenzene	8	10	0.65	19	5.8	(i)	19
Tetrachloroethene	4	40	0.0062	7.6	0.61	7.0	7.0
Toluene	27	40	0.02	91	6.0	55	55
1,2,4-Trimethylbenzene	9	10	1.5	140	47	(i)	140
1,3,5-Trimethylbenzene	10	10	0.56	43	15	(i)	43
Trichloroethene	7	37	0.0063	2.4	0.17	(i)	2.4
Vinyl Chloride	2	17	0.049	0.05	0.011	(i)	0.05
Total Xylenes	36	40	0.007	195	21	(i)	195
2-Methylnaphthalene	4	15	22	76	18	(i)	76

Table 1A
 Representative Concentrations of Chemicals of Concern Detected in Soil

4200 Alameda Avenue
 Oakland, California
 (EKI 930040.05)

Compound	Frequency of Detection		Summary of Detected Concentration (mg/kg)				Representative Concentration (mg/kg) (e)
	Number of Times Detected	Number of Analyses Performed	Minimum (a)	Maximum (b)	Arithmetic Mean (c)	95% Upper Confidence Limit (lognormal); (d)	
Naphthalene	9	15	0.51	61.5	12	(i)	61.5
1,2,4-Trichlorobenzene	4	10	5.8	9.8	3.3	(i)	9.8
PCB-1242	3	38	0.045	1.1	0.085	0.28	0.28
PCB-1254	5	39	0.021	3.4	0.18	0.41	0.41
PCB-1260	24	40	0.021	27	1.2	4.7	4.7
Arsenic	4	30	6.8	28	4.4	5.1	5.1
Total Chromium	40	40	18	110	65	75	75
Lead	32	40	5.1	660	52	89	89
Cadmium	3	10	0.53	3.7	0.73	1.6	1.6
Nickel	10	10	38	170	85	110	110
Zinc	10	10	31	560	148	450	450

Notes:

- (a) Minimum represents the lowest concentration detected.
- (b) Maximum represents the highest concentration detected.
- (c) The arithmetic mean was calculated assuming that for samples where chemicals were not reported to be present above the analytical method detection limit, the concentration of each of these chemicals is one-half of the reported detection limit. Samples were not included in the dataset to calculate the mean and 95% UCL if the detection limit exceeded the maximum detected concentration.
- (d) The 95% upper confidence limit (UCL) was calculated from the arithmetic mean of the transformed lognormal data set. Samples were not included in the dataset to calculate the mean and 95% UCL if the detection limit exceeded the maximum detected concentration.
- (e) Representative concentration is the lesser of the maximum detected value or the 95% UCL.
- (f) TPHg - total petroleum hydrocarbons as gasoline
- (g) TPHd - total petroleum hydrocarbons as diesel
- (h) TPHm - total petroleum hydrocarbons as motor oil
- (i) Variability in data results in a 95% UCL that is greater than the maximum reported concentration.

Table 1B
 Representative Concentrations of Chemicals of Concern Detected in Groundwater

4200 Alameda Avenue
 Oakland, California
 (EKI 930040.05)

Compound	Frequency of Detection		Summary of Detected Concentration (ug/L)				Representative Concentration (ug/L); (e)
	Number of Times Detected	Number of Analyses Performed	Minimum (a)	Maximum (b)	Arithmetic Mean (c)	95% Upper Confidence Limit (d)	
TPHg (f)	16	16	57	160,000	15,000	(i)	160,000
TPHd (g)	16	16	4,900	850,000	170,000	(i)	850,000
TPHm (h)	4	4	67,000	800,000	370,000	(i)	800,000
Benzene	16	16	6.2	630	180	(i)	630
Chlorobenzene	5	15	7.3	160	32	(i)	160
Chloroethane	7	15	1	130	37	(i)	130
1,2-Dichlorobenzene	7	16	1.6	300	54	(i)	300
1,3-Dichlorobenzene	4	16	1.5	1,600	130	(i)	1,600
1,4-Dichlorobenzene	5	16	4.4	2,700	200	(i)	2,700
1,1-Dichloroethane	8	15	4.8	160	54	(i)	160
1,2-Dichloroethane	1	7	17	17	3.2	(i)	17
cis-1,2-Dichloroethene	10	16	8.4	6,600	1,600	(i)	6,600
trans-1,2-Dichloroethene	7	15	4.1	170	53	(i)	170
1,2-Dichloropropane	1	6	4.9	4.9	1.3	(i)	4.9
Ethylbenzene	13	16	28	700	120	(i)	700
Toluene	12	16	12	2,500	410	(i)	2,500
Trichloroethene	1	6	3.8	3.8	1.1	(i)	3.8
Vinyl Chloride	10	16	4.1	5,200	2,000	(i)	5,200
Total Xylenes	13	16	49	3,400	550	(i)	3,400
2,4-Dimethylphenol	1	6	3,400	3,400	590	(i)	3,400
2-Methylnaphthalene	1	3	11	11	5.3	(i)	11
2-Methylphenol	1	6	330	330	81	(i)	330
4-Methylphenol	2	6	9.9	550	120	(i)	550
Naphthalene	2	5	63	160	51	(i)	160

Table 1B
 Representative Concentrations of Chemicals of Concern Detected in Groundwater

4200 Alameda Avenue
 Oakland, California
 (EKI 930040.05)

Compound	Frequency of Detection		Summary of Detected Concentration (ug/L)				Representative Concentration (ug/L); (e)
	Number of Times Detected	Number of Analyses Performed	Minimum (a)	Maximum (b)	Arithmetic Mean (c)	95% Upper Confidence Limit (d)	
Phenol	1	5	230	230	53	(i)	230
PCB-1260	1	6	31	31	7.9	(i)	31
Arsenic	8	8	13	93	40	85	85
Chromium	3	8	21	89	22	70	70
Lead	4	10	5	6,600	920	(i)	6,600

Notes:

- (a) Minimum represents the lowest concentration detected.
- (b) Maximum represents the highest concentration detected.
- (c) The arithmetic mean was calculated assuming that for samples where chemicals were not reported to be present above the analytical method detection limit, the concentration of each of these chemicals is one-half of the reported detection limit. Samples were not included in the dataset to calculate the mean and 95% UCL if the detection limit exceeded the maximum detected concentration.
- (d) The 95% upper confidence limit (UCL) was calculated from the arithmetic mean of the transformed lognormal data set. Samples were not included in the dataset to calculate the mean and 95% UCL if the detection limit exceeded the maximum detected concentration.
- (e) Representative concentration is the lesser of the maximum detected value or the 95% UCL.
- (f) TPHg - total petroleum hydrocarbons as gasoline
- (g) TPHd - total petroleum hydrocarbons as diesel
- (h) TPHm - total petroleum hydrocarbons as motor oil
- (i) Variability in data results in a 95% UCL that is greater than the maximum reported concentration.

Table 2
 Summary of Inhalation Toxicity Information for Potential Chemicals of Concern in Soil and Groundwater
 4200 Alameda Avenue
 Oakland, California
 (EKI 930040.05)

Compound	Non-Carcinogenic Toxicity Information		Carcinogenic Toxicity Information		
	Chronic Reference Dose (RfDi) (mg/kg-day)	Source (a)	Slope Factor (SF) (mg/kg-day) ⁻¹	Weight-of-Evidence Classification (b)	Source (c)
Benzene	- (d)	-	0.1	A	Cal Potency
Chlorobenzene	0.02 (e)	IRIS	-	D	-
Chloroethane	2.86	IRIS	-	-	-
2-Chlorotoluene	0.02 (e)	IRIS	-	-	-
1,2-Dichlorobenzene	0.09 (e)	IRIS	-	D	-
1,3-Dichlorobenzene	-	-	-	D	-
1,4-Dichlorobenzene	0.23	IRIS	0.04	B2	Cal Potency
1,1-Dichloroethane	0.1	HEAST	0.0057	C	Cal Potency
1,2-Dichloroethane	-	-	0.07	B2	Cal Potency
cis-1,2-Dichloroethene	0.01 (e)	HEAST	-	D	-
trans-1,2-Dichloroethene	0.02 (e)	IRIS	-	D	-
1,2-Dichloropropane	0.0011	IRIS	0.063	B2	Cal Potency
Ethylbenzene	0.29	IRIS	-	D	-
Freon 113	30 (e)	IRIS	-	-	-
n-Butylbenzene (f)	0.29	IRIS	-	D	-
sec-Butylbenzene (f)	0.29	IRIS	-	D	-
Isopropylbenzene (f)	0.29	IRIS	-	D	-
p-Isopropyltoluene (g)	2	IRIS	-	D	-
n-Propylbenzene (f)	0.29	IRIS	-	D	-
Tetrachloroethene	0.01 (e)	IRIS	0.021	under review	Cal Potency
Toluene	0.11	IRIS	-	D	-
1,2,4-Trimethylbenzene (g)	2	IRIS	-	D	-
1,3,5-Trimethylbenzene (g)	2	IRIS	-	D	-
Trichloroethene	-	-	0.01	under review	Cal Potency
Vinyl Chloride	-	-	0.27	A	Cal Potency
Total xylenes	2 (e)	IRIS	-	D	-
2,4-Dimethylphenol	0.02 (e)	IRIS	-	-	-
2-Methylnaphthalene (h)	0.04	ECAO	-	D	-

Table 2
 Summary of Inhalation Toxicity Information for Potential Chemicals of Concern in Soil and Groundwater
 4200 Alameda Avenue
 Oakland, California
 (EKI 930040.05)

Compound	Non-Carcinogenic Toxicity Information		Carcinogenic Toxicity Information		
	Chronic Reference Dose (RfDi) (mg/kg-day)	Source (a)	Slope Factor (SF) (mg/kg-day) ⁻¹	Weight-of-Evidence Classification (b)	Source (c)
2-Methylphenol	0.05 (e)	IRIS	-	C	-
4-Methylphenol	0.005 (e)	HEAST	-	C	-
Naphthalene	0.04	ECAO	-	D	-
Phenol	0.6 (e)	IRIS	-	D	-
1,2,4-Trichlorobenzene	0.01 (e)	IRIS	-	D	-
PCB-1242	0.00002 (i)	IRIS	7.7	B2	Cal Potency
PCB-1254	0.00002 (e)	IRIS	7.7	B2	Cal Potency
PCB-1260	0.00002 (i)	IRIS	7.7	B2	Cal Potency
Arsenic	0.0003 (e)	IRIS	12	A	Cal Potency
Cadmium	0.0005 (e)	IRIS	15	B1	Cal Potency
Total Chromium (j)	1.0	IRIS	-	D	-
Nickel	-	-	0.91	A	Cal Potency
Zinc	0.3 (e)	IRIS	-	D	-

Notes:

(a) Chronic reference doses obtained from U.S. EPA's Integrated Risk Information System (IRIS) or U.S. EPA's Health Effects Assessment Summary Tables (HEAST), dated March 1995, or U.S. EPA's Environmental Criteria and Assessment Office, OH (ECAO), in this order of priority.

(b) U.S. EPA weight-of-evidence classification is as follows:

A = Human Carcinogen

B1 or B2 = Probable Human Carcinogen; B1 indicates that limited human data are available; B2 indicates that there is sufficient evidence in animals and inadequate or no evidence in humans.

C = Possible Human Carcinogen

D = Not Classifiable as to Human Carcinogenicity

E = Evidence of Non-Carcinogenicity for Humans

Weight-of-evidence information obtained from IRIS or HEAST.

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Table 2
Summary of Inhalation Toxicity Information for Potential Chemicals of Concern in Soil and Groundwater
4200 Alameda Avenue
Oakland, California
(EKI 930040.05)

Notes:

- (c) Cancer slope factors obtained from California Cancer Potency Factors Updated Memorandum for the Office of Environmental Health Hazard Assessment (1 November 1994) or IRIS, in this order of priority.
- (d) Hyphen ("-") symbol indicates a respective reference dose or cancer slope factor is not available for this compound.
- (e) In the absence of an inhalation chronic reference dose or an inhalation carcinogenic slope factor, the respective oral value was used.
- (f) Health criteria for n-butylbenzene, sec-butylbenzene, isopropylbenzene, and n-propylbenzene assumed to be equivalent to ethylbenzene.
- (g) Health criteria for p-isopropyltoluene, 1,2,4-trimethylbenzene, and 1,3,5-trimethylbenzene assumed to be equivalent to total xylenes.
- (h) Health criteria for 2-methylnaphthalene assumed to be equivalent to naphthalene.
- (i) The chronic reference dose for PCB-1242 and PCB-1260 assumed to be the same as that for PCB-1254.
- (j) The toxicity information for total chromium is assumed to be the same as that for chromium(III).

Table 3
Summary of Ingestion Toxicity Information for Potential Chemicals of Concern in Soil and Groundwater

4200 Alameda Avenue
Oakland, California
(EKI 930040.05)

Compound	Non-Carcinogenic Toxicity Information		Carcinogenic Toxicity Information		
	Chronic Reference Dose (RfDo) (mg/kg-day)	Source (a)	Slope Factor (SF) (mg/kg-day) ⁻¹	Weight-of-Evidence Classification (b)	Source (c)
Benzene	- (d)	-	0.1	A	Cal Potency
Chlorobenzene	0.02	IRIS	-	D	-
Chloroethane	2.86 (e)	IRIS	-	-	-
2-Chlorotoluene	0.02	IRIS	-	-	-
1,2-Dichlorobenzene	0.09	IRIS	-	D	-
1,3-Dichlorobenzene	under review	IRIS	-	D	-
1,4-Dichlorobenzene	0.23 (e)	IRIS	0.04	B2	Cal Potency
1,1-Dichloroethane	0.1 (e)	HEAST	0.0057	C	Cal Potency
1,2-Dichloroethane	-	-	0.07	B2	Cal Potency
cis-1,2-Dichloroethene	0.01	HEAST	-	D	-
trans-1,2-Dichloroethene	0.02	IRIS	-	D	-
1,2-Dichloropropane	0.0011 (e)	IRIS	0.063	B2	Cal Potency
Ethylbenzene	0.1	IRIS	-	D	-
Freon113	30	IRIS	-	-	-
n-Butylbenzene (f)	0.1	IRIS	-	D	-
sec-Butylbenzene (f)	0.1	IRIS	-	D	-
Isopropylbenzene (f)	0.1	IRIS	-	D	-
p-Isopropyltoluene (g)	2	IRIS	-	D	-
n-Propylbenzene (f)	0.1	IRIS	-	D	-
Tetrachloroethene	0.01	IRIS	0.051	under review	Cal Potency
Toluene	0.2	IRIS	-	D	-
1,2,4-Trimethylbenzene (g)	2	IRIS	-	D	-
1,3,5-Trimethylbenzene (g)	2	IRIS	-	D	-
Trichloroethene	-	-	0.015	under review	Cal Potency
Vinyl Chloride	-	-	0.27	A	Cal Potency
Total xylenes	2	IRIS	-	D	-
2,4-Dimethylphenol	0.02	IRIS	-	-	-
2-Methylnaphthalene	0.04 (h)	ECAO	-	D	-

Table 3
Summary of Ingestion Toxicity Information for Potential Chemicals of Concern in Soil and Groundwater

4200 Alameda Avenue
Oakland, California
(EKI 930040.05)

Compound	Non-Carcinogenic Toxicity Information		Carcinogenic Toxicity Information		
	Chronic Reference Dose (RfDo) (mg/kg-day)	Source (a)	Slope Factor (SF) (mg/kg-day) ⁻¹	Weight-of-Evidence Classification (b)	Source (c)
2-Methylphenol	0.05	IRIS	-	C	-
4-Methylphenol	0.005	HEAST	-	C	-
Naphthalene	0.04	ECAO	-	D	-
Phenol	0.6	IRIS	-	D	-
1,2,4-Trichlorobenzene	0.01	IRIS	-	D	-
PCB-1242	0.00002 (i)	IRIS	7.7	B2	Cal Potency
PCB-1254	0.00002	IRIS	7.7	B2	Cal Potency
PCB-1260	0.00002 (i)	IRIS	7.7	B2	Cal Potency
Arsenic	0.0003	IRIS	1.75	A	Cal Potency
Cadmium	0.0005	IRIS	15 (e)	B1	Cal Potency
Total Chromium (j)	1.0	IRIS	-	D	-
Nickel	-	-	0.91(e)	A	Cal Potency
Zinc	0.3	IRIS	-	D	-

Notes:

(a) Chronic reference doses obtained from U.S. EPA's Integrated Risk Information System (IRIS), U.S. EPA's Health Effects Assessment Summary Tables (HEAST), dated March 1995, or U.S. EPA's Environmental Criteria and Assessment Office, OH (ECAO), in this order of priority.

(b) U.S. EPA weight-of-evidence classification is as follows:

A = Human Carcinogen

B1 or B2 = Probable Human Carcinogen; B1 indicates that limited human data are available; B2 indicates that there is sufficient evidence in animals and inadequate or no evidence in humans.

C = Possible Human Carcinogen

D = Not Classifiable as to Human Carcinogenicity

E = Evidence of Non-Carcinogenicity for Humans

Weight-of-evidence information obtained from IRIS or HEAST.

Table 3
Summary of Ingestion Toxicity Information for Potential Chemicals of Concern in Soil and Groundwater

4200 Alameda Avenue
Oakland, California
(EKI 930040.05)

Notes:

- (c) Cancer slope factors obtained from California Cancer Potency Factors Updated Memorandum for the Office of Environmental Health Hazard Assessment (1 November 1994) or IRIS, in this order of priority.
- (d) Hyphen ("-") symbol indicates a respective reference dose or cancer slope factor is not available for this compound.
- (e) In the absence of an ingestion chronic reference dose or an ingestion carcinogenic slope factor, the respective inhalation value was used.
- (f) Health criteria for n-butylbenzene, sec-butylbenzene, isopropylbenzene, and n-propylbenzene assumed to be equivalent to ethylbenzene.
- (g) Health criteria for p-isopropyltoluene, 1,2,4-trimethylbenzene, and 1,3,5-trimethylbenzene assumed to be equivalent to total xylenes.
- (h) Health criteria for 2-methylnaphthalene assumed to be equivalent to naphthalene.
- (i) The chronic reference dose for PCB-1242 and PCB-1260 assumed to be the same as that for PCB-1254.
- (j) The toxicity information for total chromium is assumed to be the same as that for chromium(III).

Table 4
Summary of Potential Exposure Pathways for Future On-site Populations

4200 Alameda Avenue
Oakland, California
(EKI 930040.05)

Future On-site Population	Exposure Pathway
● Commercial Building Occupants	● Inhalation of vapors from soil or groundwater to indoor air
● Maintenance Personnel	● Soil Ingestion ● Dermal contact with soil ● Dust inhalation of non-volatiles from soil ● Inhalation of vapors from soil or groundwater to outdoor air

Table 5
Exposure Assumptions Used in the Human Health Risk Assessment

4200 Alameda Avenue
Oakland, California
(EKI 930040.05)

Future On-Site Population	Exposure Parameter (a)	Reference
● Commercial Building Occupants		
	EF Exposure Frequency	250 days/year U.S.EPA (1989a, 1991); Cal-EPA (1992)
	ED Exposure Duration	25 years U.S.EPA (1989a, 1991); Cal-EPA (1992)
	BW Body Weight	70 kg U.S.EPA (1989a, 1991); Cal-EPA (1992)
	AT Averaging Time	6250 days; 25,550 days Cal-EPA (1992)
	Air	
	IRa Inhalation Rate of Air	20 m ³ /day U.S.EPA (1989a, 1991); Cal-EPA (1992)
● Maintenance Personnel		
	EF Exposure Frequency	2 days/year (b) Best Professional Judgment
	ED Exposure Duration	25 years U.S.EPA (1989a, 1991); Cal-EPA (1992)
	BW Body Weight	70 kg U.S.EPA (1989a, 1991); Cal-EPA (1992)
	AT Averaging Time	50 days; 25,550 days (c) U.S. EPA (1989a); Cal-EPA (1992)
	Soil	
	SAs Skin Surface Area Available for Contact with Soil	3,160 cm ² U.S. EPA (1992a)
	IRs Incidental Soil Ingestion Rate	480 mg/day U.S. EPA (1991)
	AF Soil to Skin Adherence Factor	1 mg/cm ² U.S. EPA (1992a); Cal-EPA (1992)
	Air	
	IRa Inhalation Rate of Air	20 m ³ /day U.S.EPA (1989a, 1991); Cal-EPA (1992)
	RDC Respirable Dust Concentration	1 mg/m ³ (d) Best Professional Judgment

Table 5
Exposure Assumptions Used in the Human Health Risk Assessment

4200 Alameda Avenue
Oakland, California
(EKI 930040.05)

Notes:

(a) Exposure assumptions are compiled from:

- Cal-EPA (State of California, Environmental Protection Agency), January 1994, *Preliminary Endangerment Assessment Guidance Manual*, Department of Toxic Substances Control (DTSC).
- Cal-EPA, July 1992, *Supplemental Guidance for Human Health Multimedia Risk Assessments for Hazardous Waste Sites and Permitted Facilities*, DTSC, The Office of the Science Advisor.
- U.S. EPA (U.S. Environmental Protection Agency), January 1992a, *Dermal Exposure Assessment: Principles and Applications, Interim Report*, Office of Research and Development, EPA/600/8-91/011B.
- U.S. EPA, March 1991, *Risk Assessment Guidance for Superfund - Volume I: Human Health Evaluation Manual, Supplemental Guidance, "Standard Default Exposure Factors"*, Interim Final, OSWER Directive: 9285.6-03.
- U.S. EPA, December 1989a, *Risk Assessment Guidance for Superfund, Volume I - Human Health Evaluation Manual (Part A)*, OERR, EPA/540/12-89/002.

(b) The values are based on the following assumptions:

It is assumed that 1 maintenance event in which contaminated soil is exposed occurs every 2 years. Each maintenance event is assumed to take 4 working days. Therefore, the exposure frequency for maintenance personnel is 4 days every 2 years, or 2 days/year. The exposure duration (ED) of 25 years for maintenance personnel assumes that same person performs the work over a 25 year period.

(c) Averaging time for non-carcinogenic effects, which equals the period of exposure in units of days, is listed first. Averaging time for carcinogenic effects, which equals a 70 year lifetime in units of days, is listed second.

(d) A respirable dust concentration (concentration of dust with particles less than 10 micrometers in diameter) of 1 mg/m³ corresponds to the presence of visible dust clouds. Because it is unlikely that maintenance personnel will be working in visible dust clouds 8 hours/day, a respirable dust concentration of 1.0 mg/m³ is conservative. For comparison, the permissible exposure limit (PEL) for respirable dust is 5 mg/m³ (CCR, Title 8, Section 5155, Table AC-1).

Table 6
Assumptions Used in Risk Based Corrective Action ("RBCA") Transport Models

4200 Alameda Avenue
Oakland, California
(EKI 930040.05)

Parameter	Definition	Units	Commercial
d	Lower depth of surficial soil zone	cm	100
ER	Enclosed-space air exchange rate	1/s	0.00023
f _{oc}	Fraction of organic carbon	g-C/g-soil	0.00038 (a)
h _{cap}	thickness of capillary fringe	cm	5
h _v	thickness of vadose zone	cm	L _{gw} - h _{cap}
k _s	Soil-water sorption coefficient	cm ³ -water/g-C	f _{oc} * k _{oc}
L _B	Enclosed-space volume/infiltration area ratio	cm	300
L _{crack}	Enclosed-space foundation or wall thickness	cm	15
L _{gw}	Depth to groundwater	cm	300
L _S	Depth to subsurface soil sources	cm	30 (b)
P _e	Particulate emission rate	g/cm ² -s	6.9 x 10 ⁻¹⁴
U _{air}	Wind speed above ground surface in ambient mixing zone	cm/s	340 (c)
U _{gw}	Ground water Darcy velocity	cm/year	2500
W	Width of source area parallel to wind, or ground water flow direction	cm	3000 (d)
δ _{air}	Ambient air mixing zone height	cm	200
δ _{gw}	Groundwater mixing zone thickness	cm	200
η	Areal fraction of cracks in foundations/walls	cm ² -cracks/cm ² -total area	0.001 (e)
q _{acap}	Volumetric air content in capillary fringe soils	cm ³ -air/cm ³ -soil	0.038
θ _{acrack}	Volumetric air content in foundation/wall cracks	cm ³ -air/cm ³ -total volume	0.063 (a)
θ _{as}	Volumetric air content in vadose zone soils	cm ³ -air/cm ³ -soil	0.063 (a)
θ _T	Total soil porosity	cm ³ /cm ³ -soil	0.39 (a)
θ _{wcap}	Volumetric water content in capillary fringe soils	cm ³ -water/cm ³ -soil	0.352
θ _{wcrack}	Volumetric water content in foundation/wall cracks	cm ³ -water/cm ³ -soil	0.327 (a)
θ _{ws}	Volumetric water content in vadose zone soils	cm ³ -water/cm ³ -soil	0.327 (a)
ρ _s	Soil bulk density	g-soil/cm ³ -soil	1.62 (a)
τ	Averaging time for vapor flux	s	7.88 x 10 ⁸

Notes:

- (a) Site-specific soil properties were obtained from vadose zone soils at American National Can Company site located adjacent to 4200 Alameda Avenue. (SOMA Environmental Engineering, Inc. "Baseline Health Risk Assessment American National Can Company, Oakland, California Facility", 31 January, 1994).
- (b) Depth to subsurface soil sources is assumed to be 1 foot (30 cm), which is approximately the depth where the soil was detected of chemicals of concern.
- (c) The average wind speed of 340 cm/sec (7.5 mph) was obtained from the wind rose for Oakland Airport (National Weather Service, Redwood City, CA).
- (d) Width of source area parallel to wind, or ground water flow direction for the Site is assumed to be approximately 3000 cm (90 feet), which is more appropriate for the Site.
- (e) Areal fraction of cracks in foundations/walls for commercial buildings was set to 0.001, which is appropriate for newly constructed commercial buildings (Daugherty, 1991).

Table 7A
Physical and Chemical Properties for Chemicals of Concern in Soil

4200 Alameda Avenue
Oakland, California
(EKI 930040.00)

Compound	Henry's Law Constant H_c (a) (L-H ₂ O/L-air)	Diffusivity in Air D_{air} (b) (cm ² /s)	Diffusivity in Water D_{water} (c) (cm ² /s)	Organic Carbon Partition Coeff. K_{oc} (d) (mL/g)
Benzene	2.2E-01	9.3E-02	1.1E-05	3.8E+01
Chlorobenzene	1.5E-01	7.2E-02	7.5E-06	1.6E+02
2-Chlorotoluene	1.3E-02	7.1E-02	7.2E-06	1.9E+02
1,2-Dichlorobenzene	5.0E-02	1.3E-01	7.3E-06	1.1E+03
1,1-Dichloroethane	1.8E-01	9.1E-02	9.2E-06	3.0E+01
1,2-Dichloroethane	4.1E-02	9.1E-02	9.2E-06	1.4E+01
cis-1,2-Dichloroethene	1.7E-01	9.1E-02	9.6E-06	4.9E+01
trans-1,2-Dichloroethene	2.7E-01	7.9E-02	9.6E-06	5.9E+01
Ethylbenzene	3.2E-01	7.6E-02	8.5E-06	9.5E+01
Freon 113	1.4E+01	7.2E-02	7.5E-06	3.9E+02
n-Butylbenzene	5.2E-01	6.2E-02	6.1E-06	2.5E+03
sec-Butylbenzene	4.7E-01	6.2E-02	6.1E-06	8.9E+02
Isopropylbenzene	6.1E-01	6.6E-02	6.6E-06	2.8E+03
p-Isopropyltoluene (e)	6.1E-01	6.2E-02	6.1E-06	2.8E+03
n-Propylbenzene	4.2E-01	6.6E-02	6.6E-06	7.4E+02
Tetrachloroethene	6.2E-01	7.2E-02	7.6E-06	6.6E+02
Toluene	2.6E-01	8.5E-02	9.4E-06	1.3E+02
1,2,4-Trimethylbenzene	2.4E-01	6.6E-02	6.6E-06	3.7E+03
1,3,5-Trimethylbenzene	1.6E-01	6.6E-02	6.6E-06	1.6E+03
Trichloroethene	3.8E-01	8.1E-02	8.5E-06	1.3E+02
Vinyl Chloride	1.1E+00	1.1E-01	1.1E-05	5.7E+01
Total xylenes	2.9E-01	7.2E-02	8.5E-06	2.4E+02
2-Methylnaphthalene	4.9E-02 (f)	6.4E-02	6.4E-06	7.9E+03
Naphthalene	4.9E-02	7.2E-02	9.4E-06	1.3E+03
Phenol	1.9E-05	8.4E-02	8.6E-06	1.4E+01
1,2,4-Trichlorobenzene	9.6E-02	6.6E-02	6.7E-06	9.2E+03
PCB-1242	2.4E-02	5.0E-02	4.9E-06	5.1E+03
PCB-1254	1.2E-02	4.8E-02	4.6E-06	4.1E+04
PCB-1260	1.4E-02	4.6E-02	4.5E-06	2.6E+06
Arsenic	NA (g)	NA	NA	NA
Cadmium	NA	NA	NA	NA
Total Chromium	NA	NA	NA	NA
Nickel	NA	NA	NA	NA
Zinc	NA	NA	NA	NA

Table 7A
Physical and Chemical Properties for Chemicals of Concern in Soil

4200 Alameda Avenue
Oakland, California
(EKI 930040.00)

Notes:

- (a) Dimensionless Henry's constant at 20 degrees Celcius obtained from Montgomery and Welkom (1991).
- (b) Diffusivity in air at 20 degrees Celcius estimated using Fuller's method (Lyman et al., 1990) as directed by U.S. EPA Superfund Exposure Assessment Manual (April 1988).
- (c) Diffusivity in water at 20 degrees Celcius calculated using method of Hayduk and Laudie (Lyman et al., 1990).
- (d) Organic carbon partition coefficient (K_{oc}) obtained from Montgomery and Welkom (1991). Where multiple values were available, the log values were averaged.
- (e) Physical and chemical properties for p-isopropyltoluene assumed to be equivalent to isopropylbenzene, a structurally similar compound.
- (f) Because a Henry's constant was not available for 2-methylnaphthalene, the value for naphthalene, a structurally similar compound, was used.
- (g) "NA" indicates properties not applicable for the compound.

Table 7B
Physical and Chemical Properties for Chemicals of Concern in Groundwater

4200 Alameda Avenue
Oakland, California
(EKI 930040.00)

Compound	Henry's Law Constant H_c (a) (L-H ₂ O/L-air)	Diffusivity in Air D_{air} (b) (cm ² /s)	Diffusivity in Water D_{water} (c) (cm ² /s)	Organic Carbon Partition Coeff. K_{oc} (d) (mL/g)	Solubility in Water S (e) (mg/L)
Benzene	2.2E-01	9.3E-02	1.1E-05	3.8E+01	1.8E+03
Chlorobenzene	1.5E-01	7.2E-02	7.5E-06	1.6E+02	4.7E+02
Chloroethane	5.0E-01	1.0E-01	1.1E-05	3.2E+00	4.7E+03
1,2-Dichlorobenzene	5.0E-02	1.3E-01	7.3E-06	1.1E+03	1.6E+02
1,3-Dichlorobenzene	1.5E-01	1.3E-01	7.3E-06	5.4E+02	1.2E+02
1,4-Dichlorobenzene	1.2E-01	1.3E-01	7.3E-06	1.2E+03	8.7E+01
1,1-Dichloroethane	1.8E-01	9.1E-02	9.2E-06	3.0E+01	5.1E+03
1,2-Dichloroethane	4.1E-02	9.1E-02	9.2E-06	1.4E+01	8.5E+03
cis-1,2-Dichloroethene	1.7E-01	9.1E-02	9.6E-06	4.9E+01	3.5E+03
trans-1,2-Dichloroethene	2.7E-01	7.9E-02	9.6E-06	5.9E+01	6.3E+03
1,2-Dichloropropane	9.6E-02	8.0E-02	8.1E-06	3.7E+01	2.7E+03
Ethylbenzene	3.2E-01	7.6E-02	8.5E-06	9.5E+01	1.6E+02
Toluene	2.6E-01	8.5E-02	9.4E-06	1.3E+02	5.3E+02
Trichloroethene	3.8E-01	8.1E-02	8.5E-06	1.3E+02	1.1E+03
Vinyl Chloride	1.1E+00	1.1E-01	1.1E-05	5.7E+01	4.2E+03
Total xylenes	2.9E-01	7.2E-02	8.5E-06	2.4E+02	2.0E+02
2,4-Dimethylphenol	2.7E-04	6.9E-02	6.9E-06	1.2E+02	4.2E+03
2-Methylnaphthalene	4.9E-02 (f)	6.4E-02	6.4E-06	7.9E+03	2.5E+01
2-Methylphenol	5.1E-05	7.5E-02	7.6E-06	2.2E+01	2.5E+04
4-Methylphenol	3.3E-05	7.5E-02	7.6E-06	4.9E+01	2.3E+04
Naphthalene	4.9E-02	7.2E-02	9.4E-06	1.3E+03	3.2E+01
Phenol	1.9E-05	8.4E-02	8.6E-06	1.4E+01	9.3E+04
PCB-1260	1.4E-02	4.6E-02	4.5E-06	2.6E+06	8.0E-02
Arsenic	NA (g)	NA	NA	NA	NA
Total Chromium	NA	NA	NA	NA	NA

Table 7B
Physical and Chemical Properties for Chemicals of Concern in Groundwater

4200 Alameda Avenue
Oakland, California
(EKI 930040.00)

Notes:

- (a) Dimensionless Henry's constant at 20 degrees Celcius obtained from Montgomery and Welkom (1991).
- (b) Diffusivity in air at 20 degrees Celcius estimated using Fuller's method (Lyman et al., 1990) as directed by U.S. EPA Superfund Exposure Assessment Manual (April 1988).
- (c) Diffusivity in water at 20 degrees Celcius calculated using method of Hayduk and Laudie (Lyman et al., 1990).
- (d) Organic carbon partition coefficient (Koc) obtained from Montgomery and Welkom (1991). Where multiple values were available, the log values were averaged.
- (e) Solubility in water (S) obtained from Montgomery and Welkom (1991). Where multiple values were available, the values were averaged.
- (f) Because a Henry's constant was not available for 2-methylnaphthalene, the value for naphthalene, a structurally similar compound, was used.
- (g) "NA" indicates properties not applicable for the compound.

Table 8
 Characterization of Human Health Risks Due to Inhalation of Vapors Containing Chemicals of Concern
 for Future Commercial Building Occupants

4200 Alameda Avenue
 Oakland, California
 (EKI 930040.05)

Compound	Indoor EPC from groundwater ($\mu\text{g}/\text{m}^3$); (a)	Indoor EPC from soil ($\mu\text{g}/\text{m}^3$); (a)	Assumed Indoor EPC ($\mu\text{g}/\text{m}^3$); (b)	Non-Carcinogen Chronic Daily Intake ($\text{mg}/\text{kg}\cdot\text{day}$); (c)	Carcinogen Chronic Daily Intake ($\text{mg}/\text{kg}\cdot\text{day}$); (c)	Non-Carcinogenic Inhalation RfD ($\text{mg}/\text{kg}\cdot\text{day}$); (d)	Carcinogenic Inhalation SF ($\text{mg}/\text{kg}\cdot\text{day}$)-1; (e)	Non- Carcinogenic Hazard Index; (f)	Estimated Lifetime Incremental Cancer Risk; (g)
Benzene	9.1E-03	7.9E-02	7.9E-02	1.5E-05	5.5E-06	-	0.1	-	5.5E-07
Chlorobenzene	1.3E-03	1.1E-02	1.1E-02	2.2E-06	7.7E-07	0.02	-	1.1E-04	-
Chloroethane	4.3E-03	-	4.3E-03	8.4E-07	3.0E-07	2.86	-	2.9E-07	-
2-Chlorotoluene	-	1.4E-01	1.4E-01	2.7E-05	9.5E-06	0.02	-	1.3E-03	-
1,2-Dichlorobenzene	1.5E-03	7.2E-02	7.2E-02	1.4E-05	5.1E-06	0.09	-	1.6E-04	-
1,3-Dichlorobenzene	2.1E-02	-	2.1E-02	4.2E-06	1.5E-06	-	-	-	-
1,4-Dichlorobenzene	2.9E-02	-	2.9E-02	5.7E-06	2.0E-06	0.23	0.04	2.5E-05	8.2E-08
1,1-Dichloroethane	1.9E-03	1.2E-03	1.9E-03	3.6E-07	1.3E-07	0.1	0.0057	3.6E-06	7.4E-10
1,2-Dichloroethane	6.3E-05	5.1E-04	5.1E-04	9.9E-08	3.5E-08	-	0.07	-	2.5E-09
cis-1,2-Dichloroethene	7.3E-02	2.1E-01	2.1E-01	4.1E-05	1.5E-05	0.01	-	4.1E-03	-
trans-1,2-Dichloroethene	2.5E-03	2.1E-03	2.5E-03	4.9E-07	1.8E-07	0.02	-	2.5E-05	-
1,2-Dichloropropane	2.9E-05	-	2.9E-05	5.8E-09	2.1E-09	0.0011	0.063	5.2E-06	1.3E-10
Ethylbenzene	1.2E-02	2.3E+00	2.3E+00	4.5E-04	1.6E-04	0.29	-	1.6E-03	-
Freon 113	-	4.4E-01	4.4E-01	8.5E-05	3.0E-05	30	-	2.8E-06	-
n-Butylbenzene	-	3.5E-01	3.5E-01	6.8E-05	2.4E-05	0.29	-	2.3E-04	-
sec-Butylbenzene	-	1.2E-01	1.2E-01	2.3E-05	8.3E-06	0.29	-	8.1E-05	-
Isopropylbenzene	-	6.6E-02	6.6E-02	1.3E-05	4.6E-06	0.29	-	4.5E-05	-
p-Isopropyltoluene	-	1.6E-01	1.6E-01	3.2E-05	1.1E-05	2	-	1.6E-05	-
n-Propylbenzene	-	7.1E-01	7.1E-01	1.4E-04	5.0E-05	0.29	-	4.8E-04	-
Tetrachloroethene	-	4.3E-01	4.3E-01	8.5E-05	3.0E-05	0.01	0.021	8.5E-03	6.4E-07
Toluene	3.8E-02	3.2E+00	3.2E+00	6.3E-04	2.3E-04	0.11	-	5.8E-03	-
1,2,4-Trimethylbenzene	-	9.5E-01	9.5E-01	1.9E-04	6.6E-05	2	-	9.3E-05	-
1,3,5-Trimethylbenzene	-	4.1E-01	4.1E-01	8.0E-05	2.9E-05	2	-	4.0E-05	-
Trichloroethene	7.8E-05	1.9E-01	1.9E-01	3.7E-05	1.3E-05	0.01	0.01	3.7E-03	1.3E-07
Vinyl Chloride	4.2E-01	1.5E-02	4.2E-01	8.1E-05	2.9E-05	-	0.27	-	7.8E-06
Total xylenes	4.9E-02	9.4E+00	9.4E+00	1.8E-03	6.5E-04	2	-	9.2E-04	-

Table 8
 Characterization of Human Health Risks Due to Inhalation of Vapors Containing Chemicals of Concern
 for Future Commercial Building Occupants

4200 Alameda Avenue
 Oakland, California
 (EKI 930040.05)

Compound	Indoor EPC from groundwater (ug/m ³); (a)	Indoor EPC from soil (ug/m ³); (a)	Assumed Indoor EPC (ug/m ³); (b)	Non-Carcinogen Chronic Daily Intake (mg/kg-day); (c)	Carcinogen Chronic Daily Intake (mg/kg-day); (c)	Non-Carcinogenic Inhalation RfD (mg/kg-day); (d)	Carcinogenic Inhalation SF (mg/kg-day) ⁻¹ ; (e)	Non-Carcinogenic Hazard Index; (f)	Estimated Lifetime Incremental Cancer Risk; (g)
2,4-Dimethylphenol	-	-	-	-	-	0.02	-	-	-
2-Methylnaphthalene	3.2E-05	7.0E-02	7.0E-02	1.4E-05	4.9E-06	0.04	-	3.4E-04	-
2-Methylphenol	-	-	-	-	-	0.05	-	-	-
4-Methylphenol	-	-	-	-	-	0.005	-	-	-
Naphthalene	5.8E-04	3.3E-01	3.3E-01	6.4E-05	2.3E-05	0.04	-	1.6E-03	-
Phenol	-	-	-	-	-	0.6	-	-	-
1,2,4-Trichlorobenzene	-	1.3E-02	1.3E-02	2.6E-06	9.3E-07	0.01	-	2.6E-04	-
PCB-1242	-	2.0E-04	2.0E-04	3.9E-08	1.4E-08	0.00002	7.7	1.9E-03	1.1E-07
PCB-1254	-	2.8E-05	2.8E-05	5.5E-09	2.0E-09	0.00002	7.7	2.8E-04	1.5E-08
PCB-1260	3.4E-05	5.2E-06	3.4E-05	6.6E-09	2.3E-09	0.00002	7.7	3.3E-04	1.8E-08
Arsenic	-	-	-	-	-	0.0003	12	-	-
Cadmium	-	-	-	-	-	0.0005	15	-	-
Total Chromium	-	-	-	-	-	1	510	-	-
Nickel	-	-	-	-	-	-	0.91	-	-
Zinc	-	-	-	-	-	0.3	-	-	-
Total Risk Resulting from Inhalation of Vapors Containing Chemicals of Concern:								0.03	9E-06

Table 8
Characterization of Human Health Risks Due to Inhalation of Vapors Containing Chemicals of Concern
for Future Commercial Building Occupants

4200 Alameda Avenue
Oakland, California
(EKI 930040.05)

Notes:

- (a) The exposure point concentration ("EPC") was calculated based on the volatilization models in the RBCA model (ASTM, 1995).
- (b) The assumed indoor EPC for each compound is the greater of EPC from groundwater or from soil.
- (c) Chronic Daily Intakes ("CDIs") were estimated using methodologies recommended by U.S. EPA or Cal-EPA. Refer to Table 5 for assumptions to calculate CDIs.
- (d) Chronic reference doses ("RfDs") for non-carcinogenic effects were obtained from IRIS or HEAST, in this order of priority. Origin of respective RfDs is included in Tables 2 and 3. Hyphen indicates that RfD is not available for the compound.
- (e) Slope factors ("SFs") for carcinogenic effects were obtained from Cal-EPA's California Cancer Potency Factor Memorandum (November 1994) or IRIS, in this order of priority. Origin of respective SFs is included in Tables 2 and 3. Hyphen indicates that SF is not available for the compound.
- (f) Non-carcinogenic hazard index ("HI") for compound *i* is defined as the CDI_i / RfD_i . The non-carcinogenic HI, summed for all compounds and exposure pathways, assumes that there is a level of exposure (i.e., RfD) below which it is unlikely even for sensitive populations to experience adverse health effects (U.S. EPA, 1989a). If the CDI exceeds this RfD threshold (i.e., HI greater than 1), there may be concern for potential non-carcinogenic effects.
- (g) Estimated lifetime incremental cancer risk for chemical *i* is defined as $CDI_i * SF_i$. The estimated incremental lifetime cancer risks to an individual developing cancer due to COCs is given by the sum of incremental cancer risks for all chemicals and exposure pathways.

Table 9A
 Characterization of Human Health Risks Due to Ingestion of Soils Containing Chemicals of Concern
 for Future Maintenance Personnel

4200 Alameda Avenue
 Oakland, California
 (EKI 930040.05)

Compound	Representative Concentration in Soil (mg/kg); (a)	Non-Carcinogen Chronic Daily Intake (mg/kg-day); (b)	Carcinogen Chronic Daily Intake (mg/kg-day); (b)	Non-Carcinogenic Oral RfD (mg/kg-day); (c)	Carcinogenic Oral SF (mg/kg-day) ⁻¹ ; (d)	Non-Carcinogenic Hazard Index; (e)	Estimated Lifetime Incremental Cancer Risk; (f)
Benzene	1.2	4.5E-08	1.6E-08	-	0.1	-	1.6E-09
Chlorobenzene	0.37	1.4E-08	5.0E-09	0.02	-	7.0E-07	-
2-Chlorotoluene	22	8.3E-07	3.0E-07	0.02	-	4.1E-05	-
1,2-Dichlorobenzene	8.8	3.3E-07	1.2E-07	0.09	-	3.7E-06	-
1,1-Dichloroethane	0.023	8.6E-10	3.1E-10	0.1	0.0057	8.6E-09	1.8E-12
1,2-Dichloroethane	0.028	1.1E-09	3.8E-10	-	0.07	-	2.6E-11
cis-1,2-Dichloroethene	4.2	1.6E-07	5.6E-08	0.01	-	1.6E-05	-
trans-1,2-Dichloroethene	0.033	1.2E-09	4.4E-10	0.02	-	6.2E-08	-
Ethylbenzene	34.5	1.3E-06	4.6E-07	0.1	-	1.3E-05	-
Freon113	0.61	2.3E-08	8.2E-09	30	-	7.6E-10	-
n-Butylbenzene	19	7.1E-07	2.5E-07	0.1	-	7.1E-06	-
sec-Butylbenzene	3.4	1.3E-07	4.6E-08	0.1	-	1.3E-06	-
Isopropylbenzene	3.2	1.2E-07	4.3E-08	0.1	-	1.2E-06	-
p-Isopropyltoluene	8.4	3.2E-07	1.1E-07	2	-	1.6E-07	-
n-Propylbenzene	19	7.1E-07	2.5E-07	0.1	-	7.1E-06	-
Tetrachloroethene	7	2.6E-07	9.4E-08	0.01	0.051	2.6E-05	4.8E-09
Toluene	55	2.1E-06	7.4E-07	0.2	-	1.0E-05	-
1,2,4-Trimethylbenzene	140	5.3E-06	1.9E-06	2	-	2.6E-06	-
1,3,5-Trimethylbenzene	43	1.6E-06	5.8E-07	2	-	8.1E-07	-
Trichloroethene	2.4	9.0E-08	3.2E-08	-	0.015	-	4.8E-10
Vinyl Chloride	0.05	1.9E-09	6.7E-10	-	0.27	-	1.8E-10
Total xylenes	195	7.3E-06	2.6E-06	2	-	3.7E-06	-
2-Methylnaphthalene	76	2.9E-06	1.0E-06	0.04	-	7.1E-05	-
Naphthalene	61.5	2.3E-06	8.3E-07	0.04	-	5.8E-05	-
1,2,4-Trichlorobenzene	9.8	3.7E-07	1.3E-07	0.01	-	3.7E-05	-

Table 9A
 Characterization of Human Health Risks Due to Ingestion of Soils Containing Chemicals of Concern
 for Future Maintenance Personnel

4200 Alameda Avenue
 Oakland, California
 (EKI 930040.05)

Compound	Representative Concentration in Soil (mg/kg); (a)	Non-Carcinogen Chronic Daily Intake (mg/kg-day); (b)	Carcinogen Chronic Daily Intake (mg/kg-day); (b)	Non-Carcinogenic Oral RfD (mg/kg-day); (c)	Carcinogenic Oral SF (mg/kg-day)-1; (d)	Non-Carcinogenic Hazard Index; (e)	Estimated Lifetime Incremental Cancer Risk; (f)
PCB-1242	0.28	1.1E-08	3.8E-09	0.00002	7.7	5.3E-04	2.9E-08
PCB-1254	0.41	1.5E-08	5.5E-09	0.00002	7.7	7.7E-04	4.2E-08
PCB-1260	4.7	1.8E-07	6.3E-08	0.00002	7.7	8.8E-03	4.9E-07
Arsenic	5.1	1.9E-07	6.8E-08	0.0003	1.75	6.4E-04	1.2E-07
Cadmium	1.6	6.0E-08	2.1E-08	0.0005	15	1.2E-04	3.2E-07
Total Chromium	75	2.8E-06	1.0E-06	1	-	2.8E-06	-
Nickel	110	4.1E-06	1.5E-06	-	0.91	-	1.3E-06
Zinc	450	1.7E-05	6.0E-06	0.3	-	5.6E-05	-
Total Risk Resulting from Ingestion of Soils Containing Chemicals of Concern:						0.01	2E-06

Notes:

- (a) Refer to Table 1A for compilation of representative concentrations ("RCs").
- (b) Chronic Daily Intakes ("CDIs") were estimated using methodologies recommended by U.S. EPA or Cal-EPA. Refer to Table 5 for assumptions to calculate CDIs.
- (c) Chronic reference doses ("RfDs") for non-carcinogenic effects were obtained from IRIS or HEAST, in this order of priority. Origin of respective RfDs is included in Tables 2 and 3. Hyphen indicates that RfD is not available for the compound.
- (d) Slope factors ("SFs") for carcinogenic effects were obtained from Cal-EPA's California Cancer Potency Factor Memorandum (November 1994) or IRIS, in this order of priority. Origin of respective SFs is included in Tables 2 and 3. Hyphen indicates that SF is not available for the compound.
- (e) Non-carcinogenic hazard index ("HI") for compound *i* is defined as the CDI_i/RfD_i . The non-carcinogenic HI, summed for all compounds and exposure pathways, assumes that there is a level of exposure (i.e., RfD) below which it is unlikely even for sensitive populations to experience adverse health effects (U.S. EPA, 1989a). If the CDI exceeds this RfD threshold (i.e., HI greater than 1), there may be concern for potential non-carcinogenic effects.
- (f) Estimated lifetime incremental cancer risk for chemical *i* is defined as $CDI_i * SF_i$. The estimated incremental lifetime cancer risks to an individual developing cancer due to COCs is given by the sum of incremental cancer risks for all chemicals and exposure pathways.

Table 9B
 Characterization of Human Health Risks Due to Dermal Contact With Soils Containing Chemicals of Concern
 for Future Maintenance Personnel

4200 Alameda Avenue
 Oakland, California
 (EKI 930040.05)

Compound	Representative Concentration in Soil (mg/kg)	Absorption Factor, (b)	Non-Carcinogen Chronic Daily Intake (mg/kg-day); (c)	Carcinogen Chronic Daily Intake (mg/kg-day); (c)	Non-Carcinogenic Oral RfD (mg/kg-day); (d)	Carcinogenic Oral SF (mg/kg-day) ⁻¹ ; (e)	Non-Carcinogenic Hazard Index, (f)	Estimated Lifetime Incremental Cancer Risk; (g)
Benzene	1.2	0.1	1.5E-08	5.3E-09	-	0.1	-	5.3E-10
Chlorobenzene	0.37	0.1	4.6E-09	1.6E-09	0.02	-	2.3E-07	-
2-Chlorotoluene	22	0.1	2.7E-07	9.7E-08	0.02	-	1.4E-05	-
1,2-Dichlorobenzene	8.8	0.1	1.1E-07	3.9E-08	0.09	-	1.2E-06	-
1,1-Dichloroethane	0.023	0.1	2.8E-10	1.0E-10	0.1	0.0057	2.8E-09	5.8E-13
1,2-Dichloroethane	0.028	0.1	3.5E-10	1.2E-10	-	0.07	-	8.7E-12
cis-1,2-Dichloroethene	4.2	0.1	5.2E-08	1.9E-08	0.01	-	5.2E-06	-
trans-1,2-Dichloroethene	0.033	0.1	4.1E-10	1.5E-10	0.02	-	2.0E-08	-
Ethylbenzene	34.5	0.1	4.3E-07	1.5E-07	0.1	-	4.3E-06	-
Freon 113	0.61	0.1	7.5E-09	2.7E-09	30	-	2.5E-10	-
n-Butylbenzene	19	0.1	2.3E-07	8.4E-08	0.1	-	2.3E-06	-
sec-Butylbenzene	3.4	0.1	4.2E-08	1.5E-08	0.1	-	4.2E-07	-
Isopropylbenzene	3.2	0.1	4.0E-08	1.4E-08	0.1	-	4.0E-07	-
p-Isopropyltoluene	8.4	0.1	1.0E-07	3.7E-08	2	-	5.2E-08	-
n-Propylbenzene	19	0.1	2.3E-07	8.4E-08	0.1	-	2.3E-06	-
Tetrachloroethene	7	0.1	8.7E-08	3.1E-08	0.01	0.051	8.7E-06	1.6E-09
Toluene	55	0.1	6.8E-07	2.4E-07	0.2	-	3.4E-06	-
1,2,4-Trimethylbenzene	140	0.1	1.7E-06	6.2E-07	2	-	8.7E-07	-
1,3,5-Trimethylbenzene	43	0.1	5.3E-07	1.9E-07	2	-	2.7E-07	-
Trichloroethene	2.4	0.1	3.0E-08	1.1E-08	-	0.015	-	1.6E-10
Vinyl Chloride	0.05	0.1	6.2E-10	2.2E-10	-	0.27	-	6.0E-11
Total xylenes	195	0.1	2.4E-06	8.6E-07	2	-	1.2E-06	-
2-Methylnaphthalene	76	0.15	1.4E-06	5.0E-07	0.04	-	3.5E-05	-
Naphthalene	61.5	0.15	1.1E-06	4.1E-07	0.04	-	2.9E-05	-
1,2,4-Trichlorobenzene	9.8	0.1	1.2E-07	4.3E-08	0.01	-	1.2E-05	-

Table 9B
 Characterization of Human Health Risks Due to Dermal Contact With Soils Containing Chemicals of Concern
 for Future Maintenance Personnel

4200 Alameda Avenue
 Oakland, California
 (EKI 930040.05)

Compound	Representative Concentration in Soil (mg/kg)	Absorption Factor; (b)	Non-Carcinogen Chronic Daily Intake (mg/kg-day); (c)	Carcinogen Chronic Daily Intake (mg/kg-day); (c)	Non-Carcinogenic Oral RfD (mg/kg-day); (d)	Carcinogenic Oral SF (mg/kg-day)-1; (e)	Non-Carcinogenic Hazard Index; (f)	Estimated Lifetime Incremental Cancer Risk; (g)
PCB-1242	0.28	0.15	5.2E-09	1.9E-09	0.00002	7.7	2.6E-04	1.4E-08
PCB-1254	0.41	0.15	7.6E-09	2.7E-09	0.00002	7.7	3.8E-04	2.1E-08
PCB-1260	4.7	0.15	8.7E-08	3.1E-08	0.00002	7.7	4.4E-03	2.4E-07
Arsenic	5.1	0.03	1.9E-08	6.8E-09	0.0003	1.75	6.3E-05	1.2E-08
Cadmium	1.6	0.001	2.0E-10	7.1E-11	0.0005	15	4.0E-07	1.1E-09
Total Chromium	75	0.01	9.3E-08	3.3E-08	1	-	9.3E-08	-
Nickel	110	0.01	1.4E-07	4.9E-08	-	0.91	-	4.4E-08
Zinc	450	0.01	5.6E-07	2.0E-07	0.3	-	1.9E-06	-
Total Risk Resulting from Dermal Contact with Soils Containing Chemicals of Potential Concern:							0.005	3E-07

Notes:

- (a) Refer to Table 1A for compilation of representative concentrations ("RCs").
- (b) The absorption factors were obtained from the Cal-EPA Preliminary Endangerment Assessment Guidance (DTSC, 1994).
- (c) Chronic Daily Intakes ("CDIs") were estimated using methodologies recommended by U.S. EPA or Cal-EPA. Refer to Table 5 for assumptions to calculate CDIs.
- (d) Chronic reference doses ("RfDs") for non-carcinogenic effects were obtained from IRIS or HEAST, in this order of priority. Origin of respective RfDs is included in Tables 2 and 3. Hyphen indicates that RfD is not available for the compound.
- (e) Slope factors ("SFs") for carcinogenic effects were obtained from Cal-EPA's California Cancer Potency Factor Memorandum (November 1994) or IRIS, in this order of priority. Origin of respective SFs is included in Tables 2 and 3. Hyphen indicates that SF is not available for the compound.
- (f) Non-carcinogenic hazard index ("HI") for compound *i* is defined as the CDI_i/RfD_i . The non-carcinogenic HI, summed for all compounds and exposure pathways, assumes that there is a level of exposure (i.e., RfD) below which it is unlikely even for sensitive populations to experience adverse health effects (U.S. EPA, 1989a). If the CDI exceeds this RfD threshold (i.e., HI greater than 1), there may be concern for potential non-carcinogenic effects.
- (g) Estimated lifetime incremental cancer risk for chemical *i* is defined as $CDI_i * SF_i$. The estimated incremental lifetime cancer risks to an individual developing cancer due to COCs is given by the sum of incremental cancer risks for all chemicals and exposure pathways.

Table 9C
 Characterization of Human Health Risks Due to Inhalation of Fugitive Dust Containing Non-Volatile Chemicals of Concern
 for Future Maintenance Personnel

4200 Alameda Avenue
 Oakland, California
 (EKI 930040.05)

Compound	Representative Concentration in Soil (mg/kg); (a)	Cair for non-volatiles (mg/m ³); (b)	Non-Carcinogen Chronic Daily Intake (mg/kg-day); (c)	Carcinogen Chronic Daily Intake (mg/kg-day); (c)	Non-Carcinogenic Inhalation RfD (mg/kg-day); (d)	Carcinogenic Inhalation SF (mg/kg-day) ⁻¹ ; (e)	Non-Carcinogenic Hazard Index; (f)	Estimated Lifetime Incremental Cancer Risk; (g)
Arsenic	5.1	5.1E-06	8.0E-09	2.9E-09	0.0003	12	2.7E-05	3.4E-08
Cadmium	1.6	1.6E-06	2.5E-09	8.9E-10	0.0005	15	5.0E-06	1.3E-08
Total Chromium	75	7.5E-05	1.2E-07	4.2E-08	1	-	1.2E-07	-
Nickel	110	1.1E-04	1.7E-07	6.2E-08	-	0.91	-	5.6E-08
Zinc	450	4.5E-04	7.0E-07	2.5E-07	0.3	-	2.3E-06	-
Total Risk Resulting from Inhalation of Fugitive Dust Containing Non-Volatile Chemicals of Concern:							0.00003	1E-07

Notes:

(a) Refer to Table 1A for compilation of representative concentrations ("RCs").

(b) The concentration in air (Ca) is calculated using the following equation:

$$C_a = C_s * RDC * (10^{-6} \text{ kg/mg})$$

where Cs is the representative concentration of compound in soil, RDC is the respirable dust concentration, see Table 5 for the assumption of RDC value.

(c) Chronic Daily Intakes ("CDIs") were estimated using methodologies recommended by U.S. EPA or Cal-EPA. Refer to Table 5 for assumptions to calculate CDIs.

(d) Chronic reference doses ("RfDs") for non-carcinogenic effects were obtained from IRIS or HEAST, in this order of priority. Origin of respective RfDs is included in Tables 2 and 3. Hyphen indicates that RfD is not available for the compound.

(e) Slope factors ("SFs") for carcinogenic effects were obtained from Cal-EPA's California Cancer Potency Factor Memorandum (November 1994) or IRIS, in this order of priority. Origin of respective SFs is included in Tables 2 and 3. Hyphen indicates that SF is not available for the compound.

(f) Non-carcinogenic hazard index ("HI") for compound i is defined as the CDI_i/RfD_i. The non-carcinogenic HI, summed for all compounds and exposure pathways, assumes that there is a level of exposure (i.e., RfD) below which it is unlikely even for sensitive populations to experience adverse health effects (U.S. EPA, 1989a). If the CDI exceeds this RfD threshold (i.e., HI greater than 1), there may be concern for potential non-carcinogenic effects.

(g) Estimated lifetime incremental cancer risk for chemical i is defined as CDI_i * SF_i. The estimated incremental lifetime cancer risks to an individual developing cancer due to COCs is given by the sum of incremental cancer risks for all chemicals and exposure pathways.

Table 9D
 Characterization of Human Health Risks Due to Inhalation of Vapors Containing Chemicals of Concern
 for Future Maintenance Personnel

4200 Alameda Avenue
 Oakland, California
 (EKI 930040.05)

Compound	Outdoor EPC from groundwater (ug/m ³); (a)	Outdoor EPC from soil and particulates (ug/m ³); (a)	Assumed Outdoor EPC (ug/m ³); (b)	Non-Carcinogen Chronic Daily Intake (mg/kg-day); (c)	Carcinogen Chronic Daily Intake (mg/kg-day); (c)	Non-Carcinogenic Inhalation RfD (mg/kg-day); (d)	Carcinogenic Inhalation SF (mg/kg-day) ⁻¹ ; (e)	Non-Carcinogenic Hazard Index; (f)	Estimated Lifetime Incremental Cancer Risk; (g)
Benzene	1.4E-03	1.1E-02	1.1E-02	1.7E-08	6.1E-09	-	0.1	-	6.1E-10
Chlorobenzene	1.9E-04	3.4E-03	3.4E-03	5.3E-09	1.9E-09	0.02	-	2.6E-07	-
Chloroethane	6.3E-04	-	6.3E-04	9.9E-10	3.5E-10	2.86	-	3.4E-10	-
2-Chlorotoluene	-	1.3E-01	1.3E-01	2.0E-07	7.0E-08	0.02	-	9.8E-06	-
1,2-Dichlorobenzene	2.3E-04	5.8E-02	5.8E-02	9.1E-08	3.2E-08	0.09	-	1.0E-06	-
1,3-Dichlorobenzene	3.2E-03	-	3.2E-03	5.0E-09	1.8E-09	-	-	-	-
1,4-Dichlorobenzene	4.4E-03	-	4.4E-03	6.9E-09	2.4E-09	0.23	0.04	3.0E-08	9.8E-11
1,1-Dichloroethane	2.8E-04	2.1E-04	2.8E-04	4.4E-10	1.6E-10	0.1	0.0057	4.4E-09	8.9E-13
1,2-Dichloroethane	9.7E-06	2.5E-04	2.5E-04	4.0E-10	1.4E-10	-	0.07	-	9.9E-12
cis-1,2-Dichloroethene	1.1E-02	3.8E-02	3.8E-02	6.0E-08	2.1E-08	0.01	-	6.0E-06	-
trans-1,2-Dichloroethene	3.8E-04	3.0E-04	3.8E-04	5.9E-10	2.1E-10	0.02	-	2.9E-08	-
1,2-Dichloropropane	4.5E-06	-	4.5E-06	7.0E-12	2.5E-12	0.0011	0.063	6.4E-09	1.6E-13
Ethylbenzene	1.7E-03	3.1E-01	3.1E-01	4.9E-07	1.7E-07	0.29	-	1.7E-06	-
Freon113	-	5.5E-03	5.5E-03	8.7E-09	3.1E-09	30	-	2.9E-10	-
n-Butylbenzene	-	1.7E-01	1.7E-01	2.7E-07	9.6E-08	0.29	-	9.3E-07	-
sec-Butylbenzene	-	3.1E-02	3.1E-02	4.8E-08	1.7E-08	0.29	-	1.7E-07	-
Isopropylbenzene	-	2.9E-02	2.9E-02	4.5E-08	1.6E-08	0.29	-	1.6E-07	-
p-Isopropyltoluene	-	7.6E-02	7.6E-02	1.2E-07	4.3E-08	2	-	6.0E-08	-
n-Propylbenzene	-	1.7E-01	1.7E-01	2.7E-07	9.6E-08	0.29	-	9.3E-07	-
Tetrachloroethene	-	6.3E-02	6.3E-02	9.9E-08	3.5E-08	0.01	0.021	9.9E-06	7.5E-10
Toluene	5.7E-03	5.0E-01	5.0E-01	7.8E-07	2.8E-07	0.11	-	7.1E-06	-
1,2,4-Trimethylbenzene	-	8.4E-01	8.4E-01	1.3E-06	4.7E-07	2	-	6.6E-07	-
1,3,5-Trimethylbenzene	-	3.1E-01	3.1E-01	4.8E-07	1.7E-07	2	-	2.4E-07	-
Trichloroethene	1.2E-05	2.2E-02	2.2E-02	3.4E-08	1.2E-08	0.01	0.01	3.4E-06	1.2E-10
Vinyl Chloride	6.1E-02	4.5E-04	6.1E-02	9.5E-08	3.4E-08	-	0.27	-	9.2E-09
Total Xylenes	7.3E-03	1.8E+00	1.8E+00	2.8E-06	9.9E-07	2	-	1.4E-06	-

Table 9D
 Characterization of Human Health Risks Due to Inhalation of Vapors Containing Chemicals of Concern
 for Future Maintenance Personnel

4200 Alameda Avenue
 Oakland, California
 (EKI 930040.05)

Compound	Outdoor EPC from groundwater (ug/m ³); (a)	Outdoor EPC from soil and particulates (ug/m ³); (a)	Assumed Outdoor EPC (ug/m ³); (b)	Non-Carcinogen Chronic Daily Intake (mg/kg-day); (c)	Carcinogen Chronic Daily Intake (mg/kg-day); (c)	Non-Carcinogenic Inhalation RfD (mg/kg-day); (d)	Carcinogenic Inhalation SF (mg/kg-day)-1; (e)	Non-Carcinogenic Hazard Index; (f)	Estimated Lifetime Incremental Cancer Risk; (g)
2,4-Dimethylphenol	5.6E-04	-	5.6E-04	8.7E-10	3.1E-10	0.02	-	4.4E-08	-
2-Methylnaphthalene	-	2.3E-07	2.3E-07	3.6E-13	1.3E-13	0.04	-	9.1E-12	-
2-Methylphenol	5.9E-05	-	5.9E-05	9.3E-11	3.3E-11	0.05	-	1.9E-09	-
4-Methylphenol	9.8E-05	-	9.8E-05	1.5E-10	5.5E-11	0.005	-	3.1E-08	-
Naphthalene	8.9E-05	3.3E-01	3.3E-01	5.1E-07	1.8E-07	0.04	-	1.3E-05	-
Phenol	4.6E-05	-	4.6E-05	7.3E-11	2.6E-11	0.6	-	1.2E-10	-
1,2,4-Trichlorobenzene	-	2.6E-02	2.6E-02	4.1E-08	1.5E-08	0.01	-	4.1E-06	-
PCB-1242	-	5.4E-04	5.4E-04	8.5E-10	3.0E-10	0.00002	7.7	4.2E-05	2.3E-09
PCB-1254	-	2.5E-04	2.5E-04	3.9E-10	1.4E-10	0.00002	7.7	1.9E-05	1.1E-09
PCB-1260	5.2E-06	3.6E-04	3.6E-04	5.6E-10	2.0E-10	0.00002	7.7	2.8E-05	1.6E-09
Arsenic	-	-	-	-	-	0.0003	12	-	-
Cadmium	-	-	-	-	-	0.0005	15	-	-
Total Chromium	-	-	-	-	-	1	-	-	-
Nickel	-	-	-	-	-	-	0.91	-	-
Zinc	-	-	-	-	-	0.3	-	-	-
Total Risk Resulting from Inhalation of Vapors Containing Chemicals of Concern:								0.0002	2E-08

Table 9D
Characterization of Human Health Risks Due to Inhalation of Vapors Containing Chemicals of Concern
for Future Maintenance Personnel

4200 Alameda Avenue
Oakland, California
(EKI 930040.05)

Notes:

- (a) The exposure point concentration ("EPC") was calculated based on the volatilization models in the RBCA model (ASTM, 1995).
- (b) The assumed indoor EPC for each compound is the greater of EPC from groundwater or from soil.
- (c) Chronic Daily Intakes ("CDIs") were estimated using methodologies recommended by U.S. EPA or Cal-EPA. Refer to Table 5 for assumptions to calculate CDIs.
- (d) Chronic reference doses ("RfDs") for non-carcinogenic effects were obtained from IRIS or HEAST, in this order of priority. Origin of respective RfDs is included in Tables 2 and 3. Hyphen indicates that RfD is not available for the compound.
- (e) Slope factors ("SFs") for carcinogenic effects were obtained from Cal-EPA's California Cancer Potency Factor Memorandum (November 1994) or IRIS, in this order of priority. Origin of respective SFs is included in Tables 2 and 3. Hyphen indicates that SF is not available for the compound.
- (f) Non-carcinogenic hazard index ("HI") for compound *i* is defined as the CDI_i/RfD_i . The non-carcinogenic HI, summed for all compounds and exposure pathways, assumes that there is a level of exposure (i.e., RfD) below which it is unlikely even for sensitive populations to experience adverse health effects (U.S. EPA, 1989a). If the CDI exceeds this RfD threshold (i.e., HI greater than 1), there may be concern for potential non-carcinogenic effects.
- (g) Estimated lifetime incremental cancer risk for chemical *i* is defined as $CDI_i * SF_i$. The estimated incremental lifetime cancer risks to an individual developing cancer due to COCs is given by the sum of incremental cancer risks for all chemicals and exposure pathways.

Table 10
Summary of Estimated Hypothetical Human Health Risks

4200 Alameda Avenue
Oakland, California
(EKI 930040.05)

Future On-site Population	Exposure Pathway	Estimated Non-Carcinogenic Hazard Index	Estimated Incremental Lifetime Carcinogenic Risk
● Commercial Building Occupants	● Inhalation of vapors from soil or groundwater to indoor air	0.03	9×10^{-6}
Total Estimated Risk for Commercial Building Occupants		0.03	9×10^{-6}
● Maintenance Personnel	● Soil Ingestion	0.01	2×10^{-6}
	● Dermal contact with soil	0.005	3×10^{-7}
	● Dust inhalation of non-volatiles from soil	0.00003	1×10^{-7}
	● Inhalation of vapors from soil or groundwater to outdoor air	0.0002	2×10^{-8}
Total Estimated Risk for Maintenance Personnel		0.02	2×10^{-6}

Notes:

- (a) Refer to Table 8 for individual exposure pathway risk calculations.
(b) Refer to Tables 9A through 9D for individual exposure pathway risk calculations.

Table 11
Exposure Assumptions Used to Characterize Risks
to Future Maintenance Personnel from Lead-Containing Soil

4200 Alameda Avenue
Oakland, California

Parameter	Parameter Assumption (a)	Reference
Exposure Frequency	2 days/year	Best Professional Judgment (b)
Exposure Duration	25 years	EPA (1991); DTSC (1992)
Body Weight	70 kg	EPA (1989, 1991); DTSC (1992)
Exposed Skin Surface	3,160 cm ² (c)	EPA (1992)
Ingestion Rate	240 mg/day	EPA (1991)
Inhalation Rate	20 m ³ /day	EPA (1989, 1991); DTSC (1992)
Dust Concentration	1 mg/m ³	Best Professional Judgment (b)

Notes:

(a) Exposure assumptions are compiled from:

DTSC, July, 1992, *Supplemental Guidance for Human Health Multimedia Risk Assessments for Hazardous Waste Sites and Permitted Facilities*, Cal-EPA, the Office of the Science Advisor.

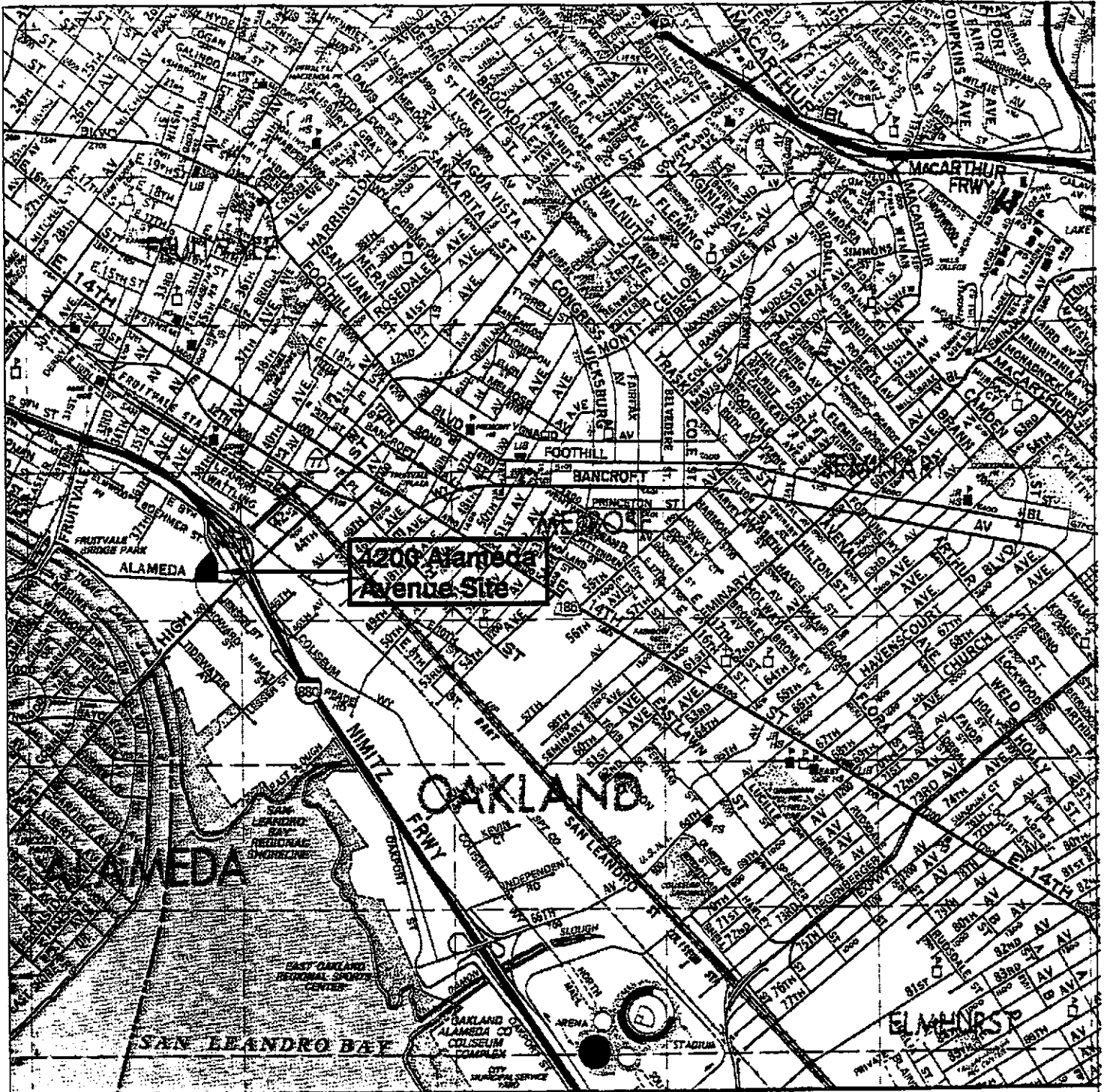
EPA, January 1992, *Dermal Exposure Assessment: Principles and Applications*, Interim Report, Office of Research and Development, EPA/600/8-91/011B.

EPA, March 1991, *Risk Assessment Guidance for Superfund - Volume I: Human Health Evaluation Manual, Supplemental Guidance, "Standard Default Exposure Factors"*, Interim Final, OSWER Directive: 9285.6-03.

EPA, December 1989, *Risk Assessment Guidance for Superfund, Volume I - Human Health Evaluation Manual (Part A)*, OERR, EPA/540/12-89/002.

(b) Refer to Table 5 for exposure assumptions for maintenance personnel.

(c) Exposed skin area assumes that future maintenance personnel wear short-sleeved shirts and long pants, and thus can dermally absorb soil-bound chemicals by direct contact with hands, forearms, and head only.



Base map from: Thomas Guide 1994 Edition.

Erler & Kalinowski, Inc.

Vicinity Map

4200 Alameda Avenue
Oakland, CA

September 1996
EKI 930040.05

Figure 1

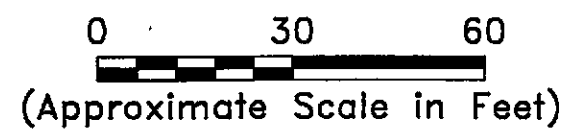
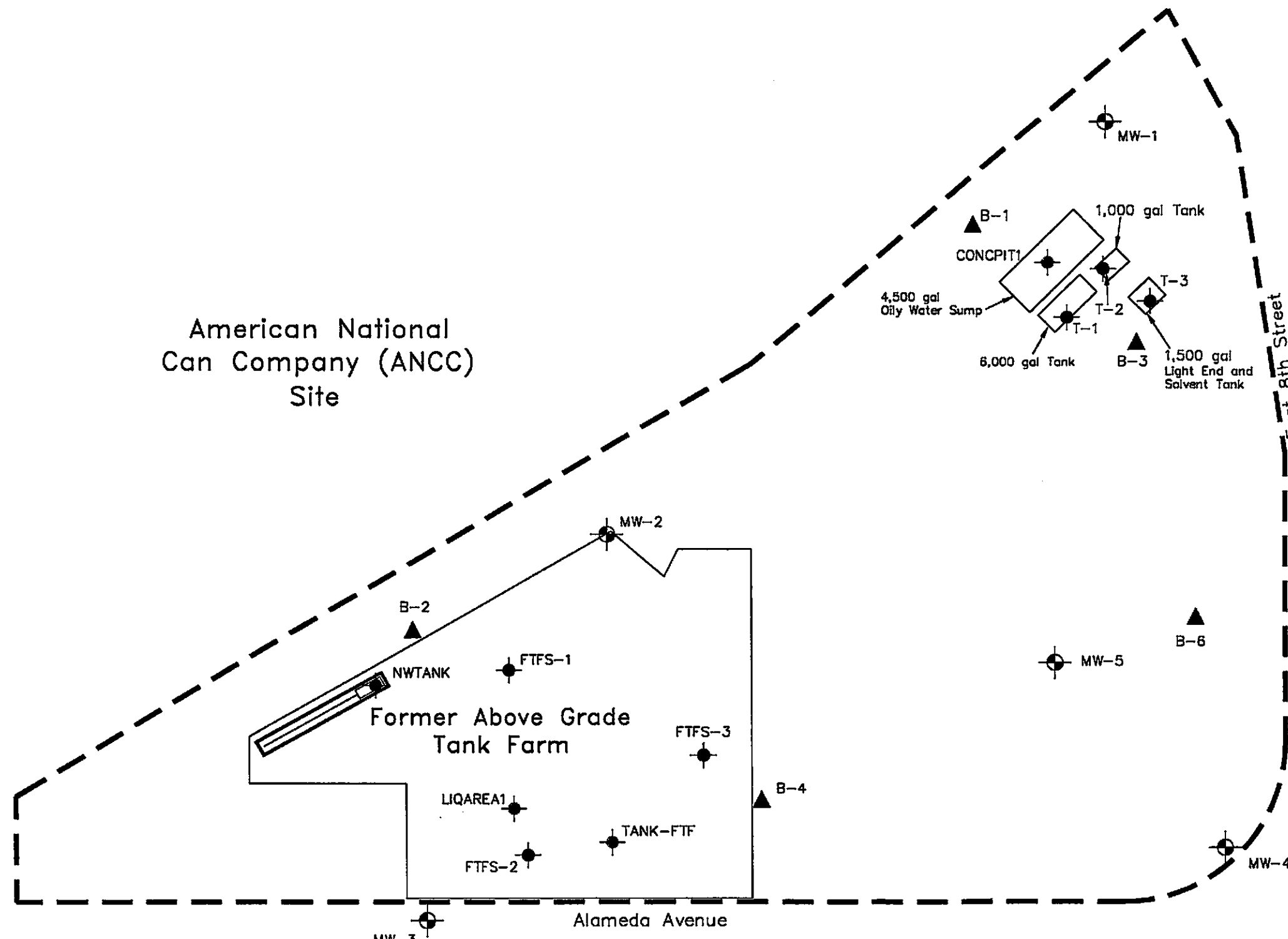


0 1540 3080



(Approximate Scale in Feet)

American National
Can Company (ANCC)
Site



LEGEND

- Site Boundary
- ⊙ Monitoring Well
- ⊙ Shallow Soil Sample
- ▲ Soil Boring
- Approximate Limits of Underground Tank and Sump Excavations

Notes:
1. All locations are approximate.

**Erler &
Kalinowski, Inc.**

Soil and Groundwater
Sampling Locations

4200 Alameda Avenue
Oakland, CA
September 1996
EKI 930040.05
Figure 2

TABLE A-1
TOTAL PETROLEUM HYDROCARBON (TPH) ANALYTICAL RESULTS OF SOIL SAMPLES

4200 Alameda Avenue
Oakland, California
(EKI 930040.05)

Sample ID	Depth (ft, bgs)	Sample Date	TPH (as gasoline) Concentration		TPH (as diesel) Concentration		TPH (as motor oil) Concentration	
			(mg/kg)	Description of Chromatogram Pattern	(mg/kg)	Description of Chromatogram Pattern	(mg/kg)	Description of Chromatogram Pattern
B-1	5.5-6.0	7/12/95	60	Pattern characteristic of weathered gasoline (C ₈ -C ₁₀) and unidentified hydrocarbons greater than C ₁₀	330	Pattern characteristic of diesel	540	Pattern characteristic of motor oil
B-1	7.0-7.5	7/12/95	1,200	Pattern characteristic of weathered gasoline (C ₈ -C ₁₂)	3,100	Unidentifiable pattern of hydrocarbons in C ₉ -C ₂₄ range	4,600	Pattern characteristic of motor oil
B-1	9.5-10.0	7/12/95	890	Pattern characteristic of weathered gasoline (C ₈ -C ₁₀) and unidentified hydrocarbons greater than C ₁₀	2,200	Pattern characteristic of diesel	2,700	Unidentifiable pattern of hydrocarbons in C ₁₆ -C ₃₆ range
B-2	1.0-1.5	7/12/95	<1.0 (a)	-	5.8	Unidentifiable pattern of hydrocarbons in C ₉ -C ₂₄ range	33	Unidentifiable pattern of hydrocarbons in C ₁₆ -C ₃₆ range
B-2	4.5-5.0	7/12/95	140	Unidentifiable pattern of hydrocarbons in C ₈ -C ₁₂ range	1,200	Unidentifiable pattern of hydrocarbons in C ₉ -C ₂₄ range	2,300	Pattern characteristic of motor oil
B-2	7.5-8.0	7/12/95	28	Pattern characteristic of weathered gasoline (C ₈ -C ₁₀) and unidentified hydrocarbons greater than C ₁₀	90	Unidentifiable pattern of hydrocarbons in C ₉ -C ₂₄ range	180	Pattern characteristic of motor oil
B-3	1.5-2.0	7/14/95	4,100	Pattern characteristic of weathered gasoline (C ₈ -C ₁₂)	1,100	Unidentifiable pattern of hydrocarbons in C ₉ -C ₂₄ range	1,600	Pattern characteristic of motor oil
B-3	3.0-3.5	7/14/95	950	Pattern characteristic of weathered gasoline (C ₇ -C ₁₂)	140	Unidentifiable pattern of hydrocarbons in C ₉ -C ₂₄ range	230	Pattern characteristic of motor oil
B-3	8.5-9.0	7/14/95	22	Pattern characteristic of weathered gasoline (C ₇ -C ₁₂)	4,400	Pattern characteristic of diesel	4,800	Pattern characteristic of motor oil

TABLE A-1
TOTAL PETROLEUM HYDROCARBON (TPH) ANALYTICAL RESULTS OF SOIL SAMPLES

4200 Alameda Avenue
Oakland, California
(EKI 930040.05)

Sample ID	Depth (ft, bgs)	Sample Date	TPH (as gasoline) Concentration		TPH (as diesel) Concentration		TPH (as motor oil) Concentration	
			(mg/kg)	Description of Chromatogram Pattern	(mg/kg)	Description of Chromatogram Pattern	(mg/kg)	Description of Chromatogram Pattern
B-4	1.0-1.5	7/13/95	490	Unidentifiable pattern of hydrocarbons in C ₈ -C ₁₂ range	2,000	Unidentifiable pattern of hydrocarbons in C ₉ -C ₂₄ range	5,400	Unidentifiable pattern of hydrocarbons in C ₁₆ -C ₃₆ range
B-4	3.5-4.0	7/13/95	1,100	Unidentifiable pattern of hydrocarbons in C ₈ -C ₁₂ range	3,500	Pattern characteristic of diesel	9,000	Unidentifiable pattern of hydrocarbons in C ₁₆ -C ₃₆ range
B-4	7.5-8.0	7/13/95	58	Pattern characteristic of weathered gasoline (C ₈ -C ₁₂)	200	Pattern characteristic of diesel	1,000	Unidentifiable pattern of hydrocarbons in C ₁₆ -C ₃₆ range
B-6	1.0-1.5	7/13/95	49	Unidentified hydrocarbons less than C ₇	500	Pattern characteristic of diesel	870	Pattern characteristic of motor oil
B-6	3.0-3.5	7/13/95	14	Unidentifiable pattern of hydrocarbons in C ₈ -C ₁₂ range	730	Unidentifiable pattern of hydrocarbons in C ₁₂ -C ₂₄ range	3,900	Unidentifiable pattern of hydrocarbons in C ₁₆ -C ₃₆ range
B-6	7.5-8.0	7/13/95	530	Unidentifiable pattern of hydrocarbons in C ₈ -C ₁₂ range	770	Pattern characteristic of diesel	1,200	Pattern characteristic of motor oil
MW-1	4.0-4.5	7/12/95	92	Pattern characteristic of weathered gasoline (C ₈ -C ₁₂)	200	Pattern characteristic of diesel	300	Pattern characteristic of motor oil
MW-1	4.5-5.0	7/12/95	32	Unidentified hydrocarbons greater than C ₈	310	Unidentifiable pattern of hydrocarbons in C ₉ -C ₂₄ range	460	Pattern characteristic of motor oil
MW-1	6.5-7.0	7/12/95	51	Unidentifiable pattern of hydrocarbons in C ₈ -C ₁₂ range	120	Pattern characteristic of diesel	200	Pattern characteristic of motor oil

TABLE A-1
TOTAL PETROLEUM HYDROCARBON (TPH) ANALYTICAL RESULTS OF SOIL SAMPLES

4200 Alameda Avenue
Oakland, California
(EKI 930040.05)

Sample ID	Depth (ft, bgs)	Sample Date	TPH (as gasoline) Concentration		TPH (as diesel) Concentration		TPH (as motor oil) Concentration	
			(mg/kg)	Description of Chromatogram Pattern	(mg/kg)	Description of Chromatogram Pattern	(mg/kg)	Description of Chromatogram Pattern
MW-2	1.5-2.0	7/13/95	<1.0	-	10	Unidentifiable pattern of hydrocarbons in C ₉ -C ₂₄ range	53	Unidentifiable pattern of hydrocarbons in C ₁₆ -C ₃₆ range
MW-2	3.0-3.5	7/13/95	290	Unidentifiable pattern of hydrocarbons in C ₈ -C ₁₂ range	1100	Unidentifiable pattern of hydrocarbons in C ₉ -C ₂₄ range	2,400	Unidentifiable pattern of hydrocarbons in C ₁₆ -C ₃₆ range
MW-2	6.0-6.5	7/13/95	260	Pattern characteristic of weathered gasoline (C ₈ -C ₁₂)	490	Pattern characteristic of diesel	920	Pattern characteristic of motor oil
MW-3	2.0-2.5	7/13/95	<1.0	-	5.9	Unidentifiable pattern of hydrocarbons in C ₉ -C ₂₄ range	21	Unidentifiable pattern of hydrocarbons in C ₁₆ -C ₃₆ range
MW-3	4.0-4.5	7/13/95	<1.0	-	2.1	Unidentifiable pattern of hydrocarbons in C ₁₄ -C ₂₄ range	<10	-
MW-3	8.0-8.5	7/13/95	<1.0	-	1.5	Unidentifiable pattern of hydrocarbons in C ₁₄ -C ₂₄ range	<10	-
MW-4	2.0-2.5	7/13/95	<1.0	-	1,300	Unidentifiable pattern of hydrocarbons in C ₁₈ -C ₂₄ range	8,600	Unidentifiable pattern of hydrocarbons in C ₁₆ -C ₃₆ range
MW-4	3.0-3.5	7/13/95	2	Pattern characteristic of gasoline	540	Unidentifiable pattern of hydrocarbons in C ₁₂ -C ₂₄ range	3,000	Unidentifiable pattern of hydrocarbons in C ₁₆ -C ₃₆ range
MW-4	8.0-8.5	7/13/95	270	Pattern characteristic of weathered gasoline (C ₈ -C ₁₂)	110	Pattern characteristic of diesel	210	Unidentifiable pattern of hydrocarbons in C ₁₆ -C ₃₆ range
MW-5	2.0-2.5	7/13/95	1,600	Pattern characteristic of weathered gasoline (C ₈ -C ₁₂)	2,300	Pattern characteristic of diesel	5,400	Unidentifiable pattern of hydrocarbons in C ₁₆ -C ₃₆ range
MW-5	3.0-3.5	7/13/95	50	Unidentified hydrocarbons greater than C ₈	480	Unidentifiable pattern of hydrocarbons in C ₈ -C ₂₄ range	1,000	Unidentifiable pattern of hydrocarbons in C ₁₆ -C ₃₆ range
MW-5	8.0-8.5	7/13/95	100	Unidentified hydrocarbons greater than C ₇	2,500	Unidentifiable pattern of hydrocarbons in C ₉ -C ₂₄ range	4,800	Unidentifiable pattern of hydrocarbons in C ₁₆ -C ₃₆ range

TABLE A-1
TOTAL PETROLEUM HYDROCARBON (TPH) ANALYTICAL RESULTS OF SOIL SAMPLES

4200 Alameda Avenue
Oakland, California
(EKI 930040.05)

Sample ID	Depth (ft, bgs)	Sample Date	TPH (as gasoline) Concentration		TPH (as diesel) Concentration		TPH (as motor oil) Concentration	
			(mg/kg)	Description of Chromatogram Pattern	(mg/kg)	Description of Chromatogram Pattern	(mg/kg)	Description of Chromatogram Pattern
T-1	4 - 4.5	4/3/96	4,000	Pattern characteristic of weathered gasoline less than C ₈	7,000	Pattern characteristic of weathered diesel and unidentified hydrocarbons in C ₉ -C ₁₄ range	6,100	Pattern characteristic of motor oil
T-2	5.5 - 6	4/3/96	2,700	Pattern characteristic of weathered gasoline less than C ₈	11,000	Pattern characteristic of diesel and unidentified hydrocarbons in C ₉ -C ₁₄ range	9,800	Pattern characteristic of motor oil
T-3	5.5 - 6	4/3/96	1,700	Pattern characteristic of weathered gasoline less than C ₈	2,400	Unidentifiable pattern of hydrocarbons in C ₉ -C ₂₄ range	2,600	Unidentifiable pattern of hydrocarbons in C ₁₆ -C ₃₆ range
NWTANK	4 - 5	5/3/96	480	Unidentifiable pattern of hydrocarbons in C ₆ -C ₁₂ range	1,800	Unidentifiable pattern of hydrocarbons in C ₉ -C ₂₄ range	5,000	Pattern characteristic of motor oil
CONCPIT1	4 - 5	6/4/96	1,300	Pattern characteristic of gasoline with hydrocarbons greater than C ₇	3,600	Unidentifiable pattern of hydrocarbons in C ₉ -C ₂₄ range	3,100	Pattern characteristic of motor oil
FTFS-1	2 - 3	4/18/96	600	Pattern characteristic of weathered gasoline	1,300	Unidentifiable pattern of hydrocarbons in C ₉ -C ₂₄ range	2,600	Pattern characteristic of motor oil
FTFS-2	2 - 3	4/18/96	89	Pattern characteristic of weathered gasoline	2,700	Pattern characteristic of weathered diesel in C ₁₆ -C ₂₄ range	7,000	Pattern characteristic of weathered diesel in C ₁₆ -C ₄₀ range
FTFS-3	2 - 3	4/18/96	330	Pattern characteristic of weathered gasoline less than C ₈	3,200	Unidentifiable pattern of hydrocarbons in C ₉ -C ₂₄ range	12,000	Pattern characteristic of motor oil
Tank-FTF	2 - 3	5/1/96	190	Unidentifiable pattern of hydrocarbons in C ₆ -C ₁₂ range	3,700	Unidentifiable pattern of hydrocarbons in C ₉ -C ₂₄ range	15,000	Pattern characteristic of motor oil
LiqAreal	2 - 3	5/1/96	150	Pattern characteristic of weathered gasoline in C ₈ -C ₁₂ range	3,800	Pattern characteristic of weathered diesel	9,400	Pattern characteristic of motor oil

Notes:

(a) Less than symbol (" $<$ ") denotes that compound was not present above the detection limit shown.

TABLE A-2
 BENZENE, TOLUENE, ETHYL BENZENE, TOTAL XYLENES (BTEX)
 ANALYTICAL RESULTS OF SOIL SAMPLES

4200 Alameda Avenue
 Oakland, California
 (EKI 930040.05)

Sample ID	Sample Depth (ft, bgs)	Sample Date	BTEX Concentration (mg/kg)			
			Benzene	Toluene	Ethyl Benzene	Total Xylenes
B-1	5.5-6.0	7/12/95	<0.05 (a)	0.16	0.32	1.9
B-1	7.0-7.5	7/12/95	<0.5	0.77	5.2	31
B-1	9.5-10.0	7/12/95	<0.5	0.99	2.7	21
B-2	1.0-1.5	7/12/95	<0.005	<0.005	<0.005	0.007
B-2	4.5-5.0	7/12/95	<0.10	0.26	0.11	0.54
B-2	7.5-8.0	7/12/95	<0.05	0.16	0.11	0.39
B-3	1.5-2.0	7/14/95	<6	<6	16	130
B-3	3.0-3.5	7/14/95	<0.5	11	4.6	33
B-3	8.5-9.0	7/14/95	0.073	0.29	0.22	1.7
B-4	1.0-1.5	7/13/95	<0.25	0.45	1.6	7.8
B-4	3.5-4.0	7/13/95	<0.5	<0.5	5.7	11
B-4	7.5-8.0	7/13/95	<0.050	<0.050	0.16	0.75
B-6	1.0-1.5	7/13/95	<0.025	0.049	0.17	0.32
B-6	3.0-3.5	7/13/95	0.14	0.29	0.1	0.42
B-6	7.5-8.0	7/13/95	<0.25	0.28	0.8	3.8
MW-1	4.0-4.5	7/12/95	<0.10	<0.10	<0.10	0.21
MW-1	4.5-5.0	7/12/95	<0.05	<0.05	<0.05	0.21
MW-1	6.5-7.0	7/12/95	<0.10	<0.10	<0.10	0.26
MW-2	1.5-2.0	7/13/95	<0.005	<0.005	<0.005	<0.005
MW-2	3.0-3.5	7/13/95	<0.25	<0.25	<0.25	0.94
MW-2	6.0-6.5	7/13/95	<0.12	<0.12	1.7	12
MW-3	2.0-2.5	7/13/95	<0.005	<0.005	<0.005	<0.005
MW-3	4.0-4.5	7/13/95	<0.005	<0.005	<0.005	<0.005
MW-3	8.0-8.5	7/13/95	<0.005	<0.005	<0.005	<0.005
MW-4	2.0-2.5	7/13/95	0.018	0.02	0.0078	0.039
MW-4	3.0-3.5	7/13/95	0.058	0.04	0.007	0.062
MW-4	8.0-8.5	7/13/95	<0.12	0.17	0.65	1.9
MW-5	2.0-2.5	7/13/95	<0.5	1.3	5	42
MW-5	3.0-3.5	7/13/95	<0.05	0.13	0.11	0.45
MW-5	8.0-8.5	7/13/95	0.058	0.12	0.29	1.4
T-1	4 - 4.5	4/3/96	<10	86	30	190
T-2	5.5 - 6	4/3/96	<8.0	84	33	190

TABLE A-2
 BENZENE, TOLUENE, ETHYL BENZENE, TOTAL XYLENES (BTEX)
 ANALYTICAL RESULTS OF SOIL SAMPLES

4200 Alameda Avenue
 Oakland, California
 (EKI 930040.05)

Sample ID	Sample Depth (ft, bgs)	Sample Date	BTEX Concentration (mg/kg)			
			Benzene	Toluene	Ethyl Benzene	Total Xylenes
T-3	5.5 - 6	4/3/96	<2.5	14	5.6	58
NWTANK	4 - 5	5/3/96	<0.50	2.0	3.0	5.3
CONCPIT1	4 - 5	6/4/96	1.5	31	12	65
FTFS-1	2 - 3	4/18/96	<0.50	0.8	2.1	11
FTFS-2	2 - 3	4/18/96	<0.12	0.31	0.3	1.4
FTFS-3	2 - 3	4/18/96	0.22	0.46	1.8	7.7
Tank-FTF	2 - 3	5/1/96	0.26	0.52	0.92	4.8
LiqAreal	2 - 3	5/1/96	0.24	0.25	0.85	2.9

Notes:

(a) Less than symbol (" $<$ ") denotes that compound was not present above the detection limit shown.

TABLE A-3
 HALOGENATED VOLATILE ORGANIC COMPOUND ANALYTICAL RESULTS OF SOIL SAMPLES

4200 Alameda Avenue
 Oakland, California
 (EKI 930040.05)

Sample ID	Sample Depth (ft, bgs)	Sample Date	Halogenated Volatile Organic Compound Concentration (mg/kg)															
			Freon 113	1,2-dichloroethane	1,2-dichloropropane	Chlorobenzene	1,2-dichlorobenzene	1,3-dichlorobenzene	1,4-dichlorobenzene	1,1,1-trichloroethane	1,1-dichloroethane	Chloroethane	Tetrachloroethene	Trichloroethene	cis-1,2-dichloroethene	trans-1,2-dichloroethene	p-Isopropyltoluene	
B-1	5.5-6.0	7/12/95	<0.01 (a)	<0.005	<0.005	0.0072	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.01	0.0062	<0.005	<0.005	<0.005	NA (b)
B-1	7.0-7.5	7/12/95	<0.01	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.01	<0.005	<0.005	<0.005	<0.005	<0.005	NA
B-1	9.5-10.0	7/12/95	<0.01	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.01	<0.5	<0.5	<0.5	<0.5	<0.5	NA
B-2	1.0-1.5	7/12/95	<0.01	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.01	<0.005	<0.005	<0.005	<0.005	<0.005	NA
B-2	4.5-5.0	7/12/95	<0.01	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.012	<0.01	<0.005	<0.005	<0.005	<0.005	<0.005	NA
B-2	7.5-8.0	7/12/95	<0.01	<0.005	<0.005	<0.005	0.0058	<0.005	<0.005	<0.005	<0.005	<0.01	<0.005	<0.005	<0.005	<0.005	<0.005	NA
B-3	1.5-2.0	7/14/95	<0.01	<0.5	<0.5	0.5	1.6	<0.5	<0.5	<0.5	<0.5	<0.01	<0.5	<0.5	<0.5	<0.5	<0.5	NA
B-3	3.0-3.5	7/14/95	<0.01	0.018	<0.005	0.014	0.13	<0.005	<0.005	<0.005	<0.005	<0.01	<0.005	<0.005	<0.005	<0.005	<0.005	NA
B-3	8.5-9.0	7/14/95	0.83	<0.2	<0.2	0.34	0.38	<0.2	<0.2	<0.2	<0.2	<0.4	0.95	0.42	0.4	<0.2	<0.2	NA
B-4	1.0-1.5	7/13/95	<0.4	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.4	<0.2	<0.2	<0.2	<0.2	<0.2	NA
B-4	3.5-4.0	7/13/95	<0.01	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.01	<0.5	<0.5	<0.5	<0.5	<0.5	NA
B-4	7.5-8.0	7/13/95	<0.1	<0.05	<0.05	<0.05	0.064	<0.05	<0.05	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.05	<0.05	NA
B-6	1.0-1.5	7/13/95	<0.02	0.028	<0.01	<0.01	0.021	<0.01	<0.01	<0.01	<0.01	<0.02	<0.01	0.12	<0.01	<0.01	<0.01	NA
B-6	3.0-3.5	7/13/95	<0.01	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.01	<0.005	0.0067	0.014	<0.005	<0.005	NA
B-6	7.5-8.0	7/13/95	<0.4	<0.2	<0.2	<0.2	0.25	<0.2	<0.2	<0.2	<0.2	<0.4	<0.2	<0.2	<0.2	<0.2	<0.2	NA
MW-1	4.0-4.5	7/12/95	<0.02	<0.01	<0.01	<0.01	0.019	<0.01	<0.01	<0.01	<0.01	<0.02	<0.01	<0.01	<0.01	<0.01	<0.01	NA
MW-1	4.5-5.0	7/12/95	<0.02	<0.01	<0.01	<0.01	0.011	<0.01	<0.01	<0.01	<0.01	<0.02	<0.01	<0.01	<0.01	<0.01	<0.01	NA
MW-1	6.5-7.0	7/12/95	<0.01	<0.005	<0.005	<0.005	0.0065	<0.005	<0.005	<0.005	<0.005	<0.01	<0.005	<0.005	<0.005	<0.005	<0.005	NA

TABLE A-3
 HALOGENATED VOLATILE ORGANIC COMPOUND ANALYTICAL RESULTS OF SOIL SAMPLES

4200 Alameda Avenue
 Oakland, California
 (EKI 930040.05)

Sample ID	Sample Depth (ft, bgs)	Sample Date	Halogenated Volatile Organic Compound Concentration (mg/kg)													
			Naphthalene	n-Propylbenzene	Toluene	1,2,4-Trichlorobenzene	1,2,4-Trimethylbenzene	1,3,5-Trimethylbenzene	Total Xylenes	n-Butylbenzene	sec-Butylbenzene	2-Chlorotoluene	Ethylbenzene	Isopropylbenzene	Vinyl Chloride	
B-1	5.5-6.0	7/12/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.01
B-1	7.0-7.5	7/12/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<
B-1	9.5-10.0	7/12/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<1
B-2	1.0-1.5	7/12/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.01
B-2	4.5-5.0	7/12/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.01
B-2	7.5-8.0	7/12/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.01
B-3	1.5-2.0	7/14/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<1
B-3	3.0-3.5	7/14/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.01
B-3	8.5-9.0	7/14/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.4
B-4	1.0-1.5	7/13/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.4
B-4	3.5-4.0	7/13/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<1
B-4	7.5-8.0	7/13/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.1
B-6	1.0-1.5	7/13/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.02
B-6	3.0-3.5	7/13/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.01
B-6	7.5-8.0	7/13/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.4
MW-1	4.0-4.5	7/12/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.02
MW-1	4.5-5.0	7/12/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.02
MW-1	6.5-7.0	7/12/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.01

TABLE A-3
 HALOGENATED VOLATILE ORGANIC COMPOUND ANALYTICAL RESULTS OF SOIL SAMPLES

4200 Alameda Avenue
 Oakland, California
 (EKI 930040.05)

Sample ID	Sample Depth (ft, bgs)	Sample Date	Halogenated Volatile Organic Compound Concentration (mg/kg)															
			Freon 113	1,2-dichloroethane	1,2-dichloropropane	Chlorobenzene	1,2-dichlorobenzene	1,3-dichlorobenzene	1,4-dichlorobenzene	1,1,1-trichloroethane	1,1-dichloroethane	Chloroethane	Tetrachloroethene	Trichloroethene	cis-1,2-dichloroethene	trans-1,2-dichloroethene		p-Isopropyltoluene
MW-2	1.5-2.0	7/13/95	<0.01	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.01	<0.005	<0.005	<0.005	<0.005	NA
MW-2	3.0-3.5	7/13/95	<0.4	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.4	<0.2	<0.2	<0.2	<0.2	NA
MW-2	6.0-6.5	7/13/95	<0.2	<0.1	<0.1	<0.1	0.12	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	NA
MW-3	2.0-2.5	7/13/95	<0.01	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.01	<0.005	<0.005	<0.005	<0.005	<0.005	NA
MW-3	4.0-4.5	7/13/95	<0.01	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.01	<0.005	<0.005	<0.005	<0.005	<0.005	NA
MW-3	8.0-8.5	7/13/95	<0.01	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.01	<0.005	<0.005	<0.005	<0.005	<0.005	NA
MW-4	2.0-2.5	7/13/95	<0.01	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.01	<0.005	<0.005	<0.005	<0.005	<0.005	NA
MW-4	3.0-3.5	7/13/95	<0.01	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.01	<0.005	0.0063	0.036	<0.005	<0.005	NA
MW-4	8.0-8.5	7/13/95	<0.2	<0.1	<0.1	<0.1	0.11	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1	NA
MW-5	2.0-2.5	7/13/95	<1.0	<0.5	<0.5	<0.5	1.1	<0.5	<0.5	<0.5	<0.5	<1.0	<0.5	<0.5	<0.5	<0.5	<0.5	NA
MW-5	3.0-3.5	7/13/95	<0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.023	<0.02	<0.01	0.091	0.22	0.033	<0.05	NA
MW-5	8.0-8.5	7/13/95	<0.1	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.05	<0.05	NA
T-1	4 - 4.5	4/3/96	NA	<6.67	<6.67	NA	<6.67	<6.67	<6.67	<6.67	<6.67	<6.67	<6.67	<6.67	<6.67	<6.67	<6.67	8.4
T-2	5.5 - 6	4/3/96	NA	<6.67	<6.67	NA	11	<6.67	<6.67	<6.67	<6.67	<6.67	7.6	<6.67	8.5	<6.67	<6.67	6.8
T-3	5.5 - 6	4/3/96	NA	<4	<4	NA	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
FTFS-1	2 - 3	4/18/96	<0.4	<0.667	<0.667	0.26	0.7	<0.667	<0.667	<0.667	<0.667	<0.667	<0.667	<0.667	<0.667	<0.667	<0.667	1
FTFS-2	2 - 3	4/18/96	<0.1	<0.5	<0.5	<0.05	<0.5	0.058	<0.5	<0.5	<0.5	<0.5	<0.5	0.062	<0.5	<0.5	<0.5	0.5
FTFS-3	2 - 3	4/18/96	<0.4	<0.5	<0.5	<0.2	0.34;0.6	0.68	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.87

TABLE A-3
 HALOGENATED VOLATILE ORGANIC COMPOUND ANALYTICAL RESULTS OF SOIL SAMPLES

4200 Alameda Avenue
 Oakland, California
 (EKI 930040.05)

Sample ID	Sample Depth (ft, bgs)	Sample Date	Halogenated Volatile Organic Compound Concentration (mg/kg)												
			Naphthalene	n-Propylbenzene	Toluene	1,2,4-Trichlorobenzene	1,2,4-Trimethylbenzene	1,3,5-Trimethylbenzene	Total Xylenes	n-Butylbenzene	sec-Butylbenzene	2-Chlorotoluene	Ethylbenzene	Isopropylbenzene	Vinyl Chloride
MW-2	1.5-2.0	7/13/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.01
MW-2	3.0-3.5	7/13/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.4
MW-2	6.0-6.5	7/13/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.2
MW-3	2.0-2.5	7/13/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.01
MW-3	4.0-4.5	7/13/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.01
MW-3	8.0-8.5	7/13/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.01
MW-4	2.0-2.5	7/13/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.05
MW-4	3.0-3.5	7/13/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.049
MW-4	8.0-8.5	7/13/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.2
MW-5	2.0-2.5	7/13/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<1.0
MW-5	3.0-3.5	7/13/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.02
MW-5	8.0-8.5	7/13/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.1
T-1	4 - 4.5	4/3/96	67	17	61	9.6	130	42	160	18	<6.67	<6.67	27	<6.67	<6.67
T-2	5.5 - 6	4/3/96	66	19	98	9.8	140	43	200	19	<6.67	22	36	<6.67	<6.67
T-3	5.5 - 6	4/3/96	29	<4	10	5.8	68	23	56	<4	<4	10	4	<4	<4
FTFS-1	2 - 3	4/18/96	6	1.9	<0.667	<0.667	14	4.7	8.1	1.4	0.96	<0.667	1.6	<0.667	<0.667
FTFS-2	2 - 3	4/18/96	1.1	0.65	<0.5	<0.5	3.4	0.69	2.1	0.58	<0.5	<0.5	0.58	<0.5	<0.5
FTFS-3	2 - 3	4/18/96	4.3	1.6	<0.5	<0.5	9.2	2.5	7.3	1.1	0.66	530	<0.5	<0.5	<0.5

TABLE A-3
 HALOGENATED VOLATILE ORGANIC COMPOUND ANALYTICAL RESULTS OF SOIL SAMPLES

4200 Alameda Avenue
 Oakland, California
 (EKI 930040.05)

Sample ID	Sample Depth (ft, bgs)	Sample Date	Halogenated Volatile Organic Compound Concentration (mg/kg)														
			Freon 113	1,2-dichloroethane	1,2-dichloropropane	Chlorobenzene	1,2-dichlorobenzene	1,3-dichlorobenzene	1,4-dichlorobenzene	1,1,1-trichloroethane	1,1-dichloroethane	Chloroethane	Tetrachloroethene	Trichloroethene	cis-1,2-dichloroethene	trans-1,2-dichloroethene	p-Isopropyltoluene
Tank-FTF	2 - 3	5/1/96	NA	<0.5	<0.5	NA	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
LiqAreal	2 - 3	5/1/96	NA	<0.5	<0.5	NA	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.622
NWTANK	4 - 5	5/3/96	NA	<0.5	<0.5	NA	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	1.9
CONCPIT1	4 - 5	6/4/96	NA	<2	<2	NA	3	<2	<2	<2	<2	<2	6.9	2.4	<2	<2	3.8

TABLE A-3
 HALOGENATED VOLATILE ORGANIC COMPOUND ANALYTICAL RESULTS OF SOIL SAMPLES

4200 Alameda Avenue
 Oakland, California
 (EKI 930040.05)

Sample ID	Sample Depth (ft, bgs)	Sample Date	Halogenated Volatile Organic Compound Concentration (mg/kg)												
			Naphthalene	n-Propylbenzene	Toluene	1,2,4-Trichlorobenzene	1,2,4-Trimethylbenzene	1,3,5-Trimethylbenzene	Total Xylenes	n-Butylbenzene	sec-Butylbenzene	2-Chlorotoluene	Ethylbenzene	Isopropylbenzene	Vinyl Chloride
Tank-FTF	2 - 3	5/1/96	0.51	<0.5	<0.5	<0.5	<0.5	1.4	0.92	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
LiqArea1	2 - 3	5/1/96	0.67	<0.5	<0.5	<0.5	4.5	0.56	1.8	0.64	<0.5	<0.5	<0.5	<0.5	<0.5
NWTANK	4 - 5	5/3/96	1	3.3	0.87	<0.5	1.5	1.2	2	1.8	1.2	530	4.1	1.3	<0.5
CONCPIT1	4 - 5	6/4/96	33	12	45	<2	95	29	110	8.7	3.4	8300	18	3.2	<2

Notes:

- (a) Less than symbol (" $<$ ") denotes that compound was not present above the detection limit shown.
- (b) "NA" indicates that compound was not analyzed.

TABLE A-4
SEMIVOLATILE ORGANIC COMPOUND ANALYTICAL RESULTS OF SOIL SAMPLES

4200 Alameda Avenue
Oakland, California
(EKI 930040.05)

Sample ID	Sample Depth (ft, bgs)	Sample Date	Semivolatile Organic Compound Concentration (mg/kg)									
			1,2-dichlorobenzene	1,3-dichlorobenzene	1,4-dichlorobenzene	2,4-dimethylphenol	2-methylnaphthalene	2-methylphenol	4-methylphenol	Naphthalene	Phenol	
B-1	-	-	-	-	-	-	-	-	-	-	-	-
B-2	-	-	-	-	-	-	-	-	-	-	-	-
B-3	-	-	-	-	-	-	-	-	-	-	-	-
B-4	-	-	-	-	-	-	-	-	-	-	-	-
B-6	-	-	-	-	-	-	-	-	-	-	-	-
MW-1	6.5-7.0	7/12/95	<0.25 (a)	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25
MW-2	6.0-6.5	7/13/95	<1.25	<1.25	<1.25	<1.25	<1.25	<1.25	<1.25	<1.25	<1.25	<1.25
MW-3	8.0-8.5	7/13/95	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25
MW-4	2.0-2.5	7/13/95	<12.5	<12.5	<12.5	<12.5	<12.5	<12.5	<12.5	<12.5	<12.5	<12.5
MW-5	8.0-8.5	7/13/95	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5
T-1	4 - 4.5	4/3/96	<50	<50	<50	<50	76	<50	<50	56	<50	
T-2	5.5 - 6	4/3/96	<12.5	<12.5	<12.5	<12.5	22	<12.5	<12.5	18	<12.5	
T-3	5.5 - 6	4/3/96	<25	<25	<25	<25	51	<25	<25	<25	<25	

TABLE A-4
SEMIVOLATILE ORGANIC COMPOUND ANALYTICAL RESULTS OF SOIL SAMPLES

4200 Alameda Avenue
Oakland, California
(EKI 930040.05)

Sample ID	Sample Depth (ft, bgs)	Sample Date	Semivolatile Organic Compound Concentration (mg/kg)									
			1,2-dichlorobenzene	1,3-dichlorobenzene	1,4-dichlorobenzene	2,4-dimethylphenol	2-methylnaphthalene	2-methylphenol	4-methylphenol	Naphthalene	Phenol	
NWTANK	4 - 5	5/3/96	<12.5	<12.5	<12.5	<12.5	<12.5	<12.5	<12.5	<12.5	<12.5	<12.5
CONCPIT1	4 - 5	6/4/96	<12.5	<12.5	<12.5	<12.5	27	<12.5	<12.5	17	<12.5	<12.5
FTFS-1	2 - 3	4/18/96	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
FTFS-2	2 - 3	4/18/96	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
FTFS-3	2 - 3	4/18/96	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
Tank-FTF	2 - 3	5/1/96	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
LiqAreal	2 - 3	5/1/96	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50

Notes:

(a) Less than symbol (" $<$ ") denotes that compound was not present above the detection limit shown.

TABLE A-5
POLYCHLORINATED BIPHENYL (PCB) ANALYTICAL RESULTS OF SOIL SAMPLES

4200 Alameda Avenue
Oakland, California
(EKI 930040.05)

Sample ID	Sample Depth (ft, bgs)	Sample Date	PCB Arochlor Concentration (mg/kg)		
			PCB-1242	PCB-1254	PCB-1260
B-1	5.5-6.0	7/12/95	<0.02 (a)	<0.02	<0.02
B-1	7.0-7.5	7/12/95	<2.0	<2.0	6.6
B-1	9.5-10.0	7/12/95	<20	<20	27
B-2	1.0-1.5	7/12/95	<0.02	<0.02	<0.02
B-2	4.5-5.0	7/12/95	<0.02	<0.02	<0.02
B-2	7.5-8.0	7/12/95	<0.02	<0.02	0.085
B-3	1.5-2.0	7/14/95	<0.2	<0.2	0.7
B-3	3.0-3.5	7/14/95	<0.02	<0.02	0.021
B-3	8.5-9.0	7/14/95	<0.4	<0.4	2.7
B-4	1.0-1.5	7/13/95	<0.02	<0.02	<0.02
B-4	3.5-4.0	7/13/95	<0.1	<0.1	<0.1
B-4	7.5-8.0	7/13/95	0.045	<0.02	0.058
B-6	1.0-1.5	7/13/95	<0.1	0.36	0.52
B-6	3.0-3.5	7/13/95	<0.02	0.021	0.024
B-6	7.5-8.0	7/13/95	<0.1	<0.1	0.48
MW-1	4.0-4.5	7/12/95	<0.02	<0.02	0.022
MW-1	4.5-5.0	7/12/95	<0.02	<0.02	<0.02
MW-1	6.5-7.0	7/12/95	<0.02	<0.02	<0.02
MW-2	1.5-2.0	7/13/95	<0.02	<0.02	<0.02
MW-2	3.0-3.5	7/13/95	<0.2	<0.2	0.89
MW-2	6.0-6.5	7/13/95	<0.02	<0.02	0.039
MW-3	2.0-2.5	7/13/95	<0.02	<0.02	0.062
MW-3	4.0-4.5	7/13/95	<0.02	<0.02	<0.02
MW-3	8.0-8.5	7/13/95	<0.02	<0.02	<0.02
MW-4	2.0-2.5	7/13/95	<0.02	<0.02	<0.02
MW-4	3.0-3.5	7/13/95	<0.02	<0.02	<0.02
MW-4	8.0-8.5	7/13/95	<0.02	<0.02	<0.02
MW-5	2.0-2.5	7/13/95	<1.0	3.4	<1.0
MW-5	3.0-3.5	7/13/95	<0.02	0.033	<0.02
MW-5	8.0-8.5	7/13/95	<0.1	0.58	<0.1
T-1	4 - 4.5	4/3/96	<100	<100	1,300
T-2	5.5 - 6	4/3/96	<100	<100	740
T-3	5.5 - 6	4/3/96	<100	<100	390

TABLE A-5
POLYCHLORINATED BIPHENYL (PCB) ANALYTICAL RESULTS OF SOIL SAMPLES

4200 Alameda Avenue
Oakland, California
(EKI 930040.05)

Sample ID	Sample Depth (ft, bgs)	Sample Date	PCB Arochlor Concentration (mg/kg)		
			PCB-1242	PCB-1254	PCB-1260
NWTANK	4 - 5	5/3/96	150	<100	110
CONCPIT1	4 - 5	6/4/96	<500	<500	2,400
FTFS-1	2 - 3	4/18/96	<100	<100	280
FTFS-2	2 - 3	4/18/96	<100	<100	260
FTFS-3	2 - 3	4/18/96	<100	<100	620
Tank-FTF	2 - 3	5/1/96	1,100	<200	980
LiqArea1	2 - 3	5/1/96	<200	<200	510

Notes:

- (a) Less than symbol (" $<$ ") denotes that compound was not present above the detection limit shown.

TABLE A-6
METAL ANALYTICAL RESULTS OF SOIL SAMPLES

4200 Alameda Avenue
Oakland, California
(EKI 930040.05)

Sample ID	Sample Depth (ft, bgs)	Sample Date	Metal Concentration (mg/kg)					
			Arsenic	Cadmium	Total Chromium	Lead	Nickel	Zinc
B-1	5.5-6.0	7/12/95	<10 (a)	NA (b)	95	<10	NA	NA
B-1	7.0-7.5	7/12/95	<5	NA	75	5.1	NA	NA
B-1	9.5-10.0	7/12/95	10	NA	55	7.2	NA	NA
B-2	1.0-1.5	7/12/95	<5	NA	20	14	NA	NA
B-2	4.5-5.0	7/12/95	<10	NA	64	<10	NA	NA
B-2	7.5-8.0	7/12/95	<5	NA	50	5.7	NA	NA
B-3	1.5-2.0	7/14/95	13	NA	58	97	NA	NA
B-3	3.0-3.5	7/14/95	<5	NA	84	15	NA	NA
B-3	8.5-9.0	7/14/95	<5	NA	110	6.5	NA	NA
B-4	1.0-1.5	7/13/95	<5	NA	23	<5	NA	NA
B-4	3.5-4.0	7/13/95	<5	NA	54	19	NA	NA
B-4	7.5-8.0	7/13/95	<5	NA	63	<5	NA	NA
B-6	1.0-1.5	7/13/95	<5	NA	61	49	NA	NA
B-6	3.0-3.5	7/13/95	<5	NA	90	24	NA	NA
B-6	7.5-8.0	7/13/95	<5	NA	91	5.3	NA	NA
MW-1	4.0-4.5	7/12/95	<10	NA	94	<10	NA	NA
MW-1	4.5-5.0	7/12/95	<10	NA	82	<10	NA	NA
MW-1	6.5-7.0	7/12/95	<5	NA	77	6.5	NA	NA
MW-2	1.5-2.0	7/13/95	6.8	NA	18	18	NA	NA
MW-2	3.0-3.5	7/13/95	<5	NA	66	38	NA	NA
MW-2	6.0-6.5	7/13/95	<5	NA	76	5.2	NA	NA
MW-3	2.0-2.5	7/13/95	<5	NA	51	31	NA	NA
MW-3	4.0-4.5	7/13/95	<5	NA	56	5.2	NA	NA
MW-3	8.0-8.5	7/13/95	<5	NA	52	<5	NA	NA
MW-4	2.0-2.5	7/13/95	28	NA	25	54	NA	NA
MW-4	3.0-3.5	7/13/95	<5	NA	61	97	NA	NA
MW-4	8.0-8.5	7/13/95	<5	NA	83	5.5	NA	NA
MW-5	2.0-2.5	7/13/95	<5	NA	53	150	NA	NA
MW-5	3.0-3.5	7/13/95	<5	NA	71	<5	NA	NA
MW-5	8.0-8.5	7/13/95	<5	NA	81	26	NA	NA
T-1	4 - 4.5	4/3/96	NA	<0.50	80	90	130	100

TABLE A-6
METAL ANALYTICAL RESULTS OF SOIL SAMPLES

4200 Alameda Avenue
Oakland, California
(EKI 930040.05)

Sample ID	Sample Depth (ft, bgs)	Sample Date	Metal Concentration (mg/kg)					
			Arsenic	Cadmium	Total Chromium	Lead	Nickel	Zinc
T-2	5.5 - 6	4/3/96	NA	1.3	110	230	83	560
T-3	5.5 - 6	4/3/96	NA	0.53	48	100	61	95
NWTANK	4 - 5	5/3/96	NA	<0.50	31	190	38	130
CONCPIT1	4 - 5	6/4/96	NA	<0.50	<0.50	<5.0	<2.5	2.2
FTFS-1	2 - 3	4/18/96	NA	<0.50	57	11	74	31
FTFS-2	2 - 3	4/18/96	NA	<0.50	54	40	74	44
FTFS-3	2 - 3	4/18/96	NA	<0.50	56	18	78	43
Tank-FTF	2 - 3	5/1/96	NA	3.7	60	660	74	410
LiqArea1	2 - 3	5/1/96	NA	<0.50	57	7.8	68	31

Notes:

- (a) Less than symbol (" $<$ ") denotes that compound was not present above the detection limit shown.
- (b) "NA" indicates that compound was not analyzed.

TABLE A-7
TOTAL PETROLEUM HYDROCARBON (TPH) ANALYTICAL RESULTS OF GROUNDWATER SAMPLES

4200 Alameda Avenue
Oakland, California
(EKI 930040.05)

Sample ID	Sample Date	TPH (as gasoline) Concentration (a)		TPH (as diesel) Concentration (a)		TPH (as motor oil) Concentration (a)	
		(ug/L)	Description of Chromatogram Pattern	(ug/L)	Description of Chromatogram Pattern	(ug/L)	Description of Chromatogram Pattern
B-1	7/12/95	24,000	Pattern characteristic of gasoline	150,000	Unidentifiable pattern of hydrocarbons in C ₉ -C ₂₄ range	160,000	Unidentifiable pattern of hydrocarbons in C ₁₆ -C ₃₆ range
B-2	7/12/95	7,000	Pattern characteristic of gasoline	30,000	Unidentifiable pattern of hydrocarbons in C ₉ -C ₂₄ range	67,000	Unidentifiable pattern of hydrocarbons in C ₁₅ -C ₃₆ range
B-4	7/13/95	160,000	Pattern characteristic of gasoline	400,000	Unidentifiable pattern of hydrocarbons in C ₉ -C ₂₄ range	800,000	Unidentifiable pattern of hydrocarbons in C ₁₅ -C ₃₆ range
B-6	7/13/95	3,100	Pattern characteristic of gasoline	330,000	Unidentifiable pattern of hydrocarbons in C ₉ -C ₂₄ range	450,000	Unidentifiable pattern of hydrocarbons in C ₁₅ -C ₃₆ range
MW-1	7/26/95	11,000	Pattern characteristic of gasoline	29,000	Unidentifiable pattern of hydrocarbons in C ₉ -C ₃₀ range	-	-
	6/24/96	7,800	Pattern characteristic of gasoline	39,000	Pattern characteristic of diesel in the C ₉ -C ₁₄ range	-	-
MW-2	7/26/95	3,600	Pattern characteristic of gasoline	22,000	Unidentifiable pattern of hydrocarbons in C ₉ -C ₃₉ range	-	-
	6/24/96	2,700	Pattern characteristic of gasoline	12,000	Unidentifiable pattern of hydrocarbons in C ₉ -C ₃₆ range	-	-
MW-3	7/25/95	200	Pattern characteristic of gasoline and unidentified hydrocarbons greater than C ₈	5,600	Unidentifiable pattern of hydrocarbons in C ₉ -C ₃₈ range	-	-
	7/25/95 dup	180	Pattern characteristic of gasoline and unidentified hydrocarbons greater than C ₁₀	7,000	Unidentifiable pattern of hydrocarbons in C ₉ -C ₃₈ range	-	-
	6/24/96	57	Pattern characteristic of gasoline	4,900	Unidentifiable pattern of hydrocarbons in C ₉ -C ₃₈ range	-	-

TABLE A-7
TOTAL PETROLEUM HYDROCARBON (TPH) ANALYTICAL RESULTS OF GROUNDWATER SAMPLES

4200 Alameda Avenue
Oakland, California
(EKI 930040.05)

Sample ID	Sample Date	TPH (as gasoline) Concentration (a)		TPH (as diesel) Concentration (a)		TPH (as motor oil) Concentration (a)	
		(ug/L)	Description of Chromatogram Pattern	(ug/L)	Description of Chromatogram Pattern	(ug/L)	Description of Chromatogram Pattern
MW-4	7/25/95	1,400	Pattern characteristic of gasoline	24,000	Pattern characteristic of crude oil	-	-
	6/24/96	5,500	Pattern characteristic of gasoline and unidentified hydrocarbons greater than C ₁₁	850,000	Unidentifiable pattern of hydrocarbons in C ₉ -C ₄₀ range	-	-
MW-5	7/26/95	4,800	Pattern characteristic of gasoline and unidentified hydrocarbons greater than C ₁₀	7,500	Unidentifiable pattern of hydrocarbons in C ₉ -C ₃₄ range	-	-
	6/24/96	2,000	Pattern characteristic of gasoline	520,000	Unidentifiable pattern of hydrocarbons in C ₉ -C ₄₀ range	-	-
	6/24/96 dup	2,200	Pattern characteristic of gasoline	360,000	Unidentifiable pattern of hydrocarbons in C ₉ -C ₄₀ range	-	-

Notes:

(a) Immiscible hydrocarbons present in groundwater samples. Measured constituents likely include quantitation of constituents in both immiscible and soluble phases.

TABLE A-8
 BENZENE, TOLUENE, ETHYL BENZENE, TOTAL XYLENES (BTEX)
 ANALYTICAL RESULTS OF GROUNDWATER SAMPLES

4200 Alameda Avenue
 Oakland, California
 (EKI 930040.05)

Sample ID	Sample Date	BTEX Concentration (ug/L); (b)			
		Benzene	Toluene	Ethyl Benzene	Total Xylenes
B-1	7/12/95	320	670	260	1,400
B-2	7/12/95	350	610	110	370
B-4	7/13/95	180	2,500	700	3,400
B-6	7/13/95	380	19	61	130
MW-1	7/26/95	630	1,300	140	870
	6/24/96	530	1,000	130	860
MW-2	7/26/95	36	37	130	660
	6/24/96	19	<10 (a)	170	340
MW-3	7/25/95	6.2	<0.5	<0.5	<0.5
	7/25/95 dup	6.2	<0.5	<0.5	<0.5
	6/24/96	6.3	<0.5	<0.5	<0.5
MW-4	7/25/95	64	12	28	49
	6/24/96	140	13	87	150
MW-5	7/26/95	78	160	56	190
	6/24/96	97	160	48	150
	6/24/96 dup	95	150	50	160

Notes:

- (a) Less than symbol (" $<$ ") denotes that compound was not present above the detection limit shown.
- (b) Immiscible hydrocarbons present in groundwater samples. Measured constituents likely include quantitation of constituents in both immiscible and soluble phases.

TABLE A-9
 HALOGENATED VOLATILE ORGANIC COMPOUND ANALYTICAL RESULTS OF GROUNDWATER SAMPLES

4200 Alameda Avenue
 Oakland, California
 (EKI 930040.05)

Sample ID	Sample Date	Halogenated Volatile Organic Compound Concentration (ug/L); (b)														
		Freon 113	1,2-dichloroethane	1,2-dichloropropane	Chlorobenzene	1,2-dichlorobenzene	1,3-dichlorobenzene	1,4-dichlorobenzene	1,1,1-trichloroethane	1,1-dichloroethane	Chloroethane	Tetrachloroethane	Trichloroethene	cis-1,2-dichloroethene	trans-1,2-dichloroethene	Vinyl Chloride
B-1	7/12/95	<100 (a)	<50	<50	160	300	1,600	2,700	<50	<50	<50; (d)	<50	<50	<50	<50	<100
B-2	7/12/95	<5.0	17	4.9	21	24	<2.5	4.4	<2.5	26	2.5	<2.5	<2.5	8.4	4.1	4.2
B-4	7/13/95	<500	<250	<250	<250	<250	<250	<250	<250	<250	<250	<250	<250	6,600	<250	4,800
B-6	7/13/95	<10	<5	<5	10	15	5.6	13	<5.0	<5	130	<5.0	<5.0	<5.0	<5.0	<10
MW-1	7/26/95	<100	<50	<50	<50	<50	<50	<50	<50	130	<100	<50	<50	2,300	91	3,100
	6/24/96	<50	<50	<50	<50	<50	<50	<50	<50	88	<100	<50	<50	2,800	110	3,100
MW-2	7/26/95	<2.5	<1.3	<1.3	7.3	48	1.5	8	<1.3	4.8	5.8	<1.3	<1.3	<1.3	<1.3	<2.5
	6/24/96	<2.5	<2.5	<2.5	7.4	88	4.0	18	<2.5	15	6.2	<2.5	3.8	20	<2.5	4.1
MW-3	7/25/95	<0.5	<0.5	<0.5	<0.5	1.7	<0.5	<0.5	<0.5	<0.5	1.2	<0.5	<0.5	<0.5	<0.5	<0.5
	7/25/95 du	<0.5	<0.5	<0.5	<0.5	1.6	<0.5	<0.5	<0.5	<0.5	1.1	<0.5	<0.5	<0.5	<0.5	<0.5
	6/24/96	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	1.0	<0.5	<0.5	<0.5	<0.5	<0.5
MW-4	7/25/95	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	2,000	50	3,500
	6/24/96	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	3,100	<100	4,200
MW-5	7/26/95	<200	<100	<100	<100	<100	<100	<100	<100	160	<200	<100	<100	3,700	130	5,200
	6/24/96	<100	<100	<100	<100	<100	<100	<100	<100	150	<100	<100	<100	2,800	160	4,200
	6/24/96 du	<100	<100	<100	<100	<100	<100	<100	<100	140	<100	<100	<100	2,800	170	4,100

TABLE A-9
HALOGENATED VOLATILE ORGANIC COMPOUND ANALYTICAL RESULTS OF GROUNDWATER SAMPLES

4200 Alameda Avenue
Oakland, California
(EKI 930040.05)

Notes:

- (a) Less than symbol (" $<$ ") denotes that compound was not present above the detection limit shown.
- (b) Immiscible hydrocarbons present in groundwater samples. Measured constituents likely include quantitation of constituents in both immiscible and soluble phases.

TABLE A-10
SEMIVOLATILE ORGANIC COMPOUND ANALYTICAL RESULTS OF GROUNDWATER SAMPLES

4200 Alameda Avenue
Oakland, California
(EKI 930040.05)

Sample ID	Sample Date	Semivolatile Organic Compound Concentration (ug/L); (c)								
		1,2-dichlorobenzene	1,3-dichlorobenzene	1,4-dichlorobenzene	2,4-dimethylphenol	2-methylnaphthalene	2-methylphenol	4-methylphenol	Naphthalene	Phenol
B-1	7/12/95	NA (a)	NA	NA	NA	NA	NA	NA	NA	NA
B-2	7/12/95	NA	NA	NA	NA	NA	NA	NA	NA	NA
B-4	7/13/95	NA	NA	NA	NA	NA	NA	NA	NA	NA
B-6	7/13/95	NA	NA	NA	NA	NA	NA	NA	NA	NA
MW-1	7/26/95	<100 (b)	<100	<100	3,400	<100	330	550	160	230
	6/24/96	NA	NA	NA	NA	NA	NA	NA	NA	NA
MW-2	7/26/95	30	<5	5.4	<5	11	<5	9.9	63	<5
	6/24/96	NA	NA	NA	NA	NA	NA	NA	NA	NA
MW-3	7/25/95	<5	<5	<5	<5	<5	<5	<5	<5	<5
	7/25/95 dup	<5	<5	<5	<5	<5	<5	<5	<5	<5
	6/24/96	NA	NA	NA	NA	NA	NA	NA	NA	NA
MW-4	7/25/95	<50	<50	<50	<50	<50	<50	<50	<50	<50
	6/24/96	NA	NA	NA	NA	NA	NA	NA	NA	NA
MW-5	7/26/95	<250	<250	<250	<250	<250	<250	<250	<250	<250
	6/24/96	NA	NA	NA	NA	NA	NA	NA	NA	NA
	6/24/96 dup	NA	NA	NA	NA	NA	NA	NA	NA	NA

Notes:

(a) "NA" indicates that compound was not analyzed.

(b) Less than symbol (" $<$ ") denotes that compound was not present above the detection limit shown.

(c) Immiscible hydrocarbons present in groundwater samples. Measured constituents likely include quantitation of constituents in both immiscible and soluble phases.

TABLE A-11
 POLYCHLORINATED BIPHENYL (PCB) ANALYTICAL RESULTS OF GROUNDWATER SAMPLES

4200 Alameda Avenue
 Oakland, California
 (EKI 930040.05)

Sample ID	Sample Date	PCB Arochlor Concentration (ug/L); (c)		
		PCB-1242	PCB-1254	PCB-1260
B-1	7/12/95	NA (a)	NA	NA
B-2	7/12/95	NA	NA	NA
B-4	7/13/95	NA	NA	NA
B-6	7/13/95	NA	NA	NA
MW-1	7/26/95	<25 (b)	<25	<25
MW-2	7/26/95	<2.5	<2.5	<2.5
MW-3	7/25/95	<2.5	<2.5	<2.5
MW3 DUP	7/25/95	<0.5	<0.5	<0.5
MW-4	7/25/95	<2.5	<2.5	<2.5
MW-5	7/26/95	<50	<10	31

Notes:

- (a) "NA" indicates that compound was not analyzed.
- (b) Less than symbol ("<") denotes that compound was not present above the detection limit shown.
- (c) Immiscible hydrocarbons present in groundwater samples. Measured constituents likely include quantitation of constituents in both immiscible and soluble phases.

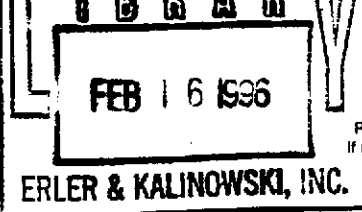
TABLE A-12
DISSOLVED ARSENIC, TOTAL CHROMIUM, AND LEAD
ANALYTICAL RESULTS OF GROUNDWATER SAMPLES

4200 Alameda Avenue
Oakland, California
(EKI 930040.05)

Sample ID	Sample Date	Dissolved Metal Concentration (mg/L); (c)		
		Arsenic	Total Chromium	Lead
B-1	7/12/95	0.088	0.089	0.008
B-2	7/12/95	0.026	<0.020	<0.0050
B-4	7/13/95	<5.0 (a)	<5.0	<5.0
B-6	7/13/95	<5.0	<0.5	6.6
MW-1	7/26/95	0.093	<0.020	<0.0050
	6/24/96	NA (b)	NA	NA
MW-2	7/26/95	0.025	<0.010	<0.0050
	6/24/96	NA	NA	NA
MW-3	7/25/95	0.017	0.021	<0.0050
	7/25/95 dup	0.013	0.024	0.005
	6/24/96	NA	NA	NA
MW-4	7/25/95	0.028	<0.010	<0.0050
	6/24/96	NA	NA	NA
MW-5	7/26/95	0.032	<0.020	0.12
	6/24/96	NA	NA	NA
	6/24/96 dup	NA	NA	NA

Notes:

- (a) Less than symbol (" $<$ ") denotes that compound was not present above the detection limit shown.
- (b) "NA" indicates that compound was not analyzed.
- (c) Analyses were performed on groundwater samples filtered in the field.



Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites¹

This standard is issued under the fixed designation E 1739; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This is a guide to risk-based corrective action (RBCA), which is a consistent decision-making process for the assessment and response to a petroleum release, based on the protection of human health and the environment. Sites with petroleum release vary greatly in terms of complexity, physical and chemical characteristics, and in the risk that they may pose to human health and the environment. The RBCA process recognizes this diversity, and uses a tiered approach where corrective action activities are tailored to site-specific conditions and risks. While the RBCA process is not limited to a particular class of compounds, this guide emphasizes the application of RBCA to petroleum product releases through the use of the examples. Ecological risk assessment, as discussed in this guide, is a qualitative evaluation of the actual or potential impacts to environmental (nonhuman) receptors. *There may be circumstances under which a more detailed ecological risk assessment is necessary* (see Ref (1)).²

1.2 The decision process described in this guide integrates risk and exposure assessment practices, as suggested by the United States Environmental Protection Agency (USEPA), with site assessment activities and remedial measure selection to ensure that the chosen action is protective of human health and the environment. The following general sequence of events is prescribed in RBCA, once the process is triggered by the suspicion or confirmation of petroleum release:

1.2.1 Performance of a site assessment;

1.2.2 Classification of the site by the urgency of initial response;

1.2.3 Implementation of an initial response action appropriate for the selected site classification;

1.2.4 Comparison of concentrations of chemical(s) of concern at the site with Tier 1 Risk Based Screening Levels (RBSLs) given in a look-up table;

1.2.5 Deciding whether further tier evaluation is warranted, if implementation of interim remedial action is warranted or if RBSLs may be applied as remediation target levels;

1.2.6 Collection of additional site-specific information as necessary, if further tier evaluation is warranted;

1.2.7 Development of site-specific target levels (SSTLs) and point(s) of compliance (Tier 2 evaluation);

1.2.8 Comparison of the concentrations of chemical(s) of concern at the site with the Tier 2 evaluation SSTL at the determined point(s) of compliance or source area(s);

1.2.9 Deciding whether further tier evaluation is warranted, if implementation of interim remedial action is warranted, or if Tier 2 SSTLs may be applied as remediation target levels;

1.2.10 Collection of additional site-specific information as necessary, if further tier evaluation is warranted;

1.2.11 Development of SSTL and point(s) of compliance (Tier 3 evaluation);

1.2.12 Comparison of the concentrations of chemical(s) of concern at the site at the determined point(s) of compliance or source area(s) with the Tier 3 evaluation SSTL; and

1.2.13 Development of a remedial action plan to achieve the SSTL, as applicable.

1.3 The guide is organized as follows:

1.3.1 Section 2 lists referenced documents,

1.3.2 Section 3 defines terminology used in this guide,

1.3.3 Section 4 describes the significance and use of this guide,

1.3.4 Section 5 is a summary of the tiered approach,

1.3.5 Section 6 presents the RBCA procedures in a step-by-step process,

1.3.6 Appendix X1 details physical/chemical and toxicological characteristics of petroleum products,

1.3.7 Appendix X2 discusses the derivation of a Tier 1 RBSL Look-Up Table and provides an example,

1.3.8 Appendix X3 describes the uses of predictive modeling relative to the RBCA process,

1.3.9 Appendix X4 discusses considerations for institutional controls, and

1.3.10 Appendix X5 provides examples of RBCA applications.

1.4 This guide describes an approach for RBCA. It is intended to compliment but not supersede federal, state, and local regulations. Federal, state, or local agency approval may be required to implement the processes outlined in this guide.

1.5 The values stated in either inch-pound or SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

¹ This guide is under the jurisdiction of ASTM Committee E-50 on Environmental Assessment and is the direct responsibility of Subcommittee E50.01 on Storage Tanks.

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² The boldface numbers in parentheses refer to the list of references at the end of this guide.

2. Referenced Documents

2.1 *ASTM Standard:*

E 1599 Guide for Corrective Action for Petroleum Releases³

2.2 NFPA Standard:

NFPA 329 Handling Underground Releases of Flammable and Combustible Liquids⁴

3. Terminology

3.1 Descriptions of Terms Specific to This Standard:

3.1.1 *active remediation*—actions taken to reduce the concentrations of chemical(s) of concern. Active remediation could be implemented when the no-further-action and passive remediation courses of action are not appropriate.

3.1.2 *attenuation*—the reduction in concentrations of chemical(s) of concern in the environment with distance and time due to processes such as diffusion, dispersion, absorption, chemical degradation, biodegradation, and so forth.

3.1.3 *chemical(s) of concern*—specific constituents that are identified for evaluation in the risk assessment process.

3.1.4 *corrective action*—the sequence of actions that include site assessment, interim remedial action, remedial action, operation and maintenance of equipment, monitoring of progress, and termination of the remedial action.

3.1.5 *direct exposure pathways*—an exposure pathway where the point of exposure is at the source, without a release to any other medium.

3.1.6 *ecological assessment*—a qualitative appraisal of the actual or potential effects of chemical(s) of concern on plants and animals other than people and domestic species.

3.1.7 *engineering controls*—modifications to a site or facility (for example, slurry walls, capping, and point of use water treatment) to reduce or eliminate the potential for exposure to a chemical(s) of concern.

3.1.8 *exposure*—contact of an organism with chemical(s) of concern at the exchange boundaries (for example, skin, lungs, and liver) and available for absorption.

3.1.9 *exposure assessment*—the determination or estimation (qualitative or quantitative) of the magnitude, frequency, duration, and route of exposure.

3.1.10 *exposure pathway*—the course a chemical(s) of concern takes from the source area(s) to an exposed organism. An exposure pathway describes a unique mechanism by which an individual or population is exposed to a chemical(s) of concern originating from a site. Each exposure pathway includes a source or release from a source, a point of exposure, and an exposure route. If the exposure point differs from the source, a transport/exposure medium (for example, air) or media also is included.

3.1.11 *exposure route*—the manner in which a chemical(s) of concern comes in contact with an organism (for example, ingestion, inhalation, and dermal contact).

3.1.12 *facility*—the property containing the source of the chemical(s) of concern where a release has occurred.

3.1.13 *hazard index*—the sum of two or more hazard quotients for multiple chemical(s) of concern or multiple exposure pathways, or both.

3.1.14 *hazard quotients*—the ratio of the level of exposure of a chemical(s) of concern over a specified time period to a

reference dose for that chemical(s) of concern derived for a similar exposure period.

3.1.15 *incremental carcinogenic risk levels*—the potential for incremental carcinogenic human health effects due to exposure to the chemical(s) of concern.

3.1.16 *indirect exposure pathways*—an exposure pathway with at least one intermediate release to any media between the source and the point(s) of exposure (for example, chemicals of concern from soil through ground water to the point(s) of exposure).

3.1.17 *institutional controls*—the restriction on use or access (for example, fences, deed restrictions, restrictive zoning) to a site or facility to eliminate or minimize potential exposure to a chemical(s) of concern.

3.1.18 *interim remedial action*—the course of action to mitigate fire and safety hazards and to prevent further migration of hydrocarbons in their vapor, dissolved, or liquid phase.

3.1.19 *maximum contaminant level (MCL)*—a standard for drinking water established by USEPA under the Safe Drinking Water Act, which is the maximum permissible level of chemical(s) of concern in water that is delivered to any user of a public water supply.

3.1.20 *Monte Carlo simulation*—a procedure to estimate the value and uncertainty of the result of a calculation when the result depends on a number of factors, each of which is also uncertain.

3.1.21 *natural biodegradation*—the reduction in concentration of chemical(s) of concern through naturally occurring microbial activity.

3.1.22 *petroleum*—including crude oil or any fraction thereof that is liquid at standard conditions of temperature and pressure (60°F and 14.7 lb/in.² absolute; (15.5°C and 10 335.6 kg/m²)). The term includes petroleum-based substances comprised of a complex blend of hydrocarbons derived from crude oil through processes of separation, conversion, upgrading, and finishing, such as motor fuels, jet oils, lubricants, petroleum solvents, and used oils.

3.1.23 *point(s) of compliance*—a location(s) selected between the source area(s) and the potential point(s) of exposure where concentrations of chemical(s) of concern must be at or below the determined target levels in media (for example, ground water, soil, or air).

3.1.24 *point(s) of exposure*—the point(s) at which an individual or population may come in contact with a chemical(s) of concern originating from a site.

3.1.25 *qualitative risk analysis*—a nonnumeric evaluation of a site to determine potential exposure pathways and receptors based on known or readily available information.

3.1.26 *reasonable maximum exposure (RME)*—the highest exposure that is reasonably expected to occur at a site. RMEs are estimated for individual pathways or a combination of exposure pathways.

3.1.27 *reasonable potential exposure scenario*—a situation with a credible chance of occurrence where a receptor may become directly or indirectly exposed to the chemical(s) of concern without considering extreme or essentially impossible circumstances.

3.1.28 *reasonably anticipated future use*—future use of a site or facility that can be predicted with a high degree of

³ Annual Book of ASTM Standards, Vol 11.04.

⁴ Available from National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269.

certainty given current use, local government planning, and zoning.

3.1.29 *receptors*—persons, structures, utilities, surface waters, and water supply wells that are or may be adversely affected by a release.

3.1.30 *reference dose*—a preferred toxicity value for evaluating potential noncarcinogenic effects in humans resulting from exposure to a chemical(s) of concern.

3.1.31 *remediation/remedial action*—activities conducted to protect human health, safety, and the environment. These activities include evaluating risk, making no-further-action determinations, monitoring institutional controls, engineering controls, and designing and operating cleanup equipment.

3.1.32 *risk assessment*—an analysis of the potential for adverse health effects caused by a chemical(s) of concern from a site to determine the need for remedial action or the development of target levels where remedial action is required.

3.1.33 *risk reduction*—the lowering or elimination of the level of risk posed to human health or the environment through interim remedial action, remedial action, or institutional or engineering controls.

3.1.34 *risk-based screening level/screening levels (RBSLs)*—risk-based site-specific corrective action target levels for chemical(s) of concern developed under the Tier 1 evaluation.

3.1.35 *site*—the area(s) defined by the extent of migration of the chemical(s) of concern.

3.1.36 *site assessment*—an evaluation of subsurface geology, hydrology, and surface characteristics to determine if a release has occurred, the levels of the chemical(s) of concern, and the extent of the migration of the chemical(s) of concern. The site assessment collects data on ground water quality and potential receptors and generates information to support remedial action decisions.

3.1.37 *site classification*—a qualitative evaluation of a site based on known or readily available information to identify the need for interim remedial actions and further information gathering. Site classification is intended to specifically prioritize sites.

3.1.38 *site-specific target level (SSTL)*—risk-based remedial action target level for chemical(s) of concern developed for a particular site under the Tier 2 and Tier 3 evaluations.

3.1.39 *site-specific*—activities, information, and data unique to a particular site.

3.1.40 *source area(s)*—either the location of liquid hydrocarbons or the location of highest soil and ground water concentrations of the chemical(s) of concern.

3.1.41 *target levels*—numeric values or other performance criteria that are protective of human health, safety, and the environment.

3.1.42 *Tier 1 evaluation*—a risk-based analysis to develop non-site-specific values for direct and indirect exposure pathways utilizing conservative exposure factors and fate and transport for potential pathways and various property use categories (for example, residential, commercial, and industrial uses). Values established under Tier 1 will apply to all sites that fall into a particular category.

3.1.43 *Tier 2 evaluation*—a risk-based analysis applying the direct exposure values established under a Tier 1 evaluation

at the point(s) of exposure developed for a specific site and development of values for potential indirect exposure pathways at the point(s) of exposure based on site-specific conditions.

3.1.44 *Tier 3 evaluation*—a risk-based analysis to develop values for potential direct and indirect exposure pathways at the point(s) of exposure based on site-specific conditions.

3.1.45 *user*—an individual or group involved in the RBCA process including owners, operators, regulators, underground storage tank (UST) fund managers, attorneys, consultants, legislators, and so forth.

4. Significance and Use

4.1 The allocation of limited resources (for example, time, money, regulatory oversight, qualified professionals) to any one petroleum release site necessarily influences corrective action decisions at other sites. This has spurred the search for innovative approaches to corrective action decision making, which still ensures that human health and the environment are protected.

4.2 The RBCA process presented in this guide is a consistent, streamlined decision process for selecting corrective actions at petroleum release sites. Advantages of the RBCA approach are as follows:

4.2.1 Decisions are based on reducing the risk of adverse human or environmental impacts,

4.2.2 Site assessment activities are focussed on collecting only that information that is necessary to making risk-based corrective action decisions,

4.2.3 Limited resources are focussed on those sites that pose the greatest risk to human health and the environment at any time,

4.2.4 The remedial action achieves an acceptable degree of exposure and risk reduction,

4.2.5 Compliance can be evaluated relative to site-specific standards applied at site-specific point(s) of compliance,

4.2.6 Higher quality, and in some cases faster, cleanups than are currently realized, and

4.2.7 A documentation and demonstration that the remedial action is protective of human health, safety, and the environment.

4.3 Risk assessment is a developing science. The scientific approach used to develop the RBSL and SSTL may vary by state and user due to regulatory requirements and the use of alternative scientifically based methods.

4.4 Activities described in this guide should be conducted by a person familiar with current risk and exposure assessment methodologies.

4.5 In order to properly apply the RBCA process, the user should avoid the following:

4.5.1 Use of Tier 1 RBSLs as mandated remediation standards rather than screening levels,

4.5.2 Restriction of the RBCA process to Tier 1 evaluation only and not allowing Tier 2 or Tier 3 analyses,

4.5.3 Placing arbitrary time constraints on the corrective action process; for example, requiring that Tiers 1, 2, and 3 be completed within 30-day time periods that do not reflect the actual urgency of and risks posed by the site,

4.5.4 Use of the RBCA process only when active remediation is not technically feasible, rather than a process that is applicable during all phases of corrective action,

4.5.5 Requiring the user to achieve technology-based remedial limits (for example, asymptotic levels) prior to requesting the approval for the RBSL or SSTL,

4.5.6 The use of predictive modelling that is not supported by available data or knowledge of site conditions,

4.5.7 Dictating that corrective action goals can only be achieved through source removal and treatment actions, thereby restricting the use of exposure reduction options, such as engineering and institutional controls,

4.5.8 The use of unjustified or inappropriate exposure factors,

4.5.9 The use of unjustified or inappropriate toxicity parameters,

4.5.10 Neglecting aesthetic and other criteria when determining RBSLs or SSTLs,

4.5.11 Not considering the effects of additivity when screening multiple chemicals,

4.5.12 Not evaluating options for engineering or institutional controls, exposure point(s), compliance point(s), and carcinogenic risk levels before submitting remedial action plans,

4.5.13 Not maintaining engineering or institutional controls, and

4.5.14 Requiring continuing monitoring or remedial action at sites that have achieved the RBSL or SSTL.

5. Tiered Approach to Risk-Based Corrective Action (RBCA) at Petroleum Release Sites

5.1 RBCA is the integration of site assessment, remedial action selection, and monitoring with USEPA-recommended risk and exposure assessment practices. This creates a process by which corrective action decisions are made in a consistent manner that is protective of human health and the environment.

5.2 The RBCA process is implemented in a tiered approach, involving increasingly sophisticated levels of data collection and analysis. The assumptions of earlier tiers are replaced with site-specific data and information. Upon evaluation of each tier, the user reviews the results and recommendations and decides whether more site-specific analysis is warranted.

5.3 *Site Assessment*—The user is required to identify the sources of the chemical(s) of concern, obvious environmental impacts (if any), any potentially impacted humans and environmental receptors (for example, workers, residents, water bodies, and so forth), and potentially significant transport pathways (for example, ground water flow, utilities, atmospheric dispersion, and so forth). The site assessment will also include information collected from historical records and a visual inspection of the site.

5.4 *Site Classification*—Sites are classified by the urgency of need for initial response action, based on information collected during the site assessment. Associated with site classifications are initial response actions that are to be implemented simultaneously with the RBCA process. Sites should be reclassified as actions are taken to resolve concerns or as better information becomes available.

5.5 *Tier 1 Evaluation*—A look-up table containing screening level concentrations is used to determine whether site conditions satisfy the criteria for a quick regulatory closure or warrant a more site-specific evaluation. Ground

water, soil, and vapor concentrations may be presented in this table for a range of site descriptions and types of petroleum products (for example, gasoline, crude oil, and so forth). The look-up table of RBSL is developed in Tier 1 or, if a look-up table has been previously developed and determined to be applicable to the site by the user, then the existing RBSLs are used in the Tier 1 process. Tier 1 RBSLs are typically derived for standard exposure scenarios using current RME and toxicological parameters as recommended by the USEPA. These values may change as new methodologies and parameters are developed. Tier 1 RBSLs may be presented as a range of values, corresponding to a range of risks or property uses.

5.6 *Tier 2 Evaluation*—Tier 2 provides the user with an option to determine SSTLs and point(s) of compliance. It is important to note that both Tier 1 RBSL and Tier 2 SSTLs are based on achieving similar levels of protection of human health and the environment (for example, 10^{-4} to 10^{-6} risk levels). However, in Tier 2 the non-site-specific assumptions and point(s) of exposure used in Tier 1 are replaced with site-specific data and information. Additional site-assessment data may be needed. For example, the Tier 2 SSTL can be derived from the same equations used to calculate the Tier 1 RBSL, except that site-specific parameters are used in the calculations. The additional site-specific data may support alternate fate and transport analysis. At other sites, the Tier 2 analysis may involve applying Tier 1 RBSLs at more probable point(s) of exposure. Tier 2 SSTLs are consistent with USEPA-recommended practices.

5.7 *Tier 3 Evaluation*—Tier 3 provides the user with an option to determine SSTLs for both direct and indirect pathways using site-specific parameters and point(s) of exposure and compliance when it is judged that Tier 2 SSTLs should not be used as target levels. Tier 3, in general, can be a substantial incremental effort relative to Tiers 1 and 2, as the evaluation is much more complex and may include additional site assessment, probabilistic evaluations, and sophisticated chemical fate/transport models.

5.8 *Remedial Action*—If the concentrations of chemical(s) of concern at a site are above the RBSL or SSTL at the point(s) of compliance or source area, or both, and the user determines that the RBSL or SSTL should be used as remedial action target levels, the user develops a remedial action plan in order to reduce the potential for adverse impacts. The user may use remediation processes to reduce concentrations of the chemical(s) of concern to levels below or equal to the target levels or to achieve exposure reduction (or elimination) through institutional controls discussed in Appendix X4, or through the use of engineering controls, such as capping and hydraulic control.

6. Risk-Based Corrective Action (RBCA) Procedures

6.1 The sequence of principal tasks and decisions associated with the RBCA process are outlined on the flowchart shown in Fig. 1. Each of these actions and decisions is discussed as follows.

6.2 *Site Assessment*—Gather the information necessary for site classification, initial response action, comparison to the RBSL, and determining the SSTL. Site assessment may be conducted in accordance with Guide E 1599. Each successive tier will require additional site-specific data and information that must be collected as the RBCA process

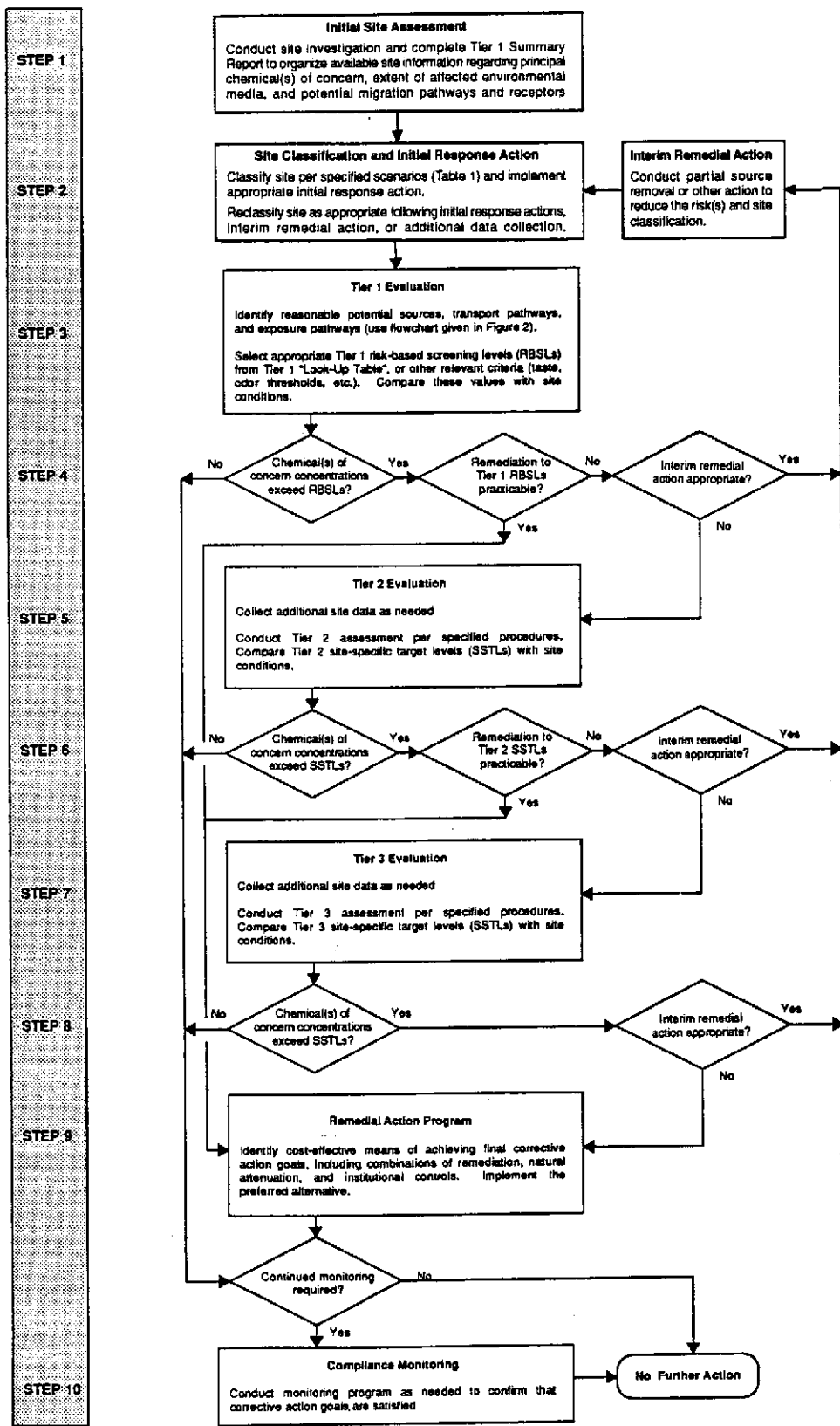


FIG. 1 Risk-Based Corrective Action Process Flowchart

proceeds. The user may generate site-specific data and information or estimate reasonable values for key physical characteristics using soil survey data and other readily available information. The site characterization data should be summarized in a clear and concise format.

6.2.1 The site assessment information for Tier 1 evaluation may include the following:

6.2.1.1 A review of historical records of site activities and past releases;

6.2.1.2 Identification of chemical(s) of concern;

6.2.1.3 Location of major sources of the chemical(s) of concern;

6.2.1.4 Location of maximum concentrations of chemical(s) of concern in soil and ground water;

6.2.1.5 Location of humans and the environmental receptors that could be impacted (point(s) of exposure);

6.2.1.6 Identification of potential significant transport and exposure pathways (ground water transport, vapor migration through soils and utilities, and so forth);

6.2.1.7 Determination of current or potential future use of the site and surrounding land, ground water, surface water, and sensitive habitats;

6.2.1.8 Determination of regional hydrogeologic and geologic characteristics (for example, depth to ground water, aquifer thickness, flow direction, gradient, description of confining units, and ground water quality); and

6.2.1.9 A qualitative evaluation of impacts to environmental receptors.

6.2.2 In addition to the information gathered in 6.2.1, the site assessment information for Tier 2 evaluation may include the following:

6.2.2.1 Determination of site-specific hydrogeologic and geologic characteristics (for example, depth to ground water, aquifer thickness, flow direction, gradient, description of confining units, and ground water quality);

6.2.2.2 Determination of extent of chemical(s) of concern relative to the RBSL or SSTL, as appropriate;

6.2.2.3 Determination of changes in concentrations of chemical(s) of concern over time (for example, stable, increasing, and decreasing); and

6.2.2.4 Determination of concentrations of chemical(s) of concern measured at point(s) of exposure (for example, dissolved concentrations in nearby drinking water wells or vapor concentrations in nearby conduits or sewers).

6.2.3 In addition to the information gathered in 6.2.1 and 6.2.2, the site assessment information for Tier 3 evaluation includes additional information that is required for site-specific modeling efforts.

6.3 *Site Classification and Initial Response Action*—As the user gathers data, site conditions should be evaluated and an initial response action should be implemented, consistent with site conditions. This process is repeated when new data indicate a significant change in site conditions. Site urgency classifications are presented in Table 1, along with example classification scenarios and potential initial responses. *Note that the initial response actions given in Table 1 may not be applicable for all sites. The user should select an option that best addresses the short-term health and safety concerns of the site while implementing the RBCA process.*

6.3.1 The classification and initial response action scheme given in Table 1 is an example. It is based on the current and

projected degree of hazard to human health and the environment. This is a feature of the process that can be customized by the user. "Classification 1" sites are associated with immediate threats to human health and the environment; "Classification 2" sites are associated with short-term (0 to 2-year) threats to human health, safety, and the environment; "Classification 3" sites are associated with long-term (greater than 2-year) threats to human health, safety, and the environment; "Classification 4" sites are associated with no reasonable potential threat to human health or to the environment.

6.3.2 Associated with each classification scenario in Table 1 is an initial response action; the initial response actions are implemented in order to eliminate any potential immediate impacts to human health and the environment as well as to minimize the potential for future impacts that may occur as the user proceeds with the RBCA process. Note that initial response actions do not always require active remediation; in many cases the initial response action is to monitor or further assess site conditions to ensure that risks posed by the site do not increase above acceptable levels over time. The initial response actions given in Table 1 are examples, and the user is free to implement other alternatives.

6.3.3 The need to reclassify the site should be evaluated when additional site information is collected that indicates a significant change in site conditions or when implementation of an interim response action causes a significant change in site conditions.

6.4 *Development of a Tier 1 Look-Up Table of RBSL*—If a look-up table is not available, the user is responsible for developing the look-up table. If a look-up table is available, the user is responsible for determining that the RBSLs in the look-up table are based on currently acceptable methodologies and parameters. The look-up table is a tabulation for potential exposure pathways, media (for example, soil, water, and air), a range of incremental carcinogenic risk levels (10E-4 to 10E-6 are often evaluated as discussed in Appendix X1) and hazard quotients equal to unity, and potential exposure scenarios (for example, residential, commercial, industrial, and agricultural) for each chemical(s) of concern.

6.4.1 The RBSLs are determined using typical, non-site-specific values for exposure parameters and physical parameters for media. The RBSLs are calculated according to methodology suggested by the USEPA. For each exposure scenario, the RBSLs are based on current USEPA RME parameters and current toxicological information given in Refs (2, 3) or peer-reviewed source(s). Consequently, the RBSL look-up table is updated when new methodologies and parameters are developed. For indirect pathways, fate and transport models can be used to predict RBSLs at a source area that corresponds to exposure point concentrations. An example of the development of a Tier 1 Look-Up Table and RBSL is given in Appendix X2. *Figure 2 and Appendix X2 are presented solely for the purpose of providing an example development of the RBSL, and the values should not be viewed as proposed RBSLs.*

6.4.2 Appendix X2 is an example of an abbreviated Tier 1 RBSL Look-Up Table for compounds of concern associated with petroleum releases. The exposure scenarios selected in the example case are for residential and industrial/commercial scenarios characterized by USEPA RME parameters for

TABLE 1 Example Site Classification and Initial Response Actions^a

Criteria and Prescribed Scenarios	Example Initial Response Actions ^b
<p>1. Immediate threat to human health, safety, or sensitive environmental receptors</p> <ul style="list-style-type: none"> ● Explosive levels, or concentrations of vapors that could cause acute health effects, are present in a residence or other building. ● Explosive levels of vapors are present in subsurface utility system(s), but no building or residences are impacted. ● Free-product is present in significant quantities at ground surface, on surface water bodies, in utilities other than water supply lines, or in surface water runoff. ● An active public water supply well, public water supply line, or public surface water intake is impacted or immediately threatened. ● Ambient vapor/particulate concentrations exceed concentrations of concern from an acute exposure or safety viewpoint. ● A sensitive habitat or sensitive resources (sport fish, economically important species, threatened and endangered species, and so forth) are impacted and affected. 	<p>Notify appropriate authorities, property owners, and potentially affected parties, and only evaluate the need to</p> <ul style="list-style-type: none"> ● Evacuate occupants and begin abatement measures such as subsurface ventilation or building pressurization. ● Evacuate immediate vicinity and begin abatement measures such as ventilation. ● Prevent further free-product migration by appropriate containment measures, institute free-product recovery, and restrict area access. ● Notify user(s), provide alternate water supply, hydraulically control contaminated water, and treat water at point-of-use. ● Install vapor barrier (capping, foams, and so forth), remove source, or restrict access to affected area. ● Minimize extent of impact by containment measures and implement habitat management to minimize exposure.
<p>2. Short-term (0 to 2 years) threat to human health, safety, or sensitive environmental receptors</p> <ul style="list-style-type: none"> ● There is potential for explosive levels, or concentrations of vapors that could cause acute effects, to accumulate in a residence or other building. ● Shallow contaminated surface soils are open to public access, and dwellings, parks, playgrounds, day-care centers, schools, or similar use facilities are within 500 ft (152 m) of those soils. ● A non-potable water supply well is impacted or immediately threatened. ● Ground water is impacted, and a public or domestic water supply well producing from the impacted aquifer is located within two-years projected ground water travel distance down gradient of the known extent of chemical(s) concern. ● Ground water is impacted, and a public or domestic water supply well producing from a different interval is located within the known extent of chemicals of concern. ● Impacted surface water, storm water, or ground water discharges within 500 ft (152 m) of a sensitive habitat or surface water body used for human drinking water or contact recreation. 	<p>Notify appropriate authorities, property owners, and potentially affected parties, and only evaluate the need to</p> <ul style="list-style-type: none"> ● Assess the potential for vapor migration (through monitoring/modeling) and remove source (if necessary), or install vapor migration barrier. ● Remove soils, cover soils, or restrict access. ● Notify owner/user and evaluate the need to install point-of-use water treatment, hydraulic control, or alternate water supply. ● Institute monitoring and then evaluate if natural attenuation is sufficient, or if hydraulic control is required. ● Monitor ground water well quality and evaluate if control is necessary to prevent vertical migration to the supply well. ● Institute containment measures, restrict access to areas near discharge, and evaluate the magnitude and impact of the discharge.
<p>3. Long-term (>2 years) threat to human health, safety, or sensitive environmental receptors</p> <ul style="list-style-type: none"> ● Subsurface soils (>3 ft (0.9 m) BGS) are significantly impacted, and the depth between impacted soils and the first potable aquifer is less than 50 ft (15 m). ● Ground water is impacted, and potable water supply wells producing from the impacted interval are located >2 years ground water travel time from the dissolved plume. ● Ground water is impacted, and non-potable water supply wells producing from the impacted interval are located >2 years ground water travel time from the dissolved plume. ● Ground water is impacted, and non-potable water supply wells that do not produce from the impacted interval are located within the known extent of chemical(s) of concern. ● Impacted surface water, storm water, or ground water discharges within 1500 ft (457 m) of a sensitive habitat or surface water body used for human drinking water or contact recreation. ● Shallow contaminated surface soils are open to public access, and dwellings, parks, playgrounds, day-care centers, schools, or similar use facilities are more than 500 ft (152 m) of those soils. 	<p>Notify appropriate authorities, property owners, and potentially affected parties, and only evaluate the need to</p> <ul style="list-style-type: none"> ● Monitor ground water and determine the potential for future migration of the chemical(s) concerns to the aquifer. ● Monitor the dissolved plume and evaluate the potential for natural attenuation and the need for hydraulic control. ● Identify water usage of well, assess the effect of potential impact, monitor the dissolved plume, and evaluate whether natural attenuation or hydraulic control are appropriate control measures. ● Monitor the dissolved plume, determine the potential for vertical migration, notify the user, and determine if any impact is likely. ● Investigate current impact on sensitive habitat or surface water body, restrict access to area of discharge (if necessary), and evaluate the need for containment/control measures. ● Restrict access to impact soils.
<p>4. No demonstrable long-term threat to human health or safety or sensitive environmental receptors</p> <p>Priority 4 scenarios encompass all other conditions not described in Priorities 1, 2, and 3 and that are consistent with the priority description given above. Some examples are as follows:</p> <ul style="list-style-type: none"> ● Non-potable aquifer with no existing local use impacted. ● Impacted soils located more than 3 ft (0.9 m) BGS and greater than 50 ft (15 m) above nearest aquifer. ● Ground water is impacted, and non-potable wells are located down gradient outside the known extent of the chemical(s) of concern, and they produce from a nonimpacted zone. 	<p>Notify appropriate authorities, property owners, and potentially affected parties, and only evaluate the need to</p> <ul style="list-style-type: none"> ● Monitor ground water and evaluate effect of natural attenuation on dissolved plume migration. ● Monitor ground water and evaluate effect of natural attenuation on leachate migration. ● Monitor ground water and evaluate effect of natural attenuation on dissolved plume migration.

^a Johnson, D. C., DeVaul, G. E., Ettinger, R. A., MacDonald, R. L. M., Stanley, C. C., Westby, T. S., and Conner, J., "Risk-Based Corrective Action: Tier 1 Guidance Manual," Shell Oil Co., July 1993.

^b Note that these are potential initial response actions that may not be appropriate for all sites. The user is encouraged to select options that best address the short-term health and safety concerns of the site, while the RBCA process progresses.

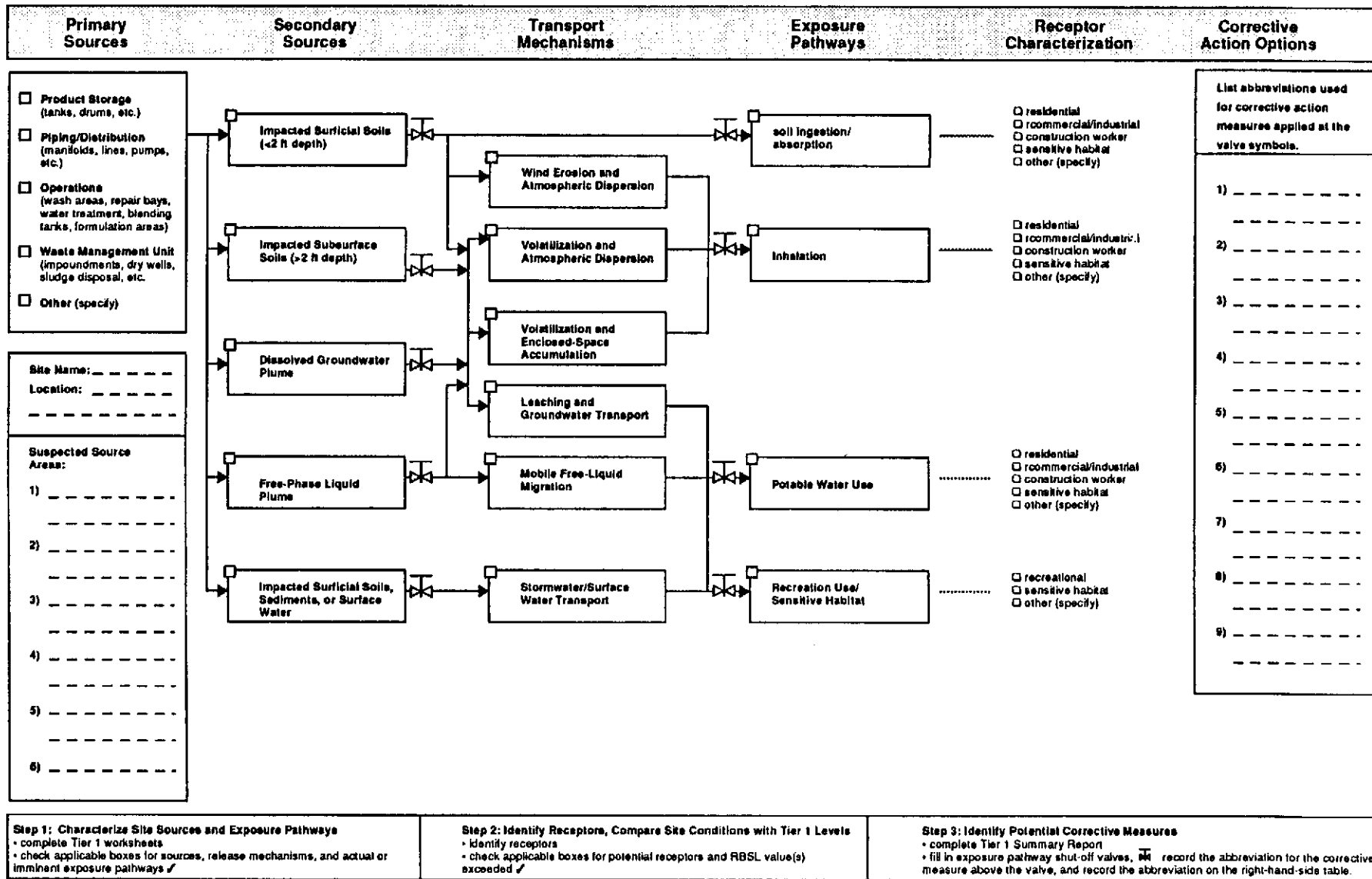


FIG. 2 Exposure Scenario Evaluation Flowchart

adult males. The assumptions and methodology used in deriving the example are discussed in Appendix X2. Note that not all possible exposure pathways are considered in the derivation of the example. *The user should always review the assumptions and methodology used to derive values in a look-up table to make sure that they are consistent with reasonable exposure scenarios for the site being considered as well as currently accepted methodologies.* The value of creating a look-up table is that users do not have to repeat the exposure calculations for each site encountered. The look-up table is only altered when RME parameters, toxicological information, or recommended methodologies are updated. Some states have compiled such tables for direct exposure pathways that, for the most part, contain identical values (as they are based on the same assumptions). Values for the cross-media pathways (for example, volatilization and leaching), when available, often differ because these involve coupling exposure calculations with predictive equations for the fate and transport of chemicals in the environment. As yet, there is little agreement in the technical community concerning non-site-specific values for the transport and fate model parameters, or the choice of the models themselves. *Again, the reader should note that the example is presented here only as an abbreviated example of a Tier 1 RBSL Look-Up Table for typical compounds of concern associated with petroleum products.*

6.4.3 Use of Total Petroleum Hydrocarbon Measurements—Various chemical analysis methods commonly referred to as total petroleum hydrocarbons (TPHs) are often used in site assessments. These methods usually determine the total amount of hydrocarbons present as a single number and give no information on the types of hydrocarbon present. The TPHs should not be used for risk assessment because the general measure of TPH provides insufficient information about the amounts of individual chemical(s) of concern present.

6.5 Comparison of Site Conditions with Tier 1 Risk-Based Screening Levels (RBSL)—In Tier 1, the point(s) of exposure and point(s) of compliance are assumed to be located within close proximity to the source area(s) or the area where the highest concentrations of the chemical(s) of concern have been identified. Concentrations of the chemical(s) of concern measured at the source area(s) identified at the site should be compared to the look-up table RBSL. If there is sufficient site assessment data, the user may opt to compare RBSLs with statistical limits (for example, upper confidence levels) rather than maximum values detected. Background concentrations should be considered when comparing the RBSLs, to the site concentrations as the RBSLs may sometimes be less than background concentrations. Note that additivity of risks is not explicitly considered in the Tier 1 evaluation, as it is expected that the RBSLs are typically for a limited number of chemical(s) of concern considered at most sites. Additivity may be addressed in Tier 2 and Tier 3 analyses. To accomplish the Tier 1 comparison:

6.5.1 Select the potential exposure scenario(s) (if any) for the site. Exposure scenarios are determined based on the site assessment information described in 6.2;

6.5.2 Based on the impacted media identified, determine the primary sources, secondary sources, transport mechanisms, and exposure pathways;

6.5.3 Select the receptors (if any) based on current and anticipated future use. Consider land use restrictions and surrounding land use when making this selection.

6.5.4 Identify the exposure scenarios where the measured concentrations of the chemical(s) of concern are above the RBSL.

6.6 Exposure Evaluation Flowchart—During a Tier 1 evaluation, the risk evaluation flowchart presented in Fig. 2 may be used as a tool to guide the user in selecting appropriate exposure scenarios based on site assessment information. This worksheet may also be used in the evaluation of remedial action alternatives. To complete this flowchart:

6.6.1 Characterize site sources and exposure pathways, using the data summarized from Tier 1 to customize the risk evaluation flowchart for the site by checking the small checkbox for every relevant source, transport mechanism, and exposure pathway.

6.6.2 Identify receptors, and compare site conditions with Tier 1 levels: For each exposure pathway selected, check the receptor characterization (residential, commercial, and so forth) where the concentrations of the chemical(s) of concern are above the RBSL. Consider land use restrictions and surrounding land use when making this selection. Do not check any boxes if there are no receptors present, or likely to be present, or if institutional controls prevent exposure from occurring and are likely to stay in place.

6.6.3 Identify potential remedial action measures. Select remedial action options to reduce or eliminate exposure to the chemical(s) of concern.

6.6.4 The exposure evaluation flowchart (Fig. 2) can be used to graphically portray the effect of the Tier 1 remedial action. Select the Tier 1 remedial action measure or measures (shown as valve symbols) that will break the lines linking sources, transport mechanisms, and pathways leading to the chemical(s) of concern above the RBSL. Adjust the mix of remedial action measures until no potential receptors have concentrations of chemical(s) of concerns above the RBSL with the remedial action measures in place. Show the most likely Tier 1 remedial action measure(s) selected for this site by marking the appropriate valve symbols on the flowchart and recording a remedial action measure on the right-hand-side of this figure.

6.7 Evaluation of Tier Results—At the conclusion of each tier evaluation, the user compares the target levels (RBSLs or SSTLs) to the concentrations of the chemical(s) of concern at the point(s) of compliance.

6.7.1 If the concentrations of the chemical(s) of concern exceed the target levels at the point(s) of compliance, then either remedial action, interim remedial action, or further tier evaluation should be conducted.

6.7.1.1 **Remedial Action**—A remedial action program is designed and implemented. This program may include some combination of source removal, treatment, and containment technologies, as well as engineering and institutional controls. Examples of these include the following: soil venting, bioventing, air sparging, pump and treat, and natural attenuation/passive remediation. When concentrations of chemical(s) of concern no longer exceed the target levels at the point of compliance, then the user may elect to move to 6.7.3.

6.7.1.2 *Interim Remedial Action*—If achieving the desired risk reduction is impracticable due to technology or resource limitations, an interim remedial action, such as removal or treatment of “hot spots,” may be conducted to address the most significant concerns, change the site classification, and facilitate reassessment of the tier evaluation.

6.7.1.3 *Further Tier Evaluation*—If further tier evaluation is warranted, additional site assessment information may be collected to develop SSTLs under a Tier 2 or Tier 3 evaluation. Further tier evaluation is warranted when:

(1) The basis for the RBSL values (for example, geology, exposure parameters, point(s) of exposure, and so forth) are not representative of the site-specific conditions; or

(2) The SSTL developed under further tier evaluation will be significantly different from the Tier 1 RBSL or will significantly modify the remedial action activities; or

(3) Cost of remedial action to RBSLs will likely be greater than further tier evaluation and subsequent remedial action.

6.7.2 If the concentrations of chemicals of concern at the point of compliance are less than the target levels, but the user is not confident that data supports the conclusion that concentrations will not exceed target levels in the future, then the user institutes a monitoring plan to collect data sufficient to confidently conclude that concentrations will not exceed target levels in the future. When this data is collected, the user moves to 6.7.3.

6.7.3 If the concentrations of chemicals of concern at the point of compliance are less than target levels, and the user is confident that data supports the conclusion that concentrations will not exceed target levels in the future, then no additional corrective action activities are necessary, and the user has completed the RBCA process. In practice, this is often accompanied by the issuing of a no-further-action letter by the oversight regulatory agency.

6.8 *Tier 2*—Tier 2 provides the user with an option to determine the site-specific point(s) of compliance and corresponding SSTL for the chemical(s) of concern applicable at the point(s) of compliance and source area(s). Additional site assessment data may be required; however, the incremental effort is typically minimal relative to Tier 1. If the user completes a Tier 1 evaluation, in most cases, only a limited number of pathways, exposure scenarios, and chemical(s) of concern are considered in the Tier 2 evaluation since many are eliminated from consideration during the Tier 1 evaluation.

6.8.1 In Tier 2, the user:

6.8.1.1 Identifies the indirect exposure scenarios to be addressed and the appropriate site-specific point(s) of compliance. A combination of assessment data and predictive modeling results are used to determine the SSTL at the source area(s) or the point(s) of compliance, or both; or

6.8.1.2 Applies Tier 1 RBSL Look-Up Table values for the direct exposure scenarios at reasonable point(s) of exposure (as opposed to the source area(s) as is done in Tier 1). The SSTLs for source area(s) and point(s) of compliance can be determined based on the demonstrated and predicted attenuation (reduction in concentration with distance) of compounds that migrate away from the source area(s).

6.8.1.3 An example of a Tier 2 application is illustrated in Appendix X5.

6.8.2 Tier 2 of the RBCA process involves the development of SSTL based on the measured and predicted attenuation of the chemical(s) of concern away from the source area(s) using relatively simplistic mathematical models. The SSTLs for the source area(s) are generally not equal to the SSTL for the point(s) of compliance. The predictive equations are characterized by the following:

6.8.2.1 The models are relatively simplistic and are often algebraic or semianalytical expressions;

6.8.2.2 Model input is limited to practicably attainable site-specific data or easily estimated quantities (for example, total porosity, soil bulk density); and

6.8.2.3 The models are based on descriptions of relevant physical/chemical phenomena. Most mechanisms that are neglected result in predicted concentrations that are greater than those likely to occur (for example, assuming constant concentrations in source area(s)). Appendix X3 discusses the use of predictive models and presents models that might be considered for Tier 2 evaluation.

6.8.3 *Tier 2 Evaluation*—Identify the exposure scenarios where the measured concentrations of the chemical(s) of concern are above the SSTL at the point(s) of compliance, and evaluate the tier results in accordance with 6.7.

6.9 *Tier 3*—In a Tier 3 evaluation, SSTLs for the source area(s) and the point(s) of compliance are developed on the basis of more sophisticated statistical and contaminant fate and transport analyses, using site-specific input parameters for both direct and indirect exposure scenarios. Source area(s) and the point(s) of compliance SSTLs are developed to correspond to concentrations of chemical(s) of concern at the point(s) of exposure that are protective of human health and the environment. Tier 3 evaluations commonly involve collection of significant additional site information and completion of more extensive modeling efforts than is required for either a Tier 1 or Tier 2 evaluation.

6.9.1 Examples of Tier 3 analyses include the following:

6.9.1.1 The use of numerical ground water modeling codes that predict time-dependent dissolved contaminant transport under conditions of spatially varying permeability fields to predict exposure point(s) of concentrations;

6.9.1.2 The use of site-specific data, mathematical models, and Monte Carlo analyses to predict a statistical distribution of exposures and risks for a given site; and

6.9.1.3 The gathering of sufficient data to refine site-specific parameter estimates (for example, biodegradation rates) and improve model accuracy in order to minimize future monitoring requirements.

6.9.2 *Tier 3 Evaluation*—Identify the exposure scenarios where the measured concentrations of the chemical(s) of concern are above the SSTL at the point(s) of compliance, and evaluate the tier results in accordance with 6.7 except that a tier upgrade (6.7.5) is not available.

6.10 *Implementing the Selected Remedial Action Program*—When it is judged by the user that no further assessment is necessary, or practicable, a remedial alternatives evaluation should be conducted to confirm the most cost-effective option for achieving the final remedial action target levels (RBSLs or SSTLs, as appropriate). Detailed design specifications may then be developed for installation and operation of the selected measure. The remedial action must continue until such time as monitoring indicates that

concentrations of the chemical(s) of concern are not above the RBSL or SSTL, as appropriate, at the points of compliance or source area(s), or both.

6.11 *RBCA Report*—After completion of the RBCA activities, a RBCA report should be prepared and submitted to the regulatory agency. The RBCA report should, at a minimum, include the following:

- 6.11.1 An executive summary;
- 6.11.2 A site description;
- 6.11.3 A summary of the site ownership and use;
- 6.11.4 A summary of past releases or potential source areas;
- 6.11.5 A summary of the current and completed site activities;
- 6.11.6 A description of regional hydrogeologic conditions;
- 6.11.7 A description of site-specific hydrogeologic conditions;
- 6.11.8 A summary of beneficial use;
- 6.11.9 A summary and discussion of the risk assessment (hazard identification, dose response assessment, exposure assessment, and risk characterization), including the methods and assumptions used to calculate the RBSL or SSTL, or both;
- 6.11.10 A summary of the tier evaluation;
- 6.11.11 A summary of the analytical data and the appropriate RBSL or SSTL used;
- 6.11.12 A summary of the ecological assessment;
- 6.11.13 A site map of the location;

6.11.14 An extended site map to include local land use and ground water supply wells;

6.11.15 Site plan view showing location of structures, aboveground storage tanks, underground storage tanks, buried utilities and conduits, suspected/confirmed sources, and so forth;

6.11.16 Site photos, if available;

6.11.17 A ground water elevation map;

6.11.18 Geologic cross section(s); and

6.11.19 Dissolved plume map(s) of the chemical(s) of concern.

6.12 *Monitoring and Site Maintenance*—In many cases, monitoring is necessary to demonstrate the effectiveness of implemented remedial action measures or to confirm that current conditions persist or improve with time. Upon completion of this monitoring effort (if required), no further action is required. In addition, some measures (for example, physical barriers such as capping, hydraulic control, and so forth) require maintenance to ensure integrity and continued performance.

6.13 *No Further Action and Remedial Action Closure*—When RBCA RBSLs or SSTLs have been demonstrated to be achieved at the point(s) of compliance or source area(s), or both, as appropriate, and monitoring and site maintenance are no longer required to ensure that conditions persist, then no further action is necessary, except to ensure that institutional controls (if any) remain in place.

APPENDIXES

(Nonmandatory Information)

X1. PETROLEUM PRODUCTS CHARACTERISTICS: COMPOSITION, PHYSICAL AND CHEMICAL PROPERTIES, AND TOXICOLOGICAL ASSESSMENT SUMMARY

X1.1 *Introduction:*

X1.1.1 Petroleum products originating from crude oil are complex mixtures of hundreds to thousands of chemicals; however, practical limitations allow us to focus only on a limited subset of key components when assessing the impact of petroleum fuel releases to the environment. Thus, it is important to have a basic understanding of petroleum properties, compositions, and the physical, chemical, and toxicological properties of some compounds most often identified as the key chemicals or chemicals of concern.

X1.1.2 This appendix provides a basic introduction to the physical, chemical, and toxicological characteristics of petroleum products (gasoline, diesel fuel, jet fuel, and so forth)⁵ and other products focussed primarily towards that information which is most relevant to assessing potential impacts due to releases of these products into the subsurface. Much of the information presented is summarized from the references listed at the end of this guide. For specific topics, the reader is referred to the following sections of this appendix:

X1.1.2.1 *Composition of Petroleum Fuels*—See X1.2.

X1.1.2.2 *Physical, Chemical, and Toxicological Properties of Petroleum Fuels*—See X1.3.

X1.1.2.3 *Chemical of Concern*—See X1.4.

X1.1.2.4 *Toxicity of Petroleum Hydrocarbons*—See X1.5.

X1.1.2.5 *Profiles of Select Compounds*—See X1.6.

X1.2 *Composition of Petroleum Products:*

X1.2.1 Most petroleum products are derived from crude oil by distillation, which is a process that separates compounds by volatility. Crude oils are variable mixtures of thousands of chemical compounds, primarily hydrocarbons; consequently, the petroleum products themselves are also variable mixtures of large numbers of components. The biggest variations in composition are from one type of product to another (for example, gasoline to motor oil); however, there are even significant variations within different samples of the same product type. For example, samples of gasoline taken from the same fuel dispenser on different days, or samples taken from different service stations, will have different compositions. These variations are the natural result of differing crude oil sources, refining processes and conditions, and kinds and amount of additives used.

⁵ "Alternative products," or those products not based on petroleum hydrocarbons (or containing them in small amounts), such as methanol or M85, are beyond the scope of the discussion in this appendix.

X1.2.2 *Components of Petroleum Products*—The components of petroleum products can be generally classified as either hydrocarbons (organic compounds composed of hydrogen and carbon only) or as non-hydrocarbons (compounds containing other elements, such as oxygen, sulfur, or nitrogen). Hydrocarbons make up the vast majority of the composition of petroleum products. The non-hydrocarbon compounds in petroleum products are mostly hydrocarbon-like compounds containing minor amounts of oxygen, sulfur, or nitrogen. Most of the trace levels of metals found in crude oil are removed by refining processes for the lighter petroleum products.

X1.2.3 *Descriptions and Physical Properties of Petroleum Products*—In order to simplify the description of various petroleum products, boiling point ranges and carbon number (number of carbon atoms per molecule) ranges are commonly used to describe and compare the compositions of various petroleum products. Table X1.1 summarizes these characteristics for a range of petroleum products. Moving down the list from gasoline, increases in carbon number range and boiling range and decreases in volatility (denoted by increasing flash point) indicate the transition to “heavier products.” Additional descriptions of each of these petroleum products are provided as follows.

X1.2.4 *Gasoline*—Gasoline is composed of hydrocarbons and “additives” that are blended with the fuel to improve fuel performance and engine longevity. The hydrocarbons fall primarily in the C4 to C12 range. The lightest of these are highly volatile and rapidly evaporate from spilled gasoline. The C4 and C5 aliphatic hydrocarbons rapidly evaporate from spilled gasoline (hours to months, depending primarily on the temperature and degree of contact with air). Substantial portions of the C6 and heavier hydrocarbons also evaporate, but at lower rates than for the lighter hydrocarbons.

X1.2.4.1 Figure X1.1 shows gas chromatograms of a fresh gasoline and the same gasoline after simulated weathering; air was bubbled through the gasoline until 60 % of its initial volume was evaporated. In gas chromatography, the mixture is separated into its components, with each peak representing different compounds. Higher molecular weight components appear further to the right along the *x*-axis. For reference, positions of the *n*-aliphatic hydrocarbons are indicated in Fig. X1.1. The height of, and area under, each peak are measures of how much of that component is present in the mixture. As would be expected by their higher volatilities, the lighter hydrocarbons (up to about C7) evaporate first and are greatly reduced in the weathered gasoline. The gas chromatogram of a fuel oil is also shown for comparison.

X1.2.4.2 The aromatic hydrocarbons in gasoline are primarily benzene (C₆H₆), toluene (C₇H₈), ethylbenzene (C₈H₁₀), and xylenes (C₈H₁₀); these are collectively referred to as “BTEX.” Some heavier aromatics are present also, including low amounts of polyaromatic hydrocarbons (PAHs). Aromatics typically comprise about 10 to 40 % of gasoline.

X1.2.4.3 Oxygenated compounds (“oxygenates”) such as alcohols (for example, methanol or ethanol) and ethers (for example, methyl tertiarybutyl ether—MTBE) are sometimes added to gasoline as octane boosters and to reduce carbon monoxide exhaust emissions. Methyl tertiarybutyl ether has been a common additive only since about 1980.

X1.2.4.4 Leaded gasoline, which was more common in the past, contained lead compounds added as octane boosters. Tetraethyl lead (TEL) is one lead compound that was commonly used as a gasoline additive. Other similar compounds were also used. Sometimes mixtures of several such compounds were added. Because of concerns over atmospheric emissions of lead from vehicle exhaust, the EPA has reduced the use of leaded gasolines. Leaded gasolines were phased out of most markets by 1989.

X1.2.4.5 In order to reduce atmospheric emissions of lead, lead “scavengers” were sometimes added to leaded gasolines. Ethylene dibromide (EDB) and ethylene dichloride (EDC) were commonly used for this purpose.

X1.2.5 *Kerosene and Jet Fuel*—The hydrocarbons in kerosene commonly fall into the C11 to C13 range, and distill at approximately 150 to 250°C. Special wide-cut (that is, having broader boiling range) kerosenes and low-flash kerosenes are also marketed. Both aliphatic and aromatic hydrocarbons are present, including more multi-ring compounds and kerosene.

X1.2.5.1 Commercial jet fuels JP-8 and Jet A have similar compositions to kerosene. Jet fuels JP-4 and JP-5 are wider cuts used by the military. They contain lighter distillates and have some characteristics of both gasoline and kerosene.

X1.2.5.2 Aromatic hydrocarbons comprise about 10 to 20 % of kerosene and jet fuels.

X1.2.6 *Diesel Fuel and Light Fuel Oils*—Light fuel oils include No. 1 and No. 2 fuel oils, and boil in the range from 160 to 400°C. Hydrocarbons in light fuel oils and diesel fuel typically fall in the C10 to C20 range. Because of their higher molecular weights, constituents in these products are less volatile, less water soluble, and less mobile than gasoline- or kerosene-range hydrocarbons.

X1.2.6.1 About 25 to 35 % of No. 2 fuel oil is composed of aromatic hydrocarbons, primarily alkylated benzenes and naphthalenes. The BTEX concentrations are generally low.

X1.2.6.2 No. 1 fuel oil is typically a straight run distillate.

X1.2.6.3 No. 2 fuel oil can be either a straight run distillate, or else is produced by catalytic cracking (a process in which larger molecules are broken down into smaller ones). Straight run distillate No. 2 is commonly used for home heating fuel, while the cracked product is often used for industrial furnaces and boilers. Both No. 1 and No. 2 fuel oils are sometimes used as blending components for jet fuel or diesel fuel formulations.

X1.2.7 *Heavy Fuel Oils*—The heavy fuel oils include Nos. 4, 5, and 6 fuel oils. They are sometimes referred to as “gas oils” or “residual fuel oils.” These are composed of hydrocarbons ranging from about C19 to C25 and have a boiling range from about 315 to 540°C. They are dark in color and considerably more viscous than water. They typically contain 15 to 40 % aromatic hydrocarbons, dominated by alkylated phenanthrenes and naphthalenes. Polar compounds containing nitrogen, sulfur, or oxygen may comprise 15 to 30 % of the oil.

X1.2.7.1 No. 6 fuel oil, also called “Bunker Fuel” or “Bunker C,” is a gummy black product used in heavy industrial applications where high temperatures are available to fluidize the oil. Its density is greater than that of water.

X1.2.7.2 Nos. 4 and 5 fuel oils are commonly produced by blending No. 6 fuel oil with lighter distillates.

X1.2.8 Motor Oils and Other Lubricating Oils—Lubricating oils and motor oils are predominately comprised of compounds in the C20 to C45 range and boil at approximately 425 to 540°C. They are enriched in the most complex molecular fractions found in crude oil, such as cycloparaffins and PNAs having up to three rings or more. Aromatics may make up to 10 to 30 % of the oil. Molecules containing nitrogen, sulfur, or oxygen are also common. In addition, used automotive crankcase oils become enriched with PNAs and certain metals.

X1.2.8.1 These oils are relatively viscous and insoluble in ground water and relatively immobile in the subsurface.

X1.2.8.2 Waste oil compositions are even more difficult to predict. Depending on how they are managed, waste oils may contain some portion of the lighter products in addition to heavy oils. Used crankcase oil may contain wear metals from engines. Degreasing solvents (gasoline, naphtha, or light chlorinated solvents, or a combination thereof) may be present in some wastes.

X1.3 Physical, Chemical, and Toxicological Characteristics of Petroleum Products:

X1.3.1 Trends in Physical/Chemical Properties of Hydrocarbons—In order to better understand the subsurface behavior of hydrocarbons it is helpful to be able to recognize trends in important physical properties with increasing number of carbon atoms. These trends are most closely followed by compounds with similar molecular structures, such as the straight-chained, single-bonded aliphatic hydrocarbons. In general, as the carbon number (or molecule size) increases, the following trends are observed:

X1.3.1.1 Higher boiling points (and melting points),

X1.3.1.2 Lower vapor pressure (volatility),

X1.3.1.3 Greater density,

X1.3.1.4 Lower water solubility, and

X1.3.1.5 Stronger adhesion to soils and less mobility in the subsurface.

X1.3.2 Table X1.2 lists physical, chemical, and toxicological properties for a number of hydrocarbons found in petroleum products. In general:

X1.3.2.1 Aliphatic petroleum hydrocarbons with more than ten carbon atoms are expected to be immobile in the subsurface, except when dissolved in nonaqueous phase liquids (NAPLs), due to their low water solubilities, low vapor pressures, and strong tendency to adsorb to soil surfaces.

X1.3.2.2 Aromatic hydrocarbons are more water soluble and mobile in water than aliphatic hydrocarbons of similar molecular weight.

X1.3.2.3 Oxygenates generally have much greater water solubilities than hydrocarbons of similar molecular weight, and hence are likely to be the most mobile of petroleum fuel constituents in leachate and ground water. The light alcohols, including methanol and ethanol, are completely miscible with water in all proportions.

X1.3.3 *Properties of Mixtures*—It is important to note that the partitioning behavior of individual compounds is affected by the presence of other hydrocarbons in the subsurface. The maximum dissolved and vapor concentrations achieved in the subsurface are always less than that of any pure compound, when it is present as one of many constituents of a petroleum fuel. For example, dissolved

benzene concentrations in ground water contacting gasoline-impacted soils rarely exceed 1 to 3 % of the ~1800-mg/L pure component solubility of benzene.

X1.3.4 Trends in Toxicological Properties of Hydrocarbons—A more detailed discussion of toxicological assessment is given in X1.5 (see also Appendix X3), followed by profiles for select chemicals found in petroleum products given in X1.6. Of the large number of compounds present in petroleum products, aromatic hydrocarbons (BTEX, PAHs, and so forth) are the constituents that human and aquatic organisms tend to be most sensitive to (relative to producing adverse health impacts).

X1.4 Chemicals of Concern for Risk Assessments:

X1.4.1 It is not practicable to evaluate every compound present in a petroleum product to assess the human health or environmental risk from a spill of that product. For this reason, risk management decisions are generally based on assessing the potential impacts from a select group of "indicator" compounds. It is inherently assumed in this approach that a significant fraction of the total potential impact from all chemicals is due to the chemicals of concern. The selection of chemicals of concern is based on the consideration of exposure routes, concentrations, mobilities, toxicological properties, and aesthetic characteristics (taste, odor, and so forth). Historically, the relatively low toxicities and dissolved-phase mobilities of aliphatic hydrocarbons have made these chemicals of concern of less concern relative to aromatic hydrocarbons. When additives are present in significant quantities, consideration should also be given to including these as chemicals of concern.

X1.4.2 Table X1.3 identifies chemicals of concern most often considered when assessing impacts of petroleum products, based on knowledge of their concentration in the specific fuel, as well as their toxicity, water solubility, subsurface mobility, aesthetic characteristics, and the availability of sufficient information to conduct risk assessments. The chemicals of concern are identified by an "X" in the appropriate column.

X1.5 Toxicity of Petroleum Hydrocarbons:

X1.5.1 The following discussion gives a brief overview of origin of the toxicity parameters (reference doses (RfDs)), and slope factors (SFs), a justification for common choices of chemicals of concern and then, in X1.6, a brief summary of the toxicological, physical, and chemical parameters associated with these chemicals of concern.

X1.5.2 *How Toxicity Is Assessed: Individual Chemicals Versus Mixtures*—The toxicity of an individual chemical is typically established based on dose-response studies that estimate the relationship between different dose levels and the magnitude of their adverse effects (that is, toxicity). The dose-response data is used to identify a "safe dose" or a toxic level for a particular adverse effect. For a complex mixture of chemicals, the same approach can be used. For example, to evaluate the toxicity of gasoline, a "pure" reference gasoline would be evaluated instead of the individual chemical. This "whole-product" approach to toxicity assessment is strictly applicable only to mixtures identical to the evaluated mixture; gasolines with compositions different from the reference gasoline might have toxicities similar to the reference, but some differences would be expected. In addition, as the composition of gasoline released to the environment changes

through natural processes (volatilization, leaching, biodegradation), the toxicity of the remaining portion may change also.

X1.5.3 An alternative to the "whole-product" approach for assessing the toxicity of mixtures is the "individual-constituent" approach. In this approach, the toxicity of each individual constituent (or a selected subset of the few most toxic constituents, so-called chemicals of concern) is separately assessed and the toxicity of the mixture is assumed to be the sum of the individual toxicities using a hazard index approach. This approach is often used by the USEPA; however, it is inappropriate to sum hazard indices unless the toxicological endpoints and mechanisms of action are the same for the individual compounds. In addition, the compounds to be assessed must be carefully selected based on their concentrations in the mixture, their toxicities, how well their toxicities are known, and how mobile they are in the subsurface. Lack of sufficient toxicological information is often an impediment to this procedure.

X1.5.4 Use of TPH Measurements in Risk Assessments—Various chemical analysis methods commonly referred to as TPH are often used in site assessments. These methods usually determine the total amount of hydrocarbons present as a single number, and give no information on the types of hydrocarbon present. Such TPH methods may be useful for risk assessments where the whole product toxicity approach is appropriate. However in general, *TPH should not be used for "individual constituent" risk assessments because the general measure of TPH provides insufficient information about the amounts of individual compounds present.*

X1.5.5 Toxicity Assessment Process—Dose-response data are used to identify a "safe dose" or toxic level for a particular observed adverse effect. Observed adverse effects can include whole body effects (for example, weight loss, neurological observations), effects on specific body organs, including the central nervous system, teratogenic effects (defined by the ability to produce birth defects), mutagenic effects (defined by the ability to alter the genes of a cell), and carcinogenic effects (defined by the ability to produce malignant tumors in living tissues). Because of the great concern over risk agents which may produce incremental carcinogenic effects, the USEPA has developed weight-of-evidence criteria for determining whether a risk agent should be considered carcinogenic (see Table X1.2).

X1.5.6 Most estimates of a "safe dose" or toxic level are based on animal studies. In rare instances, human epidemiological information is available on a chemical. Toxicity studies can generally be broken into three categories based on the number of exposures to the risk agent and the length of time the study group was exposed to the risk agent. These studies can be described as follows:

X1.5.6.1 Acute Studies—Acute studies typically use one dose or multiple doses over a short time frame (24 h). Symptoms are usually observed within a short time frame and can vary from weight loss to death.

X1.5.6.2 Chronic Studies—Chronic studies use multiple exposures over an extended period of time, or a significant fraction of the animal's (typically two years) or the individual's lifetime. The chronic effects of major concern are carcinogenic, mutagenic, and teratogenic effects. Other

chronic health effects such as liver and kidney damage are also important.

X1.5.6.3 Subchronic Studies—Subchronic studies use multiple or continuous exposures over an extended period (three months is the usual time frame in animal studies). Observed effects include those given for acute and chronic studies.

X1.5.6.4 Ideally, safe or acceptable doses are calculated from chronic studies, although, due to the frequent paucity of chronic data, subchronic studies are used.

X1.5.6.5 For noncarcinogens, safe doses are based on no observed adverse effect levels (NOAELs) or lowest observed adverse effect levels (LOAELs) from the studies.

X1.5.6.6 Acceptable doses for carcinogens are determined from mathematical models used to generate dose-response curves in the low-dose region from experimentally determined dose-response curves in the high-dose region.

X1.5.7 Data from the preceding studies are used to generate reference doses (RfDs), reference concentrations (RfCs), and slope factors (SFs) and are also used in generating drinking water maximum concentration levels (MCLs) and goals (MCLGs), health advisories (HAs), and water quality criteria. These terms are defined in Table X1.4 and further discussed in X3.6.

X1.5.8 Selection of Chemicals of Concern—The impact on human health and the environment in cases of gasoline and middle distillate contamination of soils and ground water can be assessed based on potential receptor (that is, aquatic organisms, human) exposure to three groups of materials: light aromatic hydrocarbons, PAHs, and in older spills, lead. Although not one of the primary contaminants previously described, EDB and EDC were used as lead scavengers in some leaded gasolines and may be considered chemicals of concern, when present.

X1.5.9 The light aromatics, benzene, toluene, xylenes, and ethylbenzene have relatively high water solubility and sorb poorly to soils. Thus, they have high mobility in the environment, moving readily through the subsurface. When released into surface bodies of water, these materials exhibit moderate to high acute toxicity to aquatic organisms. Although environmental media are rarely contaminated to the extent that acute human toxicity is an issue, benzene is listed by the USEPA as a Group A Carcinogen (known human carcinogen) and, thus, exposure to even trace levels of this material is considered significant.

TABLE X1.1 Generalized Chemical and Physical Characterization of Petroleum Products

	Predominant Carbon No. Range	Boiling Range, °C	Flash Point, ^a °C
Gasoline	C4 to C12	25 to 215	-40
Kerosene and Jet Fuels	C11 to C13	150 to 250	<21, ^b 21 to 55, ^c >55 ^d
Diesel Fuel and Light Fuel Oils	C10 to C20	160 to 400	>35
Heavy Fuel Oils	C19 to C25	315 to 540	>50
Motor Oils and Other Lubricating Oils	C20 to C45	425 to 540	>175

^a Typical values.

^b Jet-B, AVTAG and JP-4.

^c Kerosene, Jet A, Jet A-1, JP-8 and AVTUR.

^d AVCAT and JP-5.

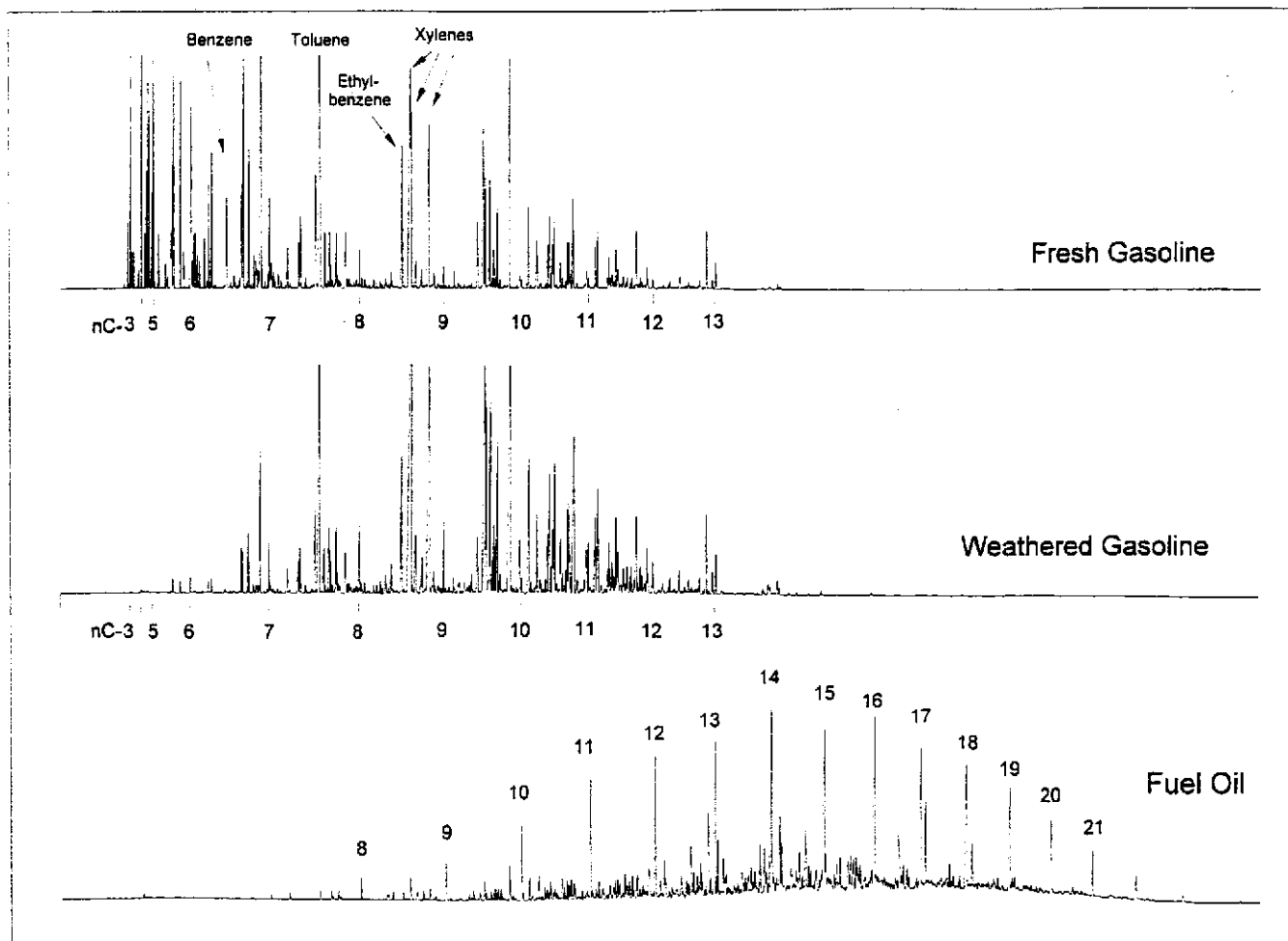


FIG. X1.1 Gas Chromatograms of Some Petroleum Fuels

X1.5.10 Polycyclic aromatics can be broken into two categories: naphthalenes and methylnaphthalenes (diaromatics) have moderate water solubility and soil sorption potential and, thus, their movement through the subsurface tends to be less than monoaromatics, but substantial movement can still occur. When released into surface bodies of water, these materials have moderate to high toxicity to aquatic organisms. The PAHs with three or more condensed rings have very low solubility (typically less than 1 mg/L) and sorb strongly to soils. Thus, their movement in the subsurface is minimal. Several members in the group of three to six-ring PAHs are known or suspected carcinogens and, thus, exposure to low concentrations in drinking water or through the consumption of contaminated soil by children is significant. In addition, materials containing four to six-ring PAHs are poorly biodegradable and, coupled with the potential to bioaccumulate in tissues of aquatic organisms, these materials have the potential to bioconcentrate (be found at levels in living tissue far higher than present in the general surroundings) in the environment.

X1.5.11 Although almost totally eliminated from use in gasolines in the United States, lead is found associated with older spills. Lead was typically added to gasoline either as tetraethyl or tetramethyl lead and may still be found in its original form in areas containing free product. Typically outside the free product zones, these materials have decom-

posed into inorganic forms of lead. Lead is a neurotoxin and lead in the blood of children has been associated with reduced intellectual development. The ingestion by children of lead-contaminated soils is an exposure route of great concern, as is the consumption of lead-contaminated drinking water. Ethylene dibromide and ethylene dichloride, used as lead scavengers in gasolines, are of concern because of their high toxicity (potential carcinogens) and their high mobility in the environment.

X1.5.12 In summary, benzene and benzo(a)pyrene (and in some cases EDB and EDC) are chemicals of concern because of their carcinogenicity. Other PAHs may also be grouped with B(a)P because of uncertainties in their carcinogenicity and because they may accumulate (bioconcentrate) in living tissue.

X1.5.13 *Toxicity and Physical/Chemical Properties for Chemicals of Concern*—A summary of health effects and physical/chemical properties for a number of chemicals of concern is provided in Table X1.2. This table provides toxicological data from a variety of sources, regardless of data quality. A refined discussion for selected chemicals of concern is given as follows. The reader is cautioned that this information is only current as of the dates quoted, and the sources quoted may have been updated, or more recent information may be available in the peer-reviewed literature.

TABLE X1.2 Chemical and Toxicological Properties of Selected Hydrocarbons

Compounds	Weight of Evidence Class ^A	Oral RfD, ^D mg/kg-day	Inhalation RfC, mg/m ³	Oral Slope Factor, ^A mg/kg-day ⁻¹	Drinking Water MCL, ^A mg/L	Solubility, ^B mg/L	Octanol/Water Partition Coefficient, ^B log <i>K_{ow}</i>	Organic Carbon Adsorption Coefficient, ^B log <i>K_{oc}</i>
Benzene	A	E	E,G	0.029 ^G	0.005	1750	2.13	1.58
Toluene	D	0.2 ^A	0.4 ^A	...	1	535	2.65	2.13
Ethylbenzene	D	0.1 ^A	1 ^A	...	0.7	152	3.13	1.98
Xylenes	D	2 ^A	0.3 ^{C,E}	...	10.0	198	3.26	2.38
n-Hexane	E	0.06 ^C , 0.6 ^D	0.2 ^D	...	...	13 ^L	...	...
MTBE	...	E	3 ^A	...	...	48 000 ^M	1.06-1.30 ^M	1.08 ^D
MEK	D	0.6 ^A	1 ^A	...	1	268 000	0.26	0.65
MIBK	...	0.05 ^C , 0.5 ^D	0.08 ^{C,E} , 0.8 ^D	...	...	...	...	...
Methanol	...	0.5 ^A	E	...	...	...	...	...
Ethanol	...	...	...	...	...	1 000 000	-0.032	0.34
TBA	...	...	...	...	...	...	...	...
Lead	B2	...	...	...	0.015 ^J	...	...	...
EDC	B2	...	...	0.091	0.006	8 520	1.48	1.15
EDB	B2	...	E	85	0.00006	4 300	1.76	1.64
PNAs:								
Pyrene	D	0.03 ^A	...	...	...	0.132	4.88	4.58
Benzo(a)pyrene	B2	...	...	7.3	0.0002 ^K	0.00120	5.98	5.59
Anthracene	D	0.3 ^A	...	...	...	0.0450	4.45	4.15
Phenanthrene	D	...	...	...	...	1.00	4.46	4.15
Naphthalene	D ^F	0.004 ^C , 0.04 ^D	...	...	...	31.0 ^L	3.28 ^L	3.11 ^P
Chrysene	B2	...	...	1.15 ^M	0.0002	0.00180	5.61	5.30
Benzo(k)fluoranthene	B2	...	...	...	0.0002 ^K	0.430	6.06	5.74
Fluorene	D	0.04 ^A	...	...	...	1.69	4.20	3.86
Fluoranthene	D	0.04 ^A	...	...	...	0.206	4.90	4.58
Benzo(g,h,i)perylene	D	...	...	...	...	0.000700	6.51	6.20
Benzo(b)fluoranthene	B2	...	...	...	0.0002 ^K	0.0140	6.06	5.74
Benzo(a)anthracene	B2	...	...	...	0.0002 ^K	0.00670	5.60	6.14

^A See Ref (2).^B See Ref (4).^C Chronic effect. See Ref (5).^D Subchronic effect. See Ref (5).^E The data is pending in the EPA-IRIS database.^F The data has been withdrawn in the EPA-IRIS database.^G The inhalation unit risk for benzene is 8.3×10^{-3} (mg/m³)⁻¹. The drinking water unit is 8.3×10^{-4} (mg/L).^H See Ref (6). Health-based criteria for carcinogenic polycyclic aromatic compounds (PAHs) with the exception of dibenzo(a,h)anthracene are set at one tenth of the level of benzo(a)pyrene due to their recognized lesser potency.^I Listed in the January 1991 Drinking Water Priority List and may be subject to future regulation (56 FR 1470, 01/14/91).^J USEPA, May 1993. Office of Drinking Water. 15 µg/L is an action level; standard for tap water.^K Proposed standard.^L See Ref (7).^M See Ref (8).^N See Ref (9).^O Estimation Equation (from (10)):(1) $\log K_{oc} = -0.55 \log S + 3.64$, where S = water solubility (mg/L)(2) $\log K_{oc} = 0.544 \log P + 1.377$ ^P See Ref (11).

X1.5.13.1 The RfD or SF values are generally obtained from a standard set of reference tables (for example, Integrated Risk Information System, IRIS (2), or the Health Effects Assessment Summary Tables, HEAST (3)). Except as noted, the toxicity evaluations that follow were taken from IRIS (2) because these are EPA-sanctioned evaluations. The information in IRIS (2), however, has typically only been peer-reviewed within the EPA and may not always have support from the external scientific community. The information in IRIS may also be subject to error (as exemplified by recent revisions in the slope factor for B(a)P and RfC for MTBE).

X1.5.13.2 HEAST (3) is a larger database than IRIS (2) and is often used as a source of health effects information. Whereas the information in IRIS (2) has been subject to data quality review, however, the information in the HEAST (3) tables has not. The user is expected to consult the original assessment documents to appreciate the strengths and limi-

TABLE X1.3 Commonly Selected Chemicals of Concern for Petroleum Products

	Unleaded Gasoline	Leaded Gasoline	Kerosene/ Jet Fuels	Diesel/ Light Fuel Oils	Heavy Fuel Oils
Benzene	X	X	X	...	...
Toluene	X	X	X	...	...
Ethylbenzene	X	X	X	...	...
Xylene	X	X	X	...	...
MTBE, TBA, MEK, MIBK, methanol, ethanol	when suspected ^A	when suspected ^A	...	...	...
Lead, EDC, EDB	...	X	...	...	...
PNAs ^B	...	...	X	X	X

^A For example, when these compounds may have been present in the spilled gasoline. These additives are not present in all gasolines.^B A list of selected PNAs for consideration is presented in Table X1.2.

tations of the data in HEAST (3). Thus, care should be exercised in using the values in HEAST (3).

X1.5.13.3 References for the physical/chemical properties

are provided in Table X1.2. All Henry's law constants quoted in text are from Ref (11) except MTBE which is from estimation: $H = (V_p)(MW)/760(S)$, where MW is the molecular weight, $V_p = 414$ mmHg at 100°F, and $S = 48\ 000$ mg/L.

X1.6 Profiles of Select Compounds:

X1.6.1 Benzene:

X1.6.1.1 *Toxicity Summary*—Based on human epidemiological studies, benzene has been found to be a human carcinogen (classified as a Group A carcinogen, known human carcinogen by the USEPA). An oral slope factor of 2.9×10^{-2} (mg/kg/day) $^{-1}$ has been derived for benzene based on the observance of leukemia from occupational exposure by inhalation. The USEPA has set a drinking water maximum contaminant level (MCL) at 5 µg/L. The maximum contaminant level goal (MCLG) for benzene is set at zero.

X1.6.1.2 Although the EPA does not usually set long-term drinking water advisories for carcinogenic materials (no exposure to carcinogens is considered acceptable), a ten-day drinking water health advisory for a child has been set at 0.235 mg/L based on hematological impairment in animals. The EPA is in the process of evaluating noncancer effects and an oral RfD for benzene is pending.

X1.6.1.3 In situations in which both aquatic life and water are consumed from a particular body of water, a recommended EPA water quality criterion is set at 0.66 µg/L. When only aquatic organisms are consumed, the criterion is 40 µg/L. These criteria were established at the one-in-one-million risk level (that is, the criteria represent a one-in-one-million estimated incremental increase in cancer risk over a lifetime).

X1.6.1.4 *Physical/Chemical Parameter Summary*—Benzene is subject to rapid volatilization (Henry's law constant = 5.5×10^{-3} m³-atm/mol) under common above-ground environmental conditions. Benzene will be mobile in soils due to its high water solubility (2.75×10^6 µg/L) and relatively low sorption to soil particles (log $K_{oc} = 1.92$) and, thus, has the potential to leach into ground water. Benzene has a relatively low log K_{ow} value (2.12) and is biodegradable. Therefore, it is not expected to bioaccumulate. In laboratory tests, when a free gasoline phase was in equilibrium with water, typical benzene concentrations in water ranged from 2.42×10^4 to 1.11×10^5 µg/L.

X1.6.2 Toluene:

X1.6.2.1 *Toxicity Summary*—Using data from animal studies, the USEPA has set an oral RfD for toluene at 0.2 mg/kg/day. In converting a NOAEL from an animal study, in which the critical effect observed was changes in liver and kidney weights, an uncertainty factor of 1000 and a modifying factor of 1 were used. The EPA has assigned an overall medium level of confidence in the RfD because, although the principal study was well performed, the length of the study corresponded to only subchronic rather than a chronic evaluation, and reproductive aspects were lacking. Based on the RfD and assuming 20 % exposure from drinking water, the EPA has set both drinking water MCL and MCLG of 1000 µg/L. Drinking water health advisories range from 1 mg/L (lifetime equivalent to the RfD) to 20 mg/L (one-day advisory for a child).

X1.6.2.2 In situations in which both aquatic life and

water are consumed from a particular body of water, the recommended water quality criterion is set at 1.43×10^4 µg/L. When only aquatic organisms are consumed, the criterion is 4.24×10^5 µg/L.

X1.6.2.3 An inhalation RfC of 0.4 mg/m³ was derived based on neurological effects observed in a small worker population. An uncertainty factor of 300 and a modifying factor of 1 were used to convert the lowest observed adverse effect level (LOAEL) to the RfC. The overall confidence in the RfC was established as medium because of the use of a LOAEL and because of the paucity of exposure information.

X1.6.2.4 *Physical/Chemical Parameter Summary*—Toluene is expected to volatilize rapidly, under common above-ground environmental conditions, due to its relatively high Henry's law constant (6.6×10^{-3} m³-atm/mol). It will be mobile in soils based on an aqueous solubility of 5.35×10^5 µg/L and relatively poor sorption to soils (estimated log $K_{oc} = 2.48$) and, hence, has a potential to leach into ground water. Toluene has a relatively low log K_{ow} (2.73) and is biodegradable. Bioaccumulation of toluene is, therefore, expected to be negligible. In laboratory tests, when a free gasoline phase was in equilibrium with water, typical toluene concentrations in water ranged from 3.48×10^4 to 8.30×10^4 µg/L.

X1.6.3 Xylenes:

X1.6.3.1 *Toxicity Summary*—Using data from animal studies, the USEPA has set an oral RfD for xylenes at 2.0 mg/kg/day. In converting a NOAEL from the animal study, in which the critical effects observed were hyperactivity, decreased body weight, and increased mortality (among male rats), an uncertainty factor of 100 and a modifying factor of 1 were used. The EPA has assigned an overall medium level of confidence in the RfD because, although the principal study was well designed and performed, supporting chemistry was not performed. A medium level of confidence was also assigned to the database. Based on the RfD and assuming 20 % exposure from drinking water, the EPA has set both drinking water MCL and MCLG of 10 000 g/L. Drinking water health advisories of 10 mg/L (lifetime, adult) and 40 mg/L (one-day, ten-day, and long-term child) are quoted by the EPA's Office of Drinking Water. No USEPA ambient water criteria are available for xylenes at this time. Evaluation of an inhalation RfC is pending.

X1.6.3.2 *Physical/Chemical Parameter Summary*—Xylenes are expected to rapidly volatilize under common above-ground environmental conditions based on their Henry's law constants (for *o*-xylene, $H = 5.1 \times 10^{-3}$ m³-atm/mol). Xylenes have a moderate water solubility (1.46 to 1.98×10^5 µg/L) (pure compound) as well as moderate capacities to sorb to soils (estimated log K_{oc} 2.38 to 2.79) and, therefore, they will be mobile in soils and may leach into ground water. Xylenes are biodegradable, and with log K_{ow} values in the range from 2.8 to 3.3, they are not expected to bioaccumulate.

X1.6.4 Ethylbenzene:

X1.6.4.1 *Toxicity Summary*—Using data from animal studies, the USEPA has set an oral RfD for ethylbenzene at 0.1 mg/kg/day. In converting a NOAEL from the animal study, in which the critical effects observed were liver and kidney toxicity, an uncertainty factor of 1000 and a modifying factor of 1 were used. The EPA has assigned an overall

TABLE X1.4 Weight of Evidence Criteria for Carcinogens

Category	Criterion
A	Human carcinogen, with sufficient evidence from epidemiological studies
B1	Probable human carcinogen, with limited evidence from epidemiological studies
B2	Probable human carcinogen, with sufficient evidence from animal studies and inadequate evidence or no data from epidemiological studies
C	Possible human carcinogen, with limited evidence from animal studies in the absence of human data
D	Not classifiable as to human carcinogenicity, owing to inadequate human and animal evidence
E	Evidence of noncarcinogenicity for humans, with no evidence of carcinogenicity in at least two adequate animal tests in different species, or in both adequate animal and epidemiological studies

low level of confidence in the RfD because the study was poorly designed and confidence in the supporting database is also low. Based on the RfD and assuming 20 % exposure from drinking water, the EPA has set both drinking water MCL and MCLG of 700 $\mu\text{g/L}$. Drinking water health advisories range from 700 $\mu\text{g/L}$ (lifetime equivalent to the RfD) to 32 mg/L (one-day advisory for a child). In situations in which both aquatic life and water are consumed from a particular body of water, a recommended ambient water criterion is set at 1400 $\mu\text{g/L}$. When only aquatic organisms are consumed, the criterion is 3280 $\mu\text{g/L}$. An inhalation RfC of 1 mg/ m^3 was derived based on developmental toxicity effects observed in rats and rabbits. An uncertainty factor of 300 and a modifying factor of 1 were used to convert the NOAEL to the RfC. Both the study design and database were rated low and, thus, the overall confidence in the RfC was established as low.

X1.6.4.2 Physical/Chemical Parameter Summary—Ethylbenzene has a relatively high Henry's law constant ($8.7 \times 10^{-3} \text{ m}^3\text{-atm/mol}$) and, therefore, can rapidly volatilize under common above-ground environmental conditions. Based on its moderate water solubility ($1.52 \times 10^5 \mu\text{g/L}$) and moderate capacity to sorb to soils (estimated $\log K_{oc} = 3.04$), it will have moderate mobility in soil and may leach into ground water. In laboratory tests, when a free gasoline phase was in equilibrium with water, typical combined ethylbenzene and xylenes concentrations in water ranged from 1.08×10^4 to $2.39 \times 10^4 \mu\text{g/L}$, due to partitioning effects. Ethylbenzene has a moderate low K_{ow} value (3.15) and is biodegradable. Therefore, it is not expected to bioaccumulate. In laboratory tests, when a free gasoline phase was in equilibrium with water, typical combined ethylbenzene and xylenes

concentrations in water ranged from 1.08×10^4 to $2.39 \times 10^4 \mu\text{g/L}$.

X1.6.5 Naphthalenes:

X1.6.5.1 Toxicity Summary—In general, poisoning may occur by ingestion of large doses, inhalation, or skin adsorption of naphthalene. It can cause nausea, headache, diaphoresis, hematuria, fever, anemia, liver damage, vomiting, convulsions, and coma. Methyl-naphthalenes are presumably less acutely toxic than naphthalene. Skin irritation and skin photosensitization are the only effects reported in man. Inhalation of the vapor may cause headache, confusion, nausea, and sometimes vomiting. The environmental concerns with naphthalenes are primarily attributed to effects on aquatic organisms. As a consequence, the EPA has not set any human health criteria for these materials (that is, there is no RfD or RfC, no drinking water MCL or MCLG or ambient water quality criteria). A risk assessment to define a RfD for these materials is presently under review by the EPA. Drinking water health advisories range from 20 $\mu\text{g/L}$ (lifetime, adult) to 500 $\mu\text{g/L}$ (one-day advisory for a child).⁶

X1.6.5.2 Physical/Chemical Parameter Summary: Naphthalene—Naphthalene has a relatively high Henry's law constant ($1.15 \times 10^{-3} \text{ m}^3\text{-atm/mol}$) and, thus, has the capacity to volatilize rapidly under common above-ground environmental conditions. It has a moderate water solubility ($3.10 \times 10^4 \mu\text{g/L}$) and $\log K_{oc}$ (3.11) and has the potential to leach to ground water. A moderate $\log K_{ow}$ value of 3.01 has been reported, but because naphthalene is very biodegradable, it is unlikely to bioconcentrate to a significant degree.

X1.6.5.3 Methyl-naphthalenes—Henry's law constants ($2.60 \times 10^{-4} \text{ m}^3\text{-atm/mol}$ and $5.18 \times 10^{-4} \text{ m}^3\text{-atm/mol}$ for 1- and 2-methyl-naphthalene, respectively) suggest that these materials have the potential to volatilize under common above-ground environmental conditions. 1-Methyl-naphthalene exhibits a water solubility similar to naphthalene ($2.60 \times 10^4 \mu\text{g/L}$ to $2.8 \times 10^4 \mu\text{g/L}$). However, solubility decreases with increasing alkylation (dimethyl-naphthalenes: $2.0 \times 10^3 \mu\text{g/L}$ to $1.1 \times 10^4 \mu\text{g/L}$, 1,4,5-trimethyl-naphthalene: $2.0 \times 10^3 \mu\text{g/L}$). These materials are, therefore, expected to be slightly mobile to relatively immobile in soil (for example, $\log K_{oc}$ is in the range from 2.86 to 3.93 for 1- and 2-methyl-naphthalenes). In aquatic systems, methyl-naphthalenes may partition from the water column to

⁶ Office of Water, USEPA, Washington, DC.

TABLE X1.5 Definitions of Important Toxicological Characteristics

Reference Dose—A reference dose is an estimate (with an uncertainty typically spanning an order of magnitude) of a daily exposure (mg/kg/day) to the general human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime of exposure.

Reference Concentration—A reference concentration is an estimate (with an uncertainty spanning perhaps an order of magnitude) of a continuous exposure to the human population (including sensitive subgroups) that is likely to be without appreciable deleterious effects during a lifetime.

Slope Factor—The slope of the dose-response curve in the low-dose region. When low-dose linearity cannot be assumed, the slope factor is the slope of the straight line from zero dose to the dose at 1 % excess risk. An upper bound on this slope is usually used instead of the slope itself. The units of the slope factor are usually expressed as (mg/kg/day).⁻¹

Drinking Water MCLs and MCLGs—Maximum contaminant levels (MCLs) are drinking water standards established by the EPA that are protective of human health. However, these standards take into account the technological capability of attaining these standards. The EPA has, therefore, also established MCL goals (MCLGs) which are based only on the protection of human health. The MCL standards are often used as clean-up criteria.

Drinking Water Health Advisories—The Office of Drinking Water provides health advisories (HAs) as technical guidance for the protection of human health. They are not enforceable federal standards. The HA's are the concentration of a substance, in drinking water estimated to have negligible deleterious effects in humans, when ingested for specified time periods.

Water Quality Criteria—These criteria are not rules and they do not have regulatory impact. Rather, these criteria present scientific data and guidance of the environmental effects of pollutants which can be useful to derive regulatory requirements based on considerations of water quality impacts.

organic matter contained in sediments and suspended solids. Methylnaphthalenes have high $\log K_{ow}$ values (greater than 3.5) and have the potential to bioaccumulate. They do, however, exhibit a moderate degree of biodegradation, which typically decreases with increased alkylation.

X1.6.6 Three to Six-Ringed PAHs—The most significant health effect for this class of compounds is their carcinogenicity, which is structure-dependent. Anthracene and phenanthrene have not been shown to cause cancer in laboratory animals. The available data does not prove pyrene to be carcinogenic to experimental animals. On the other hand, benz[a]-anthracene, benzo[a]pyrene, dibenz[a,h]anthracene, and 7,12-dimethylbenz[a]-anthracene have been shown to be carcinogenic in laboratory animals. B(a)P and pyrene are discussed in X1.6.7 and X1.6.8 as representatives of carcinogenic and noncarcinogenic effects of this class.

X1.6.7 Benzo(a)pyrene (BaP):

X1.6.7.1 Toxicity Summary—Based on animal data, B(a)P has been classified as a probable human carcinogen (B2 carcinogen) by the USEPA. A range of oral slope factors from 4.5 to 11.7 (mg/kg/day)⁻¹ with a geometric mean of 7.3 (mg/kg/day)⁻¹ has been derived for B(a)P based on the observance of tumors of the forestomach and squamous cell carcinomas in mice. The data was considered less than optimal but acceptable (note that the carcinogenicity assessment for B(a)P may change in the near future pending the outcome of an on-going EPA review). The EPA has proposed a drinking water MCL at 0.2 µg/L (based on the analytical detection limits). The MCLG for B(a)P is set at zero. In situations in which both aquatic life and water are consumed from a particular body of water, a recommended EPA water quality criterion is set at 2.8×10^{-3} µg/L. When only aquatic organisms are consumed, the criterion is 3.11×10^{-2} µg/L.

X1.6.7.2 Physical/Chemical Parameter Summary—When released to water, PAHs are not subject to rapid volatilization (Henry's law constants are on the order of 1.0×10^{-4} m³-atm/mol or less) under common environmental conditions. They have low aqueous solubility values and tend to sorb to soils and sediments and remain fixed in the environment. Three ring members of this group such as anthracene and phenanthrene have water solubilities on the order of 1000 µg/L. The water solubilities decrease substantially for larger molecules in the group, for example, benzo[a]pyrene has a water solubility of 1.2 µg/L. The $\log K_{oc}$ values for PAHs are on the order of 4.3 and greater, which suggests that PAHs will be expected to adsorb very strongly to soil. The PAHs with more than three rings generally have high $\log K_{ow}$ values (6.06 for benzo[a]pyrene), have poor biodegradability characteristics and may bioaccumulate.

X1.6.8 Pyrene:

X1.6.8.1 Toxicity Summary—Using data from animal studies, the USEPA has set an oral RfD for pyrene at 3×10^{-2} mg/kg/day. In converting a NOAEL from the animal study, in which the critical effects observed were kidney toxicity, an uncertainty factor of 3000 and a modifying factor of 1 were used. The EPA has assigned an overall low level of confidence in the RfD because although the study was well-designed, confidence in the supporting database is low. No drinking water MCLs or health advisories have been set. In situations in which both aquatic life and water are

consumed from a particular body of water, a recommended EPA water quality criterion is set at 2.8×10^{-3} µg/L. When only aquatic organisms are consumed, the criterion is 3.11×10^{-2} µg/L.

X1.6.8.2 Physical/Chemical Parameter Summary—Refer to X1.6.7.2 for BaP. Also see Table X1.2.

X1.6.9 MTBE:

X1.6.9.1 Toxicity Summary—Using data from animal studies, the USEPA has set an inhalation RfC for MTBE at 3 mg/m³. In converting a NOAEL from the animal study, in which the critical effects observed included increased liver and kidney weight and increased severity of spontaneous renal lesions (females), increased prostration (females) and swollen pericolar tissue, an uncertainty factor of 100 and a modifying factor of 1 were used. The EPA has assigned an overall medium level of confidence in the RfC because although the study was well-designed, some information on the chemistry was lacking. The confidence in the supporting database is medium to high. No drinking water MCLs or ambient water quality criteria have been set. However, a risk assessment, which may define a RfD for this material, is presently under review by EPA. Drinking water health advisories range from 40 µg/L (lifetime, adult) to 3000 µg/L (one-day advisory for a child).⁶

X1.6.9.2 Physical/Chemical Parameter Summary—The Henry's law constant for MTBE is estimated to be approximately 1.0×10^{-3} m³-atm/mol. It is, therefore, expected to have the potential to rapidly volatilize under common above-ground environmental conditions. It is very water soluble (water solubility is 4.8×10^7 µg/L), and with a relatively low capacity to sorb to soils (estimated $\log K_{oc} = 1.08$), MTBE will migrate at the same velocity as the water in which it is dissolved in the subsurface. The $\log K_{ow}$ value has been estimated to be between 1.06 and 1.30, indicating MTBE's low bioaccumulative potential. It is expected to have a low potential to biodegrade, but no definitive studies are available.

X1.6.10 Lead:

X1.6.10.1 Toxicity Summary—(The following discussion is for inorganic lead—not the organic forms of lead (tetraethyllead, tetramethyllead) that were present in petroleum products.) A significant amount of toxicological information is available on the health effects of lead. Lead produces neurotoxic and behavioral effects particularly in children. However, the EPA believes that it is inappropriate to set an RfD for lead and its inorganic compounds because the agency believes that some of the effects may occur at such low concentrations as to suggest no threshold. The EPA has also determined that lead is a probable human carcinogen (classified as B2). The agency has chosen not to set a numeric slope factor at this time, however, because it is believed that standard procedures for doing so may not be appropriate for lead. At present, the EPA has set an MCLG of zero but has set no drinking water (MCL) or health advisories because of the observance of low-level effects, the overall Agency goal of reducing total lead exposure and because of its classification as a B2 carcinogen. An action of level of 15 µg/L has been set for water distribution systems (standard at the tap). The recommended EPA water quality criterion for consumption of both aquatic life and water is set at 50 µg/L.

X1.6.10.2 *Physical/Chemical Parameter Summary*—Organic lead additive compounds are volatile (estimated Henry's law constant for tetraethyl lead = 7.98×10^{-2} m³-atm/mol) and may also sorb to particulate matter in the air. Tetraethyl lead has an aqueous solubility of 800 µg/L and an estimated log K_{oc} of 3.69 and, therefore, should not be very mobile in the soil. It decomposes to inorganic lead in dilute aqueous solutions and in contact with other environmental media. In free product (gasoline) plumes, however, it may remain unchanged. Inorganic lead compounds tightly bind to most soils with minimal leaching under natural conditions. Aqueous solubility varies depending on the species involved. The soil's capacity to sorb lead is correlated with soil pH, cation exchange capacity, and organic matter. Lead does not appear to bioconcentrate significantly in fish but does in some shellfish, such as mussels. Lead is not biodegradable.

X1.7 *Discussion of Acceptable Risk (12)*—Beginning in the late 1970s and early 1980s, regulatory agencies in the United States and abroad frequently adopted a cancer risk criteria of one-in-one-million as a negligible (that is, of no concern) risk when fairly large populations might be exposed to a suspect carcinogen. Unfortunately, theoretical increased cancer risks of one-in-one-million are often incorrectly portrayed as serious public health risks. As recently discussed by Dr. Frank Young (13), the current commissioner of the Food and Drug Administration (FDA), this was not the intent of such estimates:

X1.7.1 In applying the de minimis concept and in setting other safety standards, the FDA has been guided by the figure of "one-in-one-million." Other Federal agencies have also used a one-in-one-million increased risk over a lifetime as a reasonable criterion for separating high-risk problems warranting agency attention from negligible risk problems that do not.

X1.7.2 The risk level of one-in-one-million is often misunderstood by the public and the media. It is not an actual risk, that is, we do not expect one out of every million people to get cancer if they drink decaffeinated coffee. Rather, it is a mathematical risk based on scientific assumptions used in risk assessment. The FDA uses a conservative estimate to ensure that the risk is not understated. We interpret animal test results conservatively, and we are extremely careful when we extrapolate risks to humans. When the FDA uses the risk level of one-in-one-million, it is confident that the risk to humans is virtually nonexistent.

X1.7.3 In short, a "one-in-one-million" cancer risk estimate, which is often tacitly assumed by some policy-makers to represent a trigger level for regulatory action, actually represents a level of risk that is so small as to be of negligible concern.

X1.7.4 Another misperception within the risk assessment arena is that all occupational and environmental regulations have as their goal a theoretical maximum cancer risk of 1 in 1 000 000. Travis, et al (14) recently conducted a retrospective examination of the level of risk that triggered regulatory action in 132 decisions. Three variables were considered: (1) individual risk (an upper-bound estimate of the probability at the highest exposure), (2) population risk (an upper-limit estimate of the number of additional incidences of cancer in the exposed population), and (3) population size. The

findings of Travis, et al (14) can be summarized as follows:

X1.7.4.1 Every chemical with an individual lifetime risk above 4×10^{-3} received regulation. Those with values below 1×10^{-6} remained unregulated.

X1.7.4.2 For small populations, regulatory action never resulted for individual risks below 1×10^{-4} .

X1.7.4.3 For potential effects resulting from exposures to the entire United States population, a risk level below 1×10^{-6} never triggered action; above 3×10^{-4} always triggered action.

X1.7.5 Rodricks, et al (15) also evaluated regulatory decisions and reached similar conclusions. In decisions relating to promulgation of National Emission Standards for Hazardous Air Pollutants (NESHAPS), the USEPA has found the maximum individual risks and total population risks from a number of radionuclide and benzene sources too low to be judged significant. Maximum individual risks were in the range from 3.6×10^{-5} to 1.0×10^{-3} . In view of the risks deemed insignificant by USEPA, Rodricks, et al (15) noted that 1×10^{-5} (1 in 100 000) appears to be in the range of what USEPA might consider an insignificant average lifetime risk, at least where aggregate population risk is no greater than a fraction of a cancer yearly.

X1.7.6 Recently, final revisions to the National Contingency Plan (16) have set the acceptable risk range between 10^{-4} and 10^{-6} at hazardous waste sites regulated under CERCLA. In the recently promulgated *Hazardous Waste Management System Toxicity Characteristics Revisions (17)*, the USEPA has stated that:

"For drinking water contaminants, EPA sets a reference risk range for carcinogens at 10^{-6} excess individual cancer risk from lifetime exposure. Most regulatory actions in a variety of EPA programs have generally targeted this range using conservative models which are not likely to underestimate the risk."

X1.7.7 Interestingly, the USEPA has selected and promulgated a single risk level of 1 in 100 000 (1×10^{-5}) in the *Hazardous Waste Management System Toxicity Characteristics Revisions (17)*. In their justification, the USEPA cited the following rationale:

The chosen risk level of 10^{-5} is at the midpoint of the reference risk range for carcinogens (10^{-4} to 10^{-6}) generally used to evaluate CERCLA actions. Furthermore, by setting the risk level at 10^{-5} for TC carcinogens, EPA believes that this is the highest risk level that is likely to be experienced, and most if not all risks will be below this level due to the generally conservative nature of the exposure scenario and the underlying health criteria. For these reasons, the Agency regards a 10^{-5} risk level for Group A, B, and C carcinogens as adequate to delineate, under the Toxicity Characteristics, wastes that clearly pose a hazard when mismanaged."

X1.7.8 When considering these limits it is interesting to note that many common human activities entail annual risks greatly in excess of one-in-one-million. These have been discussed by Grover Wrenn, former director of Federal Compliance and State Programs at OSHA, as follows:

X1.7.9 State regulatory agencies have not uniformly adopted a one-in-one-million (1×10^{-6}) risk criterion in making environmental and occupational decisions. The states of Virginia, Maryland, Minnesota, Ohio, and Wisconsin have employed or proposed to use the one-in-one-hundred-thousand (1×10^{-5}) level of risk in their risk management decisions (18). The State of Maine Department of Human Services (DHS) uses a lifetime risk of one in one

hundred thousand as a reference for non-threshold (carcinogenic) effects in its risk management decisions regarding exposures to environmental contaminants (19). Similarly, a lifetime incremental cancer risk of one in one hundred thousand is used by the Commonwealth of Massachusetts as a cancer risk limit for exposures to substances in more than one medium at hazardous waste disposal sites (20). This risk limit represents the total cancer risk at the site associated with exposure to multiple chemicals in all contaminated media. The State of California has also established a level of risk of one in one hundred thousand for use in determining levels of chemicals and exposures that pose no significant risks of cancer under the Safe Drinking Water and Toxic Enforcement Act of 1986 (Proposition 65) (21). Workplace air standards developed by the Occupational Safety and Health Administration (OSHA) typically reflect theoretical risks of one in one thousand (1×10^{-3}) or greater (15).

X2. DEVELOPMENT OF RISK-BASED SCREENING LEVELS (RBSLs) APPEARING IN SAMPLE LOOK-UP TABLE X2.1

X2.1 Introduction:

X2.1.1 This appendix contains the equations and parameters used to construct the example "Look-Up" (Table X2.1). This table was prepared solely for the purpose of presenting an example Tier I matrix of RBSLs, and these values should not be viewed, or misused, as proposed remediation "standards." The reader should note that not all possible pathways have been considered and a number of assumptions concerning exposure scenarios and parameter values have been made. These should be reviewed for appropriateness before using the listed RBSLs as Tier I screening values.

X2.1.2 The approaches used to calculate RBSLs appearing in Table X2.1 are briefly discussed as follows for exposure to vapors, ground water, surficial soils, and subsurface soils by means of the following pathways:

X2.1.2.1 Inhalation of vapors,

X2.1.2.2 Ingestion of ground water,

X2.1.2.3 Inhalation of outdoor vapors originating from dissolved hydrocarbons in ground water,

X2.1.2.4 Inhalation of indoor vapors originating from dissolved hydrocarbons in ground water,

X2.1.2.5 Ingestion of surficial soil, inhalation of outdoor vapors and particulates emanating from surficial soils, and dermal absorption resulting from surficial soil contact with skin,

X2.1.2.6 Inhalation of outdoor vapors originating from hydrocarbons in subsurface soils,

X2.1.2.7 Inhalation of indoor vapors originating from subsurface hydrocarbons, and

X2.1.2.8 Ingestion of ground water impacted by leaching of dissolved hydrocarbons from subsurface soils.

X2.1.3 For the pathways considered, approaches used in this appendix are consistent with guidelines contained in Ref (26).

X2.1.4 The development presented as follows focuses only on human-health RBSLs for chronic (long-term) exposures.

X2.1.4.1 In the case of compounds that have been classi-

X1.7.10 Ultimately, the selection of an acceptable and de minimis risk level is a policy decision in which both costs and benefits of anticipated courses of action should be thoroughly evaluated. However, actuarial data and risk estimates of common human activities, regulatory precedents, and the relationship between the magnitude and variance of background and incremental risk estimates all provide compelling support for the adoption of the de minimis risk level of 1×10^{-5} for regulatory purposes.

X1.7.11 In summary, U.S. Federal and state regulatory agencies have adopted a one-in-one-million cancer risk as being of negligible concern in situations where large populations (for example, 200 million people) are involuntarily exposed to suspect carcinogens (for example, food additives). When smaller populations are exposed (for example, in occupational settings), theoretical cancer risks of up to 10^{-4} (1 in 10 000) have been considered acceptable.

As carcinogens, the RBSLs are based on the general equation:

$$\text{risk} = \text{average lifetime intake [mg/kg-day]} \times \text{potency factor [mg/kg-day]}^{-1}$$

where the intake depends on exposure parameters (ingestion rate, exposure duration, and so forth), the source concentration, and transport rates between the source and receptor. The potency factor is selected after reviewing a number of sources, including the USEPA Integrated Risk Information System (IRIS) (2) database, USEPA Health Effects Assessment Summary Tables (HEAST) (3), and peer-reviewed sources. The RBSL values appearing in Table X2.1 correspond to probabilities of adverse health effects ("risks") in the range from 10^{-6} to 10^{-4} resulting from the specified exposure. Note that this risk value does not reflect the probability for the specified exposure scenario to occur. Therefore, the actual potential risk to a population for these RBSLs is lower than the 10^{-6} to 10^{-4} range.

X2.1.4.2 In the case of compounds that have not been classified as carcinogens, the RBSLs are based on the general equation:

$$\text{hazard quotient} = \frac{\text{average intake [mg/kg-day]}}{\text{reference dose [mg/kg-day]}}$$

where the intake depends on exposure parameters (ingestion rate, exposure duration, and so forth), the source concentration, and transport rates between the source and receptor. The reference dose is selected after reviewing a number of sources, including the USEPA Integrated Risk Information System (IRIS) (2) database, USEPA Health Effects Assessment Summary Tables (HEAST) (3), and peer-reviewed sources. The RBSL values appearing in Table X2.1 correspond to hazard quotients of unity resulting from the specified exposure. Note that this hazard quotient value does not reflect the probability for the specified exposure scenario to occur. Therefore, the actual potential impact to a population for these RBSLs is lower than a hazard quotient of unity.

X2.1.5 Tables X2.2 through X2.7 summarize the equa-

TABLE X2.1 Example Tier 1 Risk-Based Screening Level (RBSL) Look-up Table^A

NOTE—This table is presented here only as an example set of Tier 1 RBSLs. It is not a list of proposed standards. The user should review all assumptions prior to using any values. Appendix X2 describes the basis of these values.

Exposure Pathway	Receptor Scenario	Target Level	Benzene	Ethylbenzene	Toluene	Xylenes (Mixed)	Napthalenes	Benzo (a)pyrene
Air								
Indoor air screening levels for inhalation exposure, $\mu\text{g}/\text{m}^3$	residential	cancer risk = $1\text{E}-06$	3.92E-01					1.86E-03
		cancer risk = $1\text{E}-04$ chronic HQ = 1	3.92E+01	1.39E+03	5.56E+02	9.73E+03	1.95E+01	1.86E-01
Outdoor air screening levels for inhalation exposure, $\mu\text{g}/\text{m}^3$	commercial/ industrial	cancer risk = $1\text{E}-06$	4.93E-01					2.35E-03
		cancer risk = $1\text{E}-04$ chronic HQ = 1	4.93E+01	1.46E+03	5.84E+02	1.02E+04	2.04E+01	2.35E-01
OSHA TWA PEL, $\mu\text{g}/\text{m}^3$	residential	cancer risk = $1\text{E}-06$	2.94E-01					1.40E-03
		cancer risk = $1\text{E}-04$ chronic HQ = 1	2.94E+01	1.04E+03	4.17E+02	7.30E+03	1.46E+01	1.40E-01
Mean odor detection threshold, $\mu\text{g}/\text{m}^3$ ^B	commercial/ industrial	cancer risk = $1\text{E}-06$	4.93E-01					2.35E-03
		cancer risk = $1\text{E}-04$ chronic HQ = 1	4.93E+01	1.46E+03	5.84E+02	1.02E+04	2.04E+01	2.35E-01
National indoor background concentration range, $\mu\text{g}/\text{m}^3$ ^C			3.20E+03	4.35E+05	7.53E+05	4.35E+06	5.00E+04	2.00E+02 ^A
			1.95E+05	6.00E+03	8.70E+04	2.00E+02		
			3.25E+00 to 2.15E+01	2.20E+00 to 9.70E+00	9.60E-01 to 2.91E+01	4.85E+00 to 4.76E+01		
Soil								
Soil volatilization to outdoor air, mg/kg	residential	cancer risk = $1\text{E}-06$	2.72E-01					RES ^D
		cancer risk = $1\text{E}-04$ chronic HQ = 1	2.73E+01	RES	RES	RES	RES	RES
	commercial/ industrial	cancer risk = $1\text{E}-06$	4.57E-01					RES
		cancer risk = $1\text{E}-04$ chronic HQ = 1	4.57E+01	RES	RES	RES	RES	RES
Soil-vapor intrusion from soil to buildings, mg/kg	residential	cancer risk = $1\text{E}-06$	5.37E-03					RES
		cancer risk = $1\text{E}-04$ chronic HQ = 1	5.37E-01	4.27E+02	2.06E+01	RES	4.07E+01	RES
	commercial/ industrial	cancer risk = $1\text{E}-06$	1.09E-02					RES
		cancer risk = $1\text{E}-04$ chronic HQ = 1	1.09E+00	1.10E+03	5.45E+01	RES	1.07E+02	RES
Surficial soil (0 to 3 ft) (0 to 0.9 m) ingestion/dermal/inhalation, mg/kg	residential	cancer risk = $1\text{E}-06$	5.82E+00					1.30E-01
		cancer risk = $1\text{E}-04$ chronic HQ = 1	5.82E+02	7.83E+03	1.33E+04	1.45E+06	9.77E+02	1.30E+01
	commercial/ industrial	cancer risk = $1\text{E}-06$	1.00E+01					3.04E-01
		cancer risk = $1\text{E}-04$ chronic HQ = 1	1.00E+03	1.15E+04	1.87E+04	2.08E+05	1.90E+03	3.04E+01
Soil-leachate to protect ground water ingestion target level, mg/kg	residential	MCLs	2.93E-02	1.10E+02	1.77E+01	3.05E+02	N/A	9.42E+00
		cancer risk = $1\text{E}-06$	1.72E-02					5.90E-01
	commercial/ industrial	cancer risk = $1\text{E}-04$ chronic HQ = 1	1.72E+00	5.75E+02	1.29E+02	RES	2.29E+01	RES
		cancer risk = $1\text{E}-06$	5.78E-02					1.85E+00
			5.78E+00	1.61E+03	3.61E+02	RES	6.42E+01	RES
Ground Water								
Ground water volatilization to outdoor air, mg/L	residential	cancer risk = $1\text{E}-06$	1.10E+01					>S ^E
		cancer risk = $1\text{E}-04$ chronic HQ = 1	1.10E+03	>S	>S	>S	>S	>S
	commercial/ industrial	cancer risk = $1\text{E}-06$	1.84E+01					>S
		cancer risk = $1\text{E}-04$ chronic HQ = 1	>S	>S	>S	>S	>S	>S
Ground water ingestion, mg/L	residential	MCLs	5.00E-03	7.00E-01	1.00E+00	1.00E+01	N/A	2.00E-04
		cancer risk = $1\text{E}-06$	2.94E-03					1.17E-05
	commercial/ industrial	cancer risk = $1\text{E}-04$ chronic HQ = 1	2.94E-01	3.65E+00	7.30E+00	7.30E+01	1.46E-01	1.17E-03
		cancer risk = $1\text{E}-06$	9.87E-03					3.92E-05
	commercial/ industrial	cancer risk = $1\text{E}-04$ chronic HQ = 1	9.87E-01	1.02E+01	2.04E+01	>S	4.09E-01	>S
		cancer risk = $1\text{E}-06$	2.38E-02					>S
Ground water—vapor intrusion from ground water to buildings, mg/L	residential	cancer risk = $1\text{E}-04$ chronic HQ = 1	2.38E+00	7.75E+01	3.28E+01	>S	4.74E+00	>S
		cancer risk = $1\text{E}-06$	7.39E-02					>S
	commercial/ industrial	cancer risk = $1\text{E}-04$ chronic HQ = 1	7.39E+00	>S	8.50E+01	>S	1.23E+01	>S

^A As benzene soluble coal tar pitch volatiles.

^B See Ref (22).

^C See Refs (23-25).

^D RES—Selected risk level is not exceeded for pure compound present at any concentration.

^E >S—Selected risk level is not exceeded for all possible dissolved levels (\leq pure component solubility).

tions and parameters used to prepare the example look-up Table X2.1. The basis for each of these equations is discussed in X2.2 through X2.10.

X2.2 Air—Inhalation of Vapors (Outdoors/Indoors)—In this case chemical intake results from the inhalation of vapors. It is assumed that vapor concentrations remain constant over the duration of exposure, and all inhaled chemicals are absorbed. Equations appearing in Tables X2.2 and X2.3 for estimating RBSLs for vapor concentrations in the breathing zone follow guidance given in Ref (26). Should the calculated RBSL exceed the saturated vapor concentration for any individual component, " $>P_{vap}$ " is entered in the table to indicate that the selected risk level or hazard quotient cannot be reached or exceeded for that compound

and the specified exposure scenario.

X2.3 Ground Water—Ingestion of Ground Water—In this case chemical intake results from ingestion of ground water. It is assumed that the dissolved hydrocarbon concentrations remain constant over the duration of exposure. Equations appearing in Tables X2.2 and X2.3 for estimating RBSLs for drinking water concentrations follow guidance given in Ref (26) for ingestion of chemicals in drinking water. Should the calculated RBSL exceed the pure component solubility for any individual component, ">S" is entered in the table to indicate that the selected risk level or hazard quotient cannot be reached or exceeded for that compound and the specified exposure scenario (unless free-phase product is mixed with the ingested water).

TABLE X2.2 Equations Used to Develop Example Tier 1 Risk-Based Screening Level (RBSLs) Appearing in "Look-Up" Table X2.1—Carcinogenic Effects^a

NOTE—See Tables X2.4 through X2.7 for definition of parameters.

Medium	Exposure Route	Risk-Based Screening Level (RBSL)
Air	inhalation ^b	$RBSL_{air} \left[\frac{\mu g}{m^3-air} \right] = \frac{TR \times BW \times AT_c \times 365 \frac{days}{years} \times 10^3 \frac{\mu g}{mg}}{SF_i \times IR_{air} \times EF \times ED}$
Ground water	ingestion (potable ground water supply only) ^b	$RBSL_w \left[\frac{mg}{L-H_2O} \right] = \frac{TR \times BW \times AT_c \times 365 \frac{days}{years}}{SF_o \times IR_w \times EF \times ED}$
Ground water ^c	enclosed-space (indoor) vapor inhalation ^d	$RBSL_w \left[\frac{mg}{L-H_2O} \right] = \frac{RBSL_{air} \left[\frac{\mu g}{m^3-air} \right] \times 10^{-3} \frac{mg}{\mu g}}{VF_{weep}}$
Ground water ^c	ambient (outdoor) vapor inhalation ^d	$RBSL_w \left[\frac{mg}{L-H_2O} \right] = \frac{RBSL_{air} \left[\frac{\mu g}{m^3-air} \right] \times 10^{-3} \frac{mg}{\mu g}}{VF_{wamb}}$
Surficial soil	ingestion of soil, inhalation of vapors and particulates, and dermal contact ^e	$RBSL_s \left[\frac{\mu g}{kg-soil} \right] = \frac{TR \times BW \times AT_c \times 365 \frac{days}{years}}{EF \times ED \left[\left(SF_o \times 10^{-3} \frac{kg}{mg} \times (IR_{soil} \times RAF_o + SA \times M \times RAF_{dl}) \right) + (SF_i \times IR_{air} \times (VF_{wee} + VF_{pl})) \right]}$ For surficial and excavated soils (0 to 1 m)
Subsurface soil ^c	ambient (outdoor) vapor inhalation ^d	$RBSL_s \left[\frac{mg}{kg-soil} \right] = \frac{RBSL_{air} \left[\frac{\mu g}{m^3-air} \right] \times 10^{-3} \frac{mg}{\mu g}}{VF_{samb}}$
Subsurface soil ^c	enclosed space (indoor) vapor inhalation ^d	$RBSL_s \left[\frac{mg}{kg-soil} \right] = \frac{RBSL_{air} \left[\frac{\mu g}{m^3-air} \right] \times 10^{-3} \frac{mg}{\mu g}}{VF_{swee}}$
Subsurface soil ^c	leaching to ground water ^d	$RBSL_s \left[\frac{mg}{kg-soil} \right] = \frac{RBSL_w \left[\frac{mg}{L-H_2O} \right]}{LF_{sw}}$

^a Note that all RBSL values should be compared with thermodynamic partitioning limits, such as solubility levels, maximum vapor concentrations, and so forth. If a RBSL exceeds the relevant partitioning limit, this is an indication that the selected risk or hazard level will never be reached or exceeded for that chemical and the selected exposure scenario.

^b Screening levels for these media based on other considerations (for example, aesthetic, background levels, environmental resource protection, and so forth) can be derived with these equations by substituting the selected target level for $RBSL_{air}$ or $RBSL_w$ appearing in these equations.

^c These equations are based on Ref (26).

^d These equations simply define the "cross-media partitioning factors," VF_v and LF_{sw} .

TABLE X2.3 Equations Used to Develop Example Tier 1 Risk-Based Screening Level (RBSLs) Appearing in "Look-Up" Table X2.1—Noncarcinogenic Effects^a

NOTE—See Tables X2.4 through X2.7 for definition of parameters.

Medium	Exposure Route	Risk-Based Screening Level (RBSL)
Air	inhalation ^b	$RBSL_{air} \left[\frac{\mu g}{m^3-air} \right] = \frac{THQ \times RfD_o \times BW \times AT_n \times 365 \frac{days}{years} \times 10^3 \frac{\mu g}{mg}}{IR_{air} \times EF \times ED}$
Ground water	ingestion (potable ground water supply only) ^b	$RBSL_{gw} \left[\frac{mg}{L-H_2O} \right] = \frac{THQ \times RfD_o \times BW \times AT_n \times 365 \frac{days}{years}}{IR_{gw} \times EF \times ED}$
Ground water ^c	enclosed-space (indoor) vapor inhalation ^d	$RBSL_{gw} \left[\frac{mg}{L-H_2O} \right] = \frac{RBSL_{air} \left[\frac{\mu g}{m^3-air} \right]}{VF_{wair}} \times 10^{-3} \frac{mg}{\mu g}$
Ground water ^c	ambient (outdoor) vapor inhalation ^d	$RBSL_{gw} \left[\frac{mg}{L-H_2O} \right] = \frac{RBSL_{air} \left[\frac{\mu g}{m^3-air} \right]}{VF_{wamb}} \times 10^{-3} \frac{mg}{\mu g}$
Surficial soil	ingestion of soil, inhalation of vapors and particulates, and dermal contact ^b	$RBSL_s \left[\frac{\mu g}{kg-soil} \right] = \frac{THQ \times BW \times AT_n \times 365 \frac{days}{years}}{EF \times ED \left(\frac{10^{-6} \frac{kg}{mg} \times (IR_{soil} \times RAF_o + SA \times M \times RAF_d)}{RfD_o} + \frac{(IR_{air} \times (VF_{sw} + VF_o))}{RfD_i} \right)}$ For surficial and excavated soils (0 to 1 m)
Subsurface soil ^c	ambient (outdoor) vapor inhalation ^d	$RBSL_s \left[\frac{mg}{kg-soil} \right] = \frac{RBSL_{air} \left[\frac{\mu g}{m^3-air} \right]}{VF_{samb}} \times 10^{-3} \frac{mg}{\mu g}$
Subsurface soil ^c	enclosed space (indoor) vapor inhalation ^d	$RBSL_s \left[\frac{mg}{kg-soil} \right] = \frac{RBSL_{air} \left[\frac{\mu g}{m^3-air} \right]}{VF_{sair}} \times 10^{-3} \frac{mg}{\mu g}$
Subsurface soil ^c	leaching to ground water ^d	$RBSL_s \left[\frac{mg}{kg-soil} \right] = \frac{RBSL_{gw} \left[\frac{mg}{L-H_2O} \right]}{LF_{sw}}$

^a Note that all RBSL values should be compared with thermodynamic partitioning limits, such as solubility levels, maximum vapor concentrations, and so forth. If a RBSL exceeds the relevant partitioning limit, this is an indication that the selected risk or hazard level will never be reached or exceeded for that chemical and the selected exposure scenario.

^b Screening levels for these media based on other considerations (for example, aesthetic, background levels, environmental resource protection, and so forth) can be derived with these equations by substituting the selected target level for RBSL_{air} or RBSL_{gw} appearing in these equations.

^c These equations are based on Ref (26).

^d These equations simply define the "cross-media partitioning factors," VF_{ij} and LF_{sw}.

X2.4 Ground Water—Inhalation of Outdoor Vapors:

X2.4.1 In this case chemical intake is a result of inhalation of outdoor vapors which originate from dissolved hydrocarbons in ground water located some distance below ground surface. Here the goal is to determine the dissolved hydrocarbon RBSL that corresponds to the target RBSL for outdoor vapors in the breathing zone, as given in Tables X2.3 and X2.4. If the selected target vapor concentration is some value other than the RBSL for inhalation (that is, odor threshold or ecological criterion), this value can be substituted for the RBSL_{air} parameter appearing in the equations given in Tables X2.2 and X2.3.

X2.4.2 A conceptual model for the transport of chemicals

from ground water to ambient air is depicted in Fig. X2.1. For simplicity, the relationship between outdoor air and dissolved ground water concentrations is represented in Tables X2.2 and X2.3 by the "volatilization factor," VF_{wamb} [(mg/m³-air)/(mg/L-H₂O)], defined in Table X2.5. It is based on the following assumptions:

X2.4.2.1 A constant dissolved chemical concentration in ground water,

X2.4.2.2 Linear equilibrium partitioning between dissolved chemicals in ground water and chemical vapors at the ground water table,

X2.4.2.3 Steady-state vapor- and liquid-phase diffusion through the capillary fringe and vadose zones to ground

TABLE X2.4 Exposure Parameters Appearing in Tables X2.2 and X2.3

Parameters	Definitions, Units	Residential	Commercial/Industrial
AT_c	averaging time for carcinogens, years	70 years	70 years ^A
AT_n	averaging time for noncarcinogens, years	30 years	25 years ^A
BW	adult body weight, kg	70 kg	70 kg ^A
ED	exposure duration, years	30 years	25 years ^A
EF	exposure frequency, days/years	350 days/year	250 days/year ^A
IR_{soil}	soil ingestion rate, mg/day	100 mg/day	50 mg/day ^A
$IR_{air-indoor}$	daily indoor inhalation rate, m ³ /day	15 m ³ /day	20 m ³ /day ^A
$IR_{air-outdoor}$	daily outdoor inhalation rate, m ³ /day	20 m ³ /day	20 m ³ /day ^A
IR_w	daily water ingestion rate, L/day	2 L/day	1 L/day ^A
LF_{sw}	leaching factor, (mg/L-H ₂ O)/(mg/kg-soil)—see Table X2.5	chemical-specific	chemical-specific
M	soil to skin adherence factor, mg/cm ²	0.5	0.5 ^B
RAF_d	dermal relative absorption factor, volatiles/PAHs	0.5/0.05	0.5/0.05 ^B
RAF_o	oral relative absorption factor	1.0	1.0
$RBSL_i$	risk-based screening level for media i, mg/kg-soil, mg/L-H ₂ O, or $\mu\text{g}/\text{m}^3\text{-air}$	chemical-, media-, and exposure route-specific	chemical-, media-, and exposure route-specific
RfD_i	inhalation chronic reference dose, mg/kg-day	chemical-specific	chemical-specific
RfD_o	oral chronic reference dose, mg/kg-day	chemical-specific	chemical-specific
SA	skin surface area, cm ² /day	3160	3160 ^A
SF_i	inhalation cancer slope factor, (mg/kg-day) ⁻¹	chemical-specific	chemical-specific
SF_o	oral cancer slope factor, (mg/kg-day) ⁻¹	chemical-specific	chemical-specific
THQ	target hazard quotient for individual constituents, unitless	1.0	1.0
TR	target excess individual lifetime cancer risk, unitless	for example, 10 ⁻⁶ or 10 ⁻⁴	for example, 10 ⁻⁶ or 10 ⁻⁴
VF_i	volatilization factor, (mg/m ³ -air)/(mg/kg-soil) or (mg/m ³ -air)/(mg/L-H ₂ O)—see Table X2.5	chemical- and media-specific	chemical- and media-specific

^A See Ref (27).

^B See Ref (28).

surface.

X2.4.2.4 No loss of chemical as it diffuses towards ground surface (that is, no biodegradation), and

X2.4.2.5 Steady well-mixed atmospheric dispersion of the emanating vapors within the breathing zone as modeled by a "box model" for air dispersion.

X2.4.3 Should the calculated $RBSL_w$ exceed the pure component solubility for any individual component, ">S" is entered in the table to indicate that the selected risk level or hazard quotient cannot be reached or exceeded for that compound and the specified exposure scenario.

X2.5 Ground Water—Inhalation of Enclosed-Space (Indoor) Vapors:

X2.5.1 In this case chemical intake results from the inhalation of vapors in enclosed spaces. The chemical vapors originate from dissolved hydrocarbons in ground water located some distance below ground surface. Here the goal is to determine the dissolved hydrocarbon RBSL that corresponds to the target RBSL for vapors in the breathing zone, as given in Tables X2.2 and X2.3. If the selected target vapor concentration is some value other than the RBSL for inhalation (that is, odor threshold or ecological criterion), this value can be substituted for the $RBSL_{air}$ parameter appearing in the equations given in Tables X2.2 and X2.3.

X2.5.2 A conceptual model for the transport of chemicals from ground water to indoor air is depicted in Fig. X2.2. For simplicity, the relationship between enclosed-space air and dissolved ground water concentrations is represented in Tables X2.2 and X2.3 by the "volatilization factor" VF_{wesp} [(mg/m³-air)/(mg/L-H₂O)] defined in Table X2.5. It is based on the following assumptions:

X2.5.2.1 A constant dissolved chemical concentration in ground water,

X2.5.2.2 Equilibrium partitioning between dissolved chemicals in ground water and chemical vapors at the ground water table,

X2.5.2.3 Steady-state vapor- and liquid-phase diffusion

through the capillary fringe, vadose zone, and foundation cracks,

X2.5.2.4 No loss of chemical as it diffuses towards ground surface (that is, no biodegradation), and

X2.5.2.5 Steady, well-mixed atmospheric dispersion of the emanating vapors within the enclosed space, where the convective transport into the building through foundation cracks or openings is negligible in comparison with diffusive transport.

X2.5.3 Should the calculated $RBSL_w$ exceed the pure component solubility for any individual component, ">S" is entered in the table to indicate that the selected risk level or hazard quotient cannot be reached or exceeded for that compound and the specified exposure scenario.

X2.6 Surficial Soils—Ingestion, Dermal Contact, and Vapor and Particulate Inhalation:

X2.6.1 In this case it is assumed that chemical intake results from a combination of intake routes, including: ingestion, dermal absorption, and inhalation of both particulates and vapors emanating from surficial soil.

X2.6.2 Equations used to estimate intake resulting from ingestion follow guidance given in Ref (26) for ingestion of chemicals in soil. For this route, it has been assumed that surficial soil chemical concentrations and intake rates remain constant over the exposure duration.

X2.6.3 Equations used to estimate intake resulting from dermal absorption follow guidance given in Ref (26) for dermal contact with chemicals in soil. For this route, it has been assumed that surficial soil chemical concentrations and absorption rates remain constant over the exposure duration.

X2.6.4 Equations used to estimate intake resulting from the inhalation of particulates follow guidance given in Ref (26) for inhalation of airborne chemicals. For this route, it has been assumed that surficial soil chemical concentrations, intake rates, and atmospheric particulate concentrations remain constant over the exposure duration.

X2.6.5 Equations used to estimate intake resulting from

the inhalation of airborne chemicals resulting from the volatilization of chemicals from surficial soils follow guidance given in Ref (26) for inhalation of airborne chemicals.

X2.6.6 A conceptual model for the volatilization of chemicals from surficial soils to outdoor air is depicted in Fig. X2.3. For simplicity, the relationship between outdoor air and surficial soil concentrations is represented in Tables

X2.2 and X2.3 by the "volatilization factor" VF_{ss} [(mg/m³-air)/(mg/kg-soil)] defined in Table X2.5. It is based on the following assumptions:

X2.6.6.1 Uniformly distributed chemical throughout the depth 0—d (cm) below ground surface,

X2.6.6.2 Linear equilibrium partitioning within the soil matrix between sorbed, dissolved, and vapor phases, where

TABLE X2.5 Volatilization Factors (VF_i), Leaching Factor (LF_{sw}), and Effective Diffusion Coefficients (D_i^{eff})

Symbol	Cross-Media Route (or Definition)	Equation
VF_{wvap}	Ground water → enclosed-space vapors	$VF_{wvap} \left[\frac{(mg/m^3-air)}{(mg/L-H_2O)} \right] = \frac{H \left[\frac{D_{sw}^{eff}/L_{GW}}{ER L_B} \right]}{1 + \left[\frac{D_{sw}^{eff}/L_{GW}}{ER L_B} \right] + \left[\frac{D_{sw}^{eff}/L_{GW}}{(D_{crack}^{eff}/L_{crack})\eta} \right]} \times 10^3 \frac{L}{m^3} A$
VF_{wamb}	Ground water → ambient (outdoor) vapors	$VF_{wamb} \left[\frac{(mg/m^3-air)}{(mg/L-H_2O)} \right] = \frac{H}{1 + \left[\frac{U_{sw}\delta_{sw}L_{GW}}{WD_{sw}^{eff}} \right]} \times 10^3 \frac{L}{m^3} B$
VF_{ss}	Surficial soils → ambient air (vapors)	$VF_{ss} \left[\frac{(mg/m^3-air)}{(mg/kg-soil)} \right] = \frac{2W\rho_s}{U_{sw}\delta_{sw}} \sqrt{\frac{D_s^{eff}H}{\theta_{ws} + k_s\rho_s + H\theta_{ss}}} \times 10^3 \frac{cm^3-kg}{m^3-g} C$ or: $VF_{ss} \left[\frac{(mg/m^3-air)}{(mg/kg-soil)} \right] = \frac{W\rho_s d}{U_{sw}\delta_{sw}r} \times 10^3 \frac{cm^3-kg}{m^3-g}$; whichever is less ^D
VF_p	Surficial soils → ambient air (particulates)	$VF_p \left[\frac{(mg/m^3-air)}{(mg/kg-soil)} \right] = \frac{P_s W}{U_{sw}\delta_{sw}} \times 10^3 \frac{cm^3-kg}{m^3-g} E$
VF_{samb}	Subsurface soils → ambient air	$VF_{samb} \left[\frac{(mg/m^3-air)}{(mg/kg-soil)} \right] = \frac{H\rho_s}{[\theta_{ws} + k_s\rho_s + H\theta_{ss}] \left(1 + \frac{U_{sw}\delta_{sw}L_s}{D_s^{eff}W} \right)} \times 10^3 \frac{cm^3-kg}{m^3-g} F$
VF_{svap}	Subsurface soil → enclosed-space vapors	$VF_{svap} \left[\frac{(mg/m^3-air)}{(mg/kg-soil)} \right] = \frac{H\rho_s \left[\frac{D_s^{eff}/L_s}{ER L_B} \right]}{1 + \left[\frac{D_s^{eff}/L_s}{ER L_B} \right] + \left[\frac{D_s^{eff}/L_s}{(D_{crack}^{eff}/L_{crack})\eta} \right]} \times 10^3 \frac{cm^3-kg}{m^3-g} A$
LF_{sw}	Subsurface soils → ground water	$LF_{sw} \left[\frac{(mg/L-H_2O)}{(mg/kg-soil)} \right] = \frac{\rho_s}{[\theta_{ws} + k_s\rho_s + H\theta_{ss}] \left(1 + \frac{U_{sw}\delta_{sw}}{W} \right)} \times 10^6 \frac{cm^3-kg}{L-g} B$
D_s^{eff}	Effective diffusion coefficient in soil based on vapor-phase concentration	$D_s^{eff} \left[\frac{cm^2}{s} \right] = D^{air} \frac{\theta_{ss}^{0.33}}{\theta_s^2} + D^{wat} \frac{1}{H} \frac{\theta_{ss}^{0.33}}{\theta_s^2} A$
D_{crack}^{eff}	Effective diffusion coefficient through foundation cracks	$D_{crack}^{eff} \left[\frac{cm^2}{s} \right] = D^{air} \frac{\theta_{crack}^{0.33}}{\theta_s^2} + D^{wat} \frac{1}{H} \frac{\theta_{crack}^{0.33}}{\theta_s^2} A$
D_{cap}^{eff}	Effective diffusion coefficient through capillary fringe	$D_{cap}^{eff} \left[\frac{cm^2}{s} \right] = D^{air} \frac{\theta_{cap}^{0.33}}{\theta_s^2} + D^{wat} \frac{1}{H} \frac{\theta_{cap}^{0.33}}{\theta_s^2} A$
D_{sw}^{eff}	Effective diffusion coefficient between ground water and soil surface	$D_{sw}^{eff} \left[\frac{cm^2}{s} \right] = (h_{cap} + h_w) \left[\frac{h_{cap}}{D_{cap}^{eff}} + \frac{h_w}{D_s^{eff}} \right]^{-1} A$
C_s^{sat}	Soil concentration at which dissolved pore-water and vapor phases become saturated	$C_s^{sat} \left[\frac{mg}{kg-soil} \right] = \frac{S}{\rho_s} \times [H\theta_{ss} + \theta_{ws} + k_s\rho_s] \times 10^6 \frac{L-g}{cm^3-kg} F$

A See Ref (29).
 B See Ref (30).
 C See Ref (31).
 D Based on mass balance.
 E See Ref (32).
 F See Ref (33).

TABLE X2.6 Soil, Building, Surface, and Subsurface Parameters Used in Generating Example Tier 1 RBSLs

NOTE—See X2.10 for justification of parameter selection.

Parameters	Definitions, Units	Residential	Commercial/Industrial
d	lower depth of surficial soil zone, cm	100 cm	100 cm
D^{air}	diffusion coefficient in air, cm^2/s	chemical-specific	chemical-specific
D^{water}	diffusion coefficient in water, cm^2/s	chemical-specific	chemical-specific
ER	enclosed-space air exchange rate, L/s 1/5	$0.00014 s^{-1}$	$0.00023 s^{-1}$
f_{oc}	fraction of organic carbon in soil, g-C/g-soil	0.01	0.01
H	henry's law constant, $(cm^3 \cdot H_2O)/(cm^3 \cdot air)$	chemical-specific	chemical-specific
h_{cap}	thickness of capillary fringe, cm	5 cm	5 cm
h_v	thickness of vadose zone, cm	295 cm	295 cm
I	infiltration rate of water through soil, cm/years	30 cm/year	30 cm/year
K_{oc}	carbon-water sorption coefficient, $cm^3 \cdot H_2O/g \cdot C$	chemical-specific	chemical-specific
K_s	soil-water sorption coefficient, $cm^3 \cdot H_2O/g \cdot soil$	$f_{oc} \times K_{oc}$	$f_{oc} \times K_{oc}$
L_G	enclosed-space volume/infiltration area ratio, cm	200 cm	300 cm
L_{crack}	enclosed-space foundation or wall thickness, cm	15 cm	15 cm
L_{GW}	depth to ground water = $h_{cap} + h_v$, cm	300 cm	300 cm
L_S	depth to subsurface soil sources, cm	100 cm	100 cm
P_o	particulate emission rate, $g/cm^2 \cdot s$	6.9×10^{-14}	6.9×10^{-14}
S	pure component solubility in water, $mg/L \cdot H_2O$	chemical-specific	chemical-specific
U_{air}	wind speed above ground surface in ambient mixing zone, cm/s	225 cm/s	225 cm/s
U_{GW}	ground water Darcy velocity, cm/year	2500 cm/year	2500 cm/year
W	width of source area parallel to wind, or ground water flow direction, cm	1500 cm	1500 cm
δ_{air}	ambient air mixing zone height, cm	200 cm	200 cm
δ_{GW}	ground water mixing zone thickness, cm	200 cm	200 cm 0.038
η	areal fraction of cracks in foundations/walls, $cm^2 \cdot cracks/cm^2 \cdot total \ area$	0.01 $cm^2 \cdot cracks/cm^2 \cdot total \ area$	0.01 $cm^2 \cdot cracks/cm^2 \cdot total \ area$
θ_{cap}	volumetric air content in capillary fringe soils, $cm^3 \cdot air/cm^3 \cdot soil$	0.038 $cm^3 \cdot air/cm^3 \cdot soil$	0.38 $cm^3 \cdot air/cm^3 \cdot soil$
θ_{crack}	volumetric air content in foundation/wall cracks, $cm^3 \cdot air/cm^3 \cdot total \ volume$	0.26 $cm^3 \cdot air/cm^3 \cdot total \ volume$	0.26 $cm^3 \cdot air/cm^3 \cdot total \ volume$
θ_{so}	volumetric air content in vadose zone soils, $cm^3 \cdot air/cm^3 \cdot soil$	0.26 $cm^3 \cdot air/cm^3 \cdot soil$	0.26 $cm^3 \cdot air/cm^3 \cdot soil$
θ_T	total soil porosity, $cm^3/cm^3 \cdot soil$	0.38 $cm^3/cm^3 \cdot soil$	0.38 $cm^3/cm^3 \cdot soil$
θ_{wcap}	volumetric water content in capillary fringe soils, $cm^3 \cdot H_2O/cm^3 \cdot soil$	0.342 $cm^3 \cdot H_2O/cm^3 \cdot soil$	0.342 $cm^3 \cdot H_2O/cm^3 \cdot soil$
θ_{wcrack}	volumetric water content in foundation/wall cracks, $cm^3 \cdot H_2O/cm^3 \cdot total \ volume$	0.12 $cm^3 \cdot H_2O/cm^3 \cdot total \ volume$	0.12 $cm^3 \cdot H_2O/cm^3 \cdot total \ volume$
θ_{ws}	volumetric water content in vadose zone soils, $cm^3 \cdot H_2O/cm^3 \cdot soil$	0.12 $cm^3 \cdot H_2O/cm^3 \cdot soil$	0.12 $cm^3 \cdot H_2O/cm^3 \cdot soil$
ρ_s	soil bulk density, $g \cdot soil/cm^3 \cdot soil$	1.7 g/cm^3	1.7 g/cm^3
τ	averaging time for vapor flux, s	$7.88 \times 10^8 s$	$7.88 \times 10^8 s$

the partitioning is a function of constant chemical- and soil-specific parameters,

X2.6.6.3 Diffusion through the vadose zone,

X2.6.6.4 No loss of chemical as it diffuses towards ground surface (that is, no biodegradation), and

X2.6.6.5 Steady well-mixed atmospheric dispersion of the emanating vapors within the breathing zone as modeled by a "box model" for air dispersion.

X2.6.7 In the event that the time-averaged flux exceeds that which would occur if all chemical initially present in the surficial soil zone volatilized during the exposure period,

then the volatilization factor is determined from a mass balance assuming that all chemical initially present in the surficial soil zone volatilizes during the exposure period.

X2.7 Subsurface Soils—Inhalation of Outdoor Vapors:

X2.7.1 In this case chemical intake is a result of inhalation of outdoor vapors which originate from hydrocarbons contained in subsurface soils located some distance below ground surface. Here the goal is to determine the RBSL for subsurface soils that corresponds to the target RBSL for outdoor vapors in the breathing zone, as given in X2.2. If the selected target vapor concentration is some value other than

TABLE X2.7 Chemical-Specific Properties Used in the Derivation Example Tier 1 RBSLs

Chemical	CAS Number	M_w , g/mol	H , $L \cdot H_2O/L \cdot air$	D^{air} , cm^2/s	D^w , cm^2/s	$\log(K_{oc})$, L/kg	$\log(K_{ow})$, L/kg
Benzene	71-43-2	78 ^A	0.22 ^A	0.093 ^A	1.1×10^{-5A}	1.58 ^A	2.13 ^A
Toluene	108-88-3	92 ^A	0.26 ^A	0.085 ^A	9.4×10^{-6D}	2.13 ^A	2.65 ^A
Ethyl benzene	100-41-4	106 ^A	0.32 ^A	0.076 ^A	8.5×10^{-6D}	1.98 ^A	3.13 ^A
Mixed xylenes	1330-20-7	106 ^A	0.29 ^A	0.072 ^D	8.5×10^{-6D}	2.38 ^A	3.26 ^A
Naphthalene	91-20-3	128 ^A	0.049 ^A	0.072 ^D	9.4×10^{-6A}	3.11 ^A	3.28 ^A
Benzo(a)pyrene	50-32-8	252 ^C	5.8×10^{-8B}	0.050 ^D	5.8×10^{-6D}	5.59 ^E	5.98 ^E

Chemical	CAS Number	SF_{so} , kg-day/mg	SF_{cr} , kg-day/mg	RID_{so} , mg/kg-day	RID_{cr} , mg/kg-day
Benzene	71-43-2	0.029 ^F	0.1 Cal.	...	...
Toluene	108-88-3	...	...	0.2 ^F	0.11 ^F
Ethyl benzene	100-41-4	...	...	0.1 ^F	0.29 ^F
Mixed xylenes	1330-20-7	...	...	2.0 ^F	2.0 ^F
Naphthalene	91-20-3	...	...	0.004 ^G	0.004 ^G
Benzo(a)pyrene	50-32-8	7.3 ^F	12	...	...

^A See Ref (34).

^B See Ref (35).

^C See Ref (7).

^D Diffusion coefficient calculated using the method of Fuller, Schettler, and Giddings, from Ref (11).

^E Calculated from K_{ow}/K_{oc} correlation: $\log(K_{oc}) = 0.937 \log(K_{ow}) - 0.006$, from Ref (11).

^F See Ref (2).

^G See Ref (3).

the RBSL for inhalation (that is, odor threshold or ecological criterion), this value can be substituted for the $RBSL_{air}$ parameter appearing in the equations given in Tables X2.2 and X2.3.

X2.7.2 A conceptual model for the transport of chemicals from subsurface soils to ambient air is depicted in Fig. X2.4. For simplicity, the relationship between outdoor air and soil concentrations is represented in Tables X2.2 and X2.3 by the "volatilization factor," VF_{samb} [(mg/m³-air)/(kg-soil)], defined in Table X2.5. It is based on the following assumptions:

X2.7.2.1 A constant chemical concentration in subsurface soils,

X2.7.2.2 Linear equilibrium partitioning within the soil matrix between sorbed, dissolved, and vapor phases, where the partitioning is a function of constant chemical- and soil-specific parameters,

X2.7.2.3 Steady-state vapor- and liquid-phase diffusion through the vadose zone to ground surface,

X2.7.2.4 No loss of chemical as it diffuses towards ground surface (that is, no biodegradation), and

X2.7.2.5 Steady well-mixed atmospheric dispersion of the emanating vapors within the breathing zone as modeled by a "box model" for air dispersion.

X2.7.3 Should the calculated $RBSL_s$ exceed the value for which the equilibrated vapor and dissolved pore-water phases become saturated, C_s^{sat} [mg/kg-soil] (see Table X2.5 for calculation of this value), "RES" is entered in the table to indicate that the selected risk level or hazard quotient cannot be reached or exceeded for that compound and the specified exposure scenario (even if free-phase product or precipitate is present in the soil).

X2.8 *Subsurface Soils—Inhalation of Enclosed-Space (Indoor) Vapors:*

X2.8.1 In this case chemical intake is a result of inhalation of enclosed-space vapors which originate from hydrocarbons contained in subsurface soils located some distance below ground surface. Here the goal is to determine the RBSL for subsurface soils that corresponds to the target RBSL for indoor vapors, as given in Tables X2.2 and X2.3. If the selected target vapor concentration is some value other than the RBSL for inhalation (that is, odor threshold or

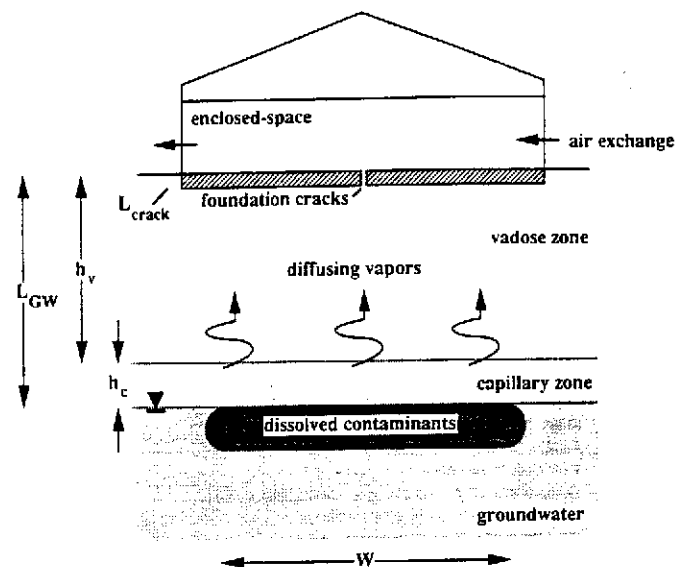


FIG. X2.2 Volatilization from Ground Water to Enclosed-Space Air

ecological criterion), this value can be substituted for the $RBSL_{air}$ parameter appearing in the equations given in Tables X2.2 and X2.3.

X2.8.2 A conceptual model for the transport of chemicals from subsurface soils to enclosed spaces is depicted in Fig. X2.5. For simplicity, the relationship between indoor air and soil concentrations is represented in Tables X2.2 and X2.3 by the "volatilization factor," VF_{sest} [(mg/m³-air)/(kg-soil)], defined in Table X2.5. It is based on the following assumptions:

X2.8.2.1 A constant chemical concentration in subsurface soils,

X2.8.2.2 Linear equilibrium partitioning within the soil matrix between sorbed, dissolved, and vapor phases, where the partitioning is a function of constant, chemical- and soil-specific parameters,

X2.8.2.3 Steady-state vapor- and liquid-phase diffusion through the vadose zone and foundation cracks,

X2.8.2.4 No loss of chemical as it diffuses towards ground surface (that is, no biodegradation), and

X2.8.2.5 Well-mixed atmospheric dispersion of the emanating vapors within the enclosed space.

X2.8.3 Should the calculated $RBSL_s$ exceed the value C_s^{sat} [mg/kg-soil] for which the equilibrated vapor and dissolved pore-water phases become saturated (see Table X2.5 for calculation of this value), "RES" is entered in the table to indicate that the selected risk level or hazard

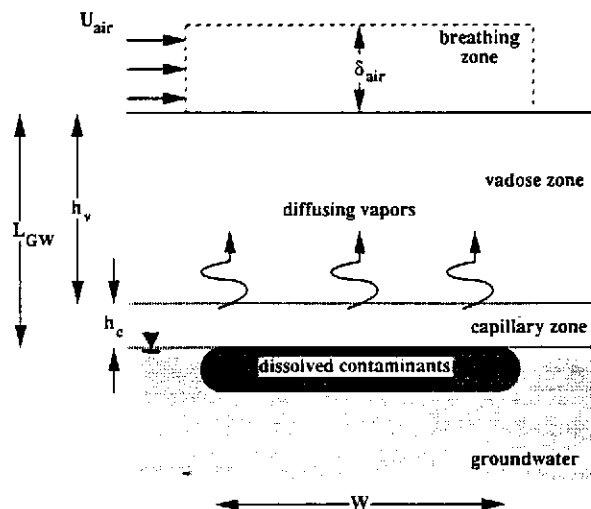


FIG. X2.1 Volatilization from Ground Water to Ambient Air

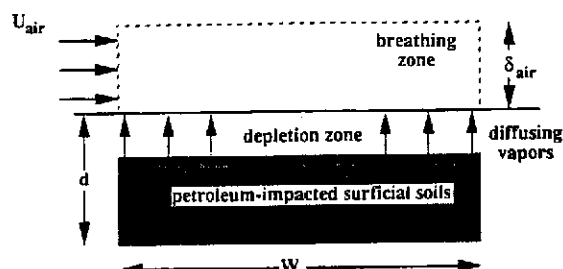


FIG. X2.3 Volatilization from Surficial Soils

quotient cannot be reached or exceeded for that compound and the specified exposure scenario (even if free-phase product or precipitate is present in the soil).

X2.9 Subsurface Soils—Leaching to Ground Water:

X2.9.1 In this case chemical intake is a result of chemicals leaching from subsurface soils, followed by inhalation of enclosed-space vapors, inhalation of outdoor vapors, or ingestion of ground water as discussed in X2.1 through X2.3. Here the goal is to determine the RBSL for subsurface soils that corresponds to the target RBSLs for the inhalation or ingestion routes. If the selected target ground water concentration is some value other than an RBSL for ground water (that is, odor threshold or ecological criterion), this value can be substituted for the RBSL_w parameter appearing in the equations given in Tables X2.2 and X2.3.

X2.9.2 A conceptual model for the leaching of chemicals from subsurface soils to ground water is depicted in Fig. X2.6. For simplicity, the relationship between ground water and soil concentrations is represented in Tables X2.2 and X2.3 by the "leaching factor," LF_{sw} [(mg/L-H₂O)/(mg/kg-soil)], defined in Table X2.5. It is based on the following assumptions:

X2.9.2.1 A constant chemical concentration in subsurface soils,

X2.9.2.2 Linear equilibrium partitioning within the soil matrix between sorbed, dissolved, and vapor phases, where the partitioning is a function of constant chemical- and soil-specific parameters,

X2.9.2.3 Steady-state leaching from the vadose zone to ground water resulting from the constant leaching rate I [cm/s],

X2.9.2.4 No loss of chemical as it leaches towards ground water (that is, no biodegradation), and

X2.9.2.5 Steady well-mixed dispersion of the leachate within a ground water "mixing zone."

X2.9.3 Should the calculated RBSL_s exceed the value for which the equilibrated vapor and dissolved pore-water phases become saturated (see Table X2.5 for calculation of this value), "RES" is entered in the table to indicate that the selected risk level or hazard quotient cannot be reached or exceeded for that compound and the specified exposure scenario (even if free-phase product or precipitate is present in the soil).

X2.9.4 In some regulatory programs, "dilution attenuation factors" (DAFs) are currently being proposed based on

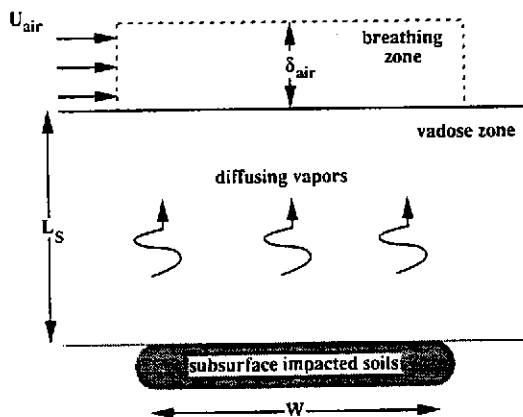


FIG. X2.4 Volatilization from Subsurface Soils to Ambient Air

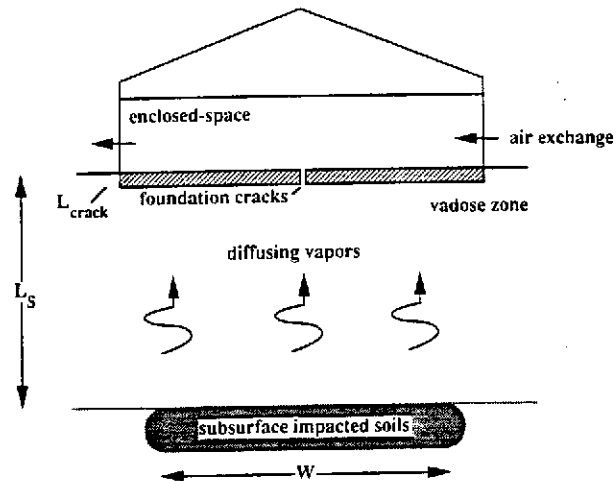


FIG. X2.5 Volatilization from Subsurface Soils to Enclosed-Space Air

fate and transport modeling results. A DAF is typically defined as the ratio of a target ground water concentration divided by the source leachate concentration, and is inherently very similar to the leachate factor, LF_{sw} , discussed here. The difference between these two terms is that LF_{sw} represents the ratio of the target ground water concentration divided by the source area soil concentration. Should a regulatory program already have a technically defensible DAF value, it can be equated to a leachate factor by the following expression:

$$LF_{sw} = \frac{DAF \times \rho_s}{[\theta_{ws} + k_s \rho_s + H\theta_{as}]} \times 10^6$$

where the parameters are defined in Table X2.6.

X2.10 Parameter Values:

X2.10.1 Table X2.4 lists exposure parameters used to calculate the RBSLs appearing in sample Look-Up Table X2.1. All values given are based on adult exposures only. With the exception of the dermal exposure parameters (SA , M , and RAF_d), the values given are reasonable maximum exposure (RME) values presented in Ref (27) and are regarded as upper bound estimates for each individual exposure parameter.

X2.10.2 The skin surface area, $SA = 3160 \text{ cm}^2/\text{day}$, is based on the average surface area of the head, hands, and

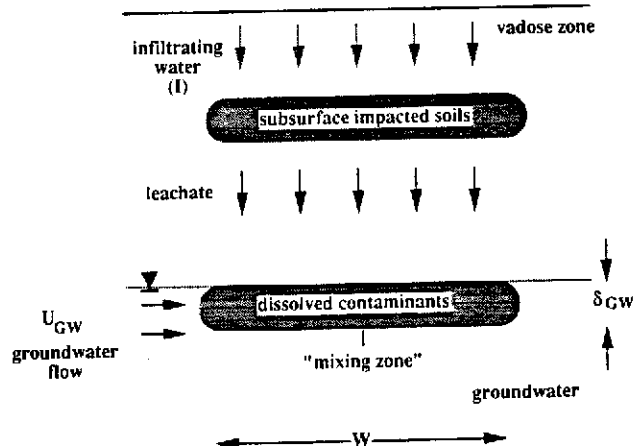


FIG. X2.6 Leaching from Subsurface Soils to Ground Water

forearms for adult males given in Ref (27). The soil-to-skin adherence factor, M [mg/cm^2], and dermal relative absorption factor, RAF_d [$\text{mg-absorbed}/\text{mg-applied}$], are based on guidance issued by Ref (28).

X2.10.3 Soil properties are based on typical values for sandy soils and are consistent with values given in Ref (30).

X2.10.4 Physical dimensions are consistent with the scale of typical underground fuel tank releases.

X2.10.5 Particulate emission rates were estimated by the approach presented by Cowherd, et al (32). It was assumed that the mode of the surficial soil size distribution was 2 mm, the erosion potential was unlimited, there was no vegetative cover, and the mean average annual wind speed was 4 m/s.

X2.10.6 The chemical-specific parameters used are de-

finied in Table X2.7.

X2.10.7 In this development, surficial soils are defined as those soils present within 1 m of ground surface. Subsurface soil RBSLs are based on assumed source depths of 1 m. Ground water is assumed to be located 3 m below ground surface.

X2.10.8 Once again, the reader is reminded that the parameter (and corresponding RBSL) values are presented here as examples only, and are not intended to be used as standards. At best, the parameters presented are reasonable values based on current information and professional judgment. The reader should review and verify all assumptions prior to using any of the example RBSLs as screening level values.

X3. USE OF PREDICTIVE MODELING IN THE RISK-BASED CORRECTIVE ACTION PROCESS

X3.1 Scope:

X3.1.1 Predictive modeling is a valuable tool that can provide information to the risk management process. In a RBCA, modeling is used to predict the location and concentration contaminants and to interpret, or extrapolate, site characterization data, historical monitoring data, and toxicological information. In addition, predictive modeling may be used in evaluation of remedial alternatives and in evaluating compliance targets in monitoring plans. This appendix discusses the following:

X3.1.1.1 Significance and use of predictive modeling in the RBCA process;

X3.1.1.2 Interpretation of predictive modeling results;

X3.1.1.3 Procedures for predictive migration models; and

X3.1.1.4 Procedures for exposure, risk, and dose-response assessment.

X3.1.2 This appendix is not intended to be all inclusive. Each predictive model is unique and may require additional procedures in its development and application. All such additional analyses should be documented in the RBCA process.

X3.2 Referenced Documents:

X3.2.1 ASTM Standards:

D 653 Terminology Relating to Soil, Rock, and Contained Fluids⁷

D 5447 Guide for Application of a Ground-Water Flow Model to a Site-Specific Problem⁸

D 5490 Guide for Comparing Ground-Water Flow Model Simulations to Site-Specific Information⁸

E 943 Terminology Relating to Biological Effects and Environmental Fate⁹

E 978 Practice for Evaluating Environmental Fate Models of Chemicals⁹

D 5609 Guide for Defining Boundary Conditions in Ground-Water Flow Modeling⁸

D 5610 Guide for Defining Initial Conditions in Ground-Water Flow Modeling⁸

D 5611 Guide for Conducting a Sensitivity Analysis for a Ground-Water Flow Model Application⁸

X3.3 Terminology:

X3.3.1 *Definitions*—For definitions of terms used in this appendix, see Terminologies D 653 and E 943.

X3.3.2 Descriptions of Terms Specific to This Appendix:

X3.3.2.1 *analytical model*—a model that uses mathematical solutions to governing equations that are continuous in space and time and applicable to the flow and transport process.

X3.3.2.2 *application verification*—using the set of parameter values and boundary conditions from a calibrated model to approximate acceptably a second set of field data measured under similar conditions.

DISCUSSION—Application verification is to be distinguished from code verification, which refers to software testing, comparison with analytical solutions, and comparison with other similar codes to demonstrate that the code represents its mathematical foundation.

X3.3.2.3 *boundary condition*—a mathematical expression of a state of the physical system that constrains the equations of the mathematical model.

X3.3.2.4 *calibration (model application)*—the process of refining the model representation of the fluid and media properties and boundary conditions to achieve a desired degree of correspondence between the model simulation and observations of the real system.

X3.3.2.5 *code validation*—the process of determining how well a modeling code's theoretical foundation and computer implementation describe actual system behavior in terms of the "degree of correlation" between calculated and independently observed cause-and-effect responses of the prototype fluid flow system (for example, research site or laboratory experiment) for which the code has been developed.

X3.3.2.6 *code verification*—the procedure aimed at establishing the completeness, consistency, correctness, and accuracy of modeling software with respect to its design criteria by evaluating the functionality and operational characteristics of the code and testing embedded algorithms and data transfers through execution of problems for which indepen-

⁷ Annual Book of ASTM Standards, Vol 04.08.

⁸ Annual Book of ASTM Standards, Vol 04.09.

⁹ Annual Book of ASTM Standards, Vol 11.04.

dent benchmarks are available.

X3.3.2.7 *computer code (computer program)*—the assembly of numerical techniques, bookkeeping, and control language that represents the model from acceptance of input

data and instructions to delivery of output.

X3.3.2.8 *conceptual model*—an interpretation or working description of the characteristics and dynamics of the physical system.

TABLE X3.1 Example Screening Level Transport Models

Description	Mathematical Approximation	Parameters
Dissolved Phase Transport: Maximum transport rate $u_{d,max}$ [cm/day] of dissolved plume	$u_{d,max} = \frac{K_s i}{\theta_s R_c}$	$C(x)$ = dissolved hydrocarbon concentration along centerline ($x, y = 0, z = 0$) of dissolved plume [g/cm ³ -H ₂ O] C_{source} = dissolved hydrocarbon concentration in dissolved plume source area [g/cm ³ -H ₂ O] i = ground water gradient [cm/cm] K_s = saturated hydraulic conductivity [cm/day] k_s = sorption coefficient [(g/g-soil)/(g/cm ³ -H ₂ O)] L = distance downgradient [cm] R_c = retardation factor = $[1 + k_s \rho_s / \theta_s]$ S_w = source width (perpendicular to flow in the horizontal plane) [cm] S_d = source width (perpendicular to flow in the vertical plane) [cm]
Minimum time $\tau_{d,min}$ [d] for leading edge of dissolved plume to travel distance, L [cm]	$\tau_{d,min} = \frac{L}{u_{d,max}}$	u = specific discharge [cm/day] $u_{d,max}$ = maximum transport rate of dissolved plume [cm/day] ^A x = distance along centerline from downgradient edge of dissolved plume source zone [cm] y = depth below water table [cm] z = lateral distance away from dissolved plume centerline [cm] α_x = longitudinal dispersivity [cm] $\approx 0.10 x$ α_y = transverse dispersivity [cm] $\approx \alpha_x / 3$ α_z = vertical dispersivity [cm] $\approx \alpha_x / 20$ λ = first-order degradation constant [d ⁻¹] θ_s = volumetric water content of saturated zone [cm ³ -H ₂ O/cm ³ -soil] ρ_s = soil bulk density [g-soil/cm ³ -soil] $\tau_{d,min}$ = minimum convective travel time of dissolved hydrocarbons to distance L [d] ^A
Steady-state attenuation [(g/cm ³ -H ₂ O)/(g/cm ³ -H ₂ O)] along the centerline ($x, y = 0, z = 0$) of a dissolved plume	$\frac{C(x)}{C_{source}} = \exp \left\{ \frac{x}{2\alpha_x} \left[1 - \sqrt{1 + \frac{4\lambda\alpha_x}{u}} \right] \right\} \cdot \left(\text{erf} \left[\frac{S_w}{4\sqrt{\alpha_x x}} \right] \right) \left(\text{erf} \left[\frac{S_d}{4\sqrt{\alpha_x x}} \right] \right)$ where: $u = K_s i / \theta_s$	$erf(\eta)$ = error function evaluated for value η C_{soil} = total soil hydrocarbon concentration [g/g-soil] $C_{v,eq}$ = equilibrium vapor concentration [g/cm ³ -vapor] ^A $C_{w,eq}$ = equilibrium dissolved concentration [g/cm ³ -H ₂ O] ^A D_{max} = maximum depth of immiscible phase penetration [cm] ^A H = Henry's Law Constant [(g/cm ³ -vapor)/(g/cm ³ -H ₂ O)] k_s = sorption coefficient [(g/g-soil)/(g/cm ³ -H ₂ O)] M_w = molecular weight [g/mol] P_v^i = vapor pressure of compound i [atm] R = gas constant = 82 cm ³ -atm/mol-K R_{spill} = radial extent of hydrocarbon impact [cm] S_i = pure component solubility [g/cm ³ -H ₂ O] T = absolute temperature [K] V_{spill} = volume of hydrocarbon released [cm ³] x_i = mol fraction of component i θ_R = volumetric residual content of hydrocarbon under drainage conditions [cm ³ -hydrocarbon/cm ³ -soil] θ_w = volumetric content of soil pore water [cm ³ -H ₂ O/cm ³ -soil] θ_v = volumetric content of soil vapor [cm ³ -vapor/cm ³ -soil] = 3.1416 π = soil bulk density [g-soil/cm ³ -soil] (C_{soil}) = concentration at which immiscible phase forms in soil [g/g-soil] ^A D^{air} = pure component diffusion coefficient in air [cm ² /day] D^{eff} = effective diffusion coefficient for combined vapor and solute transport, expressed as a vapor phase diffusion coefficient (no immiscible hydrocarbon present outside of source area) [cm ² /day] ^A D^w = pure component diffusion coefficient in water [cm ² /day] H = Henry's Law Constant [(g/cm ³ -vapor)/(g/cm ³ -H ₂ O)] k_s = sorption coefficient [(g/g-soil)/(g/cm ³ -H ₂ O)] k_v = permeability to vapor flow [cm ²] L = distance [cm] R_v = porous media "retardation" factor (no immiscible hydrocarbon present outside of source area) S_i = pure component solubility [g/cm ³ -H ₂ O] $u_{v,max}$ = maximum convective transport rate of vapors [cm/day] ^A ∇P = vapor phase pressure gradient [g/cm ² -s ²] θ_w = volumetric content of soil pore water [cm ³ -H ₂ O/cm ³ -soil]
Immiscible Phase Transport: Maximum depth D_{max} [cm] of immiscible phase penetration	$D_{max} = \frac{V_{spill}}{\theta_R \pi R_{spill}^2}$	
Equilibrium Partitioning: Vapor Concentration: $C_{v,eq}$ [g/cm ³ -vapor] Maximum vapor concentration above dissolved hydrocarbons	$C_{v,eq} = HC_{w,eq}$	
Maximum vapor concentration when immiscible hydrocarbon is present	$C_{v,eq} = \frac{x_i P_v^i M_w}{RT}$	
Maximum vapor concentrations in soil pores (no immiscible phase present)	$C_{v,eq} = \frac{HC_{soil} \rho_s}{[\theta_w + k_s \rho_s + H\theta_v]}$	
Dissolved Concentration: $C_{w,eq}$ [g/cm ³ -H ₂ O] Maximum dissolved concentration when immiscible hydrocarbon is present	$C_{w,eq} = x_i S_i$	
Maximum dissolved concentration in soil pores (no immiscible phase present)	$C_{w,eq} = \frac{C_{soil} \rho_s}{[\theta_w + k_s \rho_s + H\theta_v]}$	
Equilibrium Partitioning: Soil Concentrations [g/g-soil]: Soil concentration [C_{soil}] [g/g-soil] at which immiscible hydrocarbon phase forms in soil matrix	$(C_{soil}) = \frac{S_i}{\rho_s} [\theta_w + k_s \rho_s + H\theta_v]$	
Vapor Phase Transport: Effective porous media diffusion coefficient D^{eff} [cm ² /day] for combined vapor and solute transport, expressed as a vapor phase diffusion coefficient (no immiscible hydrocarbon present outside of source area)	$D^{eff} = \frac{\theta_w^{3.33}}{\theta_T} D^{air} + \frac{1}{H} \frac{\theta_w^{3.33}}{\theta_T} D^w$	
Porous media "retardation" factor R_v (no immiscible hydrocarbon present outside of source area)	$R_v = \left[\frac{\theta_w}{H} + \frac{k_s \rho_s}{H} + \theta_v \right]$	

TABLE X3.1 Continued

Description	Mathematical Approximation	Parameters
Maximum convective transport rate $u_{v,max}$ [cm/day] of vapors	$u_{v,max} = \frac{1}{R_v} \frac{k_v}{\mu_v} \nabla P$	β_v = volumetric content of soil vapor [cm ³ -vapor/cm ³ -soil] β_T = total volumetric content of pore space in soil matrix [cm ³ /cm ³ -soil]
Minimum time $\tau_{c,min}$ [d] for vapors to travel a distance L [cm] from source area by convection ^A	$\tau_{c,min} = \frac{L}{u_{v,max}}$	μ_v = vapor viscosity [g/cm-s] ρ_s = soil bulk density [g-soil/cm ³ -soil] $\tau_{c,min}$ = minimum time for vapors to travel a distance L [cm] by convection [day] ^A
Minimum time $\tau_{d,min}$ [d] for vapors to travel a distance L [cm] from source area by diffusion	$\tau_{d,min} = \frac{L^2}{(D^{eff}/R_v)}$	$\tau_{d,min}$ = minimum time for vapors to travel a distance L [cm] by diffusion [day] ^A
Vapor Emissions from Subsurface Vapor Sources to Open Surfaces:		C_{soil} = total soil hydrocarbon concentration [g/g-soil] $C_{v,eq}$ = equilibrium vapor concentration [g/cm ³ -vapor] ^A d = distance below ground surface to top of hydrocarbon vapor source [cm]
Maximum diffusive vapor flux F_{max} [g/cm ² -day] from subsurface vapor source located a distance d [cm] below ground surface (steady-state, constant source)	$F_{max} = D^{eff} \frac{C_{v,eq}}{d}$	D^{eff} = effective diffusion coefficient for combined vapor and solute transport, expressed as a vapor phase diffusion coefficient (no immiscible hydrocarbon present outside of source area) [cm ² /day] ^A R_v = porous media "retardation" factor (no immiscible hydrocarbon present outside of source area) ^A
Maximum time-averaged diffusive vapor flux $\langle F_{max} \rangle$ [g/cm ² -day] from subsurface soils over period from time = 0 to time = τ , single-component immiscible phase present	$\langle F_{max} \rangle = \frac{\rho_s C_{soil}}{\tau} \left\{ \sqrt{d^2 + \frac{2C_{v,eq} D^{eff} \tau}{\rho_s C_{soil}}} - d \right\}$	$u_{v,max}$ = maximum convective transport rate $u_{v,max}$ of vapors [cm/day] ^A ρ_s = soil bulk density [g-soil/cm ³ -soil] τ = averaging time [s] A_B = total area of enclosed space exposed to vapor intrusion (area of foundation) [cm ²] A_{crack} = area of foundation through which vapors are transported (area of cracks, open seams, and so forth) [cm ²] C_{soil} = total soil hydrocarbon concentration [g/g-soil] $C_{v,eq}$ = equilibrium vapor concentration [g/cm ³ -vapor] ^A d = distance between foundation/walls and hydrocarbon vapor source [cm] D^{eff} = effective diffusion coefficient through soil for combined vapor and solute transport, expressed as a vapor phase diffusion coefficient (no immiscible hydrocarbon present outside of source area) [cm ² /day] ^A D^{crack} = effective diffusion coefficient through foundation cracks [cm ² /day] ^A L_{crack} = thickness of foundation/wall [cm] $M_{w,i}$ = molecular weight of i [g/mol] $M_{w,T}$ = average molecular weight of the hydrocarbon mixture [g/mol] P_i^v = vapor pressure of pure component i [atm] Q_B = volumetric flow rate of air within enclosed space [cm ³ /s] Q_{soil} = volumetric infiltration flow rate of soil gas into enclosed space [cm ³ /s] R = gas constant = 82 atm-cm ³ /mol-K R_v = porous media "retardation" factor ^A T = absolute temperature [K] x_i = mol fraction of component i β_v = volumetric content of soil vapor [cm ³ -vapor/cm ³ -soil] ρ_s = soil bulk density [g-soil/cm ³ -soil] π = 3.1416 τ = averaging time [s] $C_{w,eq}$ = equilibrium dissolved concentration in leachate source area [g/cm ³ -H ₂ O] ^A E_B = enclosed space air exchange rate [1/d] F_{max} = vapor emission rate into enclosed space [g/day] ^A F = vapor flux [g/cm ² -day] ^A i = ground water gradient [cm/cm] K_g = saturated hydraulic conductivity [cm/day] L = downwind length of vapor emissions source area [cm] M = ground water mixing zone thickness [cm] q_i = water infiltration rate [cm/day]
Maximum combined convective and diffusive vapor flux F_{max} [g/cm ² -day] from subsurface vapor source located a distance d [cm] below ground surface	$F_{max} = R_v u_{v,max} C_{v,eq} - \frac{R_v \mu_{v,max} C_{v,eq}}{\left[1 - \exp\left(\frac{R_v u_{v,max} d}{D^{eff}}\right) \right]}$	
Vapor Emissions from Surface Soils to Open Spaces:		
Maximum time-averaged diffusive vapor flux $\langle F_{max} \rangle$ [g/cm ² -day] from surface soils over period from time = 0 to time = τ , single-component immiscible phase present	$\langle F_{max} \rangle = \rho_s C_{soil} \sqrt{\frac{2C_{v,eq} D^{eff} \tau}{\rho_s C_{soil}}}$	
Maximum time-averaged diffusive vapor flux $\langle F_{max} \rangle$ [g/cm ² -day] from surface soils over period from time = 0 to time = τ , no immiscible phase present	$\langle F_{max} \rangle = 2\rho_s C_{soil} \sqrt{\frac{D^{eff}}{\pi R_v T}}$	
Maximum time-averaged diffusive vapor flux $\langle F_{max} \rangle$ [g/cm ² -day] from surface soils over period from time = 0 to time = τ , volatile components from relatively nonvolatile immiscible phase (for example, benzene from gasoline)	$\langle F_{max} \rangle = \frac{2D^{eff} \left(\frac{x_i P_i^v M_{w,i}}{RT} \right)}{\sqrt{\pi \alpha \tau}}$	
where:		
	$\alpha = \frac{D^{eff}}{\beta_v + \frac{\rho_s R T (C_{soil}/M_{w,T})}{P_i^v}}$	

X3.3.2.9 *ground water flow model*—application of a mathematical model to represent a site-specific ground water flow system.

X3.3.2.10 *mathematical model*—mathematical equations expressing the physical system and including simplifying assumptions. The representation of a physical system by mathematical expressions from which the behavior of the

system can be deduced with known accuracy.

X3.3.2.11 *migration model*—application of a mathematical model to represent a site-specific fluid flow system.

X3.3.2.12 *model*—an assembly of concepts in the form of mathematical equations that portray understanding of a natural phenomenon.

X3.3.2.13 *sensitivity (model application)*—the degree to

TABLE X3.1 Continued

Description	Mathematical Approximation	Parameters
Vapor Emissions to Enclosed Spaces: Maximum vapor emission rate E_{max} [g/cm ² -d] to enclosed spaces from subsurface vapor sources located a distance d (cm) away from the enclosed spaces	$E_{max} = Q_B C_{v,eq} \left(\frac{D^{eff} A_B}{Q_B d} \right) \exp\left(\frac{Q_{soil} L_{crack}}{D_{crack} A_{crack}} \right) / \left[\exp\left(\frac{Q_{soil} L_{crack}}{D_{crack} A_{crack}} \right) + \left(\frac{D^{eff} A_B}{Q_{soil} d} \right) \left(\exp\left(\frac{Q_{soil} L_{crack}}{D_{crack} A_{crack}} \right) - 1 \right) \right]$	U_w = wind speed [cm/day] V_B = volume of enclosed space [cm ³] W = width of impacted soil zone [cm] δ = height of breathing zone [cm]
Hydrocarbon Vapor Dispersion: Ambient hydrocarbon vapor concentration resulting from area vapor source $C_{outdoor}$ [g/cm ³] Enclosed space vapor concentration C_{indoor} [g/cm ³]	$C_{outdoor} = \frac{FL}{U_w \delta}$ $C_{indoor} = \frac{E_{max}}{V_B E_B}$	
Leachate Transport: Leaching Impact on Ground Water: Ground water source area concentration C_{source} [g/cm ³ -H ₂ O] resulting from leaching through vadose zone hydrocarbon-impacted soils Ground water source area concentration C_{source} [g/cm ³ -H ₂ O] resulting from hydrocarbon-impacted soils in direct contact with ground water	$C_{source} = C_{w,eq} \frac{q_p W}{(K_p i M + q_p W)}$ $C_{source} = C_{w,eq}$	

^A Equation for this parameter given in this table.

TABLE X3.2 Reported Degradation Rates for Petroleum Hydrocarbons

Reference	Source of Data	Chemical Decay Rates (day ⁻¹ , [half-life days])							
		Benzene	Toluene	Ethyl-Benzene	Xylenes	O-Xylene	MTBE	Naphthalene	Benzo (a)Pyrene
Barker, et al ^A	Borden Aquifer, Canada	0.007 [99]	0.011 [63]	...	...	0.014 [50]	...	...	...
Kemblowski ^B	Eastern Florida Aquifer	0.0085 [82]	...	...	...	...	...	...	...
Chiang, et al ^C	Northern Michigan Aquifer	0.095 [7]	...	...	...	...	...	...	...
Wilson, et al ^D	Traverse City, MI Aquifer	0.007 to 0.024 [99] to [29]	0.067 [10]	...	0.004 to 0.014 [173] to [50]	...	...	...	...
Howard, et al ^E	Literature	0.0009 [730] to 0.069 [10]	0.025 [28] to 0.099 [7]	0.003 [228] to 0.116 [6]	0.0019 [365] to 0.0495 [14]	...	0.0019 [365] to 0.0866 [8]	0.0027 [258]	0.0007 [1058] to 0.0061 [114]

- ^A See Ref (36).
- ^B See Ref (37).
- ^C See Ref (38).
- ^D See Ref (39).
- ^E See Ref (40).

which the model result is affected by changes in a selected model input representing fluid and media properties and boundary conditions.

X3.3.2.14 *simulation*—in migration modeling, one complete execution of a fluid flow modeling computer program, including input and output.

DISCUSSION—for the purposes of this appendix, a simulation refers to an individual modeling run. However, simulation is sometimes also used broadly to refer to the process of modeling in general.

X3.4 Significance and Use:

X3.4.1 Predictive modeling is significant in many phases of RBCA, including the following:

X3.4.1.1 Determining the potential urgency of response based on estimated migration and attenuation rates of compounds of concern,

X3.4.1.2 Determining the extent of corrective action

based on estimated migration and attenuation rates of compounds of concern,

TABLE X3.3 Results of Exponential Regression for Concentration Versus Time^A

Site	Compound	k, % per day
Campbell, CA	benzene	1.20
	ethylbenzene	0.67
	xylene	1.12
Palo Alto, CA	benzene	0.42
	benzene	0.30
	PCE	0.46
Virginia Beach, VA	TCE	0.30
	benzene	0.42
Montrose County, CO	benzene	0.23
Provo, UT	benzene	0.16
San Jose, CA	benzene	0.10
Chemical facility	benzene	0.39
	toluene	0.39
	PCE	0.34
	TCE	0.26

^A Source: Ref (41).

X3.4.1.3 Establishing relationships between administered doses and adverse impacts to humans and sensitive environmental receptors, and

X3.4.1.4 Determining RBSLs concentrations at points of exposure.

X3.4.2 Examples of predictive modeling uses in the RBCA process include the following:

X3.4.2.1 The prediction of contaminant concentration distributions for future times based on historical trend data, as in the case of ground water transport modeling,

X3.4.2.2 The recommendation of sampling locations and sampling frequency based on current interpretation and future expectations of contaminant distributions, as in the design of ground water monitoring networks,

X3.4.2.3 The design of corrective action measures, as in the case of hydraulic control systems, and

X3.4.2.4 The calculation of site-specific exposure point concentrations based on assumed exposure scenarios, as in the case of direct exposure to surficial soils.

X3.4.3 Predictive modeling is not used in the RBCA process as a substitute for validation of site-specific data.

X3.5 Interpretation of Predictive Modeling Results:

X3.5.1 Predictive models are mathematical approximations of real processes, such as the movement of chemicals in the subsurface, the ingestion of chemicals contained in drinking water, and adverse impacts to human health and environmental resources resulting from significant exposures. One key step towards evaluating model results is to assess the accuracy and uncertainty, and to verify the model used.

X3.5.2 The accuracy of modeling-based predictions is evaluated using a post audit and is dependent upon a number of factors, including the following:

X3.5.2.1 The approximations used when describing the real system by mathematical expressions,

X3.5.2.2 The model setup, that is, the input parameters (for example, boundary conditions) used to generate the results, and

X3.5.2.3 The mathematical methods used to solve the governing equations (for example, user selection of numerical solution methods, expansion approximations, numerical parameters, and so forth).

X3.5.3 Predictive modeling results are always subject to some degree of uncertainty. It is important to quantify this uncertainty to properly interpret the results. Many times this is done with a sensitivity analysis in which the user identifies those parameters that most significantly influence the results. If most of all of the parameters do not produce "sensitivity," then the model may need to be reevaluated because it is possible that the key parameters are missing from the model.

X3.5.4 A postaudit may be performed to determine the accuracy of the predictions. While model calibration and verification demonstrate that the model accurately simulates past behavior of the system, the postaudit tests whether the model can predict future system behavior. Postaudits are normally performed several years after the initial assessment and corrective action.

X3.5.5 In the RBCA process, "conservative" is an important criterion of predictive modeling. In the initial evaluation, Tier 1, the most conservative approach, is used, which provides a worst case scenario for potential exposure and

risk. Models that, because of their simplicity, neglect factors that yield conservative results are used. Input may include conservative values such as the USEPA RME values. When a more rigorous approach is warranted, such as in Tier 2 of the RBCA process, conservative values are often used, but in conjunction with a more reasonable case scenario. This level requires more specific information about the site and may involve the use of either simple or moderately complex mathematical models. It may involve the use of most likely exposure scenario (that is, USEPA MLE values). This information is used to set conservative corrective action objectives that are still regarded as overly protective. At some sites a comprehensive assessment is required (Tier 3) where SSTLs are determined using a site-specific transport and exposure model and, in some cases, parameter distributions. Tier 3 provides the most realistic evaluation of potential exposure and risk.

X3.6 Types of Predictive Migration and Risk Assessment Models:

X3.6.1 Predictive models typically used in the RBCA process can be grouped into two broad categories:

X3.6.1.1 Migration models, and

X3.6.1.2 Exposure, risk, and dose-response assessment models.

X3.6.2 The determination of Tier 1 RBSLs or Tiers 2 and 3 SSTLs generally involves the use of combinations of both types of models. A more detailed description of each type of model is given in X3.7 and X3.8.

X3.7 Procedures for Predictive Migration Models:

X3.7.1 Migration (fate and transport) models predict the movement of a petroleum release through soil, ground water, or air, or combination thereof, over time. Most models focus on specific phenomena (for example, ground water transport) and vary in complexity, depending on assumptions made during model development. In RBCA, simplistic screening-level migration models are utilized in Tiers 1 and 2, while more complex models are utilized in Tier 3.

X3.7.2 References to many simplistic models suitable for screening-level evaluations for a number of pathways relevant to hydrocarbon contaminant releases are listed in Table X3.1. Most of the screening-level migration models have a simple mathematical form and are based on multiple limiting assumptions rather than on actual phenomena. For example, a simple model is the use of estimated ground water flow velocity to assess the travel time between the leading edge of a dissolved hydrocarbon plume and a ground water well. The travel time is approximated by the following:

$$[\text{distance to well (ft)/flow velocity (ft/years)}] = \text{travel time (years)}$$

X3.7.2.1 In the case of a relatively light compound such as benzene dissolved in ground water, the flow velocity may best be equated with the ground water flow velocity. Heavier compounds such as naphthalene may be retarded so that a flow velocity lower than the ground water velocity may be used. If miscible liquids are present on the ground water surface, such as gasoline, the liquid flow velocity may actually exceed the ground water velocity.

X3.7.3 The use of more complex models is not precluded in the RBCA process; however, given limited data and assumptions that must be made, many complex numerical

models reduce to the analytical expressions given in Table X3.1.

X3.7.4 *Migration Model Data Requirements*—Predictive migration models require input of site-specific characteristics. Those most commonly required for various simplistic models include the following:

X3.7.4.1 Soil bulk density (for a typical soil: $\approx 1.7 \text{ g/cm}^3$),

X3.7.4.2 Total soil porosity (for a typical soil: $\approx 0.38 \text{ cm}^3/\text{cm}^3$),

X3.7.4.3 Soil moisture content can be conservatively estimated in many cases. It is approximately equal to the total soil porosity beneath the water table, and typically $>0.05 \text{ cm}^3\text{-H}_2\text{O}/\text{cm}^3\text{-soil}$ in the vadose zone; this can be a critical input parameter in the case of diffusion models and may require site-specific determination unless conservative values are used,

X3.7.4.4 Fraction organic matter in soil particles ($=0.00d - 0.01$; sandy soil is often conservatively assumed); this can also be a critical parameter requiring site-specific determination unless conservative values are used),

X3.7.4.5 Hydraulic conductivity (generally site-specific determination required),

X3.7.4.6 Ground water gradient and flow direction (requires site-specific determination), and

X3.7.4.7 First-order decay-rate (generally requires site-specific calibration as models are very sensitive to this parameter); see Tables X3.2 and X3.3 and Ref (41) for a summary of measured values currently available from the literature. The data in Table X3.3 include retardation and dispersion as well as natural biodegradation in attenuation rates measured. However, sensitivity studies indicate that natural biodegradation is the dominant factor. The sensitivity studies use Ref (42). According to these sensitivity studies, an order of magnitude increase in natural biodegradation rate is 3.5 times as effective as an order of magnitude increase in retardation and 12 times as effective as an order of magnitude increase in dispersion in attenuating concentration over distance. Therefore, approximately 80 % of the attenuation shown in the Ref (41) data can be attributed to natural biodegradation.

X3.7.4.8 A similar analysis of the sensitivity of attenuation parameters for the vapor transport pathway also indicates that natural biodegradation is the predominant attenuation mechanism (43). Soil geology is not considered an attenuation mechanism directly, but is a stronger determinant of how far contamination travels than even natural biodegradation. Gasoline contamination does not travel very far in clay (less than 30 ft (9 m)) according to the vapor transport model (43).

X3.7.5 Depending on the models selected, other information may be required, such as meteorological information (wind speed, precipitation, temperature), soil particle size distributions, and nearby building characteristics.

X3.7.6 In most cases, measurements of the attenuation (decrease in concentrations) of compounds with distance away from the contaminant source area will be required to calibrate and verify the predictive capabilities of the selected models. The amount of data required varies depending on the following:

X3.7.6.1 The model code used,

X3.7.6.2 The model's sensitivity to changes in input parameters, and

X3.7.6.3 The contribution of the pathway of concern to the total incremental exposure and risk.

X3.7.7 Generally, site-specific physical and chemical properties for the most sensitive parameters are required for migration models to obtain accurate results. However, instead of site-specific data, conservative values selected from the literature may be used with appropriate caution.

3.7.8 *Migration Modeling Procedure*—The procedure for applying a migration model includes the following steps: definition of study objectives, development of a conceptual model, selection of a computer code or algorithm, construction of the model, calibration of the model and performance of sensitivity analysis, making predictive simulations, documentation of the modeling process, and performing a postaudit. These steps are generally followed in order; however, there is substantial overlap between steps, and previous steps are often revisited as new concepts are explored or as new data are obtained. The iterative modeling approach may also require the reconceptualization of the problem. The basic modeling steps are discussed as follows.

X3.7.8.1 *Modeling Objectives*—Modeling objectives must first be identified (that is, the questions to be answered by the model). The objectives aid in determining the level of detail and accuracy required in the model simulation. Complete and detailed objectives would ideally be specified prior to any modeling activities. Objectives may include interpreting site characterization and monitoring data, predicting future migration, determining corrective action requirements, or predicting the effect of proposed corrective action measures.

X3.7.8.2 *Conceptual Model*—A conceptual model of a subsurface contaminant release, such as a hydrocarbon release from an underground tank, is an interpretation or working description of the characteristics and dynamics of the physical system. The purpose of the conceptual model is to consolidate site and regional data into a set of assumptions and concepts that can be evaluated quantitatively. Development of the conceptual model requires the collection and analysis of physical data pertinent to the system under investigation.

(1) The conceptual model identifies and describes important aspects of the physical system, including the following: geologic and hydrologic framework; media type (for example, fractured or porous); physical and chemical processes; and hydraulic, climatic, and vapor properties. The conceptual model is described in more detail for ground water flow systems in Guide D 5447.

(2) Provide an analysis of data deficiencies and potential sources of error with the conceptual model. The conceptual model usually contains areas of uncertainty due to the lack of field data. Identify these areas and their significance to the conceptual model evaluated with respect to project objectives.

X3.7.8.3 *Computer Code Selection*—Computer code selection is the process of choosing the appropriate software algorithm, or other analysis technique, capable of simulating the characteristics of the physical system, as identified in the conceptual model. The types of codes generally used in the RBCA process are analytical and numerical models. The selected code should be appropriate to fit the available data

and meet the modeling objectives. The computer code must also be tested for the intended use and be well documented.

(1) Analytical models are generally based on assumptions of uniform properties and regular geometries. Advantages include quick setup and execution. Disadvantages include, in many cases, that analytical models are so simplistic that important aspects of a given system are neglected.

(2) Numerical models allow for more complex heterogeneous systems with distributed properties and irregular geometries. Advantages include the flexibility to simulate more complex physical systems and natural parameter variability. Disadvantages include that the approach is often very time-intensive and may require much more data and information to be collected.

(3) Other factors may also be considered in the decision-making process, such as the model analyst's experience and those described as follows for model construction process; factors such as dimensionality will determine the capabilities of the computer code required for the model.

X3.7.8.4 Model Construction—Model construction is the process of transforming the conceptual model into a mathematical form. The model typically consists of two parts, the data set and the computer code. The model construction process includes building the data set used by the computer code. Fundamental components of a migration model are dimensionality, discretization, boundary and initial conditions, contaminant, and media properties.

X3.7.8.5 Model Calibration—Calibration of a model is the process of adjusting input for which data are not available within reasonable ranges to obtain a match between observed and simulated values. The range over which model parameters and boundary conditions may be varied is determined by data presented in the conceptual model. In the case where parameters are well characterized by field measurements, the range over which that parameter is varied in the model should be consistent with the range observed in the field. The degree of fit between model simulations and field measurements can be quantified using statistical techniques.

(1) In practice, model calibration is frequently accomplished through trial-and-error adjustment of the model's input data to match field observations. The calibration process continues until the degree of correspondence between the simulation and the physical system is consistent with the objectives of the project.

(2) Calibration of a model is evaluated through analysis of residuals. A residual is the difference between the observed and simulated variable. Statistical tests and illustrations showing the distribution of residuals are described for ground water flow models in Guide D 5490.

(3) Calibration of a model to a single set of field measurements does not guarantee a unique solution. To minimize the likelihood of nonuniqueness, the model should be tested to a different set of boundary conditions or stresses. This process is referred to as application verification. If there is poor correspondence to a second set of field data, then additional calibration or data collection are required. Successful verification of an application results in a higher degree of confidence in model predictions. A calibrated but unverified model may still be used to perform predictive simulations when coupled with a sensitivity analysis.

X3.7.8.6 Sensitivity Analysis—Sensitivity analysis is a quantitative method of determining the effect of parameter variation on model results. Two purposes of a sensitivity analysis are (1) to quantify the uncertainty in the calibrated model caused by uncertainty in the estimates of parameters, stresses, and boundary conditions, and (2) to identify the model inputs that have the most influence on model calibration and predictions.

(1) Sensitivity of a model parameter is often expressed as the relative rate of change of a selected model calculation during calibration with respect to that parameter. If a small change in the input parameter or boundary condition causes a significant change in the output, the model is sensitive to that parameter or boundary condition.

(2) Whether a given change in the model calibration is considered significant or insignificant is a matter of judgment. However, changes in the model's conclusions are usually able to be characterized objectively. For example, if a model is used to determine whether a contaminant is captured by a potable supply well, then the computed concentration is either detectable or not at the location. If, for some value of the input that is being varied, the model's conclusions are changed but the change in model calibration is insignificant, then the model results may be invalid because, over the range of that parameter in which the model can be considered calibrated, the conclusions of the model change. More information regarding conducting a sensitivity analysis for a ground water flow model application is presented in Guide D 5611.

X3.7.8.7 Model Predictions—Once these steps have been conducted, the model is used to satisfy the modeling objectives. Predictive simulations should be documented with appropriate illustrations, as necessary, in the model report.

X3.8 Procedures for Risk, Exposure, and Dose-Response Assessment Models:

X3.8.1 "Exposure models" are used to estimate the chemical uptake, or dose, while "risk assessment models" are used to relate human health or ecological impacts to the uptake of a chemical. Risk and exposure assessment models are often combined to calculate a target exposure point concentration of a compound in air, water, or soil.

X3.8.1.1 In the case of compounds that have been classified as carcinogens, exposure and risk assessment models are generally linked by the expression:

$$\text{risk} = \text{average lifetime intake [mg/kg-day]} \times \text{slope factor [mg/kg-day]}^{-1}$$

where the intake depends on exposure parameters (ingestion rate, exposure duration, and so forth) and the concentration at point-of-exposure. The slope factor (sometimes called the "potency factor") is itself based on a model and set of underlying assumptions, which are discussed as follows.

X3.8.1.2 In the case of compounds that have not been classified as carcinogens, exposure and risk assessment models are generally linked by the expression:

$$\text{hazard quotient} = \frac{\text{average intake [mg/kg-day]}}{\text{reference dose [mg/kg-day]}}$$

where the intake depends on exposure parameters (ingestion rate, exposure duration, and so forth) and the concentration at point-of-exposure. The reference dose is itself based on a

model and set of underlying assumptions, which are discussed as follows.

X3.8.2 Toxicity Assessment: Dose-Response Models— Toxicity assessments use dose-estimates of a "safe dose" or toxic level based on animal studies. In some instances, human epidemiological information is available on a chemical. Toxicologists generally make two assumptions about the effects of risk agents at the low concentrations typical of environmental exposures:

X3.8.2.1 Thresholds exist for most biological effects; in other words, for noncarcinogenic, nongenetic toxic effects, there are doses below which no adverse effects are observed in a population of exposed individuals, and

X3.8.2.2 No thresholds exist for genetic damage or incremental carcinogenic effects. Any level of exposure to the genotoxic or carcinogenic risk agent corresponds to some non-zero increase in the likelihood of inducing genotoxic or incremental carcinogenic effects.

X3.8.3 The first assumption is widely accepted in the scientific community and is supported by empirical evidence. The threshold value for a chemical is often called the NOAEL. Scientists usually estimate NOAELs from animal studies. An important value that typically results from a NOAEL or LOAEL value is the RfD. A reference dose is an estimate (with an uncertainty typically spanning an order of magnitude) of a daily exposure (mg/kg/day) to the general human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime of exposure. The RfD value is derived from the NOAEL or LOAEL by application of uncertainty factors (UF) that reflect various types of data used to estimate RfDs and an additional modifying factor (MF), which is based on a professional judgment of the quality of the entire database of the chemical. The oral RfD, for example, is calculated from the following equation:

$$RfD = \frac{NOAEL}{(UF \times MF)}$$

X3.8.4 The second assumption regarding no threshold effects for genotoxic or carcinogenic agents is more controversial but has been adopted by the USEPA. For genotoxic and carcinogenic agents, extrapolations from high experimental doses to low doses of environmental significance require the use of mathematical models to general low dose-response curves. It should be noted that although the EPA uses the linear multi-state model to describe incremental carcinogenic effect, there is no general agreement in the scientific community that this is the appropriate model to use.

X3.8.5 The critical factor determined from the dose-response curve is the slope factor (SF), which is the slope of the dose-response curve in the low-dose region. The units of the slope factor are expressed as (mg/kg-day)⁻¹ and relate a given environmental intake to the risk of additional incidence of cancer above background.

X3.8.6 The RfD or SF values are generally obtained from a standard set of reference tables (for example, Ref (2) or Ref (3)). It is important to note that the information in IRIS has typically only been peer-reviewed within the EPA and may not always have support from the external scientific community. Whereas the information in IRIS has been subject to

agency-wide data quality review, the information in the HEAST tables has not. The user is expected to consult the original assessment documents to appreciate the strengths and limitations of the data in HEAST. Thus, care should be exercised in using the values in HEAST. Some state and local agencies have toxicity factors they have derived themselves or preferences for factors to use if neither IRIS nor HEAST lists a value. Values for a range of hydrocarbons typically of interest are presented in Table X3.1.

X3.8.7 It is important to note that in extrapolating the information obtained in animal studies to humans, a number of conservative assumptions are made.

X3.8.7.1 For noncarcinogens, an arbitrary system of default safety and uncertainty factors, as discussed (in multiples of ten), is used to convert observations, in animals to estimates in humans.

X3.8.7.2 For carcinogens, some of the most important assumptions include: (1) the results of the most sensitive animal study are used to extrapolate to humans, (2) in general, chemicals with any incremental carcinogenic activity in animals are assumed to be potential human carcinogens, and (3) no threshold exists for carcinogens.

X3.8.8 The uncertainty in the RfD and SF values are often neglected in deference to single point values which are then typically summarized in databases such as IRIS and HEAST and assumptions described are risk management policy decisions made by the USEPA. These assumptions are not explicitly defined and further obscure the conservatism in the safe dose estimate. Thus, care must be exercised in interpreting results which have as a basis these conservative toxicity evaluations.

X3.8.9 Exposure Assessment Modeling—The goal of exposure assessment modeling is to estimate the chemical uptake that occurs when a receptor is exposed to compounds present in their environment. In principal, the process for developing and using migration models presented in X3.7 is directly applicable to exposure assessment modeling. In this case the user:

X3.8.9.1 Develops a conceptual model by identifying significant exposure pathways and receptors,

X3.8.9.2 Selects a model to describe the contact rate and subsequent uptake of the chemical(s),

X3.8.9.3 Performs a sensitivity analysis to identify critical parameters,

X3.8.9.4 Selects appropriate exposure parameters (breathing rates, and so forth),

X3.8.9.5 Generates estimates of exposure and uptake, and

X3.8.9.6 Assesses the uncertainty in the estimates.

X3.8.10 There are differences between the process outlined in X3.7 and that which can be practically applied to exposure assessment modeling. For example, with the exception of exposures and impacts to environmental resources, it is difficult to calibrate exposure assessment models unless very expensive epidemiological studies are conducted.

X3.8.11 Typically, the models used to estimate uptake are simplistic algebraic expressions, such as those contained in Ref (27). Application of these equations is illustrated in Appendix X2.

X3.8.12 In many cases, exposure parameter values are available in Ref (27), but other more recent information is also available in peer-reviewed publications, and all sources

should be carefully reviewed. While point values are often selected for simplicity, statistical distributions for many of the exposure parameters are readily available for Tier 3 analyses.

X3.8.13 It is common for USEPA RME values to be used in exposure assessment calculation, as is done for the example Tier 1 Look-Up Table discussed in Appendix X2. The RME value is generally defined as a statistical upper limit of available data (generally 85 to 90 % of all values are less than the RME value). Therefore, by consistently selecting and multiplying conservative RME values the user models a scenario that is very improbable and always more

conservative than the "true" RME exposure scenario. Thus, great care must be exercised, when using combinations of these default values in risk assessments, to avoid a gross overestimation of exposure for a specific site.

X3.9 *Report*—The purpose of the model report is to communicate findings, to document the procedures and assumptions inherent in the study, and to provide detailed information for peer review. The report should be a complete document allowing reviewers and decision makers to formulate their own opinion as to the credibility of the model. The report should describe all aspects of the modeling study outlined in this appendix.

X4. INSTITUTIONAL CONTROLS

X4.1 *Introduction:*

X4.1.1 The purpose of this appendix is to provide a review of generally used institutional controls. For purposes of this appendix, "institutional controls" are those controls that can be used by responsible parties and regulatory agencies in remedial programs where, as a part of the program, certain concentrations of the chemical(s) of concern will remain on site in soil or ground water, or both. Referenced in this appendix are examples of programs from California, Connecticut, Illinois, Indiana, Iowa, Massachusetts, Michigan, Missouri, and New Jersey. In addition, federal programs, such as Superfund settlements and RCRA closure plans have used the following techniques described for some years as a mechanism to ensure that exposure to remaining concentrations of chemical(s) of concern is reduced to the degree necessary.

X4.1.2 The types of institutional controls discussed in this appendix are as follows:

- X4.1.2.1 Deed restrictions, or restrictive covenants,
- X4.1.2.2 Use restrictions (including well restriction areas),
- X4.1.2.3 Access controls,
- X4.1.2.4 Notice, including record notice, actual notice, and notice to government authorities,
- X4.1.2.5 Registry act requirements,
- X4.1.2.6 Transfer act requirements, and
- X4.1.2.7 Contractual obligations.

X4.1.3 Institutional controls for environmental remedial programs vary in both form and content. Agencies and landowners can invoke various authorities and enforcement mechanisms, both public and private, to implement any one or a combination of the controls. For example, a state could adopt a statutory mandate (see X4.2) requiring the use of deed restrictions (see X4.3) as a way of enforcing use restrictions (see X4.4) and posting signage (a type of access control, see X4.5). Thus, the institutional controls listed as follows are often used as overlapping strategies, and this blurs the distinctions between them.

X4.2 *Statutory Mandates*—Some states' emergency response programs mandate post-remediation institutional controls and impose civil penalties for noncompliance. The schemes vary from state to state, but all impose obligations on landowners to use one or more institutional controls listed in this appendix.

X4.3 *Deed Restrictions:*

X4.3.1 Deed restrictions place limits and conditions on the use and conveyance of land. They serve two purposes: (1) informing prospective owners and tenants of the environmental status of the property and (2) ensuring long-term compliance with the institutional controls that are necessary to maintain the integrity of the remedial action over time. Restraining the way someone can use their land runs counter to the basic assumptions of real estate law, so certain legal rules must be satisfied in order to make a deed restriction binding and enforceable.

X4.3.2 There are four requirements for a promise in a deed restriction (also called a "restrictive covenant") to be held against current and subsequent landowners: (1) a writing, (2) intention by both original parties that particular restrictions be placed on the land in perpetuity, (3) "privity of estate," and (4) that the restrictions "touch and concern the land."

X4.3.2.1 The first requirement is that of a writing. It is a rule of law that conveyances of land must be documented in a writing. The same rule holds for deed restrictions affecting land. Ideally, a deed restriction used as an institutional control would be written down with particularity and then recorded in the local land records office, in much the same fashion as the documentation and recordation of a sale of land. Parties may also encounter the requirement that the deed restriction be executed "under seal," a legal formality that has been abandoned in most states.

X4.3.2.2 The second requirement is that the deed restriction should precisely reflect what the parties' intentions are in regard to the scope and the duration of the restrictions. Explicitly stating in the deed restriction that the parties intend the restriction to "run with the land" (that is, last forever and bind subsequent owners) is strongly recommended.

X4.3.2.3 The third requirement, privity of estate, arises from a concern that only persons with a certain relationship to the land should be able to enforce a deed restriction. Normally, deed restrictions are promises between the buyer and the seller or between neighbors; therefore, the state or a third party may not enforce a deed restriction. However, even in states that require privity of estate, this concern is addressed if the landowner took the land with knowledge that the restrictions existed and might be enforced by these third parties. Thus, it is also strongly recommended that the deed

restriction explicitly state that the state environmental authority may enforce the restriction. Recording of the deed restriction serves as notice to anyone who later purchases or acquires an interest in the land. Therefore, privity of estate should not be a barrier to state enforcement of the deed restriction if the proper steps are taken.

X4.3.2.4 Finally, a deed restriction is only enforceable if the promise "touches and concerns the land." A rough rule of thumb to decide this point is whether the landowner's legal interest in the land is decreased in value due to the deed restriction. If the land is devalued in this way, then the restriction could be said to "touch and concern the land." Note that the focus of the inquiry is on the land itself; promises that are personal in nature and merely concern human activities that happen to take place on the land are least likely to be enforceable. Thus, any deed restriction used as an institutional control should be written so that it centers on the land and the use of the land.

X4.3.3 Due to the potential enforcement hurdles encountered by a governmental agency in enforcing a deed restriction, it may be appropriate for an individual state to seek statutory and regulatory amendments to ensure that such authority exists in regard to all deed restrictions for environmental purposes.

X4.3.4 Remedies for noncompliance with deed restrictions comes in two forms: (1) persons or agencies may sue to obtain a court order (injunction) requiring compliance or (2) if the state statute allows for it, the state's attorney general can seek enforcement of civil penalties, such as fines, for noncompliance.

X4.3.5 A state program can require a landowner to continue monitoring activities and to allow state environmental officials access to the site to monitor compliance with institutional controls. These arrangements may have to be put in a deed restriction in order to run with the land from owner to owner, but responsible parties can also be required to sign a contract making these promises. Of course, almost every state has authority to issue administrative orders to accomplish some or all of these arrangements.

X4.3.6 The preceding arrangements can also set out procedures that will be followed if some emergency requires that the remediation site be disturbed. If, for example, underground utility lines must be repaired, the landowner would follow this protocol for handling the soil and alerting the state authority.

X4.4 *Use Restrictions:*

X4.4.1 Use restrictions are usually the heart of what is in a deed restriction. Use restrictions describe appropriate and inappropriate uses of the property in an effort to perpetuate the benefits of the remedial action and ensure property use that is consistent with the applicable cleanup standard. Such techniques also prohibit any person from making any use of the site in a manner that creates an unacceptable risk of human or environmental exposure to the residual concentrations of chemical(s) of concern.

X4.4.2 Use restrictions address uses that may disturb a containment cap or any unremediated soils under the surface or below a building. A prohibition on drinking on-site (or off-site by means of well restriction areas discussed as follows) ground water may also be appropriate.

X4.4.3 As an example, a program may allow a restriction

of record to include one or more of the following:

X4.4.3.1 Restriction on property use;

X4.4.3.2 Conditioning the change of use from nonresidential on compliance with all applicable cleanup standards for a residential property;

X4.4.3.3 Restricting access; or

X4.4.3.4 Restricting disturbance of department-approved remedial effects.

X4.4.4 Well restriction areas can be a form of institutional control by providing notice of the existence of chemical(s) of concern in ground water, and by prohibiting or conditioning the construction of wells in that area.

X4.4.4.1 This technique preserves the integrity of any ground water remedial action by prohibiting or conditioning the placement and use of any or all types of wells within the area.

X4.4.4.2 Well restrictions of this nature would be subject to agency approval and public notice, and may include the restriction on constructing or locating any wells within a particular designated area. Notice of the well restriction is recorded on the land records and with various health officials and municipal officials. The restrictions can only be released upon a showing that the concentrations of the chemical(s) of concern in the well restriction area is remediated in accordance with state standards.

X4.5 *Access Controls:*

X4.5.1 Another subset of institutional controls is the control of access to any particular site. The state uses the following criteria to determine the appropriate level and means of access control:

X4.5.1.1 Whether the site is located in a residential or mixed use neighborhood;

X4.5.1.2 Proximity to sensitive land-use areas including day-care centers, playgrounds, and schools; and

X4.5.1.3 Whether the site is frequently traversed by neighbors.

X4.5.2 Access can be controlled by any of the following: fencing and gates, security, or postings or warnings.

X4.6 *Notice*—Regulations of this type generally provide notice of specific location of chemical(s) of concern on the site, and disclose any restrictions on access, use, and development of part or all of the contaminated site to preserve the integrity of the remedial action.

X4.6.2 *Record Notice:*

X4.6.2.1 Some states require that sites having releases of hazardous waste file a notice on the land records providing to any subsequent purchaser of the property information regarding the past or current activities on the site.

X4.6.2.2 The record notice requirement may be broad; the program may require any property subject to a response action to obtain a professional opinion and then prepare and record a Grant of Environmental Restriction that is supported by that opinion.

X4.6.2.3 The record notice requirement can be ancillary to a transfer act (see X4.8), in which case recording of an environmental statement is only required in conjunction with a land transaction.

X4.6.3 *Actual Notice:*

X4.6.3.1 States may require direct notice of environmental information to other parties to a land transaction.

These laws protect potential buyers and tenants, and they also help ensure that use restrictions and other institutional controls are perpetuated.

X4.6.3.2 Actual notice of an environmental defect or failure to provide notice may give a party the right to cancel the transaction and result in civil penalties. For example, landlords and sellers who do not give notice as required by the state may be liable for actual damages plus fines. Nonresidential tenants who fail to notify landowners of suspected or actual hazardous substance releases can have their leases canceled and are subject to fines.

X4.6.4 *Notice to Government Authorities*—Parties to a land transaction may also be required to file the environmental statement with various environmental authorities. Notice to the government may be required before the transaction takes place.

X4.7 *Registry Act Requirements:*

X4.7.1 Some states have registry act programs that provide for the maintenance of a registry of hazardous waste disposal sites and the restriction of the use and transfer of listed sites.

X4.7.2 A typical registry act provides that the state environmental agency establish and maintain a registry of all real property which has been used for hazardous substance disposal either illegally or before regulation of hazardous waste disposal began in that state.

X4.7.3 The state agency is responsible for investigating potential sites for inclusion on the registry. The registry includes the location of the site and a listing of the hazardous wastes on the property, and may also include a classification of the level of health or environmental danger presented by the conditions on the property. The state agency may be required to perform detailed inspections of the site to determine its priority relative to other registered sites.

X4.7.4 Owners of sites proposed for inclusion on the registry have rights of hearing and appeal, and owners of sites on the registry have rights to modify or terminate their listing. In some cases, the owner of a site proposed for inclusion on the registry may obtain the withdrawal of the proposed registration by entering into a consent agreement with the state. Such a consent agreement establishes a timetable and responsibility for remedial action.

X4.7.5 When a site appears on the state registry, the owner must comply with regulatory requirements in regard to use and transfer of the site. The use of a site listed on the registry may not be changed without permission of the state agency. In negotiations for a conveyance of a registered site, the owner may be obligated to disclose the registration early in the process, and permission of the state agency may be required to convey a registered property. Under other schemes, permission to convey is not required, but the seller must notify the state agency of the transaction.

X4.7.6 Finally, registry acts require that the listing of a property on a hazardous materials site registry be recorded in the records of the appropriate locality so that the registration will appear in the chain of title.

X4.8 *Transfer Act Requirements:*

X4.8.1 Some states have transfer act programs that require full evaluation of all environmental issues before or after the transfer occurs. It may be that within such program, institutional controls can be established by way of consent

order, administrative order, or some other technique that establishes implementation and continued responsibility for institutional controls.

X4.8.2 A typical transfer act imposes obligations and confers rights on parties to a land transaction arising out of the environmental status of the property to be conveyed. Transfer acts impose information obligations on the seller or lessor of a property (see X4.6.3). That party must disclose general information about strict liability for cleanup costs as well as property-specific information, such as presence of hazardous substances, permitting requirements and status, releases, and enforcement actions and variances.

X4.8.3 Compliance with transfer act obligations in the manner prescribed is crucial for ensuring a successful conveyance. Sometimes the transfer act operates to render a transaction voidable before the transfer occurs. Failure to give notice in the required form and within the time period required or the revelation of an environmental violation or unremediated condition will relieve the transferee and the lender of any obligation to close the transaction, even if a contract has already been executed. Moreover, violation of the transfer act can be the basis for a lawsuit to recover consequential damages.

X4.9 *Contractual Obligations:*

X4.9.1 One system for ensuring the future restriction on use of a site, or the obligation to remediate a site, is to require private parties to restrict use by contract. While this method is often negotiated among private parties, it will be difficult, if not impossible, to institutionalize some control over that process without interfering with the abilities and rights of private parties to freely negotiate these liabilities.

X4.9.2 Another avenue is for the landowner or responsible party to obligate itself to the state by contract. The state may require a contractual commitment from the party to provide long-term monitoring of the site, use restrictions, and means of continued funding for remediation.

X4.10 *Continued Financial Responsibility*—Another aspect of institutional controls is the establishment of financial mechanisms by which a responsible party ensures continued funding of remediation measures and assurance to the satisfaction of the state.

X4.11 *References:*

X4.11.1 The following references serve as examples and are current as of the fourth quarter of 1993:

X4.11.1.1 *References for Deed Restrictions:*

24 New Jersey Regulations 400 (1992) (New Jersey Administration Code § 7.26D-8.2 (e) (2))

24 New Jersey Regulations 400-02 (1992) (New Jersey Administration Code §§ 7.26D-8.1-8.4)

24 New Jersey Regulations 401 (1992) (New Jersey Administration Code § 7.26D Appendix A, Model Document, Declaration of Environmental Restrictions and Grant of Easement, Item 8)

Illinois Responsible Property Transfer Act § 7(c) (1985)

Massachusetts Regulations Code Title _____ § 40.1071 (2) (1) & (k)

Massachusetts Regulations Code, Title _____ § 40.1071(4)

Michigan Administration Code 299.5719 (3) (e) (1990)

Michigan Rules 299.5719 (2), (3) (d)

X4.11.1.2 *References for Use Restrictions:*

24 New Jersey Regulations 400 (New Jersey Administration Code § 7.26D-8.2 (d))

Michigan Administration Code 299.5719 (3) (a), (b), (g)

New Jersey Regulation 7.26D-8.4

X4.11.1.3 *References for Access Controls:*

Iowa Administration Code r. 133.4 (2) (b)
 Michigan Rule 299.4719 (3) (f)
 New Jersey Regulations § 7.26D-8.2

X4.11.1.4 References for Notice:

California Health and Safety Code § 25359.7 (1981)
 Illinois Responsible Property Transfer Act (1985)
 Indiana Code §§13-7-22.5-1-22 (1989) ("Indiana Environmental Hazardous Disclosure and Responsible Party Transfer Law")
 Massachusetts Regulations Code Title _____ §§ 40.1071-1090 (1993)
 Michigan Rule 299.5719 (3) (c)

X4.11.1.5 References for Registry Act Requirements:

Iowa Code Ann. §§ 455B.426-455B.432, 455B.411 (1) (1990)
 Missouri Code Regulations Title 10, §§ 25-10.010, 25-3.260 (1993)

X4.11.1.6 References for Transfer Act Requirements:

Connecticut General Stat. §22a-134 *et seq*
 Illinois Responsible Property Transfer Act (1985)
 Indiana Code §§ 13-7-22.5-1-22 (1989) ("Indiana Environmental Hazardous Disclosure and Responsible Party Transfer Law")
 New Jersey Senate Bill No. 1070, the Industrial Site Recovery Act, amending the environmental cleanup Responsibility Act, N.J.S.A. 13:1K-6 *et seq*
 New Jersey Spill Compensation and Control Act, N.J.S.A. 58:10-23.11 *et seq*

X4.11.1.7 Reference for Contractual Obligations:

Michigan Rule 299.5719 (2)

X4.11.1.8 Reference for Continued Financial Responsibility:

Michigan Rule 299.5719 (2)

X5. EXAMPLE APPLICATIONS OF RISK-BASED CORRECTIVE ACTION

X5.1 Introduction—The following examples illustrate the use of RBCA at petroleum release sites. The examples are hypothetical and have been simplified in order to illustrate that RBCA leads to reasonable and protective decisions; nevertheless, they do reflect conditions commonly encountered in practice.

X5.2 Example 1—Corrective Action Based on Tier 1 Risk-Based Screening Levels:

X5.2.1 Scenario—A release from the underground storage tank (UST), piping, and dispenser system at a service station is discovered during a real estate divestment assessment. It is known that there are petroleum-impacted surficial soils in the area of the tank fill ports; however, the extent to which the soils are impacted is unknown. In the past, both gasoline and diesel have been sold at the facility. The new owner plans to continue operating the service station facility.

X5.2.2 Site Assessment—The responsible party completes an initial site assessment focussed on potential source areas (for example, tanks, lines, dispensers) and receptors. Based on historical knowledge that gasoline and diesel have been dispensed at this facility, chemical analyses of soil and ground water are limited to benzene, toluene, ethylbenzene, xylenes, and naphthalene. Site assessment results are summarized as follows:

X5.2.2.1 Field screening instruments and laboratory analyses indicate that the extent of petroleum-impacted soils is confined to the vicinity of the fill ports for the tanks. A tank and line test reveals no leaks; therefore, evidence suggests that soils are impacted due to spills and overfills associated with filling the storage tank.

X5.2.2.2 The current tanks and piping were installed five years ago.

X5.2.2.3 The concrete driveway is highly fractured,

X5.2.2.4 No other sources are present,

X5.2.2.5 The site is underlain by layers of fine to silty sands,

X5.2.2.6 Ground water, which is first encountered at 32 ft (9.7 m) below ground surface, is not impacted,

X5.2.2.7 Maximum depth at which hydrocarbons are detected is 13 ft (3.9 m). Maximum detected soil concentrations are as follows:

Compound	Depth	Concentration, mg/kg
	Below Ground Surface, ft (m)	
Benzene	8 (2.4)	10
Ethylbenzene	4 (1.2)	4
Toluene	6.5 (1.9)	55

Xylenes	3.5 (1.01)	38
Naphthalene	2 (0.6)	17

X5.2.2.8 A receptor survey indicates that two domestic water wells are located within 900 ft (273.6 m) of the source area. One well is located 500 ft (152.4 m) hydraulically down-gradient from the impacted soil zone, the other well is hydraulically up-gradient. Both wells produce water from the first encountered ground water zone.

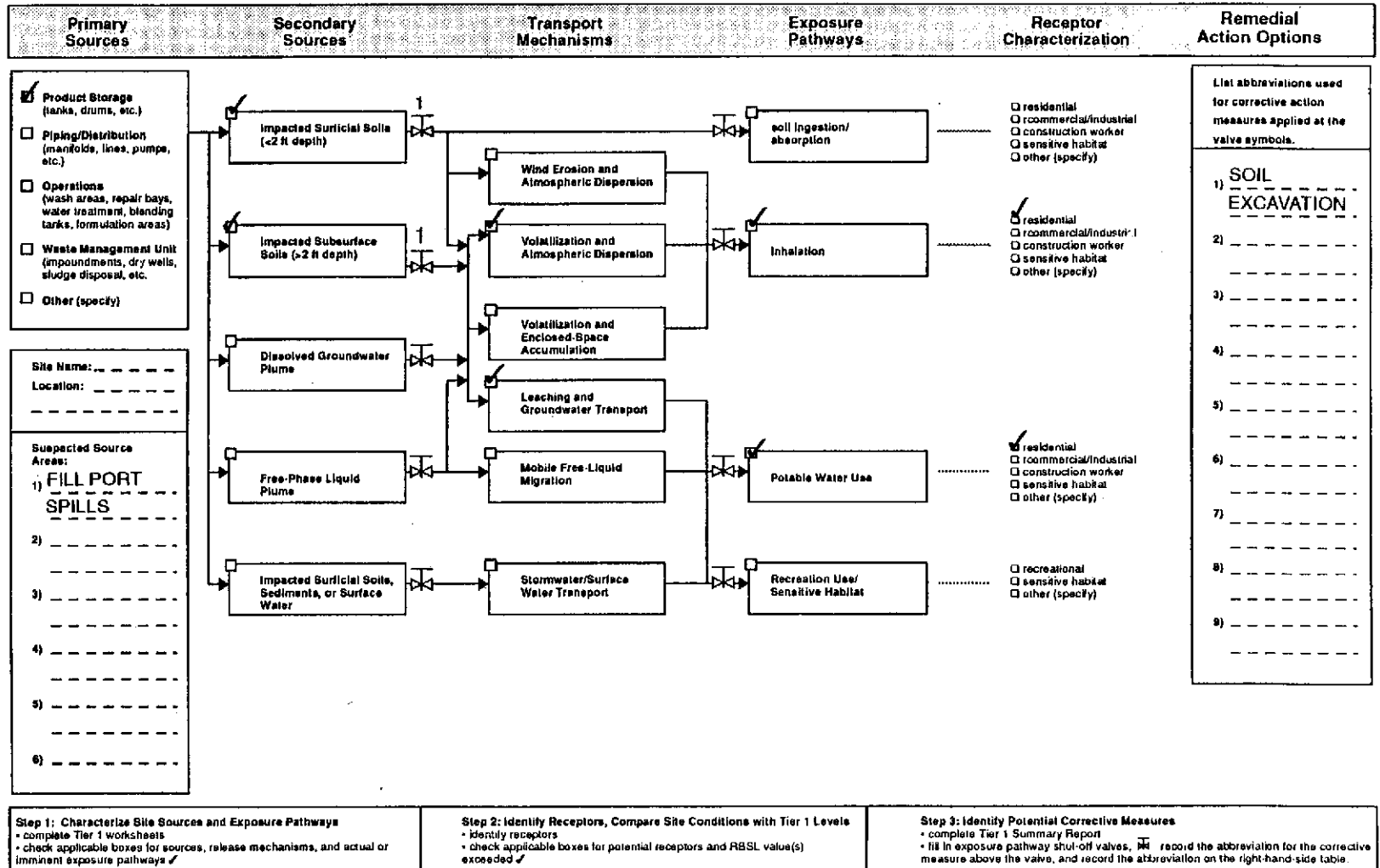
X5.2.3 Site Classification and Initial Response Action—Based on classification scenarios given in Table 1, this site is classified as a Class 3 site because conditions are such that, at worst, it is a long-term threat to human health and environmental resources. The appropriate initial response is to evaluate the need for a ground water monitoring program. At most, this would consist of a single well located immediately down-gradient of the impacted petroleum soils. The responsible party recommends deferring the decision to install a ground water monitoring system until the Tier 1 evaluation is complete, and justifies this recommendation based on no detected ground water impact, the limited extent of impacted soils, and the separation between impacted soils and first-encountered ground water. The regulatory agency concurs with this decision.

X5.2.4 Development of Tier 1 Look-Up Table of Risk-Based Screening Level (RBSL)—Assumptions used to derive example Tier 1 RBSL Look-Up Table X2.1 in Appendix X2 are reviewed and presumed valid for this site. A comparison of RBSLs for both pathways of concern indicates that RBSLs associated with the leaching pathway are the most restrictive of the two. As this aquifer is currently being used as a drinking water supply, RBSL values based on meeting drinking water MCLs are selected. In the case of naphthalene, for which there is no MCL, the RBSL value corresponding to a residential scenario and a hazard quotient of unity is used.

X5.2.5 Exposure Pathway Evaluation—Based on current and projected future use, the only two potential complete exposure pathways at this site are: (1) the inhalation of ambient vapors by on-site workers, or (2) the leaching to ground water, ground water transport to the down-gradient drinking-water well, and ingestion of ground water (see Fig. X5.1).

X5.2.6 Comparison of Site Conditions With Tier 1 RBSLs—Based on the data given in X5.2.3.7 and the RBSLs given in Look-Up Table X2.1 in Appendix X2, exceedences of Tier 1 RBSLs are noted only for benzene and toluene.

FIG. X5.1 Example 1—Exposure Evaluation Flowchart



X5.2.7 *Evaluation of Tier 1 Results*—The responsible party decides to devise a corrective action plan to meet Tier 1 standards after considering the following factors:

X5.2.7.1 The shallow aquifer is not yet affected,

X5.2.7.2 Quick (relative to rate of chemical migration) removal of the source will eliminate the need for ground water monitoring,

X5.2.7.3 The new owner plans to install new tanks within six months,

X5.2.7.4 Limited excavation of soils to meet Tier 1 criteria could be performed quickly and inexpensively when the tanks are removed, relative to the cost of proceeding to a Tier 2 analysis, and

X5.2.7.5 An excavation proposal will facilitate the real estate deal.

X5.2.8 *Tier 1 Remedial Action Evaluation*—Excavate all impacted soils with concentrations above the Tier 1 RBSLs when the current tanks are replaced. Subsequently resurface the area with new concrete pavement to reduce future infiltration and leaching potential through any remaining impacted soils. It is agreed that ground water monitoring is not necessary and the governing regulatory agency agrees to issue a No Further Action and Closure letter following implementation of the corrective action plan.

X5.3 *Example 2—RBCA Based on Tier 2 Evaluation:*

X5.3.1 *Scenario*—During the installation of new double-contained product transfer lines, petroleum-impacted soils are discovered in the vicinity of a gasoline dispenser at a service station located close to downtown Metropolis. In the past, both gasoline and diesel have been sold at this facility, which has been operating as a service station for more than twenty years.

X5.3.2 *Site Assessment*—The owner completes an initial site assessment focussed on potential source areas (for example, tanks, lines, dispensers) and receptors. Based on historical knowledge that gasoline and diesel have been dispensed at this facility, chemical analyses of soil and ground water are limited to benzene, toluene, ethylbenzene, xylenes, and naphthalene. Results of the site investigation are as follows:

X5.3.2.1 The extent of petroleum-impacted soils is confined to the vicinity of the tanks and dispensers. A recent tank and line test revealed no leaks; therefore, evidence suggests that the releases occurred sometime in the past,

X5.3.2.2 The current tanks, lines, and dispensers were installed three years ago,

X5.3.2.3 The asphalt driveway is competent and not cracked,

X5.3.2.4 Another service station is located hydraulically down gradient, diagonally across the intersection,

X5.3.2.5 The site is underlain by silty sands with a few thin discontinuous clay layers,

X5.3.2.6 Ground water, which is first encountered at 32 ft (9.7 m) below ground surface, is impacted, with highest dissolved concentrations observed beneath the suspected source areas. Dissolved concentrations decrease in all directions away from the source areas, and ground water samples taken hydraulically down gradient from a well located in the center divider of the street (about 100 ft (30.4 m) from the source area) do not contain any detectable levels of dissolved hydrocarbons,

X5.3.2.7 Ground water flow gradient is very shallow, and ground water flow velocities are at most tens of feet per year,

X5.3.2.8 Ground water yield from this aquifer is estimated to be in excess of 5 gal/min (18.9 L/min), and total dissolved solids levels are less than 700 mg/L. Based on this information, this aquifer is considered to be a potential drinking water supply,

X5.3.2.9 A shallow soil gas survey indicates that no detectable levels of hydrocarbon vapors are found in the utility easement running along the southern border of the property, or in soils surrounding the service station kiosk,

X5.3.2.10 Impacted soils extend down to the first encountered ground water. Maximum concentrations detected in soil and ground water are as follows:

Compound	Soil, mg/kg	Ground water, mg/L
Benzene	20	2
Ethylbenzene	4	0.5
Toluene	120	5
Xylenes	100	5.0
Naphthalene	2	0.05

X5.3.2.11 A receptor survey indicates that no domestic water wells are located within one-half mile of the site; however, there is an older residential neighborhood located 1200 ft (365.7 m) hydraulically down gradient of the site. Land use in the immediate vicinity is light commercial (for example, strip malls). The site is bordered by two streets and a strip mall parking lot.

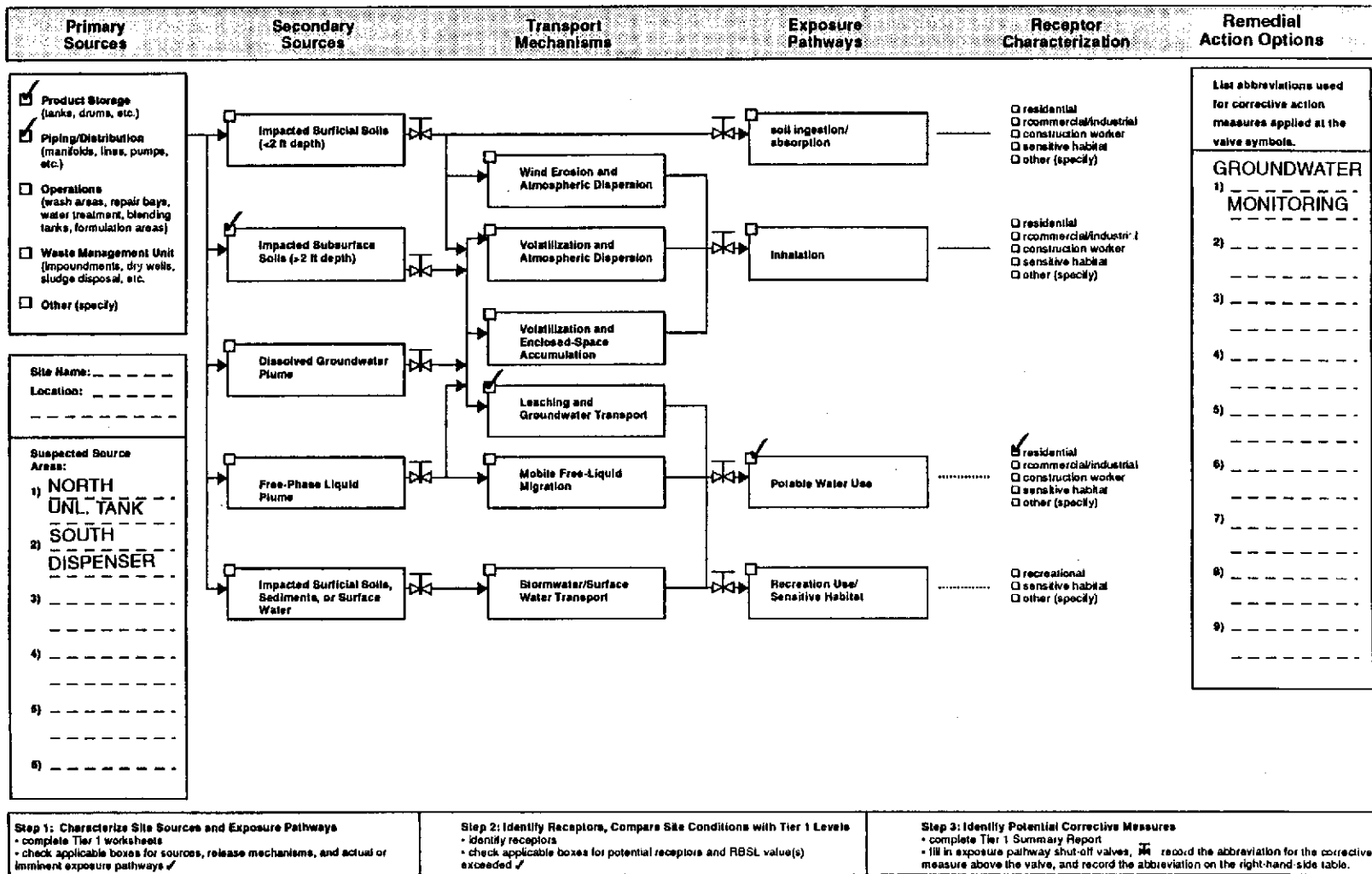
X5.3.3 *Site Classification and Initial Response Action*—Based on classification scenarios given in Table 1, this site is classified as a Class 3 site because conditions are such that, at worst, it is a long-term threat to human health and environmental resources. The appropriate initial response is to evaluate the need for a ground water monitoring program. The owner proposes that the ground water monitoring well located hydraulically down gradient in the street divider be used as a sentinel well, and be sampled yearly. The regulatory agency concurs, provided that the well be sampled every six months.

X5.3.4 *Development of Tier 1 Look-Up Table of Risk-Based Screening Level (RBSL) Selection*—Assumptions used to derive example Tier 1 RBSL Look-Up Table X2.1 in Appendix X2 are reviewed and presumed valid for this site. Due to the very low probability of the exposure pathway actually being completed in the future, MCLs are not used and the site owner is able to negotiate Tier 1 RBSLs based on a 10^{-5} risk to human health for carcinogens and hazard quotients equal to unity for the noncarcinogens (based on ground water ingestion).

X5.3.5 *Exposure Pathway Evaluation*—Based on current and projected future use, and the soil gas survey results, there are no potential complete exposure pathways at this site. The down gradient residential neighborhood is connected to a public water supply system, and there is no local use of the impacted aquifer. However, being concerned about future uncontrolled use of the aquifer, the regulatory agency requests that the owner evaluate the ground water transport to residential drinking water ingestion pathway, recognizing that there is a low potential for this to occur (see Fig. X5.2).

X5.3.6 *Comparison of Site Conditions With Tier 1 RBSLs*—Based on the data given in X5.3.2.10 and the RBSLs given in example Look-Up Table X2.1 in Appendix X2,

FIG. X5.2 Example 2—Exposure Evaluation Flowchart



exceedences of Tier 1 soil and ground water RBSLs are noted only for benzene.

X5.3.7 Evaluation of Tier 1 Results—The responsible party decides to proceed to a Tier 2 evaluation for benzene and the pathway of concern, rather than devise a corrective action plan to meet Tier 1 standards after considering the following factors:

X5.3.7.1 The shallow aquifer is impacted, but the dissolved plume appears to be stable and ground water movement is very slow,

X5.3.7.2 Excavation of soils to meet Tier 1 criteria would be expensive, due to the depth of impacted soils. Excavation would shut down the facility, and require all tanks and new lines to be removed and reinstalled,

X5.3.7.3 Costs for application of other conventional treatment methods, such as vapor extraction and pump and treat, are estimated to exceed \$300 000 over the life of the remediation, and

X5.3.7.4 A tier 2 analysis for this site is estimated to require minimal additional data, and is anticipated to result in equally protective, but less costly corrective action.

X5.3.8 Tier 2 Evaluation—The owner collects additional ground water monitoring data and verifies that:

X5.3.8.1 No mobile free-phase product is present,

X5.3.8.2 The dissolved plume is stable and ground water concentrations appear to be decreasing with time,

X5.3.8.3 Extent of the dissolved plume is limited to within 50 ft (15.2 m) of the property boundaries,

X5.3.8.4 Dissolved oxygen concentrations are higher outside of the dissolved plume, indicating some level of aerobic biodegradation,

X5.3.8.5 Ground water movement is less than 50 ft/year (15.2 m), and

X5.3.8.6 Simple ground water transport modeling indicates that observations are consistent with expectations for the site conditions.

X5.3.9 Remedial Action Evaluation—Based on the demonstration of dissolved plume attenuation with distance, the owner negotiates a corrective action plan based on the following: (1) compliance with the Tier 1 RBSLs at the monitoring well located in the street center divider, provided that deed restrictions are enacted to prevent the use of ground water within that zone until dissolved levels decrease below drinking water MCLs, (2) deed restrictions are enacted to ensure that site land use will not change significantly, (3) continued sampling of the sentinel/compliance ground water monitoring well on a yearly basis, (4) should levels exceed Tier 1 RBSLs at that point for any time in the future, the corrective action plan will have to be revised, and (5) closure will be granted if dissolved conditions remain stable or decrease for the next two years.

X5.4 Example 3—RBCA With Emergency Response and In Situ Remediation:

X5.4.1 Scenario—A 5 000-gal (18 925-L) release of super unleaded gasoline occurs from a single-walled tank after repeated manual gaging with a gage stick. Soils are sandy at this site, ground water is shallow, and free-product is observed in a nearby monitoring well within 24 h. The site is located next to an apartment building that has a basement where coin-operated washers and dryers are located for use by the tenants.

X5.4.2 Site Assessment—In this case the initial site assessment is conducted rapidly and is focussed towards identifying if immediately hazardous conditions exist. It is known from local geological assessments that the first encountered ground water is not potable, as it is only about 2 ft (0.6 m) thick and is perched on a clay aquitard. Ground water monitoring wells in the area (from previous assessment work) are periodically inspected for the appearance of floating product, and vapor concentrations in the on-site utility corridors are analyzed with an explosimeter. While this flurry of activity begins, a tenant of the apartment building next door informs the station operator that her laundry room/basement has a strong gasoline odor. Explosimeter readings indicate vapor concentrations are still lower than explosive levels, but the investigation team notes that "strong gasoline odors" are present.

X5.4.3 Site Classification and Initial Response Action—This limited information is sufficient to classify this site as a Class 2 site (strong potential for conditions to escalate to immediately hazardous conditions in the short term), based on the observed vapor concentrations, size of the release, and geological conditions. The initial response implemented is as follows:

X5.4.3.1 Periodic monitoring of the apartment basement begins to ensure that levels do not increase to the point where evacuation is necessary (either due to explosion or acute health effects). In addition, the fire marshall is notified and building tenants are informed of the activities at the site, potential hazards, and abatement measures being implemented,

X5.4.3.2 A free-product recovery/hydraulic control system is installed to prevent further migration of the mobile liquid gasoline, and

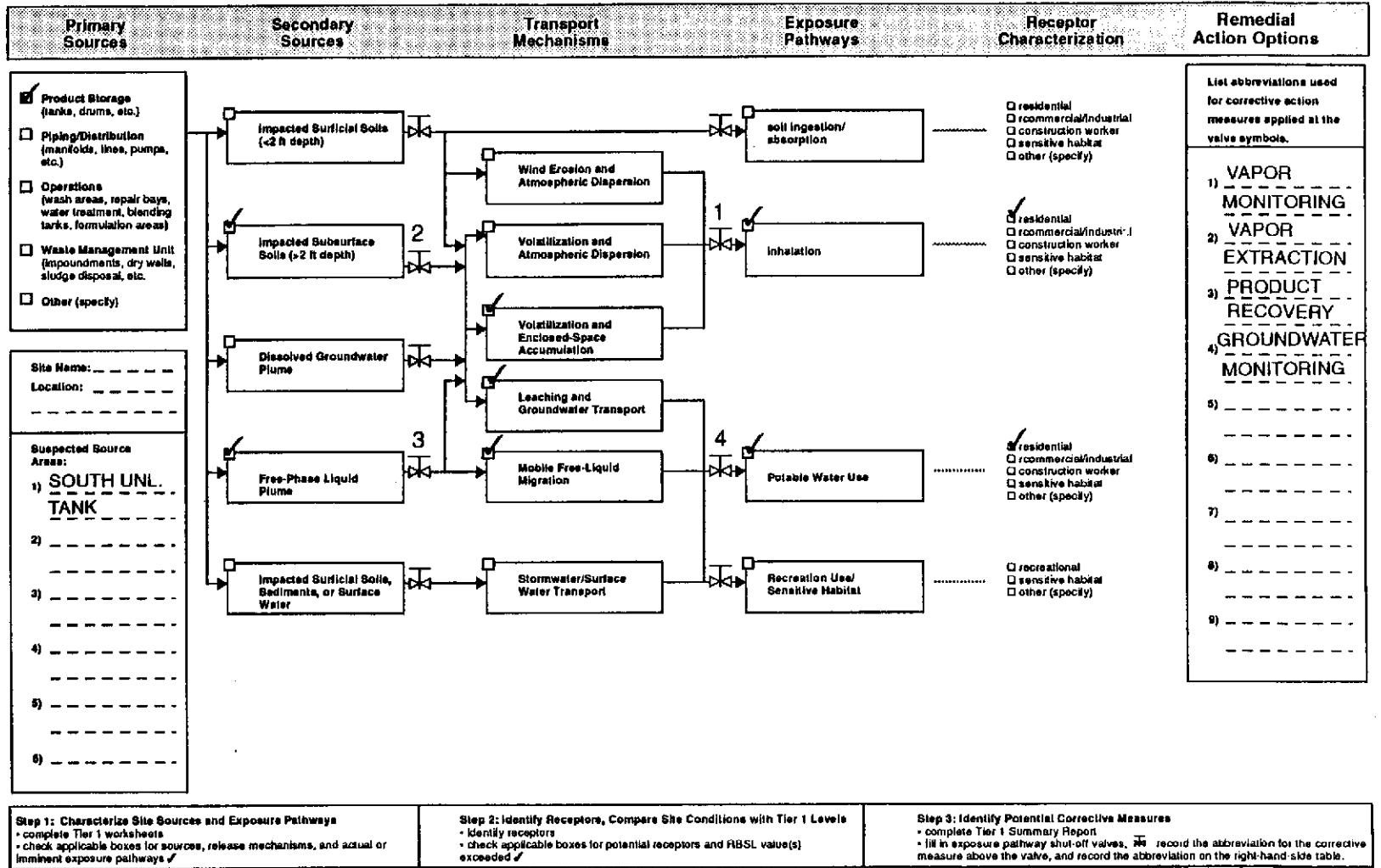
X5.4.3.3 A subsurface vapor extraction system is installed to prevent vapor intrusion to the building.

X5.4.4 Development of Tier 1 Look-Up Table of Risk-Based Screening Level (RBSL) Selection—Assumptions used to derive example Tier 1 RBSL Look-Up Table X2.1 in Appendix X2 are reviewed and presumed valid for this site. Target soil and ground water concentrations are determined based on the vapor intrusion scenario. After considering health-based, OSHA PEL, national ambient background, and aesthetic vapor concentrations, target soil levels are based on achieving a 10^{-4} chronic inhalation risk for benzene, and hazard quotients of unity for all other compounds. The agency agrees to base compliance on the volatile monoaromatic compounds in gasoline (benzene, toluene, xylenes, and ethylbenzene), but reserves the right to alter the target levels if aesthetic effects persist in the building basement at the negotiated levels.

X5.4.5 Exposure Pathway Evaluation—Given that: (1) there is a very low potential for ground water usage, (2) a 20-ft (6.1-m) thick aquitard separates the upper perched water from any potential drinking water supplies, and (3) the close proximity of the apartment building, the owner proposes focusing on the vapor intrusion—residential inhalation scenario (see Fig. X5.3). The agency concurs, but in order to eliminate potential ground water users as receptors of concern, requests that a down-gradient piezometer be installed in the lower aquifer. The owner concurs.

X5.4.6 Comparison of Site Conditions With Tier 1

FIG. X5.3 Example 3—Exposure Evaluation Flowchart



RBSLs—While a complete initial site investigation has yet to be conducted, all parties agree that currently the RBSLs are likely to be exceeded.

X5.4.7 Evaluation of Tier 1 Results—The owner decides to implement an interim corrective action plan based on Tier 1 RBSLs, but reserves the right to propose a Tier 2 evaluation in the future.

X5.4.8 Tier 1 Remedial Action Evaluation—The owner proposes expanding the vapor extraction system to remediate source area soils. In addition he proposes continuing to operate the free-product recovery/hydraulic control system until product recovery ceases. Monitoring of the piezometer placed in the lower aquifer will continue, as well as periodic monitoring of the apartment building basement. Additional assessments will be conducted to ensure that building vapors are not the result of other sources. After some period of operation, when hydrocarbon removal rates decline, a soil and ground water assessment plan will be instituted to collect data to support a Tier 2 evaluation.

X5.5 Example 4—RBCA Based on Use of a Tier 2 Table Evaluation—In circumstances where site-specific data are similar among several sites, a table of Tier 2 SSTL values can be created. The following example uses such a table.

X5.5.1 Scenario—Petroleum-impacted ground water is discovered in monitoring wells at a former service station. The underground tanks and piping were removed, and the site is now occupied by an auto repair shop.

X5.5.2 Site Assessment—The responsible party completes an initial site assessment to determine the extent of hydrocarbon-impacted soil and ground water. Because gasoline was the only fuel dispensed at the site, the assessment focussed on benzene, toluene, ethylene benzene, and xylenes (BTEX) as the chemicals of concern. Site assessment results are summarized as follows:

X5.5.2.1 The area of hydrocarbon-impacted soil is approximately 18 000 ft² (1672 m²) and the depth of soil impaction is less than 5 ft (1.5 m); The plume is off site,

X5.5.2.2 The site is covered by asphalt or concrete,

X5.5.2.3 The site is underlain by clay,

X5.5.2.4 Hydrocarbon-impacted perched ground water is encountered at 1 to 3 ft (0.3 to 0.9 m) below grade. This water is non-potable. The first potable aquifer is located over

100 ft (30 m) below grade and is not impacted. There is no free product,

X5.5.2.5 Maximum detected concentrations are as follows:

Compound	Soil, mg/kg	Ground water, mg/L
Benzene	39	1.8
Toluene	15	4.0
Ethylbenzene	12	0.5
Xylenes	140	9.0

X5.5.2.6 Ground water velocity is 0.008 ft/day (0.0024 m/day) based on slug tests and ground water elevation survey and assumed soil porosity of 50 %,

X5.5.2.7 A receptor survey indicates that the nearest down gradient water well is greater than 1.0 mile (1.6 km) away and the nearest surface water body is 0.5 miles (0.8 km). The distance to the nearest sensitive habitat is greater than 1.0 mile; however, there is a forest preserve frequented by day hikers and picnickers next to the site. The nearest home is 1000 ft (305 m) away. The commercial building on site is 25 ft (7.6 m) from the area of hydrocarbon-impacted soil.

X5.5.3 Site Classification and Initial Response Action—Based on the classification scenarios given in Table 1, this site is classified as a Class 4 site, with no demonstrable long-term threat to human health, safety, or sensitive environmental receptors, because the hydrocarbon-impacted soils are covered by asphalt or concrete and cannot be contacted, only non-potable perched water with no existing local use is impacted, and there is no potential for explosive levels or concentrations that could cause acute effects in nearby buildings. The appropriate initial response is to evaluate the need for a ground water monitoring program.

X5.5.4 Development of Tier 1 Look-Up Table of Risked-Based Screening Level (RBSL)—The assumptions used to derive the example Tier 1 RBSL Look-Up Table are presumed valid for this site.

X5.5.5 Exposure Pathway Evaluation—The complete pathways are ground water and soil volatilization to enclosed spaces and to ambient air, and direct exposure to impacted soil or ground water by construction workers. A comparison of RBSLs for these pathways of concern indicates that

TABLE X5.1 Example 1—Site Classification and Initial Response Actions

Criteria and Prescribed Scenarios	Example Initial Response Actions
<p>3. Long-term (>2 years) threat to human health, safety, or sensitive environmental receptors</p> <ul style="list-style-type: none"> ● Subsurface soils (>3 ft (0.9 m) BGS) are significantly impacted, and the depth between impacted soils and the first potable aquifer is less than 50 ft (15 m). ● Ground water is impacted, and potable water supply wells producing from the impacted interval are located >2 years ground water travel time from the dissolved plume. ● Ground water is impacted, and non-potable water supply wells producing from the impacted interval are located >2 years ground water travel time from the dissolved plume. ● Ground water is impacted, and non-potable water supply wells that do not produce from the impacted interval are located within the known extent of chemical(s) of concern. ● Impacted surface water, storm water, or ground water discharges within 1500 ft (457 m) of a sensitive habitat or surface water body used for human drinking water or contact recreation. ● Shallow contaminated surface soils are open to public access, and dwellings, parks, playgrounds, day-care centers, schools, or similar-use facilities are more than 500 ft (152 m) of those soils. 	<p>Notify appropriate authorities, property owners, and potentially affected parties, and evaluate the need to</p> <ul style="list-style-type: none"> ● Monitor ground water and determine the potential for future migration of the chemical(s) of concern to the aquifer. ● Monitor the dissolved plume and evaluate the potential for natural attenuation and the need for hydraulic control. ● Identify water usage of well, assess the effect of potential impact, monitor the dissolved plume, and evaluate whether natural attenuation or hydraulic control are appropriate control measures. ● Monitor the dissolved plume, determine the potential for vertical migration, notify the user, and determine if any impact is likely. ● Investigate current impact on sensitive habitat or surface water body, restrict access to area of discharge (if necessary), and evaluate the need for containment/control measures. ● Restrict access to impact soils.

TABLE X5.2 Example 2—Site Classification and Initial Response Actions

Criteria and Prescribed Scenarios	Example Initial Response Actions
<p>3. Long-term (>2 years) threat to human health, safety, or sensitive environmental receptors</p> <ul style="list-style-type: none"> ● Subsurface soils (>3 ft (0.9 m) BGS) are significantly impacted, and the depth between impacted soils and the first potable aquifer is less than 50 ft (15 m). ● Ground water is impacted, and potable water supply wells producing from the impacted interval are located >2 years ground water travel time from the dissolved plume. ● Ground water is impacted, and non-potable water supply wells producing from the impacted interval are located >2 years ground water travel time from the dissolved plume. ● Ground water is impacted, and non-potable water supply wells that do not produce from the impacted interval are located within the known extent of chemical(s) of concern. ● Impacted surface water, storm water, or ground water discharges within 1500 ft (457 m) of a sensitive habitat or surface water body used for human drinking water or contact recreation. ● Shallow contaminated surface soils are open to public access, and dwellings, parks, playgrounds, day-care centers, schools, or similar-use facilities are more than 500 ft (152 m) of those soils. 	<p>Notify appropriate authorities, property owners, and potentially affected parties, and evaluate the need to</p> <ul style="list-style-type: none"> ● Monitor ground water and determine the potential for future contaminant migration to the aquifer. ● Monitor the dissolved plume and evaluate the potential for natural attenuation and the need for hydraulic control. ● Identify water usage of well, assess the effect of potential impact, monitor the dissolved plume, and evaluate whether natural attenuation or hydraulic control are appropriate control measures. ● Monitor the dissolved plume, determine the potential for vertical migration, notify the user, and determine if any impact is likely. ● Investigate current impact on sensitive habitat or surface water body, restrict access to area of discharge (if necessary), and evaluate the need for containment/control measures. ● Restrict access to impact soils.

TABLE X5.3 Example 3—Site Classification and Initial Response Actions

Criteria and Prescribed Scenarios	Example Initial Response Actions
<p>2. Short-term (0 to 2 years) threat to human health, safety, or sensitive environmental receptors</p> <ul style="list-style-type: none"> ● There is potential for explosive levels, or concentrations of vapors that could cause acute effects, to accumulate in a residence or other building. ● Shallow contaminated surface soils are open to public access, and dwellings, parks, playgrounds, day-care centers, schools, or similar use facilities are within 500 ft (152 m) of those soils. ● A non-potable water supply well is impacted or immediately threatened. ● Ground water is impacted, and a public or domestic water supply well producing from the impacted aquifer is located within two-years projected ground water travel distance down gradient of the known extent of chemical(s) of concern. ● Ground water is impacted, and a public or domestic water supply well producing from a different interval is located within the known extent of chemicals of concern. ● Impacted surface water, storm water, or ground water discharges within 500 ft (152 m) of a sensitive habitat or surface water body used for human drinking water or contact recreation. 	<p>Notify appropriate authorities, property owners, and potentially affected parties, and evaluate the need to</p> <ul style="list-style-type: none"> ● Assess the potential for vapor migration (through monitoring/modeling) and remove source (if necessary), or install vapor migration barrier. ● Remove soils, cover soils, or restrict access. ● Notify owner/user and evaluate the need to install point-of-use water treatment, hydraulic control, or alternate water supply. ● Institute monitoring and then evaluate if natural attenuation is sufficient, or if hydraulic control is required. ● Monitor ground water well quality and evaluate if control is necessary to prevent vertical migration to the supply well. ● Institute containment measures, restrict access to areas near discharge, and evaluate the magnitude and impact of the discharge.

RBSLs associated with soil volatilization to an enclosed space are the most restrictive RBSLs.

X5.5.6 Comparison of Site Conditions with Tier 1 RBSLs—Based on the data given in X5.5.2 and the RBSLs given in Table X2.1, exceedances of Tier 1 RBSLs are noted for benzene in soil and ground water and toluene for ground water.

X5.5.7 Evaluation of Tier 1 Results—The responsible party decided to proceed to a Tier 2 evaluation for the pathways of concern rather than develop a corrective action plan for the following reasons:

X5.5.7.1 Only shallow perched water is impacted, and the dissolved plume is moving very slowly in tight clay,

X5.5.7.2 Excavation of soils to meet Tier 1 criteria would be expensive and would disrupt activities of the on-site business. Off-site excavation would be impractical and may not be able to clean up ground water to Tier 1 criteria,

X5.5.7.3 Other conventional treatment methods, such as pump and treat and vapor extraction, would be relatively ineffective in the heavy clay, and

X5.5.7.4 A Tier 2 evaluation for this site requires no

additional data and is expected to be an equally protective but less costly corrective action.

X5.5.8 Development of a Tier 2 Table of Site-Specific Target Levels (SSTLs)—The Tier 2 table is similar to the Tier 1 Look-Up Table with the exception that SSTLs for the pathways of concern are presented as functions of both the distance from the source to the receptor and the soil type.

X5.5.8.1 For the pathways considered, approaches for the Tier 2 table are consistent with guidelines contained in Ref (26).

X5.5.8.2 The equations, assumptions, and parameters used to construct the Tier 1 Look-Up Table and Tier 2 table are similar, except as noted as follows:

(1) Ground Water: Ingestion of Ground Water—A one-dimensional analytical mass balance equation with attenuation mechanisms of retardation, dispersivity, and first-order biological decay (in sandy soil only) was applied in conjunction with the equations in Tables X2.2 and X2.3 to calculate SSTLs. The analytical model is limited to steady-state conditions and longitudinal dispersion. The analytical solution to the mass balance equation is presented in Ref (44).

TABLE X5.4 Example Tier 2 Site-Specific Target Level (SSTL) Table—Soil and Ground Water

Exposure Pathway	Receptor Scenario	Distance to Source, ft (m)	SSTLs at Source Sandy Soil, Natural Biodegradation Carcinogenic Risk = 1×10^{-6} , HQ = 1				SSTLs at Source Clay Soil, No Natural Biodegradation Carcinogenic Risk = 1×10^{-5} , HQ = 1					
			Benzene	Ethylbenzene	Toluene	Xylene	Benzene	Ethylbenzene	Toluene	Xylene		
Soil	Soil vapor intrusion from soil to buildings, mg/kg	residential	10 (3)	0.052	18	11	450	1.7	570	300	9500	
		commercial/industrial	25 (7.6)	0.47	160	160	1.7 ^A	65	11 ^A	10 ^A	RES ^B	
	Surficial soil ingestion and dermal, mg/kg	residential	100 (30)	3.1 ^A	RES	RES	RES	RES	RES	RES	RES	
		commercial/industrial	10 (3)	0.13	39	24	980	4.3	1200	650	2.0 ^A	
	Soil lechate to protect ground water ingestion target level, mg/kg	residential	25 (7.6)	1.2	340	340	3.6 ^A	950	24 ^A	22.5 ^A	RES	
		commercial/industrial	100 (30)	8.0 ^A	RES	RES	RES	RES	RES	RES	RES	
	Ground Water	Ground water ingestion, mg/L	residential	0	0.029	3.6	7.3	73	0.029	3.6	7.3	73
			commercial/industrial	100	0.054	6.8	14	140	0.035	10	43	>S ^C
		Ground water vapor intrusion from ground water to buildings, mg/L	residential	500	0.68	90	350	>S	>S	>S	>S	>S
			commercial/industrial	0	0.099	10	20	200	0.099	10	20	200
Ground water ingestion, mg/L		residential	100	0.185	19	38	>S	0.12	29	120	>S	
		commercial/industrial	500	2.3	250	>S	>S	>S	>S	>S	>S	
Ground water vapor intrusion from ground water to buildings, mg/L		residential	10	0.11	32	17	510	5.0	>S	>S	>S	
		commercial/industrial	25	0.72	210	160	>S	1200	>S	>S	>S	
Ground water ingestion, mg/L		residential	100	>S	>S	>S	>S	>S	>S	>S	>S	
		commercial/industrial	10	0.28	70	36	>S	13	>S	>S	>S	
Ground water ingestion, mg/L	residential	25	1.9	>S	350	>S	>S	>S	>S	>S		
	commercial/industrial	100	>S	>S	>S	>S	>S	>S	>S	>S		

^A Weight percent.
^B RES—Selected risk level is not exceeded for pure compound present at any concentration.
^C >S—Selected risk level is not exceeded for all possible dissolved levels.

(2) *Ground Water: Inhalation of Outdoor Vapors*—This pathway was not considered because exposure concentrations were very low.

(3) *Ground Water: Inhalation of Enclosed-Space (Indoor) Vapors*—A one-dimensional mass balance equation following Jury, et al (31) has been used to model vapor transport (43). This model was used in conjunction with the equations in Table X2.2 and X2.3 to calculate SSTLs. The model includes concentration attenuation between the source and the building by partitioning into immobile pore water, adsorption onto soil, and biological degradation (in sandy soil only).

(4) *Subsurface Soils: Inhalation of Outdoor Vapors*—This pathway was not considered because exposure concentrations were very low.

(5) *Subsurface Soils: Inhalation of Enclosed-Space (Indoor) Vapors*—The SSTLs were calculated using the Jury model (31) as discussed in Paragraph (3) of X5.5.8.2.

(6) *Subsurface Soils: Leaching to Ground Water*—The SSTLs were calculated using the one-dimensional mass-balance equation described in Paragraph (1) of X5.5.8.2, in conjunction with the lechate factor, LF_{SW} , as discussed in X2.9.4.1.

(7) All exposure parameter values listed in Table X2.4, soil, building surface, and subsurface parameter values listed in Table X2.6, and chemical-specific properties listed in Table X2.7 have not been changed.

(8) First-order decay rates in sandy soil were assumed to be 0.2 % per day for all BTEX compounds. These rates are considered conservative. Chiang, et al (38) determined that a

DO of 2.0 mg/L is required for rapid and complete biodegradation of benzene. Chiang, et al (38) measured a biodegradation rate of 0.95 % per day, and Barker, et al (36) measured a biodegradation rate of 0.6 % per day for benzene. In general, published biodegradation rates range from 0.6 to 1.25 % per day. Chiang, et al (38) also determined that biodegradation rates may be slower and incomplete at DO concentrations below 2.0 mg/L. This is a conservative value since aerobic biodegradation continues at DO concentrations as low as 0.7 mg/L (44).

(9) Clay properties are as follows:

Total soil porosity, cm ³ /cm ³	0.05
Volumetric water content, cm ³ /cm ³	0.40
Ground water Darcy velocity, cm/s	25

X5.5.8.3 Assumptions used to derive the example Tier 2 SSTL table are reviewed and presumed valid for this site. Due to the very conservative assumptions used to calculate exposure and the small number of people potentially exposed, the Tier 2 SSTLs are based on a 10^{-5} risk to human health for carcinogens and hazard quotients equal to unity for noncarcinogens.

X5.5.9 *Comparison of Site Conditions with Tier 2 Table SSTLs*—Based on the data given in X5.5.2 and the SSTLs given in the example table, no exceedances of Tier 2 soil or ground water SSTLs are noted.

X5.5.10 *Tier 2 Remedial Action Evaluation*—Based on the fact that Tier 2 soil or ground water SSTLs are not exceeded, the responsible party negotiates a corrective action plan based on the following:

X5.5.10.1 Annual compliance monitoring of ground

water at down gradient monitoring wells will be performed to demonstrate decreasing concentrations.

X5.5.10.2 Should levels exceed Tier 2 SSTLs at any of these monitoring points at any future time, the corrective

action plan will be reevaluated, and

X5.5.10.3 Closure will be granted if dissolved concentrations remain stable or decrease for the next two years.

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