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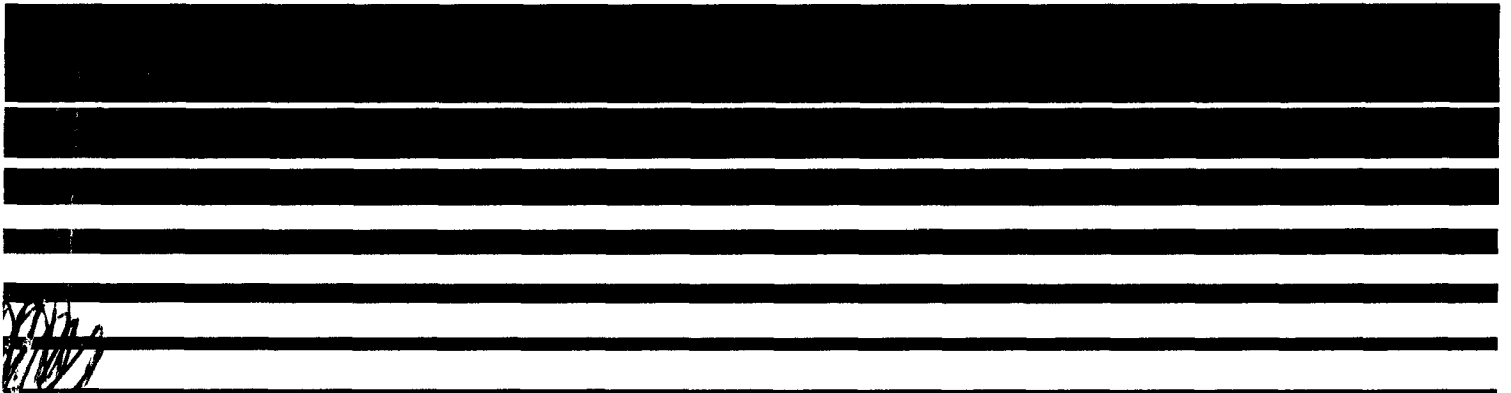
Air/Superfund

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# **AIR/SUPERFUND NATIONAL TECHNICAL GUIDANCE STUDY SERIES**

## **Assessing Potential Indoor Air Impacts for Superfund Sites**



ASSESSING POTENTIAL INDOOR  
AIR IMPACTS FOR SUPERFUND SITES

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Submitted by:

Pacific Environmental Services, Inc.  
560 Herndon Parkway, Suite 200  
Herndon, Virginia 22070

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## 1.0 INTRODUCTION

### 1.1 BACKGROUND

The Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA or "Superfund") and its reauthorization in the Superfund Amendments and Reauthorization Act (SARA) of 1986 establishes a national program for responding to releases of hazardous substances into the environment. The overarching mandate of the Superfund program is to protect human health and the environment from current and potential threats posed by these releases.

Occupants of buildings proximate to a site where such releases have occurred may potentially be exposed to the released chemicals from their transport into the indoor environment. Typical pathways for entry of site contaminants into a building include transport through the ambient air, the use of contaminated groundwater, seeps of non-aqueous liquids and groundwater through building exteriors, and intrusion of contaminated soil gases. In some cases, the resultant indoor air concentrations of site related chemicals may be high enough to warrant immediate corrective action, while in others they may be inconsequential.

Responses taken to assess whether or not an indoor air impact has occurred and the significance of that impact have varied from predictive modeling to on-site monitoring of the indoor air quality. Both the modeling and monitoring techniques used have been quite varied. Predictive modeling techniques used have ranged from quite simple screening tools to complex approaches. Although guidance exists for selection of air emission and dispersion models and information documents are available for indoor air modeling, no established guidance exists to assist with proper selection of predictive models for assessing potential indoor air impacts. Likewise, monitoring has varied from collecting grab samples to complex multi-building comparative studies. Although guidance exists for selection and use of monitoring techniques

for ambient air and soil gases and information documents are available for indoor air monitoring, no established guidance exists to assist with proper selection of methods to assess the potential site related indoor air impact.

The indoor environment, even for buildings not impacted by outdoor pollutants, is recognized to be highly polluted. Many indoor studies have shown that the normal indoor environment contains a wide variety of pollutants at higher concentrations than found outdoors. The sources of these pollutants are believed to be primarily consumer products. Indoor pollution can occur from cleaners and waxes, paints, pesticides, adhesives, cosmetic and personal care products, hobby supplies, furnishings and clothing, building materials, and heating and cooling systems, among others.

Many of the chemicals emitted by the materials are the same as chemicals released from Superfund and hazardous waste sites which severely complicates any attempt to determine the amount of any indoor air pollutant that is directly attributable to external sources. Further complicating the situation is the fact that buildings interact with the outdoor environment. The rate at which ambient air infiltrates a building is a function of several factors including wind speed, indoor-outdoor temperature differences, height of the building, and leaks in the building shell, as well as vented equipment, such as bathroom and kitchen fans or oil and gas furnaces and fireplaces. Air pressures below ambient can develop in the lower stories of a building. Although these pressure differences are small, typically between 1 and 10 pascals, they can result in the building literally sucking in soil gases through cracks and openings in below grade walls.

Site contaminant location in relation to building and contaminant source strength may also affect the rate of chemical entry into the building. Contaminant may arrive in the ambient air, in groundwater leaking into the building, from gases migrating laterally from the site, from nearby contaminated soils, and from contaminated groundwater plumes passing near or beneath the building. The amount of chemical arriving at the building then becomes a complex function of meteorological conditions and soil properties.

Determining the impact a nearby contaminated site may be having on the indoor air quality of a specific building can, thus, be seen to be a difficult task.

## 1.2 PURPOSE

This manual for assessing indoor air impacts was developed to be used for buildings proximate to Superfund sites. The procedures and methods may also be applied to other assessments of hazardous wastes and hazardous materials. The purpose is to provide information on methods and techniques that can be used to assess the potential or actual impact a Superfund site may have on the indoor air quality of buildings proximate to the site in order that the risk to the occupants from this source may be estimated. The manual is designed to provide the tools needed to assist in the identification and resolution of indoor air quality concerns at Superfund site.

## 1.3 SCOPE

This manual focuses on contaminant entry into the indoor environment via subsurface gases and ambient air. It does not address contaminant entry via direct intrusion of contaminated groundwater or indoor uses of contaminated groundwater such as showering. It also does not address radiologically contaminated sites, which, although an important consideration for some sites, is believed to be adequately covered by existing guidance for radon.

It provides summary level information on predictive modeling, on-site monitoring, and risk characterization. It contains information from indoor air studies that have been conducted using both modeling and monitoring approaches. This information was utilized to provide general information on the selection and use of models, monitoring methods, and assumptions useful in assessing site impacts on indoor air quality at levels ranging from scoping to detailed monitoring.

Individuals having different levels of scientific training and experience are likely to use this manual. Because assumptions and judgement are required in many parts of the assessment, the individuals conducting the evaluations are key elements in the process. The manual



is not intended to instruct non-technical persons how to perform technical evaluations, nor to allow professionals trained in one discipline to perform work in another.

The manual cannot address all circumstances. Users must exercise technical and management judgement, and should consult with appropriate regional and headquarters staff when encountering unusual or particularly complex technical issues. The procedures described should be viewed as flexible and can and should be tailored to specific circumstances and information needs of individual sites, and not as a rigid approach that must be conducted at every site.

## 2.0 INDOOR AIR IMPACT ASSESSMENT PROCEDURES

This Chapter presents general procedures for assessing potential Superfund site impact on indoor air in structures proximate to the site. It is recognized that the contaminant source type, location, proximity to the structure(s) and transport pathways, as well as the geology, hydrogeology, structural characteristics, and use of the structure(s) differ widely for all potential situation that may be encountered. Thus, this discussion, of necessity, is generic. Although the procedures should be generally applicable, they do not constitute a "how-to" or "cookbook" set of instructions. It is expected that proper application will require substantial expertise and professional judgement.

### 2.1 GENERAL CONCEPTS

The objective is to assess the potential exposure, and resultant risk, for occupants of buildings proximate to a Superfund sites to site contaminants via the indoor air pathway. To accomplish this objective, various techniques ranging from simple screening models to complex monitoring may be used. The confidence level in the results increases with increasing sophistication.

In recognition that conducting monitoring for buildings of a sophistication level sufficient to segregate site impacts from other potential sources can be expensive, the approach outlined is based on a graduated approach to scope the possible extent and magnitude of the possible impact before on-site detailed monitoring is executed. The approach follows these general steps:

1. Conduct simple conservative modeling to estimate the potential magnitude of the exposure.
2. If step 1 suggests a potential problem, conduct more sophisticated modeling to provide more realistic estimates of the potential exposure.

3. If Step 2 indicates a significant exposure potential exists, conduct exterior monitoring at the site to confirm model predictions and make better estimates of indoor exposures. This step may be preceded by screening level indoor monitoring.
4. When deemed necessary, conduct monitoring at the building site at a level adequate to provide the best estimate of site impact on the indoor air quality and collect data to estimate exposure and resultant risk over longer time periods.

Step 1, simple conservative modeling, is suggested in virtually all cases because it provides overall perspective and can reduce the potential for conducting unnecessary monitoring and reduce the possibility of focusing efforts based on complaints which may or may not represent the locations of most concern. Step 2, sophisticated modeling, is suggested as a follow-up to Step 1 because simple models typically over predict exposures. Executing Step 2 reduces the likelihood of conducting monitoring when, in fact, no exposure of concern may be occurring.

Step 3, exterior monitoring at a specific building location, is suggested as the primary on-site technique for assessing the site related indoor air impacts on specific structures. These techniques allow reasonable estimates of indoor air concentration without the necessity of dealing with building specific air flow patterns and indoor pollutant sources. If it is considered desirable to first conduct indoor monitoring at the screening level, it should be recognized the indoor data are useful for order of magnitude estimates only. This monitoring cannot, except in unusual cases, provide pollutant concentrations due to site impacts because of the variability in types and strengths of indoor sources.

Step 4, detailed building monitoring, is suggested only when it is necessary to obtain actual indoor air site impact data for a specific building. It is expected that this monitoring will typically only provide marginal improvements in the exposure estimates obtainable by

following Step 3. Indoor air monitoring itself is complex and requires a high level of professional expertise to obtain reasonable results. Except in unusual cases, site impacts cannot be estimated unless exterior monitoring is executed simultaneously.

The above general procedures are applicable principally to indoor air impacts associated with transport of organics (volatile and semi-volatile) by soil gases and ambient air. Impacts of particulates transported to the building may, however, be best resolved with direct indoor monitoring. This is suggested because, once inside the structure, dusts tend to settle and then be resuspended by traffic and cleaning activities. Potential risks from dusts may then be a combination of inhalation, ingestion, and dermal contact paths.

## 2.2 SCREENING LEVEL MODELING

The use of screening models corresponds to Step 1 and 2 above. They are used to obtain order-of-magnitude estimates of the potential indoor air concentrations. The simple modeling approach described in Section 2.2.1 should be viewed only as a scoping tool. The modeling tools discussed in Section 2.2.2 can be, and have been, used to estimate the risks due to the indoor air pathway in remedial investigations.

### 2.2.1 Simple Conservative Modeling

Modeling may be used to examine the possibility that site contaminants may be transported to buildings in sufficient concentration and rate to significantly impact the indoor air. This is a particularly useful step when more than one structure or type of structure may be impacted due to a fairly large contaminated zone, such as a groundwater plume or dispersion in ambient air. Information may already be available to determine whether or not a particular transport mechanism is of concern and no modeling would be needed for these mechanisms.

A minimal amount of site specific information is needed to run the simple models. For emissions from contaminated groundwater, the chemical concentration in the groundwater and depth to the top of the water table will suffice. Similar emission related information is needed for contaminants transported through ambient air. Because these

modeling results should be only used to determine whether or not more sophisticated modeling is needed, missing data may be supplied using realistically conservative estimates.

It is recommended that the air quality models SCREEN and/or TSCREEN be used for estimating the ambient air concentrations at the building(s) being considered. These models will calculate the short-term maximum concentrations at various distances from the source. Because buildings typically have air exchanges rates of 0.5 to 1 per hour, it is recommended that averaging periods less than 3 hours not be used. The use of the 24-hour maximum concentration should provide a conservative estimate even for developmental toxicants. Professional judgement should be used when estimating possible impacts for very short-term releases that could occur from sudden releases or remedial actions.

It is recommended that the simple Fickian diffusion model (Appendix A, Section A.1.1) be used to estimate the contaminant flux from contaminated groundwater and contaminated soil. The important variables are chemical concentration and distance from the building floor to the contamination because diffusivities in air and Henry's Law constants each vary by less than an order of magnitude for VOCs. Assume 100 percent of the soil gas rising under the building footprint enters the building, for all building types, and the building air exchange rate is 0.5 per hour.

A first cut approximation can be made without even running the model by assuming diffusivities in air =  $10^{-5}$ , Henry's Law constants =  $10^{-1}$  (dimensionless), air filled and total porosities both equal 0.4, building air changes per hour = 0.5, and 100 percent of the soil gas rising under the footprint of the building enters. Under these assumptions,

$$IAC \approx \frac{C_L}{L}$$

Where

IAC	=	Indoor air concentrations, $\mu\text{g}/\text{m}^3$
$C_L$	=	Concentration in groundwater, $\mu\text{g}/\text{L}$
L	=	Depth to water table, M.

Note that this is the upperbound concentration for the most volatile component in very porous completely dry soil and should be expected to yield excessively high results for less volatile compounds and for tightly packed or wet soils. The equation is of little utility when the pollutant source is within about 2 meters of the building or when direct intrusion of contaminated groundwater is occurring.

For contaminated soil, the relationship given in Equation 11 of Appendix A, Section A.1.3 may be used to estimate the soil gas concentration. For contaminated soil immediately adjacent (ie, within 1 meter) to the building, the relationships of Appendix A Section A.3.1 are recommended to calculate the indoor air concentration.

Note in particular that it is not recommended to estimate a reduction in soil gas flux entering the building based on the ratio of assumed area of floor cracks to floor area. Based on current understanding, this is a questionable assumption (See Appendix A, Section A.3).

#### 2.2.2 Screening Level 2 Modeling

Indoor air concentrations calculated using the more sophisticated modeling techniques provide the best estimate that can currently be made without sampling at the structure(s) in question. However, use of these models requires both professional modeling expertise and site-specific information. The better the site-specific information, the more likely are the model predictions to accurately represent the concentrations in the structure. Of all the terms in the various equations of Appendix A, the effective diffusivity ( $D_r^{\text{eff}}$ ) and soil permeabilities ( $K_v$ ) are likely to have the most uncertainty. This is because not only are soil properties quite variable vertically and horizontally over regions as small as a single house, soil moisture contents (and thus air filled porosity) can vary widely. It is not unusual for  $K_v$  to vary by 3 orders

of magnitude across a site the size of a typical residential lot. While the use of "average" or "typical" values for these parameters may yield fairly accurate results, it should not be expected that any current model will exactly represent the real world.

As stated in Appendix A, Section A.2, air modeling should be conducted in accordance with the guidance referenced. For emissions from groundwater and contaminated soils, any of the models of Appendix A Sections A.1 and A.3.3 may be used provided that appropriate consideration is given to the contaminant concentration in the soil and site conditions affecting the effective diffusivity.

Specifically, the model of Section A.1.1 may be used for groundwater when the refinement of Section A.1.2 is made. The model may also be used for contaminated soil when corrected for soil adsorption (Section A.1.3). Both uses of the model should be corrected using the considerations of Section A.1.6 when neat liquids (non-aqueous phase), or soil concentrations exceeding the level that calculated soil gas concentrations are greater than compound vapor pressures are present.

The model presented in section A.1.4 has a wide range of applicability for contaminated soils and groundwater. It is the preferred model for calculating soil gas flux for most applications. However, the model is not suitable for situations in which non-aqueous phase liquids or high chemical concentrations, as explained above, are present. For these applications, the model presented in Section A.1.6 is most appropriate.

All of the Models of Appendix A, Section A.1, estimate only the contaminant flux (mass of contaminant impacting on the structure per unit area of below surface walls per unit time). They do not, therefore, directly yield an estimate of indoor air concentration. To obtain the indoor air concentration, divide the calculated flux by the air exfiltration rate for the building (see Section A.3.2). It is explicitly recommended that the calculation be based on 100 percent of the flux entering the building (ie., no correction made for building resistance to intrusion, such as the fraction of floor area cracked).

The Johnson and Ettinger models presented in Appendix A, Section A.3.3, appear to provide a good representation of both contaminant

transport and the effects of building characteristics on soil gas entry into a building. Properly coupled with appropriate calculations of the contaminant source gas phase concentration and equations for building air exchange rates, the models show promise of becoming the best available short of detailed numerical simulations. The use of this model is considered appropriate for indoor air impact assessments.

### 2.3 ON-SITE EXTERIOR MONITORING

In this section the value of, and approach to, the use of monitoring in the immediate vicinity of a potentially impacted building and how this data may be combined with models to yield an estimate of the indoor impacts from Superfund chemicals is discussed. It is expected that this on-site monitoring would be conducted as a consequence of the modeling described above indicating the potential for significant impact. It is recognized that on-site monitoring may also be indicated by other considerations.

The accuracy of the values calculated from modeling is a function of the quality of input data. Generally, several assumptions will have been made in these calculations that affect the accuracy. The principal assumptions are:

1. Soil gas concentration at the soil-building interface is zero.
2. The effective vertical diffusivity is accurately represented by the data input for total and air filled porosity.
3. Effective vertical diffusivities are the same throughout the entire soil column extending an infinite distance from the building.
4. Soil gas concentrations at the contaminant source are accurately represented by the equilibrium relationships given in Appendix A for chemicals dissolved in groundwater or adsorbed to soil.
5. No adsorption or biological reaction occurs as the gas diffuses to the building.

None of these are likely to be strictly true. For example, if assumption 1 were strictly true, no chemicals would enter the building.



Exterior monitoring provides the data needed for the best estimate of chemical concentrations entering the building. These data are necessary if a reasonable estimate of Superfund site chemicals impacting the building are to be made. Note that because the typical indoor air contains such a large number of chemicals that are also found at Superfund sites, simply knowing the indoor air concentrations usually only establishes the upper bound for site impact but does not establish that the chemicals are actually from the Superfund site. Reasonable exceptions to this might be for chemicals not found in non-impacted buildings (eg., vinyl chloride) or chemical concentration exceeding the upper end of the typical range.

Since assumption 3 is typically not true, especially in the region near the building, it should be expected that soil gas concentrations, and possibly compositions, will vary from location to location around the building. Thus, the monitoring plan must be designed to take this into account in so far as practical.

The building itself exerts an influence on the surrounding soil. Because of the slight negative pressures (ie., 1 to 10 Pa) developed due primarily to thermal gradients and wind effects, the building may draw in gases from the surface as well as from several meters laterally from the building walls. Thus, in permeable soils, soil gas concentrations adjacent to basement walls, in particular, may be lowered due to dilution from surface gas. (Note that this also implies that volatile chemicals applied adjacent to the building, such as pesticides applied to shrubbery, may be rapidly drawn into the building.)

#### 2.3.1 Designing The Monitoring Plan

This section assumes that impacts on the building indoor air occur from both transport through ambient air and intrusion of soil gas. The plan should be developed considering the likely magnitude of the impact from each source. The procedures for ambient air would quantify chemical concentrations at the building arising from the Superfund site as well as any other upwind emission sources. If ambient air transport is of concern and other potential emission sources exist, upwind-

downwind sampling may be necessary. For guidance see Volume II of the Air/Superfund NTGS series (EPA-4501-89-002a).

#### Ambient Air

Monitoring ambient air for Superfund site impacts is only valid when the wind direction is from the site toward the building being monitored. Monitoring equipment should be placed in a location on the windward side of the building as free as practical from localized sources of emissions, such as lawn mowers or automobiles, and wind shields, such as out-buildings or shrubbery. Monitor intakes should normally be about five feet above ground level (about midpoint of building ground floor) and about 5 to 15 feet from the building wall. Duplicate monitors are recommended. Air samples should be collected over a period of not less than one-hour and preferably over an eight hour period. Wind speed and direction should be recorded continuously or at, at least, 30 minute intervals.

The sampling and analytical methods to be used are dependent on the known or suspected emissions from the Superfund site. For most applications, EPA methods TO-1, TO-2, or TO-14 will be adequate for organics. Particulates (inhalable) may be collected using Method IP-10. Support in selecting the methodologies should be obtained from the appropriate EPA Division.

#### Soil Gases

As stated previously, it is to be expected that soil gas concentrations will vary with location around the building due to, among several effects, soil inhomogeneity. Thus, it is necessary to measure the soil gases at various points around the building. It is recommended that soil gas probes be used to measure soil gas concentrations. The use of flux chambers is not recommended. [Flux chambers located within one to two meters of the building may give significantly negatively biased results if building underpressurization is exerting an effect on soil gas flow rates and flow directions. Low permeability zones near the surface, frozen ground, or wet surface soils (eg., from recent rains), may also result in low flux chamber results. Flux chambers located further from the building may or may not realistically represent

the diffusive flux reaching the region of the building subfloor due to inhomogeneity of soil properties around the building.]

It is recommended that at least two soil probes be installed on each side of the building. Statistical considerations presented in Appendix C of Volume II of the Air/Superfund NTGS series indicate this would be adequate to determine the average concentration within 20 percent at a 95 percent confidence level.

The objectives of soil gas monitoring are to determine the soil gas concentrations and the soil permeabilities in the zone very near the bottom of the building foundation. The probes should be installed so that the probe tips are between one-half and one meter of the building floor or basement wall. For slab-on-grade and crawl-space type constructions, the probes should be installed on an angle to go under the building.

It is recommended that slightly undersized pilot holes for the probes be made with an auger. At this time a sample of soil from near the bottom of the pilot hole should be obtained and retained for analysis needed to estimate the effective diffusivity of soil near the building. (Analyses would include bulk density, moisture content, and soil characterization, eg., sandy loam).

A volume of soil gas equal to at least two probe volumes should be drawn through the probes before samples are taken. Gas flow rates should be low (eg., 10 to 100 cm<sup>3</sup>/min.) to reduce the possibility of establishing unwanted pressure gradients.

The exact sampling and analytical methods used will depend on the contaminants expected from the Superfund site. Assistance should be obtained from the appropriate EPA Division. The following should be considered when selecting these methods.

- The indoor air concentrations will likely never exceed five percent of the soil gas concentration. Thus, very low detection limits are not required.
- A portable GC will be useful to determine the magnitude of soil gas concentrations. This or other on-site measurements will likely be necessary if adsorption tube techniques (eg., T01 and T02) are used to ensure the capacity of the tubes is not exceeded.

- The SUMMA canister technique of TO-14 may likely be the best technique where prior data on chemical compositions and concentrations are not available.

After soil gas samples are collected, the probe should be used to determine the soil permeability to gas flow. The method is quite simple. In brief, a regulated flow of compressed air is passed through the probe into the soil while measuring the flow rate and probe pressure. Pressure gauges (0-125Pa) and flow meters with range capabilities of 5 to 450 cm<sup>3</sup>/min are needed. The permeability, which assumes Darcy flow, is calculated from:

$$K_v = \frac{Q\mu}{4\pi r^2 Pa}$$

where,

$K_v$	=	Permeability, M <sup>2</sup>
$Q$	=	air flow rate, M <sup>3</sup> /s
$\mu$	=	viscosity of air, 1.83 x 10 <sup>-5</sup> Kg/m-s
$r$	=	internal radius of probe, m
$Pa$	=	pressure in pascals

Determining the soil permeability is important as it is an indicator as to whether soil gas intrusion is by diffusion or convection.

### 2.3.2 Building Inspection

A general inspection of the building should be conducted. The purpose of the inspection is to assess building construction details that can be used to judge reasonableness of parameters used to calculate final indoor air concentrations. Thus, of particular interest are building size (area of building footprint and area of below grade walls), construction type (slab-on-grade, crawl-space, or basement, basement wall construction type - poured concrete or hollow block - , and number of stories), presence of obvious cracks in floors or walls in contact with soil, and details useful for estimating building air exchange rates (see Appendix A, Section A.3). The inspection forms given in EPA 400/1-91/-033 and EPA 400/3-91/003 are recommended.

### 2.3.3 Estimation of Indoor Air Concentrations

It can be assumed that the soil gas concentrations near the building are at steady-state. That is, soil gas is diffusing to the zone of building influence at the same rate that it is entering the building. Based on the empirical evidence for radon intrusion and predictions of the Johnson and Ettinger Model (see Appendix A, Section A.3), this should result in an estimate of contaminant entry that is conservative, but not strongly so.

Data analysis should begin with a review of soil permeabilities. In regions where permeabilities are greater than  $10^{-8} \text{ cm}^2$ , soil gas flows into the building primarily by convection and at a rate directly proportional to the permeability. At permeabilities much less than  $10^{-8} \text{ cm}^2$ , intrusion is primarily by diffusion and is independent of the permeability. Thus, for permeabilities of  $10^{-8} \text{ cm}^2$ , or greater, the empirical relationship for radon presented in Appendix A, Section A.3.1, may be used to estimate the indoor air concentration. A more precise estimate for any permeability may be obtained using the Johnson and Ettinger model.

When using this model in this context, it is important to remember that the "source" is at the location soil-gas samples were collected (ie,  $L_T = 0.5\text{m}$ ) and the effective diffusivity is for the region between sampling points and the building walls. Also, the entire area of the building in contact with soil (floor plus below grade walls) should be used in the calculation.

It is possible to perform internal consistency checks based on indoor air concentrations calculated by either method. Using the calculated indoor concentrations, building air exfiltration rate, and area of exposed walls, calculate the estimated flux. Calculate the soil gas concentrations at the actual source (eg. top of water table for groundwater sources) using the relationships of Appendix A, Section A.1. Using the measured soil gas concentrations and these data, calculate the effective diffusivity using the appropriate emission model. This calculated diffusivity should be reasonable when compared to the diffusivity calculated from known or reasonable estimates of soil properties.

## 2.4 INDOOR MONITORING

There are various levels at which indoor air monitoring to assess Superfund site impact can be conducted. It should be clearly understood at the outset, however, what the utility of each level is and what conclusions may be reasonably drawn from the data.

The most simplistic approach is to conduct monitoring only inside the structure. Unless monitoring is being conducted for a specific compound from the Superfund site that is not found in non-impacted indoor environments (eg., vinyl chloride), it matters little what monitoring technique is used so long as the technique has a detection limit for the target compounds in the mid-to upper-end of the typical range for non-impacted buildings. This is because only two outcomes are possible. Either the concentrations are above the maximum reported concentrations for non-impacted structures, in which case it can be reasonably concluded that some part (unknown) of that concentration is due to the Superfund site, or the concentrations are below this maximum, in which case all that can reasonably be concluded is that if Superfund site chemicals are entering the structure, they are not causing the concentrations to exceed the typical range. In the latter case, it specifically cannot be concluded that none of the target chemicals identified are from the Superfund site. Thus, monitoring only the indoor air can, at best, demonstrate that the Superfund site has a major or minor impact on the indoor air quality. At worst, it provides information that the site may be contaminating the structure but not enough information to prove the impact is or is not occurring.

Another indoor only monitoring technique that has been used is to monitor at the suspected impacted structure and at "control" structures known or suspected not to be impacted. The objective is to obtain "typical" concentrations for non-impacted structures for use as a "background" correction. Because the number of structures typically monitored does not provide a good statistical sample of the population, data obtained this way generally provide marginal, if any, improvement over using the means and ranges from larger studies.

Combining indoor air monitoring with monitoring the potential pathway(s) (eg., soil gases and ambient air) for Superfund site impacts

is the preferred method to assess the impact of the site on the indoor air quality of specific structures when it is necessary to quantitate the impact through indoor air monitoring. The procedures, discussed in more detail below, allow refined estimates of the instantaneous concentrations and data which can be used to make estimates of the long-term concentration averages for use in risk assessment.

#### 2.4.1 Screening Level Monitoring

Screening level monitoring can be used to ascertain whether or not very high levels (relative to typical) of indoor air pollutants exist and to provide estimates of the indoor air concentrations to guide design of more refined indoor monitoring. Before this type monitoring is conducted, decisions should be made as to the appropriate follow-up action to be taken depending on the concentration levels determined by monitoring and this information communicated to the building occupants or other appropriate people (see Chapter 3). It is extremely important that everyone understand the actions to be taken if the data prove to be inconclusive with regards to site impact (ie., when concentrations are within the "typical" range for indoor pollutants).

The use of a portable gas chromatograph (EPA Method IP-1A) is suggested in this application for organic compounds. The instrument can be field calibrated and has detection limits adequate for screening level results. It has the advantage that preliminary results are immediately available. Alternatively, samples may be collected using EPA Method IP-1A or TO-14 (SUMMA canisters). The canister method offers the advantages of positive compound identification, lower detection limits, and a wider range of compounds identified, with the disadvantages of higher costs and delayed analytical results. The use of adsorption tubes (eg; EPA TO-1, TO-2, IP-1B) are not recommended for initial screening unless a rapid response instrument, such as a portable GC, is available to determine approximate concentrations. Adsorptive capacities of the tubes varies with different compounds and it is easy to underload or overload the tubes in unknown environments.

When particulate matter from the site is considered a possible route for indoor air exposure, samples of both airborne and settled dust

should be collected. The latter is needed because the larger particles deposit throughout the structure and may be intermittently resuspended by traffic or cleaning. Airborne dust may be monitored using an impactor with filter pack assembly or continuous monitor (EPA method 1P-10). EPA does not currently have guidance for collecting deposited dusts. Procedures developed by OSHA can be used [29CFR 1910.132 (a)].

Air samples should be collected over a period of at least one hour in the living area of each story of the building and the basement, if applicable. Samples should be collected at between three and six feet above the floor, near the center of the room, and at least one foot from any object. Deposited dust samples should be collected from such areas as refrigerator tops and window sills.

If soil gas intrusion is suspected, it is preferred that the building windows and doors be kept closed for the preceding 24 hours to allow establishment of normal pressure gradients. If particulate monitors are used, it is preferred that indoor smoking be discouraged for several hours before and during monitoring because of the high particle count from smoke. Any obvious potential sources of VOCs should be noted. These include spilled furnace oil, gasoline storage cans and power equipment in attached garages, paint cans, etc. Inquiries should be made to determine how much VOC containing products, such as furniture polishes and hairsprays, have been used in the past 24 hours.

If intrusion by soil gas is of primary concern and there is reason to suspect ambient air in the vicinity of the building may contain significant levels of non-site related pollutants of concern, ambient air monitoring should be conducted concurrent with indoor monitoring. If indoor and outdoor monitoring are both conducted over at least a 4-hour period, it is reasonable to subtract out the outdoor concentrations to obtain an estimate of indoor concentrations due to indoor sources and potential site chemical impact.

If the only route of concern is infiltration of site contaminants in the ambient air, indoor monitoring is not required. The average outdoor concentration near the building may be used as a good approximation of the indoor concentrations related to site emissions.



#### 2.4.2 Refined Monitoring For Indoor Air Impacts Of Sites

The objective of the monitoring discussed below is to determine with high accuracy the actual impact from a Superfund site on the indoor air of a specific structure. The discussion is predicated on the assumption that site impacts are from soil gas intrusion and organic and particulate matter transported via the air pathway. With only slight modification in the procedures, the impacts of groundwater or non-aqueous phase liquids seeping directly into the structure may be determined. However, in these cases, it is expected that indoor air concentrations would be sufficiently high that decisions could be made using screening techniques discussed in the previous section.

The procedures allow estimation of concentrations in all stories of the building and effective air exchange rates in the case of poorly mixed buildings. Explicitly not included is short-circuiting - pollutants exiting directly to outside without mixing with indoor air. Short-circuiting can occur when fireplaces or forced air combustion devices (eg., oil and gas furnaces) are in operation on the lowest floor of the building. Additional causes may be clothes dryers or bathroom fans vented to outside.

The procedures are not prescriptive nor detailed enough to encompass all possible cases. Professional expertise and judgement are required especially in such areas as potential pathways to consider, target compound selection, sampling and analysis methods, and exact positioning of the monitors.

The procedures also include collecting data useful for making long-term predictions of indoor concentrations based on short-term testing. [Professional judgement is needed in deciding if this information is needed for the particular assessment]. This is not an exact science and, although the analysis should provide reasonable results, the accuracy will depend on how close conditions are on the test day(s) to average conditions for the structure under test. It is suggested that monitoring be conducted on several different days under conditions that approximate the range of normal meteorological and building operating conditions for the particular building site.

### Data To Be Collected

The following data needs listing is provided to give orientation to types of information and equipment needed.

- Outdoor air concentrations for all target species. This includes upwind-downwind monitoring of the Superfund site in some cases.
- Indoor air concentrations for all target species on all building levels.
- Surface sampling for deposited particulates if particulate transport from the site is considered.
- Soil gas concentrations for all target volatile compounds
- Indoor and outdoor temperatures
- Complete building inspection
- Physical volume of each level of the building
- Effective air exchange rate for the building
- Wind speed and direction
- Indoor-outdoor pressure difference
- Barometric pressure
- Soil permeability to vapor flow

The last 6 items are required only when long-term estimates of indoor air concentrations are needed. Monitoring should be conducted over a period not less than four hours and preferably at least eight hours.

### Soil Gas Monitoring

When Superfund site impact via transport of pollutants through soil is of concern, soil gas monitoring at the structure being investigated is required. The general procedures were described in a previous section. In this case, however, although the actual concentration is

important, the concentrations of compounds relative to each other, rather than actual concentrations, are of utmost importance. (The reasons for this will be discussed under Data Analysis).

Although soil gas concentrations should not vary significantly over periods as short as one day, it is considered good practice to collect an integrated sample over the same time period as ambient air and indoor air sampling. This is particularly important if measurable rainfall or significant changes in barometric pressure occur within 12 hours before or during sampling. Rainfall and decreasing barometric pressure may increase soil gas flow into the building. Increasing barometric pressure may decrease soil gas intrusion.

Measuring soil permeabilities to vapor flow is not essential to data analysis. However, it provides extra data that may be useful. If soil gas relative compositions vary significantly at different locations, soil permeabilities may be used to estimate relative contributions from each location.

#### Ambient Air Monitoring

When Superfund site impact via transport through ambient air is of concern, ambient air monitoring is required. Monitoring at the potentially impacted structure should, however, be conducted in all cases to correct for target species from all sources that may enter by this pathway.

Determining the site related fraction of the total amount of chemicals measured at a monitoring station adjacent to a potentially impacted structure can range from quite simple to complex. The simplest case is when no other significant source of target species exists between the structure and the site and beyond the site. The most complex is the opposite situation, but little real difference is presented if the other source is beyond the Superfund site. In these complex cases, monitoring upwind and downwind (between the site and the secondary pollutant source and relative to the direction toward the structure being tested) of the Superfund site as well as at the structure would be required. Significant sources of target species between the structure being tested and the Superfund site would require a second

monitoring station between the Superfund site and the secondary source. Resolution of these cases would require significant professional expertise in both monitoring and dispersion modeling. A general guide to the requirements can be found in Section 4 of Volume II of the Air/Superfund NTGS Series. Although these cases may not be typical, special circumstances may warrant their evaluation so as not to overestimate the contribution of this pathway to the indoor air concentrations.

For the ambient air mode of transport, determining the actual concentrations of target species is important. And, because the concentrations will, in general, be low, methods with low detection limits are needed. In general, methods such as TO-1 or TO-14 will suffice for determining the organics but it is recommended that assistance be obtained from the appropriate EPA Division. Particulate methods used should be capable of collecting integrated samples in various size ranges. It is preferred that the same monitoring methods be used outdoors and indoors.

It is preferred that ambient air sampling begin at least one hour and preferably two hours before indoor air monitoring begins and continue until at least 30 minutes before indoor monitoring is complete. Because most buildings have hourly air exchange rates in the 0.5 to 1 range, air entering the building in the period before indoor sampling remains in the building for a substantial time. Conversely, outdoor air concentration fluctuations in the final 30 minutes, unless very large, have virtually no effect on the average indoor air concentration measured. Because indoor air is reasonably well mixed, concentrations inside rise and fall in an exponential relationship (Introduction to Indoor Air Quality: A Reference Manual, EPA/400/3-91/003, page 7):

$$C_{i,T} = C_o + (C_{i_o} - C_o) e^{-ACH (T-T_o)}$$

where,

- $C_{i,T}$  = indoor air concentration at time T
- $C_o$  = outdoor air concentration
- $C_{i_o}$  = indoor air concentration at time  $T_o$
- ACH = air exchange per hour

The above equation assumes  $C_o$  is constant.

Ambient air monitors should be located between 5 and 15 feet from the building with sampler intakes about five to six feet above ground level. The location should be such that the effects of windshields (eg., shrubbery) is minimized. Local sources, such as lawn mowers, should be moved to a downwind location if possible. Wind speed and wind direction should be recorded continuously during monitoring.

Ambient air monitoring to assess the air transport pathway should obviously only be conducted when the prevailing wind is from the Superfund site toward the monitoring location. Calm winds or significant wind direction fluctuations can result in significant negative bias in the results. These are relatively unimportant if this pathway is not of concern. Wind speed and direction should still be monitored for use in air exchange rate and building under-pressure calculations.

It should be noted that in the special case where Superfund site impact is only from the air transport pathway, indoor monitoring is not necessary (except for deposited particulates). This is because the average indoor air concentrations of target species attributable to the Superfund site will be equal to their average concentration in the outside air. If short-term effects, such as from remedial actions, are being evaluated, the building air exchange rate may need to be determined and indoor air concentrations evaluated using the equation above (or suitable modification dependent on fluctuations in the outdoor concentrations).

#### Indoor Air Monitoring

Indoor air monitoring is conducted to obtain the total concentrations of target species arising from ambient air infiltration, soil gas intrusion, and indoor sources. Information should be collected that allows characterization of building dynamics such that reasonable estimates can be made under conditions different from those existing during monitoring. This will allow more realistic risk assessment estimates to be made.

If soil gas intrusion is suspected, best monitoring conditions exist when the indoor temperature is at least 10°F higher than outside and windspeeds are steady and exceed about five miles per hour. Under

these conditions reasonable building air exchange rates and under-pressurizations develop. The worst condition for monitoring is when the indoor temperature is lower than the outdoor temperatures and winds are calm. Under these conditions, the lowest level(s) of the building have a slight over-pressurization and soil gas entry may be restricted or eliminated. Monitoring should be avoided if significant precipitation or barometric pressure fluctuations have occurred in the preceding 12 hours.

Because air circulation patterns in the building vary with forced air circulation rates, outside wind speed and direction, indoor-outdoor temperature differences, and indoor thermal gradients, several activities should be completed before locating monitors. Estimate the volume of the structure by measuring outside dimensions, as well as each room in the building. Set up equipment to measure the effective air exchange rate. It is highly recommended that this be done using a tracer gas method. Procedures for this are given in EPA Method IP-4. In this procedure, a known quantity of tracer, such as sulfur hexafluoride, is released into the building, well mixed, and the concentration decrease measured as a function of time. It is preferable to monitor the tracer simultaneously in as many rooms of the building as possible. Using the equation presented in the above section on Ambient Air monitoring and assuming the concentration of tracer gas in the outdoor air is zero,

$$C_{i,T} = C_{i_0} e^{-\nu T}; T = \text{time since tracer release.}$$

But  $C_{i_0}$  is the mass of tracer released divided by the effective air volume of the building and  $\nu$  is the infiltration rate,  $Q$ , divided by the effective air volume,  $V$ . Thus,

$$C_{i,T} = \frac{m_{SF_6}}{V} e^{-\frac{QT}{V}}$$

$$\ln C_{i,T} = \ln \left[ \frac{mgSF_6}{V} \right] - \frac{QT}{V}$$

Thus, a plot of  $\ln C_{i,T}$  versus  $T$  yields a straight line with an intercept at  $T = 0$  (equal to the first term on the right side of the equation) from which the effective air volume of the building can be estimated and slope (equal to  $-Q/V$ , building air exchange rate) from which the infiltration flow rate can be estimated. Furthermore, since

$Q = L [A\Delta T + B\mu^2]^{0.5}$  from EPA 400/3-9/003, page 8, the information collected may be used to estimate infiltrations under various meteorological conditions. In the above equation,

- $L$  = leakage area of building
- $A$  = Stack coefficient
- $\Delta T$  = Indoor-outdoor temperature difference
- $B$  = wind coefficient
- $\mu$  = average wind speed

The above EPA document provides the appropriate values for  $A$  and  $B$ . Thus,  $L$ , the leakage area may be estimated. Obviously, indoor and outdoor temperatures and wind speed should be monitored during this testing. The relative tracer decay rates in different rooms of the building are indicative of air movement and may be used to locate the samplers.

If this level of sophistication is considered unnecessary for the particular application, the effective leakage area can be determined using the fan pressurization-depressurization method and the infiltration rate calculated from the above equation. Although the method is less accurate, primarily due to uncertainty in the actual air volume of the building, it is simpler to conduct. Air exchange rates should not simply be estimated for indoor air monitoring of the level discussed here.

It is also important to measure the pressure difference between the inside and outside of the building. This pressure difference will likely be in the range of zero to ten pascals. It will vary with height in the building. Building under-pressurization is effected by indoor-

outdoor temperature difference and wind speed. Thus, it is important that these variables also be measured. The indoor pressure monitoring location should be between three and six feet above floor level in the lowest level of the building. (See Appendix A, Section A.3.3, Equation 24.)

Monitors for target species should be located on each level of the building. Preferred locations are in the living spaces (living rooms, dens, bedrooms). They should be located in the breathing zone, three to six feet above floor level, and approximately in the center of the room. Monitors should not be located near obstructions or obvious sources of pollutants.

Selection of monitoring methods depends on the target species selected. In most cases, indoor air methods IP-1A (canisters) or IP-1B will suffice for organics although specific methods may have to be used for some species. Airborne particulates should be collected using EPA method IP-9 when airborne transport of Superfund site particulates is of concern. In this case, deposited dusts should also be collected [OSHA procedure, 29CFR 1910.132(a)].

Indoor air samples should be collected over a period of at least four hours; eight hours of sampling is preferred. During this period, minimal indoor activity should occur. Pollutant generating activities such as housecleaning, furniture polishing, and indoor smoking should be discouraged. Windows and exterior doors should remain closed to the maximum extent practical.

### Data Analysis

A hypothetical case is presented in Tables 2.1, 2.2, and 2.3 to assist with following the text below. For this example, monitoring data are given for the ambient air adjacent to the building, upwind background ambient air, soil gas, and the indoor air at two levels in the building. The monitoring data collected for the three target compounds are tabulated in Table 2.1.

The first step should be to consider the impact due to pollutants in ambient air. It can be assumed that the average target species concentration in the indoor air attributable to this pathway is the same



as the average target species concentration in the ambient air. Subtract the total average concentrations of target species in ambient air from the average concentrations measured at each indoor monitoring location (in Table 2.1, column 1 is subtracted from columns 5 and 6 to yield the results in columns 5 and 6 of Table 2.2). The resulting indoor concentrations are the sum of target species concentrations resulting from indoor sources and soil gas intrusion.

If Superfund site impact via the ambient air pathway is of concern, determine the average target species concentrations in the ambient air from the upwind monitoring and modeling results and tabulate these as "Indoor air concentrations due to Superfund Site Target Species in Ambient Air" (column 3 is subtracted from column 2, both in Table 2.1, to yield column 3 of Table 2.2). Note that if this pathway is of concern and appropriate corrections are not made for non-site sources, the total target species concentration measured in the ambient air must be considered to be from the Superfund site. These concentrations will be the same for all indoor monitoring locations.

Using data from the soil gas monitoring and the indoor air concentration residuals obtained by subtracting the total average ambient air target species concentrations (column 2 of either Table 2.1 or 2.2) from the total average concentration measured at each monitoring location, the site contribution due to soil gas intrusion can be calculated. Because neither the soil gas flow rate nor the source strength of all indoor sources is known, the calculation is based on the relative concentrations of target species in soil gas and the indoor air residuals above. If it is assumed that soil gas components are not differentially absorbed indoors, then they should appear at all locations in the same ratios.

Thus, first divide the soil gas concentrations of all target species by the highest measured concentration in the soil gas (all concentrations are, thus, expressed as a fraction between zero and one). In this example, all soil gas concentrations in column 3 of Table 2.1 are divided by 100 to yield the ratios in column 2 of Table 2.3.

Table 2.1. Hypothetical Monitoring Data

Contaminant	Ambient Air at Building	Ambient Air Background	Conc. in Soil Gas	Conc. at Monitor 1	Conc. at Monitor 2
TCE	0.01	0.005	100	4.0	2.5
PCE	0.002	0.001	50	2.0	1.5
Benzene	0.1	0.05	60	4.6	4.6

Table 2.2. Hypothetical Data Corrected For Ambient Air

Contaminant	Ambient Air at Building	Indoor Air Conc. from SF site	Conc. in Soil Gas	Conc. at Monitor 1	Conc. at Monitor 2
TCE	0.01	0.005	100	3.99	2.49
PCE	0.002	0.001	50	1.998	1.498
Benzene	0.1	0.05	60	4.5	4.5

Table 2.3. Hypothetical Data Corrected for Soil Gas Ratio

Contaminant	Soil Gas Conc. Ratios	Monitor 1 Ratio	Monitor 2 Ratio	Max Soil Gas Monitor 1	Max Soil Gas Monitor 2
TCE	1.00	3.99	2.49	3.99	2.49
PCE	0.50	3.996	2.996	1.995	1.245
Benzene	0.60	7.5	7.5	2.394	1.494

Now divide the appropriate indoor air residual concentrations at each monitoring location by the soil gas fraction for that compound. In this example, for monitor location 1, the 3.99 for TCE was divided by 1.00, the 1.998 for PCE was divided by 0.5, and the 4.5 for benzene was divided by 0.6 to yield the results in column 3 of Table 2.3.

Identify the lowest non-zero quotient from this operation for each monitoring location and multiply all soil gas fractions by these numbers. In this example, 3.99 for TCE is the lowest ratio for monitor location 1. Thus, the results of this step, given in column 5 of Table 2.3, are obtained by multiplying 3.99 by 1 for TCE, 0.5 for PCE, and 0.6 for benzene. The results are the maximum potential concentrations at each sampling location from soil gases.

These concentrations should be added to the values calculated above for site impact via the ambient air pathway (column 3 of Table 2.2) to obtain the total site related concentrations to which occupants may be exposed (summation not shown).

#### 2.4.3 Making Long-term Estimates from Short-term Monitoring Data

The data above could be used for a preliminary risk characterization. However, it is preferred that prediction of longer-term average concentrations be made for risk evaluation purposes. General procedures to make this estimate are presented below.

First estimate the building air infiltration rate and air exchange rate under the appropriate long-term meteorological conditions. Using the building leakage area estimated from the tracer gas testing (or the fan depressurization test), estimate the long-term average air infiltration rate from:

$$Q = L[A\Delta T + B\mu^2]^{0.5}$$

using appropriate long-term average values for wind speed and indoor-outdoor temperature differences. Unless long-term meteorological conditions are similar to those existing during monitoring, divide Q by the measured physical volume of the building (rather than the estimated effective volume) to obtain average air exchanges per unit time.

Secondly, estimate ambient air concentrations at the building for Superfund site related chemicals due to the air transport mechanism.

The ambient air concentrations determined during monitoring can be used to calibrate an air dispersion model for use in this estimation.

Thirdly, estimate the soil gas flow rate into the building under the long-term meteorological conditions. Estimate the soil gas flow rate into the building during the on-site monitoring from:

$$Q_{\text{soil}} = Q C_i / C_{\text{soil}}$$

where,

$Q$  = estimated building air infiltration rate

$C_i$  = calculated indoor air average concentration of chemicals  
in soil gas

$C_{\text{soil}}$  = chemical concentration in soil gas

Now calculate  $K$  from

$$Q_{\text{soil}} = K P_a$$

where,

$P_a$  = the indoor-outdoor pressure difference measured  
during monitoring

$K$  = a constant comprised of building specific terms

If soil gas intrusion is primarily by diffusion, the  $Q_{\text{soil}}$  calculated can be used for the long-term average. However, if soil gas intrusion is primarily by convection,  $Q_{\text{soil}}$  is proportional (See Johnson and Ettinger, Environmental Science and Technology, Vol. 25, No. 8, 1991, page 1449) to the building under-pressurization, as indicated by the above equation for  $K$ . Thus, by using  $P_a$  calculated for the building under-pressurization from equation 24 of Appendix A,  $Q_{\text{soil}}$  under different meteorological conditions can be estimated from the above relationship. The measured building under-pressurization during monitoring should be used to calibrate Equation 24 for site specific conditions. This implicitly assumes soil gas concentrations remain constant. This may need adjustment if the source strength varies with periods short compared to the averaging time.

The above procedure allows reasonable estimates to be made of long-term indoor concentrations from short term data. Using the risk assessment procedures outlined in Section 3, reasonable assessments of the indoor air impact of a site can be made.

### 3.0 HAZARD ANALYSIS

Inhalation of contaminants in indoor air is but one of the exposure pathways considered in risk assessments. Explicit guidance for the conduct of risk assessments is given in "Risk Assessment Guidance for Superfund: Volume 1 Human Health Evaluation Manual". The Manual has three parts:

- (1) baseline risk assessment given in Part A, EPA/540/1-89/002
- (2) development of preliminary remediation goals given in Part B, Publication 9285.7-01B
- (3) remedial alternatives risk evaluation given in Part C, publication 9285.7-01C

This chapter considers the potential impacts on indoor air to be from soil gas, chemical volatilization from contaminated groundwater use and ambient air infiltration. The procedures are useful for exposures occurring during baseline, remedial actions, and post clean-up. Information is provided to estimate risks for cancer and non-cancer effects and for short-term and long-term impacts. It is explicitly assumed that adequate information has been developed on indoor air chemical concentrations and the likely exposed population.

#### 3.1 INCREMENTAL INDOOR AIR RISKS

The risk assessment procedures detailed in RAGS/HHEM are predicated on evaluating the incremental risks due to contaminants originating at the Superfund site. Modeling predications can be, and are, used to estimate emissions from specific site sources and potential chemical concentrations at various on-site and off-site locations. These models do not incorporate chemical releases from non-site sources, although such releases may be modeled to provide comparative background information. Likewise, monitoring data are adjusted for background to assess incremental site impacts. For example, ambient air monitoring is conducted up-wind and down-wind of the site, up-gradient and down-gradient wells are used for releases to ground water, and contaminant

concentrations in background soils are used to determine site contributions to the total.

For consistency it is necessary that equivalent procedures be followed when assessing potential site impacts on indoor air quality. Since it has been well established that indoor air typically contains a wide variety of chemicals found at Superfund sites, and, in many cases, in concentrations high enough to be of concern, risk estimates based on the total measured indoor air concentrations may reasonably be expected to frequently result in substantial overestimates of site impacts. Risk estimates based on predictive modeling would not be expected to include non-site impacts and therefore are in agreement with current EPA guidance.

Risk estimates based on combinations of exterior monitoring (eg., ambient air and soil gases) may contain some extraneous risk due to non-site related chemicals. For example, ambient air measurements made outside the building being evaluated may contain chemicals transported from non-site locations such as industrial operations, auto exhaust, roadway paving, and pesticide applications. Soil gases may also contain chemicals from materials deposited on or in the ground within a few meters of the structure such as pesticide application or fuel oil spills.

Risk estimates based only on indoor air monitoring would be a combination of possible site related impacts and probable non-site related impacts from the many potential indoor sources. As such, they would not follow the basic guidelines (ie, assess site related impacts). To be useful, these data must be corrected for background in so far as practical. EPA guidance provides that if background risk might be a concern, it should be calculated separately from site-related risk (RAGS/HHEM Part A, Section 5.7).

Current EPA guidance, therefore, is that efforts to distinguish between site-related and non-site related impacts on indoor air would be required. The study design must, therefore, provide a way to distinguish among site related indoor impacts, pollutants from indoor sources, and background concentrations in ambient air. Only the site related potential risks need to be calculated (non-site related risks may be

calculated but this is not necessarily required). No current EPA guidance provides for summing the potential risks from site related and non-site related impacts.

### 3.2 RISK COMMUNICATION

Section 8.6 of RAGS/HHEM Part A states:

"The results of the baseline evaluation should not be taken as a characterization of absolute risk. An important use of the risk and hazard index estimates is to highlight potential sources of risk at a site so that they may be dealt with effectively in the remedial process. It is the responsibility of the risk assessment team to develop conclusions about the magnitude and kinds of risk at the site and the major uncertainties affecting the risk estimates. It is not the responsibility of the risk assessment team to evaluate the significance of the risk in a program context, or whether and how the risk should be addressed, which are risk management decisions."

The ultimate user of the risk characterization results will be the RPM or other risk manager for the site.

It is important that the indoor air impact assessment contain a discussion of:

- confidence that the key site-related contaminants were identified and discussion of contaminant concentrations relative to background concentration ranges;
- level of confidence in the quantitative toxicity information used to estimate risks and presentation of qualitative information on the toxicity of substances not included in the quantitative assessment;
- level of confidence in the exposure estimates for key exposure pathways and related exposure parameter assumptions;
- the magnitude of the cancer risks and non-cancer hazard indices relative to the Superfund site remediation goals in the NCP (e.g., the cancer risk range of  $10^{-4}$  to  $10^{-7}$  and non cancer hazard index of 1.0);
- the major factors driving the site risks (e.g., substances, pathways, and pathway combinations);

- the major factors reducing the certainty in the results and the significance of these uncertainties (e.g., adding risks over several substances and pathways);

Assessment of potential risks due to the indoor air pathway for buildings located proximate to Superfund sites may be initiated as a result of individual property owner requests, community requests, preliminary assessments, baseline investigations, or assessment of remedial alternatives. In all cases, it is important to bear in mind that good communication with the affected people is critical to their acceptance of the results and recommendations. RPMs are encouraged to work with the risk assessor and community relations coordinator to develop the appropriate means for communication.

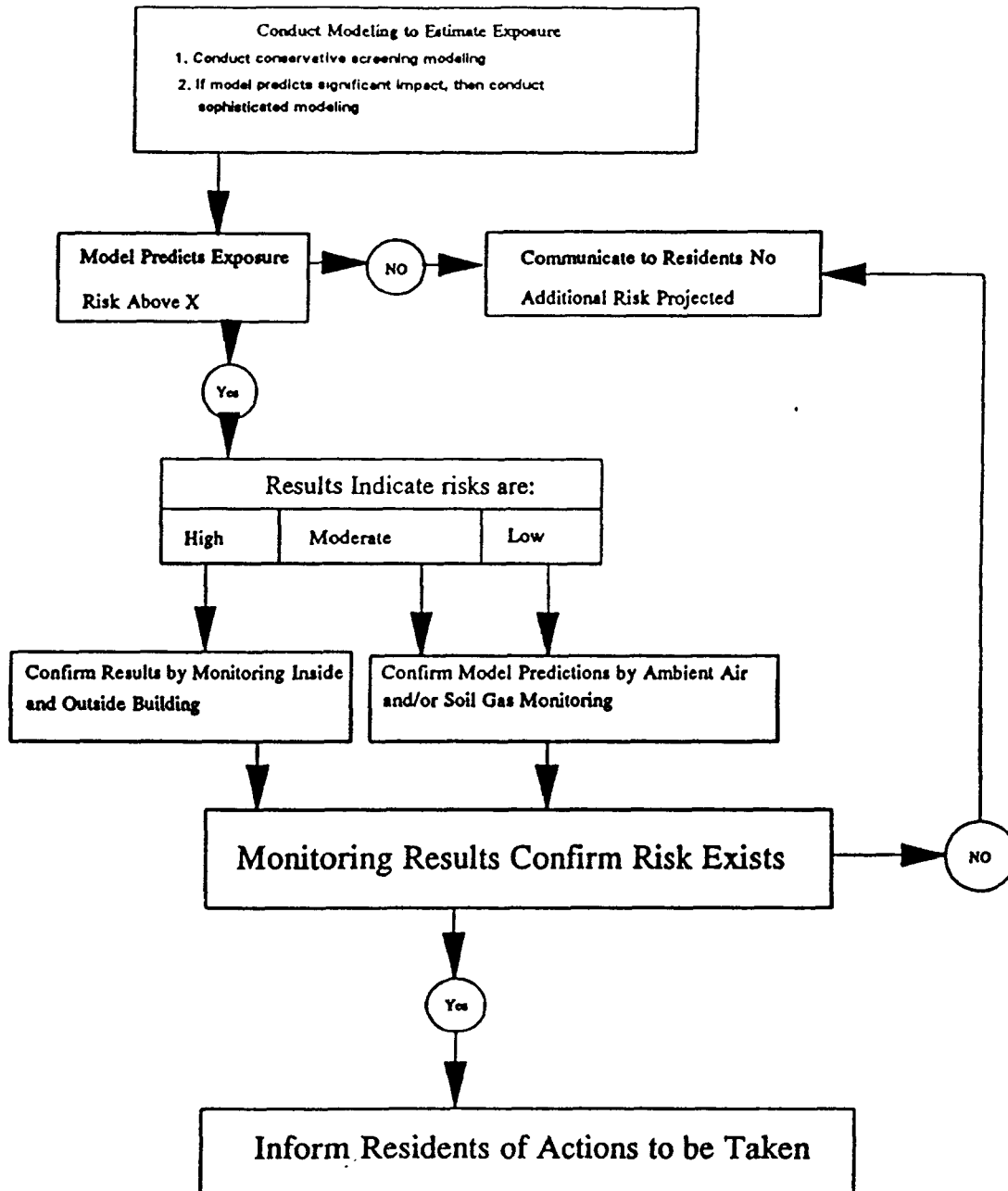
It is important in estimating risks due to exposure to indoor air to recognize that pollutant sources other than Superfund sites normally exist in buildings. In fact, prior studies indicate the cancer risk factor for private residences not proximate to Superfund sites may be  $10^{-4}$  or higher. While this fact may be communicated to building occupants, as well as other general risk information, it must be understood that, in general, people view and accept voluntary and involuntary risks differently. Thus, the potentially affected population may express different perceptions and acceptabilities for equivalent risks arising from exposure to chemicals used in routine household activities and the same chemicals originating from a Superfund site.

Experience has shown that it is important to develop a management plan prior to initiation of an indoor air impact assessment. While the plan will vary with site-specific considerations, it should be adequate to communicate the sequence of actions to be taken to evaluate exposures and risks, the methodology that will be employed, the levels of risks upon which decisions will be made, and actions to be taken based upon those decisions. An illustrative decision tree is presented in Figure 3-1.

In this illustration, potential exposures, and resultant risks, are first estimated based on the use of reasonable predictive models. If the simple screening model predicts significant exposures, then a more sophisticated model is run to give a better, and more realistic,



Figure 3-1. Illustrative Decision Tree



estimate of the indoor concentrations likely to exist. If the simple screening model, which is conservative, does not indicate concentrations could be high enough to cause concern, there is no reason to run the more sophisticated models, which would only reduce the estimated concentrations. If the modeling predicts exposures which would pose risks above a predetermined value, on-site monitoring, varying with the level of risk estimated, is conducted. If the on-site monitoring confirms the model predictions, then predetermined actions may be taken based on the estimated risk level.

Whatever decision tree is developed for a particular site should be communicated to the potentially affected public before the plan is executed. The meaning of the cancer risk factors (eg.,  $1 \times 10^{-4}$ ) and hazard indices should also be communicated.

Consider, for example, the following case which was developed for a specific chemical at a specific site. Information developed during the screening phase indicated the potential for significant indoor exposures to a chemical with estimated excess lifetime cancer risks to humans as detailed below.

Apportioned Lifetime Risk from a Four-year Exposure

AGE	100 ppb/v	10 ppb/v	1 ppb/v	0.2 ppb/v	0.1 ppb/v
0 to 5	2.3 E-2	2.3 E-3	2.3 E-4	4.6 E-5	2.3 E-5
6 to 9	5.8 E-3	5.8 E-4	5.8 E-5	1.2 E-5	5.8 E-6
10 to 13	4.6 E-3	4.6 E-4	4.6 E-5	9.3 E-6	4.6 E-6
14 to 17	3.5 E-3	3.5 E-4	3.5 E-5	7.0 E-6	3.5 E-6
18 to 21	2.3 E-3	2.3 E-4	2.3 E-5	4.6 E-6	2.3 E-6

These data suggest that children, especially very young children and neonates, may be unusually sensitive to the chemical. In this case no children resided in the buildings on a full-time basis but were present on a regular basis as frequent visitors or for daycare purposes. Thus,

it would be relatively simple for parents to take measures to reduce exposure time for their children.

Before on-site monitoring took place, it was determined that temporary corrective actions could be taken, if needed, and effectiveness confirmed within twelve days after the monitoring data was available. It was also determined that permanent remedial action, if needed, could be taken, and its effectiveness determined within 60 days.

The following decision scheme was then designed for actions to be taken depending on the actual concentrations determined by on-site monitoring:

0.2 to 10 ppb/v	If the concentration were to be found to be within this range, permanent remedial action would be taken to bring the levels below 0.2 ppb/v. The action would be instituted and effectiveness confirmed within sixty days.
10 to 100 ppb/v	If the concentration were to be found to be within this range, temporary corrective actions would be instituted to bring the levels below 10 ppb/v. This action would be instituted and confirmed within twelve days. The temporary action would be followed by a permanent remedial action to bring the levels below 0.2 ppb/v. The permanent action would be instituted and effectiveness confirmed within sixty days.

### 3.3 OVERVIEW OF RISK ASSESSMENT GUIDANCE

The purpose of the balance of this chapter is to provide an overview of the Superfund guidance (RAGS Part A) for the indoor air pathway. As such, it must be understood that it does not contain the detail necessary for untrained personnel to conduct a risk assessment. Risk assessment data, even in cases where accepted cancer or non-cancer

risk factors are available, should be reviewed with a trained professional for site specific adjustments that might be necessary.

### 3.3.1 Exposure

The first step considered is exposure of the affected population. The fact that certain concentration of pollutants exist in the indoor air does not in and of itself constitute a risk. The magnitude, frequency, and duration of that exposure for the affected individuals (or grouping such as adults and children) must be defined. The average exposure can be expressed as a function of time or of body weight. Exposure normalized for time and body weight is termed "intake" and is expressed in units of mg chemical/Kg body weight-day. Thus, there are three categories of variables for intake:

- chemical concentrations
- population (contact rate, exposure frequency and duration, and body weight)
- averaging time

The intake variable values should be selected so that the combination of all intake variables results in an estimate of the reasonable maximum exposure for the pathway. "Reasonable" is not based solely on quantitative information and requires professional judgement. EPA guidelines for "reasonable" generally use the 95th or 90th percentile values for contact rate, exposure frequency, and duration. If statistical data are not available, use reasonable conservative estimates. Professional judgement is required to estimate the exposure time and exposure duration for exposure to indoor air. Both can vary with building type (home, school, workplace) and age.

Some chemicals can produce an effect after a single or very short-term exposure to relatively low concentrations. These chemicals include acute toxicants such as skin irritants and neurological poisons, and developmental toxicants. At sites where these types of chemicals are present, it is important to assess exposure for the shortest time period that could result in an effect. For acute toxicants this is usually a single exposure event or a day, although multiple exposures over several days also could result in an effect. For developmental toxicants, the

time period of concern is the exposure event. This is based on the assumption that a single exposure at the critical time in development is sufficient to produce an adverse effect. It should be noted that the critical time referred to can occur in almost any segment of the human population (i.e., fertile men and women, the conceptus, and the child up to the age of sexual maturation).

When evaluating longer-term exposure to non-carcinogenic toxicants, intakes are calculated by averaging intakes over the period of exposure (i.e., subchronic or chronic daily intakes). For carcinogens, intakes are calculated by prorating the total cumulative dose over a lifetime. This distinction relates to the currently held scientific opinion that the mechanism of action for each category is different. The approach for carcinogens is based on the assumption that a high dose received over a short period of time is equivalent to a corresponding low dose spread over a lifetime (EPA 1986b). This approach becomes problematic as the exposures in question become more intense but less frequent, especially when there is evidence that the agent has shown dose-rate related carcinogenic effects. It is necessary to consult a toxicologist to assess the level of uncertainty associated with the exposure assessment for carcinogens.

### 3.3.2 Toxicity Assessment

Health impacts of indoor air chemicals may be divided into two broad classes: non-carcinogenic effects and carcinogenic effects. However, there are additional considerations within each broad class.

A reference dose, RfD, is the toxicity value most often used for evaluating non-carcinogenic effects resulting from exposures at Superfund sites. Note that carcinogens may exhibit non-carcinogenic effects and that RfDs for these chemicals should also be sought. Various types of RfDs are available. These include route of exposure (e.i., oral and inhalation), critical effect (i.e., developmental and others), and length of exposure event (chronic, subchronic, or single event). A chronic RfD is an estimate of a daily exposure level for the human population, including sensitive subpopulations, that is unlikely to result in an appreciable risk of deleterious effects during a lifetime.

Chronic RfDs should be used to evaluate potential non-carcinogenic effects associated with exposure of from seven years to lifetime. Subchronic RfDs ( $RfD_s$ ) should be used to evaluate effects from exposure periods of two weeks to seven years. Developmental RfDs ( $RfD_{dT}$ ) are used to evaluate the potential effects on a developing organism following a single exposure event. General use of the RfDs assumes a threshold type mechanism in which no adverse effect is observed below the RfD. However, RfDs are generally considered to have an uncertainty spanning an order of magnitude or more and are not viewed as a strict scientific demarcation between toxic and non-toxic levels.

Carcinogenic effects are considered to have no threshold and, thus, calculations are based on the presumption that any exposure carries a finite probability of a carcinogenic response. For Superfund purposes, the relationship between dose and response is considered to be linear in the low-dose region and represented by the slope factor. This factor generally represents the upper 95th percent confidence limit on the probability of a response per unit intake of a chemical over a lifetime. Most carcinogenic slope factors (CSF) are based on administered dose, however, some data are based on the absorbed dose. Care should be exercised in the selection and application of these two different slope factors. Toxicity values for carcinogenic effects may also be expressed in terms of risk per unit concentration of the chemical in the medium where human contact occurs.

### 3.3.3 Sources of Toxicity Values

EPA's Integrated Risk Information System (IRIS) is a data base containing up-to-date health risk and regulatory information for numerous chemicals. It contains only those RfDs and slope factors that have been verified by appropriate work groups. Information in IRIS supersedes all other sources. Only if information is not in IRIS should other sources be consulted. IRIS is only available on-line. For information on how to use the database, contact IRIS User Support (513/569-7254).

The Health Effects Summary Tables (HEAST) summarize interim, and some verified, RfDs and slope factors and contains toxicity information

for specific chemicals. HEAST also provides references to supporting toxicity information. HEAST is published quarterly and can be obtained from the Superfund Docket (202/382-3046)

The Agency for Toxic Substances and Disease Registry (ATSDR) is developing toxicological profiles for 275 hazardous substances identified at Superfund sites. The profiles contain general toxicity information and levels of exposure associated with various endpoints. Health effects in humans are discussed by exposure route (e.g., oral, inhalation, and dermal) and duration (eg. acute, intermediate and chronic). Information on the status of a particular profile can be obtained by contacting ATSDR or the National Technical Information Service (NTIS) at 703/487-4650 or 800/336-4700.

EPA's Environmental Criteria and Assessment Office (ECAO) may be contacted at 513/569-7300 for general toxicological information as well as for technical guidance on the evaluation of chemicals without toxicity values. ECAO will respond to contractor requests only upon identification of the RPM or regional risk assessment contact. ECAO should be contacted before using references other than those cited in IRIS or HEAST to see if more current information is available. Any derivation of toxicity values should be done only in conjunction with the regional risk assessment contact, who will submit the derivation to ECAO for approval.

#### 3.3.4 Quantifying Risks

Following the above procedures, chemical intakes and appropriate RfDs and slope factors will have been obtained. Before proceeding with calculations, it is highly recommended that the information be consolidated into tabular format to ensure the proper data are used in the calculations. Specific checks should be made to ensure:

- All RfDs and CSFs are based on inhalation as the route of exposure
- All RfDs and CSFs are expressed in the same units as used for chemical intake. Toxicity values obtained from IRIS are generally expressed as ambient air concentrations (ie.,  $\text{mg}/\text{m}^3$ ) instead of administered dose (ie.,  $\text{mg}/\text{Kg}\text{-day}$ ).

- Non-cancer effects are considered for carcinogens.
- The proper RfDs are used for the exposure scenarios. Do not use chronic RfDs for short-term exposures (except as initial screening values) and do not convert short-term exposures to equivalent lifetime values to compare with chronic RfDs. Use only subchronic or shorter-term toxicity values that compare well with the estimated exposure duration.
- All intakes and toxicity values are expressed as administered dose. A few chemicals listed in IRIS (eg., trichloroethylene) have the CSF expressed as absorbed dose.
- Averaging times (AT) for non-carcinogenic risks are equal to the exposure duration (ED). ATs for carcinogenic effects are always 70 years.

The table must have the data separated such that carcinogenic and non-carcinogenic risks can be summed separately. (It is best to present these in separate tables). Also, the table must have the data for non-carcinogenic risks presented such that short-term, subchronic, chronic, and developmental risks, as appropriate for the scenario being considered, can be summed individually.

For carcinogenic effects, multiply the appropriate calculated intakes by the slope factors for the chemicals. For non-carcinogenic effects, divide the appropriate calculated intakes by the RfDs for the chemicals. Note that this procedure gives, for carcinogens only, an upper-bound estimate of the lifetime incremental risk of developing cancer. For non-carcinogens, this yields a non-cancer hazard quotient (HQ), the value of which is not a measure of statistical probability of non-cancer effects.

For carcinogenic effects, sum only the individual risks calculated using the slope factors. This sum represents the total upper-bound incremental lifetime cancer risk.

For non-carcinogenic effects, several separate summations can be made. If more than one exposure duration (ie, chronic, subchronic, short-term, or developmental) was considered, each must be summed separately. Do not sum all non-cancer HQs either by summing individual data or summing totals for chronic, subchronic, etc. Furthermore, sum



only those Hqs corresponding to exposures that will be occurring simultaneously. These sums are designated Hazard Indices (HI).

At this point, one or more tables will exist which contain individual and total cancer risk factors and non-cancer hazard quotients and hazard indices. Understanding the meaning of and limitations of these results is discussed in the following section.

### 3.3.5 Data Limitations and Interpretations

#### 3.3.5.1 Carcinogenic Effects

It was assumed in the preceding that the cancer risk could be calculated by multiplying intake by the slope factor. This is valid in the low-dose portion of the dose response curve. For estimated risks above 0.01, this assumption may no longer be valid and risk may be calculated using the one-hit equation:

$$\text{Risk} = 1 - \exp [-(I)(AF)]$$

where all terms are as previously defined.

Unless the total risk number calculated is dominated by the risks from one or two chemicals, the total cancer risk may be overstated. This can occur because slope factors are upper 95th percentile estimates of potency and upper 95th percentiles of probability distributions are not strictly additive.

The total risk summation procedures gave equal weight to class A, B, and C carcinogens as well as to slope factors derived from human or animal data. The calculation, therefore, may overestimate the risk from some chemicals.

The summation procedure explicitly assumes the actions of the carcinogens are independent. This assumption ignores possible synergistic or antagonistic effects among chemicals and assumes similarity in mechanisms and metabolism. These assumptions are made because data to quantitatively assess mixture interactions are generally not available.

#### 3.3.5.2 Non-Carcinogenic Effects

The hazard quotient calculated assumes no effect below  $HQ = 1$ . The level of concern does not increase linearly as  $HQ$  approaches or exceeds unity. The RfDs are not based on the same severity of toxic effects and the slope of the dose-response curve can vary widely among different chemicals. However, for  $HQ \geq 1$ , there is concern for potential non-cancer effects which increases as  $HQ$  increases.

The hazard indices (HI) calculated assume that simultaneous subthreshold (ie,  $HQ < 1$ ) exposures to several chemicals could result in an adverse health effect and that the magnitude of the concern is proportional to the sum of the HQs. Although an HI exceeding unity may be of concern, the level of concern is higher if individual Hqs exceed unity. Since the HIs are derived from Hqs for compounds that may not be expected to induce the same type of effect or that do not act by the same mechanism, they can overestimate the potential for effects. If the HI is greater than unity as a consequence of summing several Hqs of similar value, it would be appropriate to segregate the compounds by effect and by mechanism of action and to derive separate his for each group. This analysis is not simple and should be performed by a toxicologist.

## **APPENDIX A. PREDICTIVE SCREENING TECHNIQUES**

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## APPENDIX A. PREDICTIVE SCREENING TECHNIQUES

Conducting sampling of the indoor environment at each and every potentially impacted structure proximate to all sites would be an enormous undertaking. Furthermore, simply having indoor air quality (IAQ) data for one day or even a week would likely be of limited usefulness since the IAQ at other times would not be known. It is reasonable to expect that chemical intrusion into a building would be different at different times of the year and would also be effected by occupant activities such as heating or cooling the building among others. Thus, single point data alone gives little indication as to whether the instant IAQ was typical for that particular structure.

Modeling provides an opportunity to estimate the IAQ for a variety of site conditions and structure types. It should be recognized, however, that model results inevitably depend on the quality of input data available. Seldom is all site specific data needed by the models actually available. The simplifying assumptions used to substitute for this data likely will not be exact for any particular site. Thus, while model results can provide reasonable estimates, one should not expect highly accurate results. Because modeling can give estimates for a range of scenarios, it can provide information to assess the likely level of site impact on the structures and provide an informed basis upon which to select areas for actual monitoring.

Presented here are some of the models available for estimating the rate at which subsurface chemicals and chemicals in ambient air can be transported into the region near a building, models to estimate the infiltration of those chemicals into the building, and models to estimate the concentration of the chemicals in the indoor environment.

### A.1 MODELS TO ESTIMATE CONTAMINANT FLUX

Except in the case of direct groundwater intrusion into a building, chemicals in the nearby and underlying soils must volatilize into the soil gas and migrate to the below grade walls before they can infiltrate a building. Models in this section describe several approaches, varying in complexity, for estimating this source strength.

#### A.1.1 Farmer Model

The Farmer model <sup>(1)</sup> is a fairly simple screening tool. It was originally developed for estimating emission rates from covered landfills without internal gas generation. It is the basis for this type model currently recommended in EPA's Superfund Exposure Assessment Manual (SEAM). The SEAMS model differs from the Farmer model in that the SEAM model assumes completely dry soil, contains an explicit term for surface area, and an explicit term for estimating soil gas concentration from waste composition.

The Farmer model can be used for calculating emissions from chemicals dissolved in groundwater and for contaminated soils. It explicitly assumes that the source pollutant concentration (ie., chemical concentration in groundwater or soil) is not decreased by transport of the chemical to the surface and the depth to the top of the pollutant source remains constant. The model considers the flux rate of chemicals to be a result of Fickian diffusion of the vapor through the soil matrix.

By assuming complete equilibrium is established between chemicals in the soil gas and the groundwater and soil and ignoring all attenuating factors such as biodegradation, it is possible to estimate the chemical concentration in each phase. For the typically low chemical concentrations in groundwater or soil (the high concentration case is discussed later), the vapor concentration of the chemical in the soil pore vapor can be estimated assuming the chemical equilibrium follows Henry's Law and is unaffected by other components of the system.

The soil gas concentration at the contaminant source (eg. water table surface) is calculated from:

$$C_g = \frac{C_{lH}}{RT} \quad (1)$$

where,

$C_g$	=	Chemical concentration in vapor phase (g/cm <sup>3</sup> )
$C_l$	=	Liquid phase concentration of chemical (g/cm <sup>3</sup> )
$H$	=	Henry's Law constant (atm - m <sup>3</sup> /mole)
$R$	=	Universal gas constant (8.2 x 10 <sup>-5</sup> atm - m <sup>3</sup> /mole-°K)
$T$	=	Soil temperature (°K)

[Note: Some tabulations of the Henry's Law constants use different units. Dimensionless constants ( $H/RT$ ) are common. It is important that proper units be used.]

Once in the vapor phase, the chemical diffuses through the soil at a rate dependent on the soil porosity, pore space geometry, the chemical's air diffusion coefficient, and concentration gradient between the source and point of exit from the soil. The effective diffusion coefficient ( $D_s$ ) is calculated from:

$$D_s = \frac{D_A P_a^{10/3}}{P_T^2} \quad (2)$$

where,

$D_A$  = Vapor phase diffusion coefficient in air  
( $\text{cm}^2/\text{sec}$ )

$P_a$  = Air filled soil porosity (unitless)

$P_T$  = Total soil porosity (unitless)

The steady-state flux ( $J$ ) is then calculated from:

$$J = \frac{D_s (C_g - C_2)}{L} \quad (3)$$

where,

$C_2$  = Vapor phase concentration at point of soil exit  
( $\text{g}/\text{cm}^3$ )

$L$  = Distance from source to point of exit (cm)

Typically,  $C_2$  is set to zero to maximize the flux.

Expressed in complete form, the modeling equation is:

$$J = \frac{D_A C_1 H P_a^{10/3}}{R T L P_T^2} \quad (4)$$

Using the above units,  $J$  is calculated in grams per second per square centimeter at the point of exit (ground surface or building floor). This only provides an estimate of the rate at which chemicals

are reaching the building. Estimates of the amount of this flux actually entering the building are needed to estimate indoor air concentrations. This is considered later in this Appendix.

Because the equation ignores all possible attenuating factors, it is likely this model overpredicts the contaminant flux. However, due to its simplicity, this approach provides a simple method to estimate, at a screening level, the likely maximum rate at which chemicals would be transported to a building.

#### A.1.2 Correction for Transport Resistance of Capillary Fringe <sup>2</sup>

There is not a clean separation between saturated soil in the groundwater and air filled soil above. There exists a capillary fringe above the top of the groundwater table in which the soil pores are also filled with water (in the upper region of the fringe, the soil moisture content is below saturation but still elevated in comparison to the soil above the fringe). Because water in the fringe does not move laterally with the bulk groundwater, chemical concentrations in the fringe are not necessarily the same as in the bulk groundwater. Contaminants in the bulk groundwater must diffuse through this fringe before diffusing through the air-filled fraction of the soil pores in the unsaturated zone. Because molecular diffusivities in water are characteristically four orders of magnitude smaller than through air (eg., air filled soil pores), the concentration of volatile components can be expected to be lower at the top of the fringe as compared to the concentration at the fringe-groundwater interface. The presence of even a thin capillary fringe should impede transport of volatile components from the groundwater. Note that the Farmer model essentially assumes this fringe is small compared to the distance from the top of the groundwater table and that the volatile component concentration is the same at the top of the fringe as in the bulk groundwater. This is a conservative assumption that maximizes the emission flux.

The depth of a capillary fringe is dependent primarily on the size of soil particles. As the particle size decreases, the depth of the fringe increases. Thus, for sandy soils a small fringe would be expected, whereas for a clayey soil a substantial capillary fringe is likely. The correction would normally be considered only in cases where



a significant capillary fringe is expected and when estimates made using the Farmer model indicate a moderately high impact on indoor air. If the Farmer model predicts a low impact, there is no reason to make this correction (except to estimate even lower potential impacts). If the Farmer model predicted high potential impacts, application of this correction would likely result in a substantially reduced estimated impact but would likely still indicate on-site soil gas monitoring was needed.

If the fringe is considered to provide transport resistance, the total effective diffusivity is represented by:

$$D_T = L \left[ \int_0^L \frac{dX}{D_e(X)} \right]^{-1} \quad (5)$$

where,

- $D_T$  = Total effective diffusivity
- $L$  = Distance from water table - capillary fringe interface to point of surface exit of volatile component (eg., ground surface or basement floor)
- $X$  = A vertical coordinate

$$D_e(X) = D_A \frac{(P_T - P_w(X))^{10/3}}{P_T^2} + \frac{D_w}{H} \frac{(P_w(X))^{10/3}}{P_T^2} \quad (6)$$

- $D_w$  = Diffusivity of contaminant in water
- $H$  = Dimensionless Henry's law constant (concentration in air per concentration in water)

Note that equation 6 is similar to equation 2, but explicitly corrects for the variable water-and air-filled porosities across the capillary fringe.

Above the capillary fringe, equation 5 is easily solved since  $P_T - P_w(x)$  from equation 6 becomes the same  $P_a$  from equation 2 and the second term on the right side of equation 6 can be assumed to be very small in comparison to the first term.

The problem then can be reduced further to:

$$\frac{D_T}{L} = \left[ \frac{L_c}{D_{cap}} + \frac{L-L_c}{D_s} \right]^{-1} \quad (7)$$

where,

$L_c$  = Height of capillary fringe

$D_{cap}$  = Effective diffusivity through capillary fringe,

and:

$$\frac{D_{cap}}{L_c} = \left[ \int_0^{L_c} \frac{d_x}{D_e(x)} \right]^{-1} = \left[ \int_0^{L_T} \frac{d_x}{D_e(x)} + \int_{L_T}^{L_c} \frac{d_x}{D_e(x)} \right]^{-1} \quad (8)$$

where,

$L_T$  = Height of the saturated portion of the capillary fringe

This is readily solved if high resolution spatial data are available for moisture profile within the capillary fringe. Field measurements of soil moisture content with, for example, a piezometer would be required for accurate determinations. For this modeling approach, it is essential that the thickness of the saturated portion of the fringe ( $L_T$ ) be determined fairly accurately since this is the region where it is anticipated that most of the resistance occurs.

Using equation 6,

$$\int_0^{L_T} \frac{d_x}{D_e(x)} = \frac{L_T H}{P_T^{2/3} D_w} \quad (9)$$

One approach to solving the last integral in equation 8 when adequate water-filled porosity data are not available for the region  $L_T$  to  $L_c$ , is to assume constant water-filled porosity equal to the average in the saturated and unsaturated zones.

The calculated value of  $D_T$  should be substituted for  $D_s$  in equation 3 to apply the correction to the Farmer model for transport from groundwater.

#### A.1.3 Correction for Adsorption to Soil

When making estimates of emission flux based on chemical concentrations in soils, it is necessary to consider their adsorption to the soil particles and how the strength of that adsorption affects the concentration in the soil gas. In this case, the compound will be distributed among soil particles, soil pore moisture, and soil gas.

Equilibrium between the solid and liquid phases for the compound can be expressed by: <sup>3,4</sup>

$$C_s = K_d C_L \quad (10)$$

where,

$$\begin{aligned} C_s &= \text{Concentration in soil} \\ C_L &= \text{Concentration in soil moisture} \\ K_d &= \text{Slope of adsorption isotherm} \end{aligned}$$

$K_d$  primarily represents adsorption to organic matter and can be represented by:

$$K_d = K_{oc} f_{oc}$$

where,

$$\begin{aligned} K_{oc} &= \text{Organic carbon in soil to water partition coefficient} \\ f_{oc} &= \text{Fraction of organic carbon in soil} \end{aligned}$$

From equation 1,  $C_g = HC_L$  (using the dimensionless Henry's Law constant).

Thus,

$$C_g = \frac{HC_s}{K_{oc} f_{oc}} \quad (11)$$

This correction is typically not included in models based on pollutant concentrations in groundwater because the concentration in the liquid phase can be directly determined and related to the concentration in the soil gas as previously described. It is used when modeling emissions using bulk soil concentrations. The correction is only applicable to cases where the chemical concentration in the soil is low (defined as a concentration for which the soil gas concentration calculated from Equation 11 is less than that calculated from the vapor pressure of the pure compound).

This correction would normally be used only in cases where the soil has a high organic matter content and when the simple screening model (Farmer) does not provide clear indication of significant potential for indoor air impacts. In these cases, application of the more complex model may well show that there is a low potential for impacts and on-site monitoring is not required.

#### A.1.4 FAVN Model <sup>2</sup>

Modeling presented in the preceeding parts of this Appendix is used to estimate instantaneous surface chemical flux based on instantaneous chemical concentrations in the soil or groundwater. The FAVN model can be used to calculate the long-term average vapor flux of a volatile compound from contaminated soil or groundwater when the time to completely evaporate the compound exceeds the exposure period for the calculation. The equation upon which it is based was obtained from EPA's Superfund Exposure Assessment Manual<sup>5</sup> (equation 2-19).

$$FAVN_{longterm} = \frac{C_B}{t} \left[ \left( L^2 + \frac{2tD_T H C_w}{C_B} \right)^{1/2} - L \right] \quad (12)$$

where,

$FAVN_{longterm}$	=	Time-average vapor flux to the surface over period t (mg/m <sup>2</sup> -day)
$C_B$	=	Bulk contaminant concentration in soil (mg/m <sup>3</sup> )
t	=	Averaging period (days)

L	=	Distance from basement bottom or ground surface to top of contaminated zone (m)
$D_T$	=	Effective diffusivity of contaminant through soil pores ( $m^2/d$ )
H	=	Dimensionless Henry's Law coefficient
$C_w$	=	Contaminant concentration in pore water ( $mg/m^3$ )

When calculating the flux from groundwater, with a clean soil layer between the top of the water table and the surface,  $D_T$  should be calculated as given in Section 3.1.2 to correct for resistance in the capillary fringe.

The following relationships may be of use in application of the model:

- from equation 10,

$$\frac{C_w}{C_B} = K_d = K_{oc} f_{oc}$$

- from equation 1,

$$C_B = HC_w$$

- from equation 2,

$$D_T = D_s = \frac{D_A P_a^{10/3}}{P_T^2}, \text{ in the unsaturated zone}$$

#### A.1.5 Emissions From Contaminated Soil <sup>6</sup>

For a soil column with an initial uniform vertical chemical distribution, the top layers of soil are depleted of volatile chemicals by the process of volatilization and diffusion, forming a decontaminated zone at the top. Over time, the size of the uncontaminated zone increases and the size of the contaminated zone decreases. Hence, the instantaneous emission rate, which is proportional to the depth of the contaminated zone, decreases with time. The modeling equations in this section are particularly suited to cases in which the soil contaminant

concentrations are low, the contaminant(s) have moderate to low volatilities, and average emission rates over long time periods are desired. The model cannot be used if chemical concentrations are so high that the soil gas concentration calculated from Equation 11 exceeds that calculated from the vapor pressure of the pure compound (see next section for that case).

Several authors<sup>7, 8, & 9</sup> have solved second-order differential equations to simulate the transport of vapors through soil and waste. The analytical solutions to these equations generally differ due to the initial and boundary conditions that are applied to the equations. These conditions are designated according to the specific situation being modeled, i.e., the nature and distribution of contamination at the site of interest, and the variation in source concentrations with time. The following assumptions are made in the derivation of the following equations:

The chemicals are uniformly distributed throughout the soil column; no transport of chemicals by water movement occurs; the total porosity is equal to the sum of air-filled and moisture-filled porosity; soil properties are constant in both time and space; diffusion in air is the rate-controlling step, with all other partitioning occurring instantly; adsorption is reversible; and the fraction of organic carbon in soil is constant in time and space.

In a one-dimensional, homogeneous, porous medium, the generalized mass conservation equation without convection for chemicals undergoing a first-order biodegradation can be expressed as<sup>7</sup>:

$$\frac{\partial C_a}{\partial t} = \alpha \frac{\partial^2 C_a}{\partial z^2} - \mu C_a \quad (13)$$

where,

$C_a$  = Chemical concentrations in soil pores, g/m<sup>3</sup>;  
 $\mu$  = Net degradation rate, day;  
 $z$  = Soil depth below the surface, m;  
 $t$  = Time, sec; and

$\alpha$  = The effective diffusion coefficient,  $m^2/sec$ , given as:

$$\alpha = \frac{D_G}{\frac{\rho_b K_d}{H} + \frac{\theta_m}{H} + \theta_a} + \frac{D_L}{\rho_b K_d + \theta_m + \theta_a H}$$

Where,

- $D_G$  = Effective air diffusion coefficient,  $m^2/s$ ;
- $D_L$  = Effective water diffusion coefficient,  $m^2/s$ ;
- $D_{ai}$  = Air diffusivity,  $m^2/s$ ;
- $D_w$  = Water diffusivity,  $m^2/s$ ;
- $\theta$  = Total soil porosity,  $\theta = \theta_a + \theta_m$ ,  $cm^3/cm^3$ ;
- $\theta_a$  = Air-filled soil porosity,  $cm^3/cm^3$ ;
- $T$  = Exposure interval, sec.;
- $\theta_m$  = Moisture-filled soil porosity,  $\theta_m = w\rho_b$ ,  $cm^3/cm^3$ ;
- $w$  = Moisture content, g water/g soil;
- $\rho$  = Soil particle density,  $g/cm^3$ ;
- $\rho_b$  = Dry bulk density of soil,  $\rho_b = (1-\theta)\rho$ ,  $g/cm^3$ ;
- $K_d$  = Distribution coefficient,  $cm^3/g$ ; and
- $H$  = Henry's Law constant, dimensionless.

The initial and boundary conditions used here are kept the same as those used by the USEPA<sup>8</sup> in the development of advisory levels for PCB cleanup:

Initial Concentration:  $C_a = (H/K_d)C_{so}$  @  $t = 0$ ,  $z > 0$

Boundary Condition 1:  $C_a = (H/K_d)C_{so}$  @  $t > 0$ ,  $z = \infty$

Boundary Condition 2:  $C_a = 0$  @  $t > 0$ ,  $z = 0$

$C_{so}$  = concentration in bulk soil

The solution to Equation 13 using the stated conditions is:

$$C_a = \left(\frac{H}{K_d}\right) C_{so} * \operatorname{erf}\left[\frac{z}{2} (\alpha t)^{1/2}\right] \theta^{-\mu t} \quad (14)$$

where  $\operatorname{erf}(n)$  is the error function of the argument  $n$ .

Under the stated boundary conditions, Equation 14 can be used to estimate the instantaneous mass flux of chemical vapors at the soil-air interface,  $N_a$ , as a function of time:

$$N_a = D_G \frac{\partial C_a}{\partial z} \Big|_{at, z=0} = \frac{D_G H C_{so}}{[(\pi \alpha t)^{1/2} (K_d)]} \cdot \theta^{-\mu t} \quad (15)$$

Using Equation 15, the time-average mass flux,  $\bar{N}_a$ , over the interval  $t$  has been estimated to be (USEPA 1986):

$$\bar{N}_a = \frac{2 D_G H C_{so}}{[(\pi \alpha t)^{1/2} (K_d)]} \cdot \theta^{-\mu t} \quad (16)$$

If this general equation is simplified by assuming that contaminants move predominantly in the vapor phase (ie., unsaturated soil - second term in  $\alpha$  disappears); the chemical biodegradation rate is negligible (last term in Equation 16 = 1); the total soil porosity is equal to the air-filled soil porosity and, thus, the effective diffusivity,  $D_G$ , is represented by  $\theta_a^{4/3} D_{ai}$ , Equation 16 becomes identical to the solution developed by the USEPA<sup>8</sup>.

It should be noted that the solution presented above applies to cases with an infinite depth source of constant concentration (see stated boundary conditions). Thus, although the zone of contamination is constantly receding from the initial upper boundary, some chemical remains at all times. This differs from the simpler models which assume a constant depth to the contamination. However, applying these conditions to chemical sources of finite depth, may results in an overestimate of soil concentrations, emission rates, and ambient air concentrations, depending on averaging times used, and is therefore conservative but not overly so.

#### A.1.6 Emissions from Soils Containing High Chemical Concentrations<sup>6</sup>

This model is presented for use when the chemical concentration in the soil is sufficiently high that the soil gas concentration calculated from equation 11 exceeds that calculated from the vapor pressure of the compound.

The vapor concentration in the soil pores cannot exceed the saturation vapor concentration. Therefore,



$$C_g < C_{sv} = \frac{pMW}{RT}$$

where:

- $C_{sv}$  = Saturation vapor concentration ( $\text{g}/\text{m}^3$ );
- $p$  = Vapor pressure (atm);
- $MW$  = Molecular weight ( $\text{g}/\text{gmole}$ );
- $R$  = Gas constant ( $\text{atm}\cdot\text{m}^3/\text{gmole}\cdot^\circ\text{K}$ ); and
- $T$  = Temperature ( $^\circ\text{K}$ ).

The chemical concentration in soil corresponding to the saturation point vapor concentration can be estimated from the knowledge of vapor pressure and air-soil partitioning in accordance with Equation 11:

$$C_{sv} = \frac{H}{K_d} C_{ss} \quad (17)$$

where:

- $C_{ss}$  = soil concentration corresponding to the saturation vapor concentration ( $\mu\text{g}/\text{g}$ )

For soil concentrations greater than  $C_{ss}$ , chemical vapor emission rates can be estimated by assuming that at any time the soil and chemical approach their steady-state concentrations,  $(H/K_d)(C_{ss}/z)$ :

$$\frac{\partial C_a}{\partial z} = \frac{H}{K_d} \frac{C_{ss}}{z} \quad (18)$$

and a linear soil concentration profile exists in the layer of chemical-depleted soil (USEPA 1986). Based on the assumed linear soil concentration profile and a simple mass balance, the layer of chemical-depleted soil is:

$$\frac{dz}{dt} = \frac{D_g \cdot \frac{\partial C_a}{\partial z}}{p_b \left( \frac{1}{2} C_{ss} - C_{so} \right) - \frac{1}{2} C_L \theta_m - \frac{1}{2} \frac{H}{K_d} C_{ss}} \quad (19)$$

Substituting Equation 18 into Equation 19 and integrating the resulting equation over the time interval 0 to t, gives:

$$z = \sqrt{\frac{2 D_G C_{ss} \frac{H}{K_d} t}{\frac{1}{2} \{ C_{ss} (p_b + \frac{H}{K_d} \theta_a) + C_L H \theta_m \} + p_b (C_{so} - C_{ss})}}$$

The chemical vapor emission rate under saturation condition is:

$$N_A = D_G \frac{\partial C_a}{\partial z} = D_G \frac{H C_{so}}{K_d z}$$

or

$$N_A = \frac{\sqrt{(D_G \cdot C_{ss}) \{ 2 p_b C_{so} + \theta_a C_{ss} \cdot \frac{H}{K_d} + \theta_m C_L H p_b \cdot C_{ss} \}}}{\sqrt{t \cdot \frac{K_d}{H}}}, \text{ at } z = 0 \quad (20)$$

If  $\theta_m = 0$ ,  $\theta_r = \theta_a$ , and  $D_G = \theta_a^{4/3} D_{ai}$ , Equation 20 is identical to the solution developed by the USEPA (1986). The current equation allows estimates based on actual soil moisture information rather than assuming completely dry soil as would be the case using the above assumptions.

## A.2 AIRBORNE POLLUTANTS

Under appropriate meteorological conditions, airborne pollutants from many sources, including a Superfund site, may simultaneously impact the indoor air quality of structures proximate to a superfund site. Considerable guidance currently exists for the selection and use of appropriate emission and dispersion models. Table A-1 lists the principal sources of information. Additional assistance may be obtained from the EPA Office of Air Quality Planning and Standards and from modelers in each of the 10 EPA Regional offices.

**TABLE A-1**  
**INFORMATION SOURCES AIRBORNE POLLUTANT MODELING**

TITLE	DESCRIPTION	REFERENCE
NTGS Series: Volume I, Application of Air Pathway Analysis for Superfund Applications	Defines general procedures for the conduct of Air Pathway Analyses	EPA-450/1-89-001
NTGS Series: Volume II, Estimation of Baseline Air Emissions at Superfund Sites	Provides descriptions of monitoring and modeling techniques for common uncontrolled sites	EPA-450/1-89-002a
NTGS Series: Volume III, Estimation of Air Emissions from Cleanup Activities at Superfund Sites	Provides procedures for estimating air emissions from remedial action.	EPA-450/1-89-003
Superfund Exposure Assessment Manual	Provides description of modeling techniques for common uncontrolled sites	EPA-540/1-88-001
Guideline on Air Quality Models (Revised)	Discusses general modeling techniques, model summaries, and guidance on best use of models	EPA-450/2-78-027R
Screening Procedures for Estimating the Air Quality Impact of Stationary Sources	Provides guidance on the use of screening procedures and as user's guide for SCREEN model, interactive PC-based used to estimate short-term maximum concentration from single sources.	EPA-450/4-88-010
Industrial Source Complex (ISC) Dispersion Model User's Guide	Provides a detailed discussion of the ISC Model	Vol 1: EPA-450/4-88-002a Vol 2: EPA-450/4-88-002b
TSCREEN: A Model for Screening Toxic Air Pollutant Concentration	PC-based model for estimating maximum short-term concentrations for a variety of release scenarios from Superfund sites and other sources of toxic releases. Downloadable from SCRAM BBS (see below).	EPA-450/4-90-013 PB-89-234340
User's Guide for the Fugitive Dust Model	Provides guidance on use of the model. The FDM is particularly applicable to modeling problems that involve particle deposition. It appears to be a better predictor of particle concentrations for problems involving fugitive dust sources and deposition than the Industrial source Complex (ISC) model. Downloadable from SCRAM BBS (see below).	EPA-910/9-88-202R PB90-502410
Area Source Dispersion Algorithms for Emission Sources at Superfund Sites	Analyzes and compares five short-term area source models (FDM, ISCST, PAL, RAM, SHORTZ) and three long-term (sector average) models (ISCLT, CDM, VALLEY) >	EPA-450/4-89-020 PB90-142753
Support Center for Regulatory Air Models Bulletin Board System (SCRAM BBS).	Provides computer model code, test data, utility programs, bulletins, news and messages, maintained by EPA Office of Air Quality Planning and Standards. Free access to all persons involved in air quality modeling is provided. Computer, modem, and communication package required.	Bulletin Board Telephone No. is (919)541-5742

### A.3 RELATING EMISSIONS TO INDOOR AIR CONCENTRATIONS

In the case studies presented in Appendix C, a wide range of assumptions were made for estimating the percentage of the contaminant flux that actually entered the building. In this section we present estimating techniques based on both empirical relationships developed from monitoring data and models. The models presented here are analytic rather than numerical. Numeric models are also available and have been used for modeling radon intrusion. It should also be noted that inadequate field data currently exists to validate the modeling connecting soil gas flux rate to indoor air concentrations.

#### A.3.1 Empirical Relationship Based on Radon Data<sup>(2)</sup>

Soil is believed to be the dominant source of radon in indoor air. In the United States, the mean indoor radon concentration in the living space of single-family dwellings is believed to be about 55 Bq/m<sup>3</sup>.<sup>(10,11,12)</sup> This conclusion is based on measurements in 1,270 homes in which there was no basis for expecting elevated indoor concentrations.

The mean concentration of radon in basements is about twice the mean value for above-ground living spaces.<sup>(13,14)</sup> Alter and Oswald<sup>(13)</sup> reported 9,000 long-term (1-month to 1-year) measurements in basements yielding an average concentration of 520 Bq/m<sup>3</sup> and 12,000 nonbasement indoor measurements yielding an average concentration of 260 Bq/m<sup>3</sup>. Cohen<sup>(14)</sup> reported an average concentration of 300 Bq/m<sup>3</sup> from 10,000 short-term (2 days to 1 week) measurements in basements and an average concentration of 135 Bq/m<sup>3</sup> from 34,000 short-term measurements in living spaces. Although these data show higher indoor concentrations than are believed to exist for the population as a whole because of the large number of measurements made in houses with suspected elevated indoor concentrations<sup>(12)</sup>, the data should be reliable as an indicator of relative basement/living space concentrations.

Cohen<sup>(14)</sup> reported the following data from annual average indoor radon measurements in the living spaces of houses across the country:

Substructure Type	Number of Houses	Average $^{222}\text{Rn}$ conc. In Living Space (Bqm <sup>-3</sup> )
Basement	266	59
Slab-on-grade	85	48
Crawl space	84	47

Thus, one can see that although building substructure influences the rate of entry, it is not necessarily a dominant effect. In the case of radon, the available evidence on the effect of the building substructure indicates a wide range of outcomes. At one extreme, the basement walls and floor may serve as an effective barrier, reducing radon entry relative to the diffusive flux from uncovered soil. At the other extreme, the presence of leaks in the substructure and depressurization of the lower part of the building may lead to a radon entry rate exceeding that which would result from unimpeded molecular diffusion through the floor and walls. The outcome in any specific case cannot yet be reliably predicted *a priori* from observable properties of foundations. Thus, although it must be recognized that the outcome may be substantially different for a specific structure, for screening purposes it can be assumed that building substructure has little effect on the soil gas intrusion rate.

The undepleted concentration of radon in soil gas can be estimated from data compiled by Nazaroff et.al.<sup>(14)</sup> The calculated maximum radon ( $^{222}\text{Rn}$ ) concentration in soil pores from these data is 32,000 Bq/m<sup>3</sup>, consistent with measured data. Comparing this soil gas concentration to the 55 Bq/m<sup>3</sup> average above for indoor living spaces yields a ratio of 0.0017 ( $55\text{Bq/m}^3/32,000\text{Bq/m}^3 = 0.0017$ ). Based on the discussion above which indicates the basement concentration is twice the average concentration in the living space, the basement concentration/soil gas concentration would be 0.0034.

It is important to understand that the soil gas concentration referred to here is that found or calculated for the immediate vicinity of the building (defined by Nazaroff, Jury, and Rogers <sup>(2)</sup> as a volume extending 2 meters laterally from the basement walls and 1 meter below the floor). It is not the soil gas concentration that would be calculated from Equation 1 of this Appendix.

#### A.3.2 Typical Simplified Assumptions Used

Estimations of indoor air concentrations are typically based on:

$$C_{in} = \frac{E}{Q} \quad (21)$$

where,

$C_{in}$  = indoor air concentration  
 $E$  = contaminant infiltration rate  
 $Q$  = building ventilation rate

The assumptions used to derive both  $E$  and  $Q$  are important in arriving at a realistic value of  $C_{in}$ . Note, for example, that the equation predicts that as the building ventilation rate approaches zero (minimum is the soil gas intrusion rate unless the building is completely sealed in which case the expression is indeterminant), the indoor air concentration approaches the concentration in the soil gas.

As a first approximation, some modelers assume that soil gas enters only by diffusion into the building and that

$$E = J \cdot A \cdot F \quad (22)$$

where,

$J$  = Contaminant flux estimated from source model (g/m<sup>2</sup>s)  
 (See Section 3.1)  
 $A$  = Area of building floor (m<sup>2</sup>)  
 $F$  = Fraction of floor through which soil gas can enter.

and

$$Q = \frac{ACH}{3600} \cdot V \quad (23)$$

where,

ACH = building air changes per hour  
V = volume of building (m<sup>3</sup>)

Mueller et al<sup>(15)</sup> reports that typical ACH for single family residences range from 0.5 to 1.5, with new or retrofitted energy-efficient structures generally ranging from 0.5 to 0.8 but with some as low as 0.2. For general case application, choosing any reasonable value in this range has only a modest effect on the final predicted indoor contaminant concentration and is easily within the likely error for the contaminant flux rate.

As a first assumption for E, it is frequently assumed that for contaminant entry into buildings with dirt floors or ventilated crawl spaces, a reasonable conservative assumption is that  $F = 1$  (ie, all soil gas enters the building). Measured data for radon<sup>(16)</sup> indicates  $0.7 \leq F \leq 1.0$  for single family homes with ventilated crawl spaces.

For buildings with slab floors, a typical assumption mode is that  $F = 0.001$ . Data used to support this is obtained from Carlos et al<sup>(17)</sup>, who reports that the average California home has an open area of 2- to 10-cm<sup>2</sup> per m<sup>2</sup> of floor space and Grumund et al<sup>(18)</sup> who concluded that the area of cracks to total floor space is 0.01 to 0.1 percent. Some modelers assume soil gas enters only through an assumed 0.5 cm-wide crack around the building perimeter at the slab/wall interface (note that this approach results in decreasing F as the floor area increases). The technical literature does not support the use of the assumptions based on percent cracked area of the floor for the attenuation and their use is not recommended. For screening purposes, it is recommended that F be set to 1 in all cases.

With these assumptions, it is a simple matter to calculate  $C_{in}$  using the flux rate calculated by any method from Section A.1. Models

for the more complex case in which pressure coupling to the building must be considered are given in the following section.

### A.3.3 Incorporating Building Impacts on Infiltration Rate

It is well recognized that buildings can develop negative pressures (relative to ambient pressure) as a result of temperature differences and wind effects. The American society of Heating, Refrigerating, and Air-Conditioning Engineering (ASHRAE) adopted equation 24 <sup>(19)</sup> to calculate this pressure difference,  $\Delta P$ :

$$\Delta P = \frac{P_v + \Delta P_c}{1 + (A_w/A_L)^{1/N}} \quad (24)$$

where,

- $P_v$  = static pressure over the building, Pa
- $\Delta P_c$  = pressure difference due to thermal gradient, Pa
- $A_w, A_L$  = area of building on windward and leeward side,  $m^2$
- $N$  = empirical exponent = 0.65 (Wadden & Scheff, 1983)
- and  $P_v$  =  $0.6008 V^2$ ,  $V$  = wind velocity in meters per second;
- $\Delta P_c$  =  $0.0342 Ph (T_i - T_o)/T_i T_o$

where,

- $V$  = wind velocity, M/S
- $P$  = atmospheric pressure, Pa
- $h$  = distance from neutral pressure plane, m
- $T_o, T_i$  = outdoor and indoor temperatures, respectively, °K

Evaluation indicates that pressure differences due to thermal gradients are generally small (eg. about 1.5 Pa for a 25°F difference) and that wind effects dominate in equation 24. Typical values of  $\Delta P$  are



1 to 10 Pa. It should also be recognized that there are many other potential sources in building that can lead to negative (and, in some cases, positive) pressures. Among those resulting in negative pressures are bathroom and kitchen fans, attic fans, forced air combustion devices (eg., oil and gas fired furnaces), fireplaces, and leaking air supply ducts located in crawl spaces. Systems resulting in positive pressures are typically found in certain types of commercial buildings, however, it should be recognized that leaking air return ducts located in crawl spaces or attics may cause the indoor pressure to be higher than Equation 24 would predict.

Soil-gas entry due to depressurization of basements and crawl-spaces has been experimentally demonstrated by a number of researchers<sup>16,18,19,20</sup>. The current level of understanding is that both diffusion and convection contribute to vapor intrusion and specific site characteristics determine the significance of each. A number of researchers<sup>(16,18,19,20,21)</sup> have attempted to model the transport for radon. Johnson and Ettinger<sup>22</sup> have adapted this work and extended it to the case of chemical vapors. This model is described in this section. For details of the derivation one should consult the original paper.

There are three basic derived equations for this model. They correspond to:

- 1) Contaminant source is infinite (with respect to modeling time of interest) and vapor infiltration is through cracks/opening in the foundation
- 2) Soil gas transport into the building is substantially higher through relatively permeable walls (eg., concrete block construction below grade) than through foundation cracks and openings.
- 3) Contaminant is located near the building and decreases with time (ie, this case provides an average when the contaminant source would become depleted over the averaging period used).

The model equation corresponding to case 1 above (section A.3.3.1) is probably the most useful for general application. In this case it would be assumed that the distance from the source to the building does

not change with time (ie.,  $L_t$  in Equation 25 is a constant) and does not change in composition over the time of interest for the calculation. The equation would be used for structures with crawl spaces and slab floor construction with solid (eg., poured concrete) below grade walls.

The modeling equation corresponding to case 2 above (section A.3.3.2) is applicable to construction which uses hollow concrete block construction below grade (including cases where the large voids are filled with poured concrete). This is a fairly common construction technique for houses with basements. Soil gas entry into homes with this type construction is discussed in EPA's guidance for radon reduction techniques<sup>(24)</sup>. The model formulation presented assumes an infinite source at constant depth as does the first equation.

The model equation corresponding to case 3 above (section A.3.3.3) is applicable to cases where a long term average concentration is needed and it is reasonably expected that significant changes will occur in the mass of chemical in the soil (and, therefore, the source to building distance will change significantly) over the time period of interest. The model should not be applied when the contaminant is near (within 2 meters) and intrusion into the building is dominated by convective flow. One of the other two model equations should be used to make estimates for the time this condition exists. This third model equation may then be applied for the time period that intrusive flow is diffusion dominated.

The models below require an estimate of the source vapor concentration,  $C_{\text{source}}$ , because what is calculated is the ratio of the concentration inside the building to the soil gas concentration at the source (ie the " $\alpha$ " in the equations). Two main approaches are used in vapor transport modeling; in the first  $C_{\text{source}}$  is assumed to be proportional to the residual level in the soil, and in the second  $C_{\text{source}}$  is independent of the residual level, but is a function of composition. The former is applicable in the limit of "low" residual levels where compounds are sorbed to the soil, dissolved in the soil moisture, and present in the vapor space; the latter is applicable for "high" residual levels where free-phase liquid or precipitate is trapped in the soil interstices. It is important to note that if one chooses an incorrect model for predict-

ing  $C_{\text{source}}$ , then it is possible to over- or under-predict the actual  $C_{\text{source}}$  value by orders of magnitude. Section A.1 provides a limited discussion of models to estimate  $C_{\text{source}}$  for both cases.

In the following equations, the symbol " $\alpha$ " (alpha) is the ratio of the contaminant concentration in the indoor air to the soil gas concentration at the source (ie.,  $\alpha = C_{\text{building}}/C_{\text{source}}$ ).

#### A.3.3.1 Model for Infinite Source, Vapor Infiltrating Through Cracks

The derived equation is:

$$\alpha = \frac{\left[ \frac{D_T^{\text{eff}} A_B}{Q_{\text{building}} L_T} \right] \times \exp \left( \frac{Q_{\text{soil}} L_{\text{crack}}}{D_{\text{crack}} A_{\text{crack}}} \right)}{\exp \left( \frac{Q_{\text{soil}} L_{\text{crack}}}{D_{\text{crack}} A_{\text{crack}}} \right) + \left[ \frac{D_T^{\text{eff}} A_B}{Q_{\text{building}} L_T} \right] + \left[ \frac{D_T^{\text{eff}} A_B}{Q_{\text{soil}} L_T} \right] \left[ \exp \left( \frac{Q_{\text{soil}} L_{\text{crack}}}{D_{\text{crack}} A_{\text{crack}}} \right) - 1 \right]} \quad (25)$$

where,

$\alpha$	=	$C_{\text{building}}/C_{\text{source}}$
$D_T^{\text{eff}}$	=	overall effective diffusion coefficient, $\text{cm}^2/\text{s}$
$A_B$	=	cross-sectional area through which contaminants may pass (can be approximated by area of floor and below grade walls), $\text{cm}^2$
$Q_{\text{building}}$	=	building ventilation rate, $\text{cm}^3/\text{s}$
$L_T$	=	distance from contaminant source to building foundation, $\text{cm}$
$Q_{\text{soil}}$	=	volumetric flow rate of soil gas into the building
$L_{\text{crack}}$	=	thickness of foundation, $\text{cm}$
$D_{\text{crack}}$	=	effective vapor-pressure diffusion coefficient through the crack, $\text{cm}^2/\text{s}$
$A_{\text{crack}}$	=	area of cracks/openings through which vapors can pass, $\text{cm}^2$

Interesting features of the equation are:

(a)  $(Q_{\text{soil}} L_{\text{crack}} / D^{\text{crack}} A_{\text{crack}}) \rightarrow \infty$ . In this limit convection is the dominant transport mechanism through the basement (building) floor and walls. then,

$$\alpha \rightarrow \frac{\left[ \frac{D_T^{\text{eff}} A_B}{Q_{\text{building}} L_T} \right]}{\left[ \frac{D_T^{\text{eff}} A_B}{Q_{\text{soil}} L_T} \right]} + 1$$

If the source lies directly beneath the foundation ( $L_T \rightarrow 0$ ), then  $\alpha \rightarrow Q_{\text{soil}} / Q_{\text{building}}$ , which is the proper result for convection-dominated transport of a vapor stream with concentration  $C_{\text{source}}$ . If the source is "far" from the basement (i.e.,  $D_T^{\text{eff}} A_B / Q_{\text{soil}} L_T \rightarrow 0$ ), then transport is limited by diffusion from the source to foundation, and  $\alpha \rightarrow (D_T^{\text{eff}} A_B / Q_{\text{building}} L_T)$ . Note that these results are independent of the cracked area of the floor and walls. This is because contaminant vapors are swept into the building as fast as they are transported to the soil adjacent to the floor and walls.

(b)  $(Q_{\text{soil}} L_{\text{crack}} / D^{\text{crack}} A_{\text{crack}}) \rightarrow 0$ . In this limit diffusion is the dominant transport mechanism through the basement floor and walls. When  $D_T^{\text{eff}} A_B L_{\text{crack}} / D^{\text{crack}} A_{\text{crack}} L_T \gg 1$ , then diffusion through the floor and walls is the rate limiting mechanism, and there is a vapor concentration "buildup" below the building or basement.

(c)  $Q_{\text{building}} \rightarrow 0$ . This limit corresponds to a perfectly sealed (no ambient air exchange) basement,  $Q_{\text{soil}}$  must also approach zero, and the model predicts that  $\alpha \rightarrow 1$ ; this is, the indoor contaminant vapor concentration approaches the contaminant vapor concentration in the soil gas.

Sample calculations were presented for this equation using the following parameters:

$$\begin{aligned} A_B &= 7\text{m} \times 10\text{m} + 2(2\text{m} \times 10\text{m}) = 138 \text{ m}^2 = 138 \times 10^4 \text{ cm}^2 \\ L_{\text{crack}} &= 6 \text{ in.} = 15 \text{ cm} \end{aligned}$$

$$\begin{aligned}
Q_{\text{building}} &= 7 \text{ m} \times 10 \text{ m} \times 3 \text{ m} \times 0.5 \text{ volume exchanges/h} = 105 \text{ m}^3/\text{h} \\
&= 2.9 \times 10^4 \text{ cm}^3/\text{s} \\
D^{\text{air}} &= 0.087 \text{ cm}^2/\text{s} \text{ (benzene)} \\
D^{\text{H}_2\text{O}} &= 0.087 \times 1.0 \times 10^{-5} \text{ cm}^2/\text{s} \\
H &= 0.18 \text{ cm}^3 \text{ of H}_2\text{O}/\text{cm}^3 \text{ of air (benzene)} \\
\theta_m &= 0.07 \text{ g of H}_2\text{O}/\text{cm}^3 \text{ of soil} \\
\epsilon_T &= 0.38 \text{ cm}^3/\text{cm}^3 \text{ of soil} \\
\rho_b &= 1.7 \text{ g/cm}^3 \\
\Delta P &= 1.0 \text{ Pa} = 10 \text{ g/cm} \cdot \text{s}^2
\end{aligned}$$

and estimating  $Q_{\text{soil}}$  from

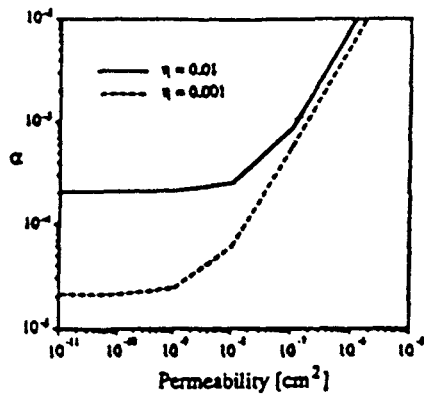
$$Q_{\text{soil}} = \frac{2\pi\Delta P k_v X_{\text{crack}}}{\mu \ln[2Z_{\text{crack}}/r_{\text{crack}}]} \frac{r_{\text{crack}}}{Z_{\text{crack}}} \ll 1$$

which is an analytical solution for flow to a cylinder of length  $X_{\text{crack}}$  and radius  $r_{\text{crack}}$  located a depth  $Z_{\text{crack}}$  below ground surface; this is an idealized model for soil gas flow to cracks located at floor/wall seams.  $k_v$  is the soil permeability to vapor flow ( $\text{cm}^2$ ) and  $\mu$  is the vapor viscosity ( $\text{g/cm} \cdot \text{s}$ ). For this sample problem,  $Z_{\text{crack}} = 2 \text{ m}$ ,  $X_{\text{crack}}$  is taken to be the total floor/wall seam perimeter distance (34 m), and for consistency  $r_{\text{crack}}$  is given by

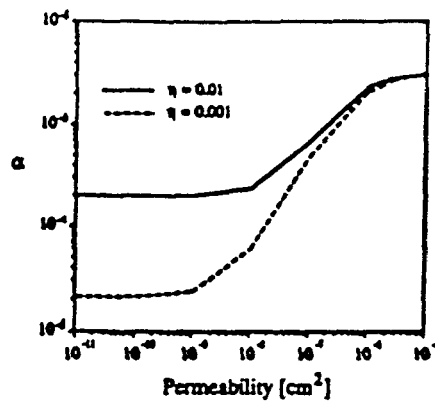
$$r_{\text{crack}} = \eta A_{\text{B}}/X_{\text{crack}}$$

where the ratio  $\eta = A^{\text{crack}}/A_{\text{B}}$ , so that  $0 \leq \eta \leq 1$ . For reference,  $\eta = 0.01$  corresponds to  $r_{\text{crack}} = 4.1 \text{ cm}$  for the values of  $A_{\text{B}}$  and  $X_{\text{crack}}$  given above;  $r_{\text{crack}} = 1 \text{ cm}$  corresponds to  $\eta = 0.0025$ .

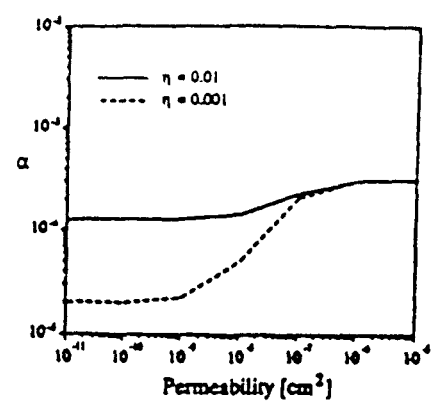
The results in graphical form are:



$$L_T = 0$$



$$L_T = 100 \text{ cm}$$



$$L_T = 1000 \text{ cm}$$

For a contaminant source adjacent to the building ( $L_T = 0$ ),  $\alpha$  is proportional to the soil permeability to vapor flow,  $K_v$ , at  $K_v > 10^{-8} \text{ cm}^2$  (permeable soils). In this example,  $0.001 < \alpha < 0.01$  for  $10^{-7} < K_v < 10^{-6}$ , which happens to fall in the range of values typically reported for radon studies (see section A.3.1). The results also predict that, for practical purposes, it can be concluded that the effect of crack size on contaminant vapor intrusion rates will be relatively insignificant in the limit of convective-dominated transport.

For  $L_T = 100 \text{ cm}$  and  $1000 \text{ cm}$ , the dependence of  $\alpha$  on  $k_v$  is a sigmoidal-shaped curve, where  $\alpha$  becomes independent of  $k_v$  for both "large" and "small" soil permeabilities. For less permeable soils, soil gas flow rates are so low that vapor intrusion is governed entirely by the relative rates of diffusion through the soil and foundation. As the soil becomes more permeable, the "sweeping" of contaminant vapors into the building by soil gas flow increases the intrusion rate. At some point, however, the ability of the contaminant to diffuse from the contaminant vapor source to the region of soil gas flow limits the rate of contaminant vapor transport into the building. For highly permeable

soils, therefore,  $\alpha$  becomes independent of the soil permeability to vapor flow and only weakly dependent on foundation properties.  $\alpha$  and the intrusion rate become less dependent on foundation properties as the distance to the contaminant source increases. This can be seen from the convergence of the curves at both high and low values of the soil permeability, and the  $\eta = 0.01$  and  $\eta = 0.001$  predictions as  $L_T$  increases. That is, the further the source is from the building, the less it matters what the building foundation is. In the limit of infinite separation between the source and the building, diffusion through soil becomes the limiting transport mechanism and the building substructure does not matter at all.

#### A.3.3.2 Modeling Using Relatively Permeable Foundation Walls

Garbesi and Sextro<sup>(20)</sup> conducted a field study of a building with basement walls constructed of hollow concrete blocks which were subsequently backfilled with concrete and coated with asphalt sealant on the exterior. No evidence of cracks at the wall-floor interface was observed. Their experimental work showed good pressure coupling between the basement and soil which they interpreted to imply the entire wall area had a measurable permeability and soil gas could infiltrate over this entire area.

The Johnson and Ettinger model for this case is:

$$\alpha = \frac{\left[ \frac{D_T^{eff} A_B}{Q_{building} L_T} \right] \exp\left(\frac{Q_{soil} L_F}{D^F A_B}\right)}{\exp\left(\frac{Q_{soil} L_F}{D^F A_B}\right) + \left[ \frac{D_T^{eff} A_B}{Q_{building} L_T} \right] + \left[ \frac{D_T^{eff} A_B}{Q_{soil} L_T} \right] \left[ \exp\left(\frac{Q_{soil} L_F}{D^F A_B}\right) - 1 \right]} \quad (26)$$

This equation is similar to equation 25 except  $A_{crack}$  is replaced by the area of the basement walls and floor,  $A_B$ ,  $D^{crack}$  is replaced by  $D^f$ , the effective diffusion coefficient through the porous foundation floor and walls, and  $L^{crack}$  is replaced by the foundation/wall thickness,  $L_F$ . While eqs 26 and 25 appear similar, they can predict quite different results. Equation 26 is independent of the area of cracks/openings

because intrusion is assumed to occur uniformly over the floor/wall area. For a given  $Q_{\text{soil}}$ , therefore, the soil gas velocity through the floor/walls is lower for the permeable floor/wall case. The impact of this is that eq 26 may predict that transport through the foundation is diffusion dominated, while for the same conditions equation 25 would predict that it is convection dominated.

#### A.3.3.3 Model for Source Depletion Over Time

Equation 25 provides a screening estimate of indoor vapor concentrations, but does not account for depletion of the contaminant vapor source. This is reasonable when short-term exposures are being estimated and it provides a conservative (upper bound) estimate for long-term exposures. It is not appropriate, however, when more realistic long-term exposure estimates are desired and it is unlikely that the source will remain constant for a long period of time. This model formulation considers the depletion due to transport.

In this approach it is recognized that the separation between contaminant source and the building increases with time due to source depletion. It is assumed that the rate at which a steady-state vapor concentration profile is established is much greater than the rate at which depletion occurs. Implicit in this approach is the assumption that depletion occurs first from the layers of contaminant closest to the building floor and walls, and the mass of contaminant incorporated in the soil disappears, beginning at the edge closest to the building. This is a reasonable assumption for diffusion-dominated transport to the building-soil interface, but not valid for convection-dominated transport from contaminated soil adjacent to a building floor.

For time periods less than the time required for total depletion of the contaminant, the average emission rate is given by:

$$\langle E \rangle = \frac{\rho_b C_R \Delta H_c A_B}{\tau} \left( \frac{L_T^0}{\Delta H C} \right) [(\beta^2 + 2\psi\tau)^{1/2} - \beta] \quad (27)$$

The corresponding long-term average attenuation coefficient  $\langle \alpha \rangle$  is then



$$\langle \alpha \rangle = \frac{\rho_b C_R \Delta H_c A_B}{Q_{building} C_{source} \tau} \left( \frac{L_T^0}{\Delta H_c} \right) [(\beta^2 + 2 \psi \tau)^{1/2} - \beta] \quad (28)$$

While this approach is more sophisticated than equation 25, increasing sophistication usually increases the amount of site-specific information required. More sophisticated screening models are usually also based on additional assumptions, and one must be careful to ensure that these assumptions are valid for specific site characteristics.

For equation 27 and 28, the following definitions apply:

$\rho_b$  = soil density, g/cm<sup>3</sup>

$C_R$  = average residual contaminant level in soil, g/g

$\Delta H_c$  = thickness of the contaminant layer, cm

$T$  = time

$L_T^0$  = initial contaminant-building floor separation, cm

$$\psi = D_T^{eff} C_{source} / (L_T^0)^2 \rho_b C_R$$

$$\beta = \left( \frac{D_T^{eff} A_B}{L_T^0 Q_{soil}} \right) \left[ 1 - \exp \left( - \frac{Q_{soil} L_{crack}}{D_{crack} A_{crack}} \right) \right] + 1$$

#### A.3.4 Impact of Contaminated Outdoor Air

All of the preceding discussion in this chapter has assumed that the outdoor air is contaminant free. To be conservative, we have also ignored other building characteristics that would affect the estimated indoor pollutant concentration. In the following, we attempt to remedy both assumptions. This discussion is based on modeling equations presented in EPA/400/3-91/003, "Introduction to Indoor Air Quality - A Reference Manual." (This manual is a rich source of information.)

The generalized mass balance equation for indoor air is:

$$\frac{dC_i}{dt} = (1 - F_b) \nu C_o + \frac{S}{kV} - m\nu C_i - \frac{\lambda}{kV} - \frac{qFC_i}{kV} \quad (29)$$

where,

- $C_i$  = indoor concentration (mass/volume);
- $F_b$  = fraction of outdoor concentration intercepted by the building envelope and not mixing with indoor air (dimensionless fraction);
- $\nu$  = air exchange rate (1/time);
- $C_o$  = outdoor concentration (mass/volume);
- $S$  = indoor source generation rate (mass/time);
- $V$  = actual indoor volume;
- $kV$  = effective indoor volume where  $k$  is a dimensionless fraction;
- $\lambda$  = decay rate (mass/time);
- $q$  = flow rate through air cleaning device (volume/time);
- $F$  = efficiency of the air cleaning device (dimensionless fraction);
- $T$  = time; and
- $m$  = mixing factor.

$F_b$  is included because not all outdoor air contaminants that move into a structure reach the inside. Some fraction,  $F_b$ , is intercepted by the cracks and crevices in the building envelope which decreases the amount that actually reaches the indoor air.

$kV$ , the effective indoor volume, is included because the actual indoor volume available for contaminants dispersal depends on the degree of air circulation.  $k$  is less than one when there is no forced mixing and the degree of circulation depends on thermal gradients indoors.

$\lambda$ , the decay rate, is included to allow accounting for losses due to indoor chemical reactions, and adsorption of contaminants on indoor surfaces. Removal of contaminants by mechanical means through air cleaning devices is dependent on flow through the device and  $F$ , the fractional efficiency for removal of the particular contaminant.

The mixing factor  $m$  is the ratio of the concentration of the exiting air to the concentration of the indoor air. When the two concentrations are the same, the air is said to be completely mixed, and  $m$  equals one. When contaminants are exhausted directly from their source,  $m$  will be  $>1$ . The complete mixing assumption is often used to estimate average concentrations over time periods greater than 1 hour.

Equation 29 was developed for ambient air infiltration and additional contaminant sources and sinks inside the structure. However, it appears that, with little error, since soil gas comprises a very small fraction of the indoor air, the source term  $S$  could be replaced with the equivalent term from soil gas modeling.

For the simple case where  $\lambda$ ,  $F$ , and  $F_b$  equal zero and  $m = 1$ , equation 29 reduces to :

$$\frac{dC_i}{dt} = \nu(C_o - C_i) + \frac{S}{kV} ,$$

and the equilibrium concentration (when  $dC_i/dt = 0$ ) would be given by:

$$C_i = C_o + \frac{S}{k\nu V} . \quad (30)$$

then if  $C_o = 0$  and  $K = 1$ , equation 30 is identical to equation 21.

#### A.4 SOURCES OF DATA FOR MODEL PARAMETERS

The models presented in this Appendix require a variety of input parameters for chemical and soil properties. Listed below are sources of information for many of the more important parameters.

Model Parameter	Reference Number(s)
Henry's Law constant	1, 25, 26, 27, 28
Diffusion Coefficient	1, 5, 25, 29, 31
Soil Porosity	5, 30

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## **APPENDIX B. MONITORING METHODS**

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## APPENDIX B. MONITORING METHODS

In this section information is provided on monitoring methods relevant to an indoor air impact assessment and types of compounds typically found in indoor environments. These methods include those applicable to measuring pollutants outside the building which may enter, as well as indoor monitoring methods. The general applicability and procedures are described. References are provided for details of the methods.

The information provides only a summary of the relevant methods. Successful application requires skilled professionals and rigorous QA/QC programs.

### B.1 METHODS FOR USE OUTSIDE BUILDINGS

Pollutants outside a building may enter through many openings in the structure. This includes organics and particulates in the ambient air and gases in the soil in the immediate vicinity of the building. Outdoor measurements needed to obtain data required in the various approaches of Section 2 include:

- Temperature
- Wind velocity
- Barometric pressure
- Organics concentrations in ambient air
- Particulate matter in ambient air
- Chemical concentrations in soil gases
- Soil permeability to gas flow

Methods for the latter four are described here. It should be noted that in some cases it may be preferable to use an indoor method outdoors to achieve consistency in measurements.

#### B.1.1 Organics in Ambient Air

Because buildings have a relatively high rate of air exchange with the outside air (air exchange rates of 0.5 to 1 building volume per hour are typical for a building with windows and doors closed), pollutant concentrations in ambient air can be significant in an assessment.

Ambient air may contain many pollutants not associated with the nearby Superfund site (e.g., auto exhaust, lawn chemicals, industrial emissions, etc.). It is important to recognize that, unless an assessment is to be made for background risks also, the sampling method and analytical finish need only address known or suspected site related pollutants.

Whichever of the following sampling methods is selected, the equipment should be located so as to minimize collection of pollutants from nearby sources such as automobiles, gasoline powered equipment, and oil storage tanks. It should be located on the windward side of the building away from windshields such as trees and bushes. The intake should be about 5 feet above ground level (approximately at the midpoint of the ground level story of the building) and 5 to 15 feet away from the building.

Ambient air sampling should begin between 1- and 2-hours before indoor air sampling begins. This is recommended because concentration fluctuations during this period will be reflected inside the building for several hours since the building effectively acts as an equalization chamber. Likewise, for monitoring periods exceeding 4 hours, consideration may be given to terminating ambient air sampling up to 30 minutes before terminating indoor sampling.

Very complex monitoring situations can occur if ambient air transport of Superfund site emissions is of concern. In these cases additional sources emitting compounds of interest may exist upwind of the Superfund site as well as between it and the building being investigated. In these cases multiple monitoring stations and site specific modeling could be required to distinguish the impact of the site from the other sources. Information on various monitoring techniques for these complex situations can be found in Section 4.3 of EPA 450/1-89-002a (volume II of the Air/Superfund NTGS Series).

As a special case, it should be recognized that if the ambient air pathway is the only pathway of concern for Superfund site impact from non-particulates on the indoor air quality, there is no reason to conduct indoor monitoring. That is because the average long-term concentration of Superfund site related chemicals (except possibly

particulates) would be the same as the outdoor average at the building location.

#### B.1.1.1 Methods

In general EPA Methods TO-1, TO-14, IP-1A, or IP-1B will encompass the types of organics normally associated with a Superfund site. However, certain specific types of compounds (e.g., pesticides) may require specific methods. All "TO-x" methods can be found in "Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air," EPA 600/4-84-041 and supplements EPA 600/4-87-006 and EPA 600/4-89-018. All "IP-x" methods can be found in "Compendium of Methods for the Determination of Air Pollutants in Indoor Air," EPA 600/4-90-010. It should be noted that the methods in the latter reference are not currently certified and should not be regarded as officially recommended or endorsed by EPA. One source of these and other methods is the U.S. EPA Air Methods Database prepared by the EPA Environmental Response Team. Information about this PC-based software package can be obtained by calling 1-800-999-6990.

##### TO-14 and IP-1A Methods

Both of these methods use pre-evacuated SUMMA® passivated stainless steel containers to collect whole air samples. The canisters can be used to collect grab samples or time integrated samples. For most efforts related to indoor air monitoring, time integrated samples are needed.

For time integrated samples a flow restricting device must be used to control sampling rate. A mass flow controller is preferred for this use because a critical orifice flow restrictor results in decreasing flow rate into the canister as the canister pressure approaches atmospheric. Greater sampling volumes can be obtained by using a metal bellows type pump to boost final canister pressures to as high as 30 psi.

This method allows convenient integration of samples over a specified time period, remote sampling and central analysis, ease of shipping and storing samples, unattended sample collection, and collection of sufficient volumes to allow assessment of measurement precision and/or analysis of samples by several analytical systems. Contamination

is a critical issue with canister-based systems because the canister is the last element in the sampling train. Thus, as with all sampling systems, care must be used in the selection, cleaning, and handling of both canisters and associated sampling apparatus.

Although the method has been used for many VOCs and SVOCs (i.e., compounds with vapor pressures greater than  $10^{-7}$  mm Hg at 25°C), it has been validated for less than 40 compounds (See Table B.1). Furthermore, minimal documentation is currently available demonstrating VOC stability in subatmospheric pressure canisters.

One of the primary advantages of the canister methods is that the sample volume that can be collected is not limited by the "break through" capacity as are methods using solid sorbents. This is particularly advantageous when sampling in areas of unknown concentrations or where concentrations are varying during sampling.

Canister samples are analyzed using a high resolution gas chromatograph coupled to one or more appropriate detectors. Although non-specific detectors such as flame ionization (FID), electron capture (ECD), or photoionization (PID) may be less expensive per analysis and in some cases more sensitive than specific detectors, they suffer from variable specificity and sensitivity, non-positive compound identifications, and lack of resolution of co-eluting compounds. It is strongly recommended that specific detectors be used for positive identification and primary quantification. The recommended detectors are mass spectrometer operating in either the selected ion monitoring mode (for use when a specific set of compounds are to be determined) or the SCAN mode for identification of all compounds.

#### Methods TO-1 and IP-1B

These methods are based on the collection of VOCs on Tenax® solid adsorbent. Integrated sampling over periods up to 12 hours can be performed. The air to be sampled is drawn through the Tenax® loaded cartridge by small, portable pumps. As with any adsorption method, knowledge of flow rate and volume sampled are important data.

TABLE B.1  
VOLATILE ORGANIC COMPOUND DATA SHEET<sup>a</sup>

COMPOUND (SYNONYM)	FORMULA	MOLECULAR WEIGHT	BOILING POINT (°C)	MELTING POINT (°C)	CAS NUMBER
Freon 12 (Dichlorodifluoromethane)	Cl <sub>2</sub> CF <sub>2</sub>	120.91	-29.8	-158.0	
Methyl chloride (Chloromethane)	CH <sub>3</sub> Cl	50.49	-24.2	-97.1	74-87-3
Freon 114 (1,2-Dichloro-1,1,2,2-tetrafluoroethane)	ClCF <sub>2</sub> CClF <sub>2</sub>	170.93	4.1	-94.0	
Vinyl chloride (Chloroethylene)	CH <sub>2</sub> =CHCl	62.50	-13.4	-1538.0	75-01-4
Methyl bromide (Bromomethane)	CH <sub>3</sub> Br	94.94	3.6	-93.6	74-83-9
Ethyl chloride (Chloroethane)	CH <sub>3</sub> CH <sub>2</sub> Cl	64.52	12.3	-136.4	75-00-3
Freon 11 (Trichlorofluoromethane)	CCl <sub>3</sub> F	137.38	23.7	-111.0	
Vinylidene chloride (1,1-Dichloroethene)	C <sub>2</sub> H <sub>2</sub> Cl <sub>2</sub>	96.95	31.7	-122.5	75-35-4
Dichloromethane (Methylene chloride)	CH <sub>2</sub> Cl <sub>2</sub>	84.94	39.8	-95.1	75-09-2
Freon 113 (1,1,2-Trichloro-1,2,2-trifluoroethane)	CF <sub>2</sub> ClCCl <sub>2</sub> F	187.38	47.7	-36.4	
1,1-Dichloroethane (Ethylidene chloride)	CH <sub>3</sub> CHCl <sub>2</sub>	98.96	57.3	-97.0	74-34-3
cis-1,2-Dichloroethylene	CHCl=CHCl	96.94	60.3	-80.5	
Chloroform (Trichloromethane)	CHCl <sub>3</sub>	119.38	61.7	-63.5	67-66-3
1,2-Dichloroethane (Ethylene dichloride)	ClCH <sub>2</sub> CH <sub>2</sub> Cl	98.96	83.5	-35.3	107-06-2
Methyl chloroform (1,1,1-Trichloroethane)	CH <sub>3</sub> CCl <sub>3</sub>	133.41	74.1	-30.4	71-55-6
Benzene (Cyclohexatriene)	C <sub>6</sub> H <sub>6</sub>	78.12	80.1	5.5	71-43-2
Carbon tetrachloride (Tetrachloromethane)	CCl <sub>4</sub>	153.82	76.5	-23.0	56-23-5
1,2-Dichloropropane (Propylene dichloride)	CH <sub>3</sub> CHClCH <sub>2</sub> Cl	112.99	96.4	-100.4	78-87-5
Trichloroethylene (Trichloroethene)	ClCH=CCl <sub>2</sub>	131.29	87	-73.0	79-01-6
cis-1,3-Dichloropropene (cis-1,3-dichloropropylene)	CH <sub>3</sub> CCl=CHCl	110.97	76		
trans-1,3-Dichloropropene (cis-1,3-Dichloropropylene)	ClCH <sub>2</sub> CH=CHCl	110.97	112.0		
1,1,2-Trichloroethane (Vinyl trichloride)	CH <sub>2</sub> ClCHCl <sub>2</sub>	133.41	113.8	-36.5	79-00-5
Toluene (Methyl benzene)	C <sub>6</sub> H <sub>5</sub> CH <sub>3</sub>	92.15	110.6	-95.0	108-88-3
1,2-Dibromoethane (Ethylene dibromide)	BrCH <sub>2</sub> CH <sub>2</sub> Br	187.88	131.3	9.8	106-93-4
Tetrachloroethylene (Perchloroethylene)	Cl <sub>2</sub> C=CCl <sub>2</sub>	165.83	121.1	-19.0	127-18-4
Chlorobenzene (Phenyl chloride)	C <sub>6</sub> H <sub>5</sub> Cl	112.56	132.0	-45.6	108-90-7
Ethylbenzene	C <sub>6</sub> H <sub>5</sub> C <sub>2</sub> H <sub>5</sub>	106.17	136.2	-95.0	100-41-4
m-Xylene (1,3-Dimethylbenzene)	1,3-(CH <sub>3</sub> ) <sub>2</sub> C <sub>6</sub> H <sub>4</sub>	106.17	139.1	-47.9	
p-Xylene (1,4-Dimethylxylene)	1,4-(CH <sub>3</sub> ) <sub>2</sub> C <sub>6</sub> H <sub>4</sub>	106.17	138.3	13.3	
Styrene (Vinyl benzene)	C <sub>6</sub> H <sub>5</sub> CH=CH <sub>2</sub>	104.16	145.2	-30.6	100-42-5
1,1,2,2-Tetrachloroethane	CHCl <sub>2</sub> CHCl <sub>2</sub>	167.85	146.2	-36.0	79-34-5
o-Xylene (1,2-Dimethylbenzene)	1,2-(CH <sub>3</sub> ) <sub>2</sub> C <sub>6</sub> H <sub>4</sub>	106.17	144.4	-25.2	
1,3,5-Trimethylbenzene (Mesitylene)	1,3,5-(CH <sub>3</sub> ) <sub>3</sub> C <sub>6</sub> H <sub>3</sub>	120.20	164.7	-44.7	108-67-8
1,2,4-Trimethylbenzene (Pseudocumene)	1,2,4-(CH <sub>3</sub> ) <sub>3</sub> C <sub>6</sub> H <sub>3</sub>	120.20	169.3	-43.8	95-63-6
m-Dichlorobenzene (1,3-Dichlorobenzene)	1,3-Cl <sub>2</sub> C <sub>6</sub> H <sub>4</sub>	147.01	173.0	-24.7	541-73-1
Benzyl chloride (α-Chlorotoluene)	C <sub>6</sub> H <sub>5</sub> CH <sub>2</sub> Cl	126.59	173.3	-39.0	100-44-7
o-Dichlorobenzene (1,2-Dichlorobenzene)	1,2-Cl <sub>2</sub> C <sub>6</sub> H <sub>4</sub>	147.01	180.5	-17.0	95-50-1
p-Dichlorobenzene (1,4-Dichlorobenzene)	1,4-Cl <sub>2</sub> C <sub>6</sub> H <sub>4</sub>	147.01	174.0	53.1	106-46-7
1,2,4-Trichlorobenzene	1,2,4-Cl <sub>3</sub> C <sub>6</sub> H <sub>3</sub>	181.45	213.5	17.0	120-82-1
Hexachlorobutadiene (1,1,2,3,4,4-Hexachloro-1,3-butadiene)					

a - EPA 600/4-90-010

The method offers some advantages over the canister methods but has significant limitations and overall is complex and difficult to use. The primary, if not only, advantage is that the method has been validated for more compounds than the canister methods (See Table B.2). Note that although small, portable (even personal sampling) pumps may be used, mass flow controllers are recommended to ensure flow stability. A 10% deviation in initial and final flow rates may invalidate data collected using cartridges with that pump.

Limitations of the method include:

- Breakthrough volumes of some compounds, such as vinyl chloride, are very low. The lowest breakthrough volume limits the volume of sample that can be collected. (See Table B.3).
- High benzene backgrounds from Tenax® are common
- Sensitive to high humidity
- Contamination with compounds of interest (e.g., benzene, toluene, chloroform, methylene chloride, etc.) commonly encountered problem
- Variable desorption rates for compounds adsorbed on adsorbent
- Necessary to know approximate range of contaminate concentrations
- Overall accuracy of method is unknown.

The analytical finish for this method is similar to that for the canister method above. The primary differences are that the compounds must be thermally desorbed from the Tenax® before injecting it into the gas chromatograph and that each cartridge can be analyzed only once. It is strongly recommended, therefore, that the mass spectrometer be operated in the SCAN mode.

TABLE B.2  
COMPOUNDS IDENTIFIED AND QUANTIFIED BY AUTOMATED  
GC-MS-DS PROCEDURE WITH TYPICAL DETECTION LIMITS IN  
FULL SCAN MODE<sup>a</sup>

<u>Compound</u>	<u>Quantitation Mass (m/z)</u>	<u>Detection Limits (ng)</u>
perfluorotoluene (internal standard)*	217	0.3
benzene*	78	2.6
methylbenzene*	91	2.0
1,2-dimethylbenzene*	106	0.5
1,3,5-trimethylbenzene	120	2.5
ethylbenzene*	91	1.6
ethylbenzene*	104	1.7
(1-methylethyl) benzene	105	1.1
butylbenzene	91	0.7
1-methyl-4-(1-methylethyl) benzene	119	4.0
chlorobenzene*	112	1.7
bromobenzene	156	14.1
1,2-dichlorobenzene*	146	12.4
1-ethenyl-4-chlorobenzene	138	2.0
trichloromethane	83	2.7
tetrachloromethane*	82	2.1
bromochloromethane*	130	2.1
bromotrichloromethane*	163	1.6
dibromomethane*	174	4.5
tribromomethane*	171	8.5
1,1-dichloroethane*	63	5.7
1,2-dichloroethane	62	3.8
1,1,1-trichloroethane*	99	1.7
1,1,2-trichloroethane*	85	2.1
1,1,1,2-tetrachloroethane	31	0.9
1,1,2,2-tetrachloroethane	83	6.5
pentachloroethane*	167	1.8
1,1-dichloroethane*	961	6.9
trichloroethene*	132	0.8
tetrachloroethene	166	2.6
bromoethane*	108	7.8
1,2-dibromoethane*	107	3.3
1-chloropropane*	42	1.7
2-chloropropane*	43	3.4
1,2-dichloropropane	63	4.0
1,3-dichloropropane	76	9.6
1,2,3-trichloropropane	753	4.7
1-bromo-3-chloropropane	158	1.6
3-chloro-1-propene	41	1.6

TABLE B.2 -- continued

<u>Compound</u>	<u>Quantitation Mass (m/z)</u>	<u>Detection Limits (ng)</u>
1,2-dibromopropane*	121	14.4
2-chlorobutane	57	3.5
1,3-dichlorobutane	55	0.5
1,4-dichlorobutane	55	8.2
2-3-dichlorobutane*	90	5.1
1,4-dichloro-2-butane (cis)	752	1.9
3,4-dichloro-1-butane	75	6.5
tetrahydrofuran	72	1.2
1,4-dioxane	88	3.9
1-chloro-2,3-epoxypropane	71	8.1
2-chloroethoxyethene	631	8.2
benzaldehyde*	77	5.9
acetophenone	105	2.9
benzonitrile	103	1.3
ISOMER GROUPS		
1,3- & OR 1,4-dimethylbenzene	106	0.5
1,2- & OR 1,3-dichlorobenzene*	146	1.3
2- & OR 3- & OR 4-chloro-1-methylbenzene*	126	0.5
SURROGATE GROUPS AND INTERNAL STANDARDS		
4-bromofluorobenzene (BFB)	95	
chlorobenzene-d <sub>5</sub>	117	
1,4-dichlorobenzene	150	
1,4-difluorobenzene	114	

\* Compounds used to calibrate GC-MS-DS on a daily basis either by direct injection or on spiked adsorbent tubes.

a - EPA 600/4-90-010



TABLE<sup>a</sup> B.3  
BREAKTHROUGH VOLUMES<sup>b</sup> AND SAFE SAMPLING VOLUMES<sup>b</sup> FOR  
TENAX-GC AND TENAX-TA

	Tenax-GC breakthrough volume <sup>b</sup> 38°C	Tenax-TA breakthrough volume <sup>b</sup> 20°C    35°C	Tenax-GC safe sampling volume <sup>c</sup> 38°C	Tenax-TA safe sampling volume <sup>c</sup> 20°C    35°C
Acetaldehyde	0.6	0.6    0	0.3	<1    <1
Acrolein	4	5    2	1.7	2    <1
Acrylonitrile	-	8    3	-	3    1
Allyl chloride	-	8    3	-	3    1
Benzene	19	36    15	8.2	14    6
Benzyl chloride	300	440    200	130	175    80
Bromobenzene	300		130	
Carbon tetrachloride	8	27    13	3.5	11    5
Chlorobenzene	150	184    75	6.5	5    2
Chloroform	8	13    5	4	5    2
Chloroprene	-	26    12	-	10    5
Cresol	440	570    240	191	230    95
p-Dichlorobenzene	510	820    330	221	290    130
1,4-Dioxane	-	58    24	87	23    10
Ethylene dibromide	60	77    35	26	30    14
Ethylene dichloride	-	29    12	-	12    5
Ethylene oxide	-	0.5    0.3	-	<1    <1
Formaldehyde	-	0.6    0.2	-	<1    <1
Hexachlorocyclo- pentadiene	-	2000    900	-	800    360
Methyl bromide	0.8	0.8    0.4	0.4	<1    <1
Methyl chloroform	-	9    4	-	3    2
Methylene chloride	3	5    2	1.5	2    <1
Nitrobenzene	-	520    240	-	200    95
Perchloroethylene	-	100    45	-	40    18
Phenol	-	300    140	-	120    55
Propylene oxide	3	3    1	1.5	1    <1
Trichloroethylene	21	45    17	8.5	18    7
Vinyl chloride	0.6	.06    .03	.03	<1    <1
Vinylidene chloride	-	4    2	-	2    <1
Xylene	200	177    79	89	70    32

<sup>a</sup>EPA 600/4-90/010

<sup>b</sup>Breakthrough volumes expressed as liters/gram of sorbent.

<sup>c</sup>Safe sampling volume = {[Breakthrough volume (L/g)]/1.5} x 0.65 grams of sorbent.

<sup>d</sup>Breakthrough volumes for other chemicals can be extrapolated on the basis of boiling points for chemicals in the same chemical class.

### Other Methods for Specific Organic Classes

Other site related organic compounds of potential interest include aldehydes and ketones, pesticides, and polynuclear aromatic hydrocarbons.

Aldehyde and ketone concentrations may be determined by either EPA Methods T0-5 or IP-6A. The methods have different sampling techniques but similar analysis techniques (both use high pressure liquid chromatography (HPLC)). In Method T0-5, ambient air is drawn through a midjet impinger sampling train containing 10 mL of a 2N HCl/0.05% 2,4-dinitrophenylhydrozine (DNPH) reagent. Aldehydes and ketones react with the DNPH to form stable derivatives which can be separated using HPLC. Method IP-6A uses a prepackaged silica gel cartridge coated with acidified DNPH. The relatively high pressure drop across the cartridges ( $\approx 30$  inches of water) limits flow rates to about 1.5 liters/minute. Some experimentation with HPLC operating conditions is necessary for good compound separation. Table B.4 gives sensitivities versus sampled volume.

Pesticides may be determined using EPA Methods 608 (EPA 600/4-82-057) or Method IP-8. The latter is preferred for the current purpose and is briefly described. Ambient air is drawn through a cartridge filled with polyurethane foam (PUF) at a rate of 1 to 5 liters/minute. Concentrations of 0.01 to 50  $\mu\text{g}/\text{m}^3$  can be determined with sampling periods of 4 to 24 hours. The PUF is recovered and extracted with an ether/hexane mixture. The extract is concentrated and analyzed using gas-liquid chromatography with electron capture detector. Compounds listed in Table B.5 have been determined with this method.

Polynuclear aromatic hydrocarbons (PAHs) may be determined using EPA Method T0-13 or IP-7. Method T0-13 is a high volume method applicable only to outdoor environments. IP-7 is a low volume method but has detection capabilities adequate for indoor air impact assessments. The method is applicable to PAHs adsorbed on particulates as well as in the vapor phase. It also can be adapted for use with a PM-10 cut-point sampling nozzle.

In Method IP-7, air is drawn through a filter backed by either an XAD-2 or PUF filled cartridge. Up to 30  $\text{m}^3$  can be sampled at a rate of

TABLE B.4  
SENSITIVITY (ppb, v/v) OF SAMPLING/ANALYSIS USING  
ADSORBENT CARTRIDGE FOLLOWED BY HPLC

Compound	Sample Volume, L										
	10	20	30	40	50	100	200	300	400	500	1000
Formaldehyde	1.45	0.73	0.48	0.36	0.29	0.15	0.07	0.05	0.04	0.03	0.01
Acetaldehyde	1.36	0.68	0.45	0.34	0.27	0.14	0.07	0.05	0.03	0.03	0.01
Acrolein	1.29	0.65	0.43	0.32	0.26	0.13	0.06	0.04	0.03	0.03	0.01
Acetone	1.28	0.64	0.43	0.32	0.26	0.13	0.06	0.04	0.03	0.03	0.01
Propionaldehyde	1.28	0.64	0.43	0.32	0.26	0.13	0.06	0.04	0.03	0.03	0.01
Crotonaldehyde	1.22	0.61	0.41	0.31	0.24	0.12	0.06	0.04	0.03	0.02	0.01
Butyraldehyde	1.21	0.61	0.40	0.30	0.24	0.12	0.06	0.04	0.03	0.02	0.01
Benzaldehyde	1.07	0.53	0.36	0.27	0.21	0.11	0.05	0.04	0.03	0.02	0.01
Isovaleraldehyde	1.15	0.57	0.38	0.29	0.23	0.11	0.06	0.04	0.03	0.02	0.01
Valeraldehyde	1.15	0.57	0.38	0.29	0.23	0.11	0.06	0.04	0.03	0.02	0.01
o-tolualdehyde	1.02	0.51	0.34	0.25	0.20	0.10	0.05	0.03	0.03	0.02	0.01
m-tolualdehyde	1.02	0.51	0.34	0.25	0.20	0.10	0.05	0.03	0.03	0.02	0.01
p-tolualdehyde	1.02	0.51	0.34	0.25	0.20	0.10	0.05	0.03	0.03	0.02	0.01
Hexanaldehyde	1.09	0.55	0.36	0.27	0.22	0.11	0.05	0.04	0.03	0.02	0.01
2,5-dimethylbenzaldehyde	0.97	0.49	0.32	0.24	0.19	0.10	0.05	0.03	0.02	0.02	0.01

Note: ppb values are measured at 1 atm and 25°C; sample cartridge is eluted with 5 mL acetonitrile, and 25 mL are injected onto HPLC column.

Note: Maximum sampling flow through a DNPH-coated Sep-PAK<sup>®</sup> cartridge is about 1.5 L per minute.

TABLE B.5

PESTICIDES DETERMINED BY GAS CHROMATOGRAPHY/  
ELECTRON CAPTURE DETECTOR (GC-ECD)

Aldrin	Folpet
BHC ( $\alpha$ -and $\beta$ -Hexa- chlorocyclohexanes)	Heptachlor
Captan	Heptachlor epoxide
Chlordane, technical	Hexachlorobenzene
Chlorothalonil	Lindane ( $\gamma$ -BHC)
Chlorpyrifos	Methoxychlor
2,4,-D esters	Mexacarbate
<u>p,p</u> ,-DDT	Mirex
<u>p,p</u> ,-DDE	<u>trans</u> -Nonachlor
Dieldrin	Oxychlordane
Dichlorvos (DDVP)	Pentachlorobenzene
Dicofol	Pentachlorophenol
2,4,5-Trichlorophenol	Ronnel

up to 20 liters per minute without significant breakthrough. Because some of the PAH collected by the filter may volatilize and be collected on the adsorbent, the two should not be analyzed separately. The filter and adsorbent are extracted in Soxhlet extractors, cleaned up with silica gel column chromatography and analyzed using gas chromatography (with FID or MS detector) or by HPLC. In general, MS operated in SCAN mode is preferred because of the positive compound identifications.

#### B.1.2 Particulates

Methods are available to determine total suspended particulates and respirable ( $<10\mu\text{m}$ ) particles. In many cases only the latter will be of concern. However, in some cases consideration may be given to the larger particulate. Those particles that penetrate the building envelope will rapidly deposit on indoor surfaces. Exposure to these particulates may occur through dermal contact, ingestion, or inhalation if resuspended by occupant traffic or during such normal activities as cleaning.

Total suspended particles may be determined by the High-Volume Method given in Section 2.2 of "Quality Assurance Handbook for Air Pollution Measurement System: Volume II - Ambient Air Specific Methods," EPA 600/4-77-027a. Ambient air is drawn into a covered housing through a filter (nominal 8 x 10 inch), with a collection efficiency of at least 99 percent for particle size  $0.3\mu\text{m}$ , at 1.1 to  $1.7\text{ m}^3/\text{min}$ . Particles up to  $50\mu\text{m}$  (aerodynamic diameter) collect on the filter surface. Air containing up to  $750\mu\text{g}/\text{m}^3$  may be sampled for up to 24 hours at this rate. Particulate concentration is determined by dividing air volume sampled into the weight of particulate collected by the filter. It should be noted that because of the high air volume sampled, the method is not applicable to indoor air sampling.

Method IP-10A can be used to determine the concentration of particulate in both the  $<2.5\mu\text{m}$  and 2.5 to  $10\mu\text{m}$  ranges. The method contains both a fixed site monitor and a personal sampler. Only the fixed site monitor is recommended here for outdoor ambient air monitoring. The monitor operates on the principle of impaction. The horizontal slotted inlet prevents very large particles from entering. Either a one-stage or two-stage impactor assembly can be used to trap particles

above  $10\mu\text{m}$  or  $2.5\mu\text{m}$ , respectively. Particulate passing the impactor section is collected on a filter for subsequent weighing. Note that particles in both size ranges cannot be collected simultaneously with a single monitor. It is possible to connect two sampling heads to the same pump assembly to simultaneously collect in both size ranges. The limit of detection for a 12 hour sampling period at the specified sampling rate of 4 liters per minute is  $4\mu\text{g}/\text{m}^3$ .

The sampler does not use a critical orifice to control flow rate. Thus, a feedback control from a mass flow meter is required to vary pump speed in order to maintain flow constant with  $\pm 5$  percent.

### B.1.3 Organics in Soil Gases

Knowledge of the chemical concentrations in soil gases near a building will be important when site impact via the underground pathway is of concern. These situations can arise when soil gases migrate directly from the site (e.g., landfills), the nearby soil is contaminated, or the underlying groundwater is contaminated. As discussed in Section 2, it is important in these cases to determine concentrations in soil gas very near the building (i.e., in the region between 0.5 and 1 meter from the underground walls and floor). Gases in this soil region are most likely to diffuse through building cracks or be drawn into the building as a result of building underpressurization.

Because soil properties are inhomogeneous, both vertically and horizontally, it is expected that concentrations will vary around the building. Therefore, soil gas concentrations must be measured at several locations around the building. Following the approach used in Appendix C of Volume II of the Air/Superfund NTGS Series (EPA-450/1-89-002a), it is estimated that a minimum of two sampling points should be used on each side of the building (typical residential building). It is preferred that one additional sample be collected from directly under the building (approximate center). It may not be practical to collect this sample for slab-on-grade or basement constructions because a hole would have to be made in the floor. Efforts to collect this sample should be made, if possible. Buildings of this type generally have a very permeable zone (1 to 4 inches in depth) immediately below the slab

due either to the use of a gravel bed underlying the slab or gaps formed by soil not making continuous contact with the slab.

The preferred technique for collecting soil gas samples is the soil vapor (ground) probe. The installation of probes is simple. A small diameter pipe ( $\approx 0.5$  inch OD) is inserted into the ground to the desired depth either by hammering or driving it down a slightly undersized pre-augured hole. The use of pre-augured holes is recommended if soil permeabilities, described below, are to be measured. Retractable centering probe tips should be used to keep soil out of the probe. The probe should be withdrawn a minimum of two inches to expose soil at the probe tip.

A minimum of two probe volumes of soil gas should be extracted before samples are taken. Because soil gas concentrations must be fairly elevated if indoor air impact is to be of significant concern, low detection limits are not typically required. (Soil gas intrusion rates into a building are typically less than 5 percent of ambient air infiltration rates.) However, positive compound identification and accurate concentrations relative to other measured compounds are needed.

It is preferred that integrated samples be collected over at least one hour when indoor air monitoring is not being also conducted. If indoor air monitoring is also being conducted, integrated samples over the same time period should be collected. (Although soil gas concentrations should not vary significantly over this time period, some variation is possible and it is best to eliminate this uncertainty.)

In most cases, canister sample collection and analysis procedures such as those given in EPA Methods TO-14 or IP-1A are preferred because prior knowledge of actual concentrations is not required and concerns over breakthrough volumes are eliminated. However, professional judgement is required in the selection of technique based on known or suspected contamination at the site. For example, it may be possible to adapt IP-7 for pesticides or IP-8 for PAHs if soil contamination in the immediate vicinity of the building is known or suspected. Sampling flow rates, and, thus, sample volumes, would need to be kept low to reduce concern about drawing in surface air.

#### B.1.4 Soil Permeability to Gas Flow

The permeability of soil to gas flow can be an important indicator of the rate at which soil gas can enter a building. If the permeability is low (i.e., below  $10^{-8}\text{cm}^2$ ), it is unlikely building underpressures have much effect on the rate of intrusion and gases will enter primarily by diffusion. In this case, soil gas concentrations below the building may be higher than estimated from modeling equations. As the permeability increases, however, building pressure becomes more important and may result in gases several meters from the building being drawn inside. This effect reduces the soil gas concentration (relative to model assumptions) at the soil-building interface but increases the intrusion rate thus resulting in higher indoor concentrations. In essence, this is the reason predictive models assume a soil gas concentration of zero at the basement floor-soil interface.

Permeabilities are easy to measure using the soil gas probes discussed above. Permeabilities should not be measured until after soil gas samples have been obtained because the injected gas will distort concentration measurements. Permeabilities are determined by measuring the gas pressure in the probe as a metered flow of air is passed through the probe into the soil. A cylinder of compressed air, flow meters with ranges from about 5 to 500  $\text{cm}^3/\text{min.}$ , and a differential pressure gauge with a range of 0 to 125 pascals are needed. Probe pressure should be measured at three or more flow rates to obtain a good average. The permeability is calculated, assuming Darcy flow, from

$$K_v = \frac{Q \mu}{4\pi r^2 \text{Pa}}$$

where,

$K_v$  = Permeability,  $\text{m}^2$

$Q$  = Air Flow rate,  $\text{m}^3/\text{s}$

$\mu$  = Viscosity of air,  $1.83 \times 10^{-5} \text{ Kg/m-s}$

$r$  = Internal radius of probe,  $\text{M}$

$\text{Pa}$  = Probe pressure in pascals

The probe tip internal diameter should be measured to within  $\pm 0.005$  inches before inserting into the soil and after extraction. Method reference is contained in DMSA Action LTD., "Review of Existing Information and evaluation for possibilities of research and development of



instrumentation to determine future levels of radon at a proposed building site.", Report INFO-0096, Atomic Energy Control Board, Ottawa, Canada (1985).

## B.2 METHODS FOR USE INSIDE BUILDINGS

Critical measurements to be made indoors include those to determine pollutant concentrations and those to determine air exchange rates. Both are discussed here.

### B.2.1 Pollutant Measurement Methods

The air inside a typical building may contain hundreds of compounds (over 3800 compounds have been identified in tobacco smoke alone). To assess the potential impacts from a nearby contaminated site, it is only necessary to monitor for those compounds identified with the site. Because these compounds are also common in building materials and consumer products, their detection in the indoor air does not necessarily indicate their origin.

Discussion of appropriate sampler locations is included in Section 2. Principal considerations in locating samplers are:

- Air exchange rates in the area should be large compared to sampling volume.
- Samplers should be located in the normal breathing zone (i.e., 3 to 5 feet above floor level).
- At least one sampling location should be established on each level of the building.
- Samplers should not be located near obstructions, air supply or return registers, or local pollutant sources.
- Exterior windows and doors should be kept closed as much as possible. All indoor doors should be open.
- Sampling is best conducted under conditions that yield building underpressurizations of several pascals. Low rates of air infiltration and soil gas convective intrusion may result from low building underpressurizations.

In general it is recommended that indoor air monitoring use methods listed in the "Compendium of Methods for the Determination of Air

Pollutants in Indoor Air," EPA-600/4-90/010. In particular it is recommended that:

- Method IP-1A, Appendix B, use of portable gas chromatograph, be used for initial screening investigations and to assist in calculating proper sample size for methods based on use of solid adsorbents.
- Method IP-1A, canister, be used for collection of most target VOCs. Analytical finish by GC-MS in SIM or SCAN mode.
- Method IP-1B, Tenax® cartridge, be used only for compounds not quantifiable by IP-1A. Analytical finish by GC-MS in SCAN mode.
- Method IP-6A, solid adsorbent, be used for aldehydes/ketones. Method TO-5 may also be used.
- Method IP-7, PUF/XAD solid adsorbents, be used for PAHs. Note that if the PUF adsorbent is used, the method may also be used to determine pesticides. GC-MS in SIM or SCAN mode is the preferred analytical finish.
- Method IP-8, PUF adsorbent, be used for pesticides. The low sample volume collected in this method may be inadequate for PAH quantitation in indoor and ambient air. GC-MS in SIM or SCAN mode is the preferred analytical finish.
- Method IP-10a, size specific impactor, be used for airborne particulate matter. The single stage impactor collecting particles up to 10 $\mu$ m aerodynamic diameter is preferred. The stationary microenvironmental exposure monitor (MEM) is preferred. Collected particulates may be subjected to additional analysis if desired.

Specific circumstances may also warrant collection of deposited dusts/chemicals. The OSHA Method, described in 29 CFR 1910.132(a), may be used to collect deposited material for characterization. The method cannot be used for air inhalation estimates. Collection procedure is simple. A Whatman 42 filter is moistened with an appropriate solvent and used to wipe a known area (generally about 100 cm<sup>2</sup>). The filter is folded, with exposed side in, and folded again to form a 90-degree angle at the center of the filter. The filter is placed in a clean vial for transport to the laboratory. A blank filter that is also moistened with

the solvent should be submitted in a separate vial. Clean gloves, impervious to the solvent used and potential contaminants, should be worn during all phases of collection.

#### B.2.2 Air Infiltration Rates

Knowledge of air infiltration rates is not necessary to determine site related impacts on indoor air quality for the time period over which sampling occurred. However, if any estimate is to be made of likely concentrations at other times, knowledge of the infiltration rate and building air changes per unit time during the sampling period are required.

Preferred techniques to make these measurements are IP-4A and IP-4B which are both tracer gas methods. Indirect measurements can be made using the fan pressurization/depressurization method (ASTM-779). Because the ASTM method significantly affects building air infiltration rates, it cannot be used immediately before ( $\approx 12$  hours) or during indoor monitoring.

Method IP-4A can be used to obtain the integrated air exchange rate over the monitoring period. This method uses constant emitting perfluorocarbon (PFT) sources which must be placed in the building at least 8 hours before monitoring begins. One source is required for about every 500 ft<sup>2</sup> of living area. They are temperature sensitive and care must be used in placement. Samples are collected on activated charcoal spherules inside capillary adsorption tubes over the entire monitoring period. The tubes are analyzed by GC-ECD. The method includes cleanup for other compounds that respond to the ECD detector.

The method is applicable to small and large buildings and can be used to determine interzonal flows as well as exchange rates. The method assumes the effective exchange volume of the building is equal to the physical volume. Poor mixing within the building may effect this assumption.

Method IP-4B is a tracer concentration decay method. In this method, a tracer, such as SF<sub>6</sub>, is injected into the structure, thoroughly mixed and its concentration measured over time. The concentration decreases due to air exchange with outside air. Tracer concentrations can be measured on-site with a GC-ECD or SF<sub>6</sub> specific detectors. Grab

samples or time-integrated samples for off-site analysis can also be obtained.

Adequate mixing in the indoor environment is critical to the success of this method. Local fans and/or heating system fans should be used to obtain tracer concentration throughout the structure within 5 percent of the average. It is preferred that measurements be made in several locations on each floor of the building. Tracer injections can be made at about one-hour intervals to obtain a series of infiltration measurements. If sufficient difference exists in meteorological conditions during these measurements, it is possible to characterize the effects of temperature, wind, and structural factors on the infiltration rates.

Tracer concentration is assumed to follow

$$C = C_0 \exp (-IT)$$

where,

C = Concentration at time T

C<sub>0</sub> = Concentration at T = 0

I = Air exchange rate

T = Time

The air exchange rate can be obtained from the slope of a LnC versus time plot.

When using either Method IP-4A or 4B, measurements should be made of indoor and outdoor temperatures, wind velocity, barometric pressure, and building underpressurization.

In the ASTM Method, a large fan is mounted on a door connected to the outside. The fan is used to draw air out of and force air into the building at several differential pressures. Flow rates are determined from a fan calibration curve. The effective leakage area is calculated from

$$L = Q/(2\Delta P\rho)^{-0.5}$$

where,

L = Leakage area

Q = Air flow rate

$\Delta P$  = Pressure difference across building shell

$\rho$  = Density of air

Infiltration rates and air exchange rates can then be estimated using

$$Q = L(A\Delta T + B\mu^2)^{0.5} \text{ from page 8 of EPA 400/3-91/003}$$

where,

Q = Air infiltration rate, CFM

L = Effective leakage area, in<sup>2</sup>

$\Delta T$  = Indoor-outdoor temperature difference, °F

$\mu$  = Wind speed, mph

A = Stack coefficient

B = Wind coefficient

Values for A and B are in the above document.

### B.3 INDOOR AIR POLLUTANTS

Literally hundreds of compounds have been detected in indoor air. Over 3,800 compounds have been detected in tobacco smoke alone. The sources of the compounds are many and include building materials, furnishings, cleaners and waxes, paints, pesticides, hobby supplies, combustion devices, and personal care products. It has been estimated (Tancrede et al, "The Carcinogenic Risk of Some Organic Vapors Indoors: A Theoretical Study", Atmospheric Environment, Vol. 21, No. 10, 1987) that cancer risks from exposure to indoor air probably well exceeds  $1 \times 10^{-4}$ .

Many of the compounds typically associated with a contaminated site are also present in typical non-impacted indoor environments. This significantly complicates monitoring efforts to differentiate site contributions to indoor air concentrations. The data currently available indicates that compounds detected and concentrations of those compounds is a function of many factors including building type (e.g., office, residence, school, etc.), age, and location.

Although many studies of indoor air exposures have been made (most notable is The Total Exposure Assessment Methodology (TEAM) Study - see EPA 600/6-87-002Q for summary and analysis), it does not appear to be feasible at this time to tabulate the averages and ranges for individual compounds in all types of potentially impacted structures in a way that would be useful for determining site impacts from indoor air concentrations. The TEAM studies do, however, have a substantial amount of

information on averages and ranges for many compounds in a number of different building types. This may be considered the best currently available source of information on typical concentrations.

Examples of some specific compound measurements are contained in EPA 400/3-91-003, "Introduction to Indoor Air Quality: A Reference Manual." EPA 600-R-92-02, "Indoor Air Quality Data Base for Organic Compounds," provides the best current summary of data on organics from studies over the last decade. This data base contains information on over 220 organic compounds. The compounds most frequently reported in the studies reviewed were: formaldehyde, tetrachloroethylene, 1,1,1-trichloroethane, trichloroethylene, benzene, p-dichlorobenzene, toluene, ethylbenzene, xylene, decane, and undecane. It should be noted that not every study monitored for the same compounds or used similar methods.

## **APPENDIX C. CASE STUDIES**

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## APPENDIX C

### CASE STUDIES

The potential impacts of Superfund sites on the indoor air quality of nearby buildings have been investigated in a number of cases. This Appendix documents a sample of such cases. The examples cover a range of site conditions, potential types of indoor air impacts, phases in the Superfund program, and judgements of investigating personnel.

It should be noted that, in most cases, additional work beyond that presented here has been conducted. Therefore, this Appendix should be read in the context that it presents partial results of investigations and should not be construed as the final analysis of the potential site impact. The purpose is to provide an overview of the modeling and monitoring techniques that have been used and the relative success of these techniques.

It is not intended as a review of all possible case types. It is also not intended as documentation that indoor air impacts have been shown to occur. It is hoped that sufficient detail is provided to allow site investigations to avoid some of the major pitfalls in assessing indoor air impacts.

#### C.1 BUILDINGS ON LANDFILL SITES

The Landfill extends over approximately ten acres of land. It received both municipal and industrial wastes from about 1910 to 1967. The wastes included drummed industrial wastes and uncontained liquid wastes. Prior to 1964, open burning took place at the site. After closure, when the wastes were covered by approximately two feet of soil, the property was subdivided and sold for both residential and commercial development. Based on verbal reports of methane buildup in buildings currently located on the site, a study was conducted in three commercial buildings in late 1985. The results of the study indicated the presence

of methane in one of the buildings at levels well below the lower explosive limit for methane in air, even in the floor cracks where levels were most highly concentrated. However, the concern existed that the methane entering buildings acts as a carrier gas for toxic species. Preliminary soil gas analysis conducted by the regulated party's contractor utilizing a portable chromatograph indicated the presence of eleven toxic chemical species.

Therefore, indoor air quality sampling for volatile organic chemicals was performed at the site. It took place between approximately 9 AM and 5 PM on a day in September, 1990.

The purpose of this study was to collect data of a quality sufficient to document the presence of any toxic volatile organic chemicals in buildings constructed on the former landfill site which may pose a health risk to their occupants.

The buildings sampled were selected on the basis of an on-site reconnaissance visit conducted jointly by EPA and State personnel as well as existing data. They are single-family residences referred to here as Building A and Building B. Both homes are of split-foyer design and have garages adjacent to finished portions of their lower levels. Aside from automobile storage, miscellaneous small gasoline engines (and the fuel for such) are commonly kept in such indoor areas. The garage in Building A, in particular, smelled strongly of fuels and solvents (HNU readings were 2 ppm). Virtually all of the tentatively identified compounds detected are known components of gasoline. Both homes are inhabited by cigarette smokers. Although no smoking took place during the sampling period, information on the prior 24 hours was not obtained.

Sampling and analytical methodologies were tailored for purposes of identifying and quantifying the compounds listed in Table C-1. Compounds of interest were selected based on preliminary data developed during the soil gas sampling conducted in November and March and April 1989. EPA personnel performed both the field sampling activities and the analytical work.

TABLE C-1 Targeted Compounds
A - Tenax
Benzene
Ethylbenzene
Tetrachloroethylene
Toluene
Trichloroethylene
1, 1, 1-trichloroethane
m, p-xylene
o-xylene
B - Spherocarb
Trans-1, 2-dichloroethylene
Vinyl Chloride

Sampling and analysis of indoor air conformed to Method T0-1, Method for the Determination of Volatile Organic Compounds in Ambient Air using Tenax Adsorption and Gas Chromatography/Mass Spectrometry (GC/MS) and Method T0-2, Method for the Determination of Volatile Organic Compounds in Ambient Air by Carbon Molecular Sieve Adsorption and GC/MS, from the Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air, EPA-600/4-84-041, May 1987.

One sampling station was located on each of the lower two floors of each building. Each station on the lower floors consisted of primary and secondary tubes in series plus a duplicate (of each type of tube). Each station on the upper floors, consisting of single tubes of each type, was located upstairs on the main living level in the kitchen. The lower-level station in each building was expected to produce the highest readings of any of the stations. Because, the possibility of breakthrough of the species through the cartridges, with resultant loss of accuracy, was greatest at this point, the series tube configurations were utilized there to gauge breakthrough. A single cartridge of each

type was also set up outdoors to monitor ambient concentrations, for comparison with those measured indoors.

Samples were collected over an 8-hour period, utilizing personal constant-flow pumps to draw ambient air through cartridges containing adsorbents. Certain nonpolar volatile organic compounds having boiling points in the range of approximately 25 to 95 °C were captured on Tenax GC (poly 2,6-Diphenyl phenylene oxide). Other more volatile compounds having boiling points ranging from -26 to +50°C (which will pass through Tenax adsorbent) were collected on a carbon molecular sieve (CMS) adsorbent, Spherocarb.

A sample volume requirement of approximately 10 liters dictated a flow rate of approximately 21 ml/min over the 8-hour sampling period. Sampling cartridges were positioned in the "breathing zone" (approximately three feet above floor level).

Occupants were requested to eliminate, insofar as is possible, the opening of any doors or operation of ventilation/exhaust fans (clothes driers act as exhaust fans) for a minimum of 24 hours preceding the sampling period. Windows remained closed for 24 hours preceding sampling. Door openings were kept to a minimum during the sampling period.

During the eight hour period while the pumps were running, methane levels were measured utilizing an Organic Vapor Analyzer (OVA) in the gas chromatograph mode, with the output going to a strip-chart recorder. An Hnu (which does not respond to methane) was used for total non methane readings. The highest methane readings obtained were 8 ppm (directly above a cat litter pan).

Temperature, barometric pressure and relative humidity (RH) were measured periodically inside the buildings throughout the eight-hour sampling period. Temperature readings were obtained with an Ertco thermometer, pressure with a Taylor aneroid barometer and relative humidity with a Bacharach Instrument sling psychrometer. Inside temperatures were fairly constant at 22-23°C and RH was constant at 42-44 percent. The test report did not give barometric pressure.

### C.1.1 Quality Assurance/Quality Control

#### Cartridge Conditioning

Cartridges were thermally conditioned in a Tekmar Model 5100 Thermal Conditioner two days prior to sampling with a nitrogen purge rate of approximately 100 ml/min. Tenax cartridges were conditioned for 14 hours at 250°C. Spherocarb cartridges were conditioned for 15 hours at 399° C.

After the Tenax cartridges were conditioned, they were injected with 5 microliters of a surrogate solution, composed of deuterated Benzene (d6), Toluene (d8) and bromofluorobenzene in methanol, using the flash vaporization technique. The cartridges were then refrigerated prior to field sampling activities.

#### Pump Calibration

Prior to sampling, the pumps were calibrated using a Mini-Buck commercial primary standard flow meter with optical sensing of bubble passage. Following sample collection, calibrations were again checked with the Mini-Buck. The criterion for the difference between the initial and final flow rates is no more than 15%. Where the difference exceeds 15%, the data is reported as an estimated value. Four pumps exhibited a flow rate difference of more than 15%.

#### Sample Storage and Transportation

- Cartridges were stored in individual containers following conditioning for transportation and storage. The individual containers were sealed in jars containing granulated charocal to minimize the possibility of cross-contamination.

- Cartridges were stored in a clean laboratory freezer maintained at approximately -20 to 0° C following conditioning, and were returned to said freezer following sample collection while awaiting analysis.

- Cartridges were transported to and from the field in an ice-filled cooler.

### Blanks

One cartridge of each type used in the sampling process accompanied the sampling cartridges to the field and was handled in precisely the same manner as the sample cartridges, except that they remained in their containers to serve as field blanks.

A laboratory blank of each type used remained in the freezer and was subject to the same criteria as the field blanks.

The results of the analysis of the Tenax trip blank showed it to be contaminated with two compounds, 1,1,1-trichloroethane and benzene. The Tenax laboratory blank was found to be contaminated with four compounds, 1,1,1-trichloroethane, benzene, toluene and 1, 2, 3-trichlorobenzene. All of the sample cartridge data for benzene, with two exceptions, met the criterion and were considered valid from the standpoint of blank contamination. All of the Tenax cartridge data for toluene met the criterion for blank contamination.

No contamination was found on either the trip or laboratory Spherocarb cartridges.

### Breakthrough

Breakthrough of compounds through the adsorption medium was assessed by a comparison of the levels found on the primary-secondary cartridge pairs. Secondary, or backup cartridges must meet the criterion of containing less than 20% of the amount of each species found on the primary cartridge of each pair. At Building B, two compounds failed the criterion. At Building A, all the components failed the criterion with the exception of benzene. None of the Spherocarb primary-secondary pairs exhibited any breakthrough.

### Precision

Each sampling event consisted of the collection of an additional set of parallel samples collected simultaneously at different flow rates. Agreement between parallel samples should generally be within  $\pm 25\%$  if the concentration is at least 10 times greater than the minimum detection level. None of the targeted Tenax compounds detected at this level failed the criterion. Methylene chloride was the only compound detected on Spherocarb which failed the criterion.

#### C.1.2 Results

Much of the chemical concentration data from this study were qualified because of:

- Four pumps not meeting flow-rate acceptance criterion
- Poor recovery on two cartridges
- Blank contamination for 1,1,1-Trichloroethane and benzene
- Breakthrough on primary cartridges using Tenax (precision criteria were met however).

Summarized results are in Table C-2.

TABLE C.2 Maximum Concentrations of Targeted Compounds Found <sup>(1)</sup> (PPBV/V)			
A - Tenax			
	Building B	Building A	Ambient
benzene	5.9	17*	ND <sup>(3)</sup>
ethylbenzene	2.6	7.7*	ND
tetrachloroethylene	0.34	0.52	ND
toluene	19*	56*	ND
trichloroethylene	0.04*	ND	ND
1,1,1-trichloroethane	3*	5.2*	ND
m,p-xylene	8.4 <sup>(2)</sup>	25 <sup>(2)*</sup>	ND

\* - Estimated Value

B - Spherocarb			
trans-1,2-dichloroethylene	ND	ND	ND
vinyl chloride	ND	ND	ND
(1) - 18 other compounds were detected; the highest was 15 ppb V/V for isopropylbenzene (2) - Reported as total o,m,p-xylenes (3) - ND - not detected in any sample			



### C.1.3 CONCLUSION REACHED

The test report stated,

"In summary, all eight of the targeted compounds detected in the homes studied here have potential sources apart from the underlying landfill and are, in fact, not uncommon in a household environment. Therefore, it is impossible to determine with complete certainty which compounds are actually migrating into the homes from past landfilling and which are present merely as a result of typical household activities.

Finally, whether or not these levels constitute a health hazard must be determined by a risk analysis."

The complete test report was submitted to the residents along with a cover letter that states, in part:

For Building A;

"The levels of chemicals detected in your home were comparable to those found in the average home.

At this time we do not know the origin of these chemicals. As we are planning to complete the Remedial Investigation of the landfill in the summer of 1992, we hope, at that time to determine the source of these indoor pollutants."

For Building B;

"The levels of chemicals detected in your home were found to be slightly higher than those normally found in an average home. However, the levels detected in your home do not pose an immediate health threat.

At this time we do not know the origin of these chemicals. As we are planning to complete the Remedial Investigation of the landfill in the summer of 1992, we hope, at that time to determine the source of these indoor pollutants.

The chemicals identified in your home at slightly elevated levels are: benzene, ethylbenzene, toluene, and xylenes. Apart from the landfill, possible sources of these indoor air pollutants are numerous."

### C.1.4 Comments On The Study

This case provides a good example of some of the pitfalls of indoor air monitoring. The study met its primary objective which was to "document the presence of any toxic volatile organic chemicals in

buildings.... which may pose a health risk to their occupants." However, because the indoor air concentrations of chemicals of the same identity as those associated with the Superfund site were similar to typical indoor concentrations, no conclusive statements about the source of the chemicals could be made. This would be true even if all sampling and analysis had gone perfectly.

In retrospect, because the study design was such the contribution of site chemicals to the indoor air concentrations could not be determined, it would have been preferable to state the purpose as: Determine whether or not indoor air contaminants were of types and concentrations to suggest significant intrusion of site related chemicals. With this as the purpose, it would have been easier to develop a risk communication plan that had specific follow-up steps depending on the contaminant concentrations determined. Building occupants could, then, have been advised before monitoring took place what actions would be taken depending on the concentrations found in this screening study.

## C.2 BUILDINGS NEAR LANDFILL

The Landfill is in South King County, Washington. Puget Sound is slightly more than a mile to the west. Residential areas surround the site, with the exception of a commercial strip along Highway 99 to the west and a stand of second-growth mixed conifer-hardwood forest on the north. Two elementary schools and a community college are within one mile of the site. Interstate 5 (I-5) borders the site on the east. Approximately one mile east of I-5 is the Green River, which meanders north, becomes the Duwamish River, and enters Puget Sound. Figure C-1 shows the location of the landfill and the landmarks in its vicinity.

From 1945 to 1966, the site was operated as a gravel pit. The pit originally was adjacent to a peat bog lake located northeast of the center of the present landfill. As the pit was mined, water was drawn from the lake to wash silt and clay from the gravel and sand, then the water was returned to the lake. Silt and clay built up on the lake bottom. Near the end of the operation of the gravel mine the barrier between the lake and the gravel pit was broken, allowing the silty lake water to flow into the gravel pit. As a result, a clay/silt layer underlies much, but not all, of the landfill.

In January 1966, the 60-acre site was leased and used as a landfill for nonputrescible waste, which includes organic material that decomposes slowly, such as demolition debris and wood wastes. The landfill received demolition debris from commercial haulers and wood wastes and yard trimmings. Records beginning in 1980 indicate that some industrial wastes also were deposited. Information included in EPA's Emergency and Remedial Response Information System (ERRIS) files indicates that the landfill may have received industrial liquid and sludge wastes before 1980.

# LANDFILL

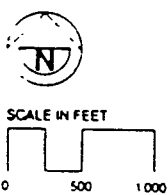
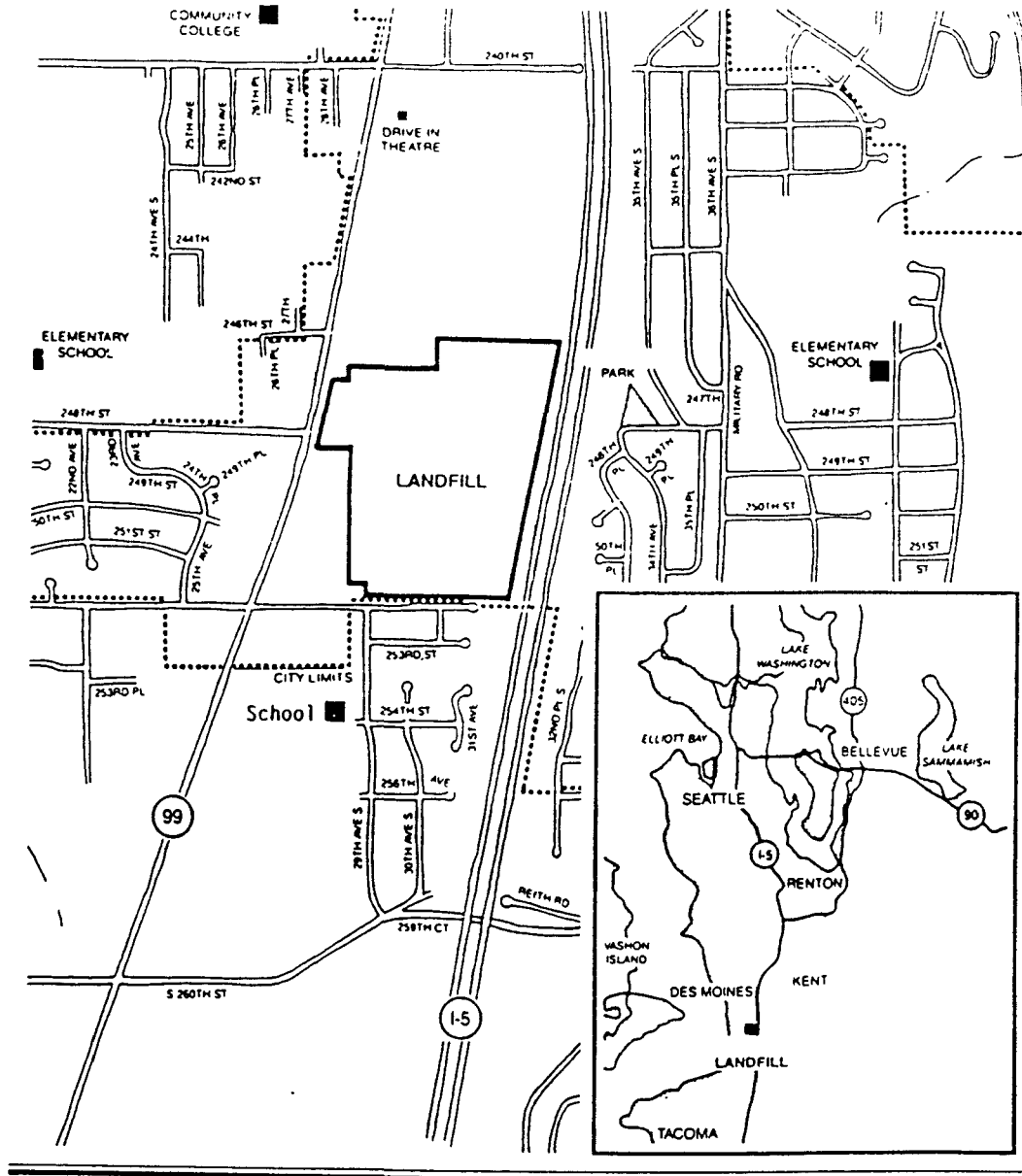


FIGURE C-1  
Location Map

During the course of operations at the landfill, an estimated 3 million cubic yards of solid waste were deposited covering approximately 40 acres up to about 130 feet deep in places. The east side of the landfill rises above the adjacent property; the landfill surface slopes downward to the northwest corner. The landfill was closed in October 1983. The entire site was covered with 6 to 24 inches of a silt/sand material when operations ceased; it now appears as an open grassy area with scattered shrubs and a few areas of exposed soil. Approximately 102 acres of land east of I-5 currently drain directly into the solid waste.

#### C.2.1 Nature And Extent Of The Problem

Potential problems related to solid waste landfills similar to the Landfill mainly derive from the combustible gas that is a byproduct of decomposition, and leachate, i.e., water or other liquid that has come into contact with the waste. Methane, carbon dioxide, and small amounts of hydrogen sulfide are normally generated by the decomposition of landfill wastes. Small amounts of toxic volatile organics are commonly found as well. These gases can be released to the atmosphere or migrate offsite by means of underground pathways. Leachate can flow or seep offsite to contaminate surface water or it can infiltrate the groundwater underlying the landfill if no artificial or natural barriers exist. The Landfill is a natural drainage basin from which no surface water exits. However, depending on subsurface conditions, groundwater contamination is possible.

The landfill was closed in the fall of 1983 and extensive testing of gas and water in the landfill and its vicinity began. Samples of leachate and groundwater from monitoring wells in and around the landfill and gas samples from gas probes indicated the presence of organic and inorganic contaminants with a high potential for offsite migration. In May 1986, the EPA placed the site on its National Priority List for cleanup and a remedial investigation was initiated.

Initial remedial measures were taken to control the offsite migration of gas and prevent possible emissions from the landfill

surface; gas extraction wells were installed offsite and gas migration control wells were installed on the perimeter of the landfill.

#### Combustible Gas

Combustible gas, primarily methane ( $\text{CH}_4$ ), was detected at concentrations up to 10,000 ppm in the basements of homes near the Landfill in 1985. A series of gas probes were installed around the site perimeter to monitor gas concentrations. Gas was found in many of the probes. Measures were taken to seal cracks in building foundations. Numerous shallow and some deep probes were installed offsite. A program to monitor homes for gas was established. Data from the offsite probes and the monitoring program indicated that the gas had migrated up to approximately 2,600 feet from the landfill and was seeping into homes at that distance. Additional probes were installed farther from the site. The sealing programs within homes and businesses was expanded, and some families were evacuated.

In September 1985, and again in september 1986, a series of onsite gas migration control wells around the perimeter of the landfill were installed as initial remedial measures. Designed to prevent offsite gas migration by withdrawing and venting the gas, these wells are connected by manifold piping to motor blowers and flares. As part of final landfill closure, portions of this system will be replaced by permanent equipment that will remain in operation for the indefinite future.

#### Leachate

It is estimated that over 50 million gallons per year of surface water (drainage and direct precipitation) enter the landfill. Measurements of water levels in leachate monitoring wells indicate that stormwater discharge from drainage pipes produces rapid and significant increases in water levels within the solid waste. Since there is no surface runoff from the landfill, leachate must eventually enter the groundwater system if it does not remain in the landfill. Leachate flows to the southeast corner of the landfill and then downward and then east and west away from a mound located beneath the Sand Aquifer sink. Based on chloride concentrations, leachate is calculated to be indistinguishable from background groundwater at a maximum of 3,000 feet from

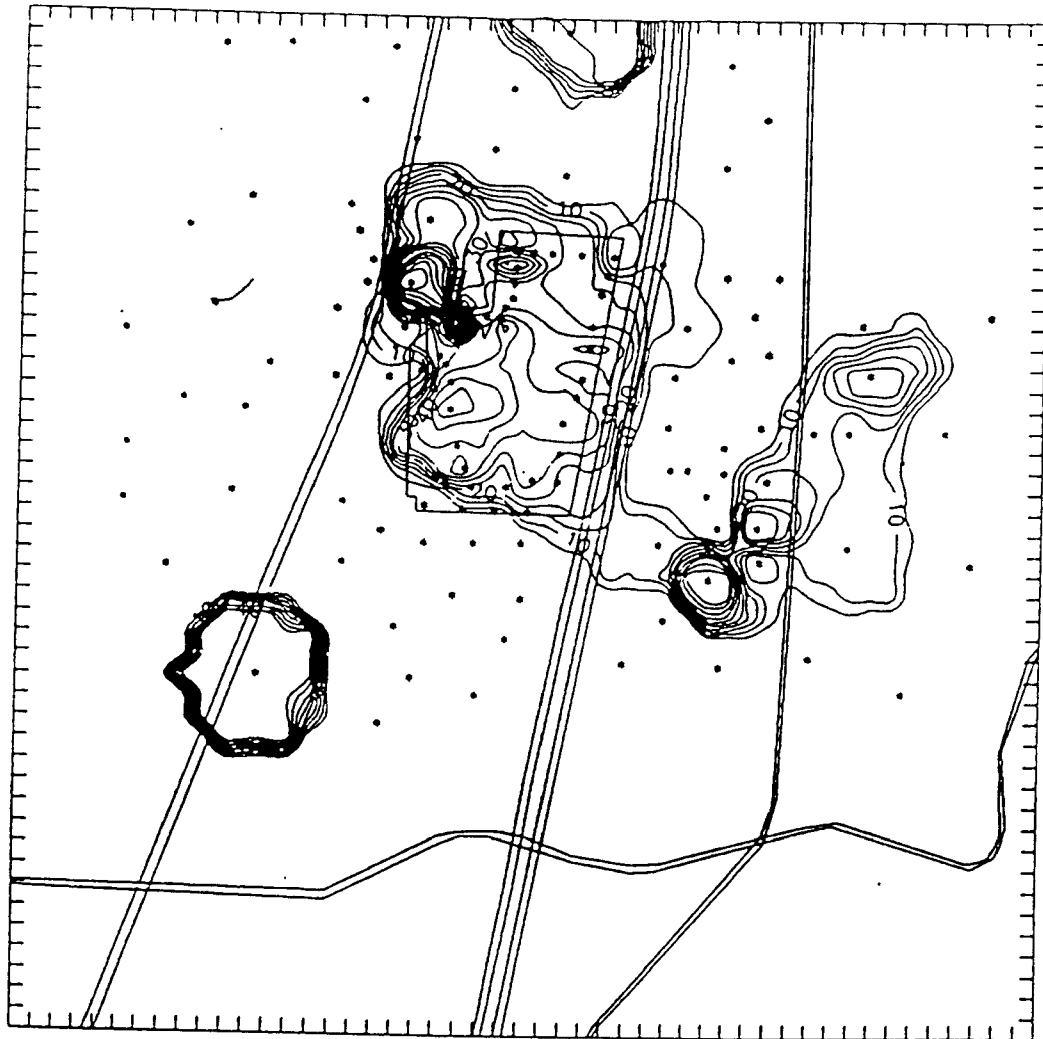
the landfill boundary to the east and southeast and 1,500 feet from the landfill boundary to the west.

#### Offsite Gas Monitoring

Data recorded from the monitoring probes were computerized and used to generate gas concentration isopleths (maps showing gradients of gas concentrations) for the areas surrounding the Landfill.

The isopleths for February 1986, shown in Figures C-2 and C-3, represent the status of landfill gas migration just after the Phase I onsite gas migration control system was put into continuous operation. Methane was detected northwest of the landfill in concentrations over 75%, north in concentrations over 25%, and east and southwest in concentrations over 40%. Methane was detected in the deep soil zone in all directions from the landfill and in concentrations over 90% in some areas.

LANDFILL



Note: All sets of probes and  
wells may not be shown

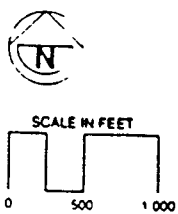
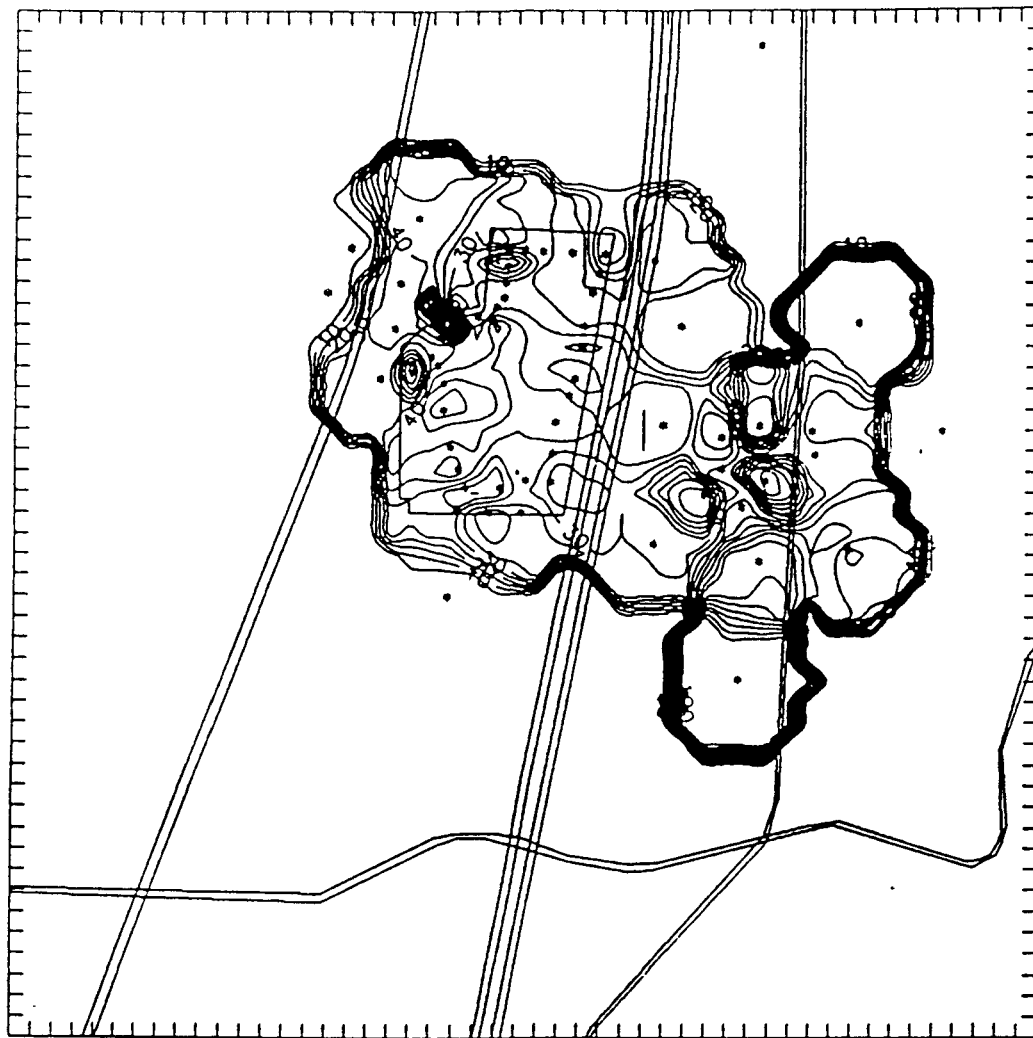


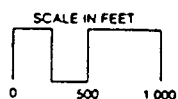
FIGURE C-2  
Shallow Gas Concentration  
Isopleth, February, 1986



# LANDFILL



Note: All sets of probes and  
wells may not be shown



**FIGURE C-3**  
Deep Gas Concentration  
Isopleth, February, 1986

Field measurements were taken using the following instruments:

- Hnu PI-101 photoionization detector (total non-methane volatile organic compounds)
- MSA 361 portable detector (combustible gas, hydrogen sulfide, and oxygen)
- Fyrite carbon dioxide analyzer

Gas samples were collected in Tedlar bags and shipped. Gas samples were analyzed for Hazardous Substances List volatile organic compounds (HSL VOC) by gas chromatography/mass spectrometry (GC/MS) in accordance with USEPA Method 624 guidelines.

This analysis found that subsurface gas collected from the onsite gas extraction wells and flare manifolds contained a wide variety of substances, including 23 USEPA HSL VOCs. The compounds found most frequently and in the highest concentrations in the onsite subsurface gas included ethylbenzene, vinyl chloride, total xylenes, toluene, and benzene. The maximum concentrations of these compounds were in the low parts-per-million (ppm) range.

TABLE C-3  
ESTIMATED ONSITE/OFFSITE ATTENUATION OF PRIMARY  
HSL VOCs DETECTED IN SUBSURFACE GAS SAMPLES

CAS#	Target Compound	MAXIMUM CONCENTRATION			MEAN CONCENTRATION		
		On-Site (ppb)	Off-Site (ppb)	Atten. (%)	On-Site (ppb)	Off-Site (ppb)	Atten. (%)
100-41-4	Ethylbenzene	16,610	127	99.2	2,825	44	98.4
1330-20-7	Xylenes (total)	29,195	106	99.6	3,419	19	99.4
108-88-3	Toluene	24,044	68	99.7	1,920	18	99.1
71-43-2	Benzene	1,384	185	86.6	318	28	91.2
100-42-5	Styrene	508	134	73.6	41	18	56.1
75-01-4	Vinyl Chloride	31,215	275	99.1	2,807	35	98.8
Attenuation (%) = $\frac{\text{Onsite Concn. (ppb)} - \text{Offsite Concn. (ppb)}}{\text{Onsite Concn. (ppb)}} \times 100$							

Vinyl chloride was frequently associated with the BTX-group compounds in onsite subsurface gas, but during sampling offsite, it was found at only two of the gas monitor probe locations, both south of the landfill.

The analysis concluded that offsite migration of at least some of the contaminants consistently identified in landfill gas has occurred, possibly in all directions away from the landfill. The basis for this conclusion is the presence of the BTX-group compounds in gases found onsite and offsite. However, offsite concentrations of most BTX-group compounds were attenuated by more than 98 percent (Table C-3). Furthermore, no BTX compounds were found beyond 2,300 feet from the landfill perimeter. Because BTX-group compounds are also present in gas from other sources, their presence in a particular sample of offsite gas is not conclusive evidence that the gas originated from the landfill; it is only further evidence that the gas may have originated in the landfill.

#### Mechanisms for Gas Movement

Where gas migration potential exists, the inherent slight pressure of gas being generated by decomposition, fluctuations in barometric pressure, and fluctuations in water table may create mechanisms for gas movement.

The low gas generation pressures in the landfill initially move the gas away from the points of origin through the paths of least resistance. The generation pressures are estimated to be in the range of two inches of water column, based upon measurements in other landfills. Changes in atmospheric pressure of -9.5 inches of water column are common during the winter months as high pressure ridges give way to low pressures during storms. This can create a relatively strong pressure differential between the air or gas within the soil or landfill and the air at the ground surface.

When barometric pressure is falling, the air or gas within the soil or landfill tends to flow toward the ground surface through the paths of least resistance. When barometric pressure is rising, air from the ground surface tends to move down into the soil both vertically and

horizontally. The combined effect of the generation pressures and the barometric changes is a pumping action within the soils.

#### C.2.2 Prevention Of Gas In Structures

Several residences adjacent to control well installations typically recorded levels of methane above 10,000 ppm despite repeated efforts to seal the foundations of those structures until the control wells were turned on. According to gas monitoring data, all gas was effectively removed from these structures within one day of the startup of the offsite control wells. Further, gas has remained out of structures in the vicinity of the landfill since the implementation of the offsite control wells. Combustible gas above 100 parts per million has not been recorded in a structure in the vicinity since November 1986.

#### C.2.3 Comments On The Study

The study demonstrated that landfill gas migrated from the site independently from contaminated groundwater. It demonstrates the difficulty in preventing soil gas intrusion by retrofit patching of existing buildings and the effectiveness of soil gas extraction wells. The data suggests that vinyl chloride is migrating in the direction of groundwater flow rather than with near surface gases.

Because of the high concentrations of methane detected in the initial phase of the investigation, few data were obtained related to other gases that might also be migrating. This initial oversight, while understandable, significantly reduced the data needed for an accurate baseline assessment.

### C.3 BUILDINGS OVER GROUNDWATER PLUME (A)

The site is located at the southern end of San Francisco Bay. In 1982 and 1983, it was discovered that three facilities (identified here as A, B, and C) in the city had leaking underground tanks contaminating soil and groundwater. All three were placed on the National Priorities List (NPL). Facility C has since been removed from the NPL and is being regulated under the Resource Concentration and Recovery Act (RCRA). Although each site has its own source of pollution, the off-site groundwater pollution areas have merged and the sites are being treated as one unit.

The area is heavily populated with commercial, light industrial, and residential use. According to the 1980 Census information, there are approximately 4,000 people living in the general area of the off-site groundwater contamination:

The off-site area is determined by the extent of the groundwater contamination of volatile organic compounds. The plume of contaminated groundwater extends approximately one and three-quarters mile north of the site. This area is composed of light industry and residential housing. The former junior high school is located west to northwest of the site.

The closest residential neighborhood begins about 1/4 mile north of the site. According to the 1980 Census, of the approximately 1,500 housing units, 54% are single family homes and 24% have 10 or more units. The area consists of modest single family homes interspersed with small apartment complexes. Within 3/4 mile of the site is a mobile home park which is primarily occupied by senior citizens.

A former elementary school houses approximately 200 children per day. These children attend either a state child development program, a state preschool, or a YMCA day-care program and a Head Start Program, all operating at the school facility. There is at least a half acre of grassy land on the side of the facility that is not included in the fenced off playground. This is used as a neighborhood playground.

### C.3.1 Nature and Extent of Problem

Chlorinated volatile organic compounds (VOCs) are the major contaminants tested for and found in soils and groundwater. Highest concentrations were found around the leaking underground tanks. The tanks and much of the contaminated soil were removed from the sites in 1983 and 1984. Soils with a total VOC concentration as high as 15,700 parts per million (PPM) were excavated. Soil boring samples were obtained in 1988 at the A and B Facilities. The data are in Table C-4.

#### Groundwater

The VOC contamination in groundwater is currently monitored by 29 wells on the A site and 30 wells on the B site, in addition to 83 off-site wells. There are 7 extraction wells on the A site and 6 extraction wells on the B site. There are 23 off-site extraction wells. The on-site extraction wells have been in operation since 1985, and the off-site wells began operation in 1986 and 1988.

Three major water-bearing zones (aquifers) - defined as the A-, B-, and C-aquifer zones - exist at the site. The A-aquifer is the shallowest and the C-aquifer is the deepest of these three zones. The B-aquifer is further divided into the B1 through B5 zones. The approximate depths (below ground level) at which these zones occur at the A site are as follows: A: 10-28 ft; B1: 28-50 ft; B3: 70-90 ft; B4: 90-110 ft; and B5: 110-123 ft. A regional aquitard, the B-C aquitard, is reportedly located at the depth range from 100-150 feet below ground level. The C-aquifer, which supplies most of the municipal water in the region, is located below the regional aquitard.

The aquifer zones appear to consist of mostly discontinuous layers and lenses of fine to coarse sand, gravels, and often a substantial proportion of clay and silt. These predominantly discontinuous layers and lenses are separated and/or isolated by low-permeability clays and silts (aquitards).

TABLE C-4

## VOCS IN ON-SITE SOILS, 1988

## FACILITY A

	Soil Concentration (ppm)			
	Outside Building		Inside Building	
	Subsurface	Aquitard	Subsurface	Aquitard
Vinyl Chloride	nd	nd-3.2	nd	nd
cis-1,2-Dichloroethylene	nd-0.004	0.001-2.6	nd-0.3	6.5
Trichloroethylene	0.023-1.2	nd-0.82	0.045-1.6	nd
Tetrachloroethylene	nd-0.7	nd	nd-0.3	nd
1,2-Dichloroethylene	nd-2.8	nd	nd-1.8	nd

## FACILITY B

	Soil Concentration (ppm)			
	Building 1		Building 2	
	Excavated	Remaining	Excavated	Remaining
1,1,1-Trichloroethane	<0.01-3.42	nt	nd-0.007	nd
trans-1,2-Dichloroethylene	nt	nd-12.9	nd-0.001	nd-0.0016
Trichloroethylene	<0.01-186	nd-80.0	nd-0.127	nd-0.015
Tetrachloroethylene	nt	nd-35.0	nd-0.004	nd-0.0025
1,2-Dichlorobenzene	nt	nd-242	nt	nt

nd = not detected above detection limits

nt = not tested

Based on the well monitoring results at the site, it appears the bulk of the VOC contamination is confined to the A-, B1- B2-, and B3-aquifers. However, low concentrations of VOCs have been detected in the B4-aquifer. On-site VOC concentrations in the fourth quarter of 1990 at the A and B Facilities are given in Table C-5 and C-6.

Off-site VOC concentration in groundwater for the fourth quarter of 1990 are given in Table C-7. The data were from predetermined wells that were not necessarily in the middle of the plume. The maximum concentration of trichloroethylene, 1, 2-dichloroethylene, 1, 1-dichloroethane, and tetrachloroethylene exceeded drinking water standards.

#### Soil Gas

On March 12, 1991, the soil surface emission of organic vapors was analyzed using a flux chamber at off-site locations just to the north of Facility A and near the former Junior High School. The soil moisture content and ambient temperature during this sampling period were not typical for this area and would tend to under-represent typical organic vapor emission from the soil. Another sampling round was conducted on April 28, 1991. One sampling location north of Facility A was repeated while the rest of the samples were taken on the former elementary school property. The data are given in Table C-8. [Note: The ATSDR draft report on this site states that data collected using the neutral pressure isolation flu chamber may be inappropriate for estimating flux into buildings.]

#### Indoor Air Monitoring

Indoor air monitoring has been conducted only at Facility B. On May 16, 1991, a crude analysis for organic compounds was made using a hand-held detector. All readings were below the limit of detection (0.5 to 1.0 ppm). On May 18, 1991, sampling was conducted inside and outside the building. One-hour samples were collected at each location five feet above ground. The results are in Table C-9.



TABLE C-5

## ON-SITE VOC CONCENTRATIONS IN GROUNDWATER

## FACILITY A

	Drinking Water Standards	Aquifer Concentration			
		A	B1	B2	B3
Dichloromethane	40 <sup>a</sup>	nd-85	nd-260	nd-200	2.0
Dichlorofluoromethane	100 <sup>a</sup>	nd-1600	nd-460	nd-140	nd
1,2-Dichloroethane	0.5 <sup>b</sup>	nd	nd-140		
1,1,1-Trichloroethane	200 <sup>b,c</sup>	nd-120	nd	nd-16	nd
Freon 113	1200 <sup>d</sup>	nd-120	nd-320	nd-1.0	nd
Vinyl chloride	0.5 <sup>b</sup>	nd-1600	220-460	1.0-140	nd
1,2-Dichloroethylene	6,10 <sup>e</sup>	38-7800	660-8600	5.0-1600	1.0
Trichloroethylene	5 <sup>b,e</sup>	nd-1700	380-1500	8.0-490	1.0
Dichlorobenzene	0-130 <sup>f</sup>	nd-170	nd-220	nd	nd

nd = not detected above detection limits

<sup>a</sup> California Action Level<sup>b</sup> California MCL<sup>c</sup> Federal MCL<sup>d</sup> proposed California MCL<sup>e</sup> proposed California MCL for the cis- and trans-forms, respectively<sup>f</sup> California Action Levels that differ according to the specific form of dichlorobenzene

TABLE C-6  
ON-SITE VOC CONCENTRATIONS IN GROUNDWATER

FACILITY B

	Drinking Water Standards	Aquifer Concentration (ppb)		
		A	B1	B2
1,1,1-Trichloroethane	200 <sup>b</sup>	nd-20	nd-10	nd-4.3
Freon 113	1200 <sup>a</sup>	nd	nd-270	nd-550
Vinyl chloride	0.5 <sup>c</sup>	nd-3.3	nd-7800	nd
1,2-Dichloroethylene	6,10 <sup>d</sup>	nd-930	nd-52,000	nd-16
Trichloroethylene	5 <sup>b</sup>	nd-1400	nd-19,000	nd-4200
Tetrachloroethylene	5 <sup>c</sup>	nd-20	nd-17	nd-65
1,2-Dichlorobenzene	130 <sup>a</sup>	nd-3.4	nd	nd

nd = not detected above detection limits

<sup>a</sup> proposed California MCL

<sup>b</sup> Federal MCL

<sup>c</sup> California MCL

<sup>d</sup> proposed California MCL for the cis- and trans-forms, respectively

<sup>e</sup> California Action Level

TABLE C-7

## OFF-SITE VOC CONCENTRATIONS IN GROUNDWATER

	Drinking Water Standards	Aquifer Concentration			
		A	B1	B2	B3
Dichloromethane	40 <sup>a</sup>	nd-6	nd-8.9	nd-10	nd
Chloroform	100 <sup>a</sup>	nd-11	nd-2.6	nd-65	nd-0.3
1,1-Dichloroethane	5 <sup>b</sup>	nd-2.6	nd-110	nd	nd
1,1,1-Trichloroethane	200 <sup>c</sup>	nd-7	nd-1700	nd-7	nd
Freon 113	1200 <sup>b</sup>	nd-26	nd-160	nd	nd-200
1,1-Dichloroethylene	6 <sup>c</sup>	nd-1.4	nd-2.5	nd	nd
1,2-Dichloroethylene	6 <sup>b</sup>	nd-16	nd-160	nd	nd
Trichloroethylene	5 <sup>d</sup>	nd-530	nd-2400	nd-2400	nd-2400
Tetrachloroethylene	5 <sup>c</sup>	nd-1.2	nd	nd	nd

nd = not detected above detection limits

<sup>a</sup> California MCL for total trihalomethanes<sup>b</sup> proposed California MCL<sup>c</sup> California MCL<sup>d</sup> proposed California MCL for the cis- and trans-forms, respectively

**TABLE C-8**  
**ORGANIC CHEMICALS IN OFF-SITE SOIL VAPOR**  
(concentrations are given in parts per billion)

	March 12, 1991		April 28, 1991	
	Facility B	Former Junior High School	Facility B	Former Elementary School
Dichloromethane	nt	nt	nt	nt
Dichlorodifluoromethane	nt	nt	nt	nt
1,1-Dichloroethane	nd	nd	nt	nt
1,1,1-Trichloroethane	0.43,4.3	nd-0.73	0.56	0.18-0.38
Freon 113	0.40,6.9	nd-1.8	0.95	0.13-0.35
Vinyl chloride	nd, 1.3	nd	nt	nt
1,1-Dichloroethane	nd	nd	nt	nt
cis-1,2-Dichloroethylene	nd, 0.56	nd	nd	nt
trans-1,2-Dichloroethylene	nd	nd	nd	nt
Trichloroethylene	nd	nd	nt	nd-0.60
Tetrachloroethylene	nd	nd	nt	nt
1,2-Dichlorobenzene	nd, nd	nd-0.97	nt	nt

nd = not detected above detection limits

nt = not tested

TABLE C-9

## ORGANIC CHEMICALS IN AMBIENT AIR AT THE FACILITY B

(Air concentrations are given in parts per billion)

	Inside Building				Outside Building		EMEG
	Production	Support	Storage	Office	Trench	Fenceline	
Dichloromethane	nt	nt	nt	nt	nt	nt	300
Dichlorodifluoromethane	nt	nt	nt	nt	nt	nt	--
1,2-Dichloroethane	nt	nt	nt	nt	nt	nt	30
1,1,1-Trichloroethane	0.4	3.0	3.2	0.6	0.6	0.3	55*
Freon 113	nt	nt	nt	nt	nt	nt	--
Vinyl chloride	nd	nd	nd	nd	nd	nd	5
1,2-Dichloroethylene	nd	nd	nd	nd	nd	nd	--
Trichloroethylene	<0.1	0.15	0.1	0.09	0.2	4.12	30
Tetrachloroethylene	0.1	nd	nd	0.1	0.2	nd	9
Dichlorobenzene	nd	nd	nd	nd	nd	nd	800 +

nd = not detected above detection limits

nt = not tested

\* California Applied Action Level

+ for 1,4-dichlorobenzene

### C.3.2 Indoor Air Modeling Results

Estimates of indoor air concentrations were made, using models, for current residences, the former elementary school, and possible future apartment complexes. The Farmer model (see Appendix A of this report) was used to estimate emission flux at ground surface. Based on assumptions about building construction (area of the flooring through which gas could infiltrate is the dominant factor) and building air exchange rates, the indoor air concentrations were then calculated. The modeling results are given in Tables C-10 through C-12. [The tables show that identical groundwater concentrations and contaminant vapor phase concentrations were used for the average and plausible worst cases.]

### Interpretation of Results

The Agency for Toxic Substances and Disease Registry (ATSDR) reviewed the above data (as well as other data not presented here) and estimated cancer and non-cancer risks based on their standard methodology. The analysis indicated that only current off-site residences (not including the former elementary school) have any increased risk from exposure to chemicals volatilizing from the groundwater plume. The upperbound lifetime excess cancer risk was estimated to be  $1 \times 10^{-4}$  (low increased risk) for average case conditions, and  $2 \times 10^{-3}$  (moderate increased risk) for the plausible maximum conditions. The summary of the ATSDR report states that the site is an indeterminate public health hazard because of potential human exposure to concentrations of chemicals that upon long-term exposure could cause adverse health effects.

### C.3.3 Comments on Case Study

1. As noted by ATSDR, use of the flux chamber to check emission flux predictions of the model at ground surface may be valuable, but flux chamber data may be inappropriate as flux source data for infiltration into a building due to negative pressure in the building.

2. The modeling report states that convective flow due to building vacuum (ie. stack effect) is generally more important than simple diffusion into the building. Only diffusion into the buildings

TABLE C-10

## ESTIMATION OF INDOOR AIR CONCENTRATION OF VOCS

## RESIDENCES DOWNGRADIENT FROM SITE

CHEMICAL	GROUNDWATER CONC.		Henry's Law Constant (atm·m <sup>3</sup> /mol)	Diffusivity (m <sup>2</sup> /s)	VAPOR PHASE CONC.		CHEMICAL FLUX RATE		ESTIMATED INDOOR AIR CONC.	
	Geometric Mean (ug/L)	Maximum (ug/L)			Average (g/m <sup>3</sup> )	Plausible Maximum (g/m <sup>3</sup> )	Average (g/m <sup>2</sup> ·s)	Plausible Maximum (g/m <sup>2</sup> ·s)	Average (ug/m <sup>3</sup> )	Plausible Maximum (ug/m <sup>3</sup> )
1,1-Dichloroethylene	4.3	4.3	1.64E-01	1.01E-05	2.71E-02	2.71E-02	1.44E-09	5.58E-09	4.24E-00	1.84E-01
Tetrachloroethylene	2.1	2.1	2.30E-02	7.40E-06	1.87E-03	1.97E-03	7.74E-11	2.89E-10	2.27E-01	8.77E-01
Trichloroethylene	120	120	8.90E-03	8.12E-06	4.37E-02	4.37E-02	1.88E-09	7.25E-09	5.50E-00	2.13E-01
1,1-Dichloroethane	2.5	2.5	5.70E-03	9.60E-06	5.82E-04	5.82E-04	2.96E-11	1.14E-10	8.68E-02	3.38E-01
cis-1,2-Dichloroethylene	14	14	6.60E-03	1.00E-05	3.78E-03	3.78E-03	2.00E-10	7.73E-10	5.87E-01	2.27E-00
trans-1,2-Dichloroethylene	11	11	6.56E-03	1.00E-05	2.85E-03	2.95E-03	1.56E-10	6.03E-10	4.58E-01	1.77E-00
Freon 113	21	21	3.90E-01	9.00E-06	3.35E-01	3.35E-01	1.60E-08	6.16E-08	4.88E-01	1.81E-02
1,1,1-Trichloroethane	6.3	6.3	2.80E-02	7.80E-06	7.21E-03	7.21E-03	2.98E-10	1.15E-09	8.73E-01	3.37E-00

TABLE C-11

## ESTIMATION OF INDOOR AIR CONCENTRATION OF VOCS

## FORMER ELEMENTARY SCHOOL

CHEMICAL	GROUNDWATER CONC.		Henry's Law Constant (atm <sup>3</sup> ·m <sup>3</sup> )/mol	Diffusivity (m <sup>2</sup> /s)	VAPOR PHASE CONC.		CHEMICAL FLUX RATE		ESTIMATED INDOOR AIR CONC.	
	Geometric Mean (ug/L)	Maximum (ug/L)			Average (g/m <sup>3</sup> )	Plausible Maximum (g/m <sup>3</sup> )	Average (g/m <sup>2</sup> ·s)	Plausible Maximum (g/m <sup>2</sup> ·s)	Average (ug/m <sup>3</sup> )	Plausible Maximum (ug/m <sup>3</sup> )
1,1-Dichloro-ethylene	4.3	4.3	1.54E-01	1.01E-05	2.71E-02	2.71E-02	1.44E-09	5.58E-08	7.80E-03	3.01E-02
Tetrachloro-ethylene	2.1	2.1	2.30E-02	7.40E-06	1.97E-03	1.97E-03	7.74E-11	2.99E-10	4.18E-04	1.61E-03
Trichloro-ethylene	120	120	8.90E-03	8.12E-06	4.37E-02	4.37E-02	1.88E-09	7.25E-08	1.01E-02	3.91E-02
1,1-Dichloro-ethane	2.5	2.5	5.70E-03	9.60E-06	5.82E-04	5.82E-04	2.96E-11	1.14E-10	1.60E-04	6.18E-04
cis-1,2-Di-chloroethylene	14	14	6.60E-03	1.00E-05	3.78E-03	3.78E-03	2.00E-10	7.73E-10	1.08E-03	4.17E-03
trans-1,2-Di-chloroethylene	11	11	6.50E-03	1.00E-05	2.95E-03	2.95E-03	1.56E-10	6.03E-10	8.43E-04	3.26E-03
Freon 113	21	21	3.90E-01	9.00E-06	3.35E-01	3.35E-01	1.60E-08	6.16E-08	8.61E-02	3.33E-01
1,1,1-Tri-chloroethane	6.3	6.3	2.80E-02	7.80E-06	7.21E-03	7.21E-03	2.98E-10	1.15E-09	1.61E-03	6.21E-03



TABLE C-12

## ESTIMATION OF INDOOR AIR CONCENTRATION OF VOCs

## FUTURE ON-SITE RESIDENCES

CHEMICAL	GROUNDWATER CONC.		Henry's Law Constant (atm <sup>3</sup> m <sup>3</sup> /mol)	Diffusivity	VAPOR PHASE CONC.		CHEMICAL FLUX RATE		ESTIMATED INDOOR AIR CONC.	
	Geometric Mean (ug/L)	Maximum (ug/L)			Average (g/m <sup>3</sup> )	Plausible Maximum (g/m <sup>3</sup> )	Average (g/m <sup>2</sup> s)	Plausible Maximum (g/m <sup>2</sup> s)	Average (ug/m <sup>3</sup> )	Plausible Maximum (ug/m <sup>3</sup> )
1,1-Dichloroethylene	9.5	9.5	1.54E-01	1.01E-05	5.98E-02	5.98E-02	3.19E-09	1.23E-08	4.74E-02	1.83E-01
Tetrachloroethylene	13	13	2.30E-02	7.40E-06	1.22E-02	1.22E-02	4.79E-10	1.85E-09	7.12E-03	2.75E-02
Trichloroethylene	560	560	8.90E-03	8.12E-06	2.04E-01	2.04E-01	8.75E-09	3.38E-08	1.30E-01	5.03E-01
Vinyl chloride	240	240	6.90E-01	1.07E-05	6.77E-00	6.77E-00	3.83E-07	1.48E-06	5.70E-00	2.20E-01
1,2-Dichlorobenzene	97	97	1.93E-03	7.11E-06	7.65E-03	7.65E-03	2.88E-10	1.11E-09	4.28E-03	1.65E-02
1,1-Dichloroethane	18	18	5.70E-03	9.60E-06	4.19E-03	4.19E-03	2.13E-10	8.24E-10	3.17E-03	1.22E-02
cis-1,2-Dichloroethylene	160	160	6.60E-03	1.00E-05	4.32E-02	4.32E-02	2.29E-09	8.83E-09	3.40E-02	1.31E-01
trans-1,2-Dichloroethylene	88	88	6.56E-03	1.00E-05	2.36E-02	2.36E-02	1.25E-09	4.83E-09	1.86E-02	7.18E-02
Freon 113	47	47	3.90E-01	9.00E-06	7.49E-01	7.49E-01	3.57E-08	1.38E-07	5.31E-01	2.05E-00
1,1,1-Trichloroethane	5.7	5.7	2.80E-02	7.80E-06	6.52E-03	6.52E-03	2.69E-10	1.04E-09	4.01E-03	1.55E-02

was considered. No explanation for not considering convection was given.

3. Whereas gas was considered to infiltrate buildings through the entire floor area for current private residences, infiltration through only a 0.5 cm crack around the perimeter was allowed for the former elementary school and future residences. For example, for the school, this assumes only 0.08 percent of the soil gas flux enters. For future residences the assumption is 0.2 percent flux entry. The assumption that gas entry rates are a direct function of the percent cracked area is not supportable and could result in significant under-predictions of indoor air levels.

4. The modelling approach made no attempt to correct for the capillary fringe above the groundwater. While this is appropriate for an initial simple screening approach, it should be recognized that this could lead to large overestimations of contaminant flux to the surface.

5. Incorrect Henry's Law Constants were used leading to a potential overestimation of flux by a factor of about 50. (Non-dimensional values used in a dimensional equation).

Because of the opposing influence of item 2 through 5, the relevance of the model predictions is uncertain. Recognizing that the initial modeling approach was simplistic, in retrospect it would have been preferred to conduct more refined modeling before releasing the data or conducting on-site monitoring.

#### C.4 BUILDINGS OVER GROUNDWATER PLUME (B)

The site (Figure C-4), a former printed circuit board manufacturing facility, is located at the southern end of San Francisco bay. The facility operated from 1970 to 1985. The U.S. Environmental Protection Agency (EPA) placed the site on the National Priorities List (NPL) on February 1, 1990.

The primary site of both wet and dry manufacturing processes was the "wet floor" building where waste waters containing heavy metals and organic compounds were released to the "wet floor" and then discharged to the neutralization sump. Other solvents and wastes were placed in drums and disposed of off-site. It is still unclear exactly how the chemicals discharged to the "wet floor" or the neutralization sump were released to the soil and then the ground water.

In 1985 manufacturing stopped. As part of the plant closure process, soil and ground-water investigations were initiated. The investigation showed chlorinated volatile organic compounds (VOCs) and metals (copper, lead and nickel) are the major contaminants found in the soil and ground-water samples. The highest concentration of organic contaminants in the soils was found around the sump and the "wet floor". The sump and surrounding contaminated soil and the contaminated soil beneath the "wet floor" were removed.

Seven wells on the site and 24 off-site wells (Figure C-4) currently monitor the VOC contamination in the groundwater. The ground water monitoring indicates that the plume extends north underneath Interstate 101 (1/8 mile) and west of the site approximately a quarter mile. Remediation of the groundwater began around 1986. Currently there are 3 extraction wells on the site and 4 extraction wells off-site.

The site consists of a number of high-ceiling one-story buildings now occupied by other businesses. Light industry and businesses also rent the other four buildings that were once part of the manufacturing complex.

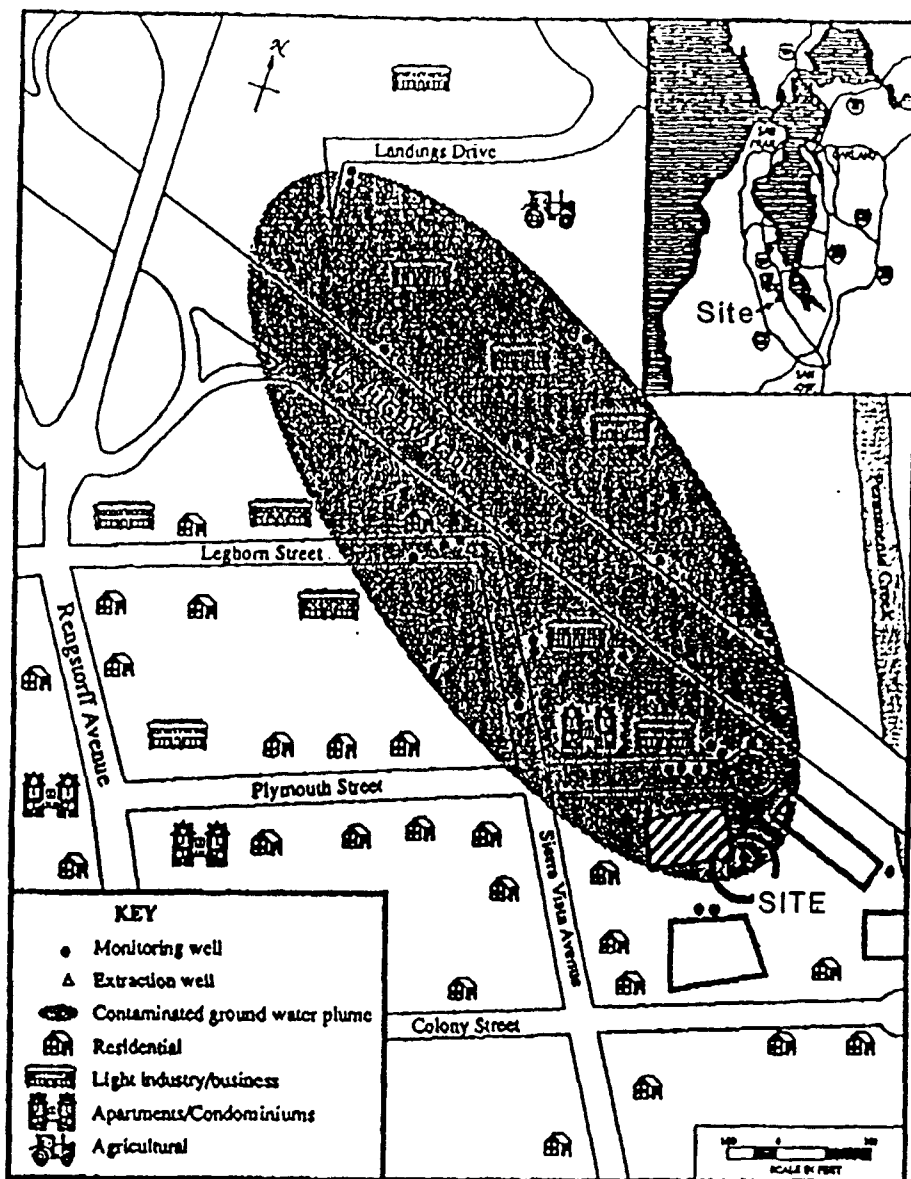


Figure 1. Contaminated ground-water plume.

FIGURE C-4

According to 1990 census information, approximately 1000 people live in the 10 block area surrounding the plume of groundwater contamination connected with the site. The bulk of the population resides on the south side of Highway 101, with 1990 census information showing only 10 people living on the north side of Interstate Highway 101.

Land in the area surrounding the site has been used for residential, commercial, and agricultural purposes for many years. The areas surrounding the site are zoned for a mixture of multiple family and two family residential units, and general and limited industrial use. Within the four block vicinity of the site, there are 409 housing units with many of these being 14 unit complexes.

The area north of Highway 101 is zoned light industrial and planned community designation. This type of zoning is designed for research and development, office space, and light manufacturing. No new housing is allowed under this zoning. Within this area approximately 20 acres of land are used for commercial farming. Two schools are located northwest within a half mile of the site. The nearest city park is one-half mile southwest of the site.

Four major water-bearing zones (aquifers)-defined as the A-, B-, intermediate - and C- zones-exist at the site. The A-aquifer is the shallowest and the C-aquifer is the deepest of these three zones. The approximate depths (below ground level) at which these zones occur at the site are as follows: A: 10-20 feet; B: 30-40 feet; and intermediate: 60-75 feet. A regional impermeable zone, the B-C aquitard, is reportedly located at a depth range from 100-150 feet below ground level. The C-aquifer, which supplies most of the municipal water in the region, is located below the regional aquitard.

#### C.4.1 Nature and Extent of Problem

Between August 1985 and August 1986, the neutralization sump and some surrounding soil (70 cubic feet) was excavated and sequentially backfilled to grade level with pea gravel, well-compacted clay, and asphalt. In September 1986, about 255 cubic yards of soil were excavated under the "wet floor".

In May 1987, soil samples were taken at five feet depth from borings at the sump and soil around it and analyzed for organic contami-

nants ("wet floor" soil was not analyzed). Results are shown in Table C-13. Results of the post-remediation analyses showed the presence and levels of various organic contaminants not originally found in the neutralization sump area.

TABLE C-13  
ORGANIC CONTAMINANTS IN ON-SITE SUBSURFACE SOIL

	Sump Before (4/85)	Sump After (5/87)	" Wet Floor" Before (10/86)	"Wet Floor" After ---
1,1-Dichloroethane	nd	nd-24	na	na
1,1,1-Trichloroethane	10	nd-69	na	na
1,1-Dichloroethylene	7.3	nd	na	na
t-1,2-Dichloroethylene	nd	nd-110	na	na
Trichloroethylene	nd	41-220	nd-100	na

nd = not detected above detection limits  
na = not analyzed

Since 1986, 7 on-site monitoring wells have been installed to characterize the vertical and horizontal extent of contamination. The most contaminated wells are located near to or downgradient, north to northwest, from the sump excavation. The migration of contaminants through the major water-bearing aquifers is being monitored. The two shallowest aquifers (A and B1) are contaminated with dichloroethane, 1,1,1-trichloroethane, 1,1-dichloroethylene, trans-1, 2-dichloroethylene, and trichloroethylene at concentrations exceeding state or federal drinking water standards (Table C-14).

Three extraction wells were installed on-site: two draw from the A-aquifer and one draws from the B-aquifer. The untreated ground water is discharged by permit into the sanitary sewer system.

TABLE C-14

## ORGANIC CONTAMINANTS IN ON-SITE MONITORING WELLS

Data are taken from the quarterly monitoring well report, fourth quarter, 1990. The historical range of contaminant concentrations for each aquifer is given with the highest concentration currently measured in that aquifer given in parenthesis.

	Drinking Water Standards	Aquifer Concentration (ppb)		
		A	B	Intermediate
1,1- & 1,2-Dichloroethane	0.5 <sup>a</sup>	nd- 13 (4)	nd- 20(nd)	nd
1,1,1-Trichloroethane	200 <sup>a,b</sup>	nd- 45 (6.2)	nd-13,000(1.8)	nd
1,1-Dichloroethylene	6 <sup>a</sup>	nd- 17(1.4)	nd- 1,000 (nd)	nd
t-1,2-Dichloroethylene	10 <sup>c</sup>	nd- 36(7.03)	nd- 14(4.3)	nd
Trichloroethylene	5 <sup>a,b</sup>	nd-122(20)	1.3 - 7,500(26)	nd

nd = not detected above detection limits

<sup>a</sup>California MCL

<sup>b</sup>Federal MCL

<sup>c</sup>proposed California MCL

Starting in late 1986, 24 off-site monitoring wells were installed to assess the extent and severity of the migration of contaminants from the site. The two shallowest aquifers (A and B) were found to be contaminated with organic compounds. Six chlorinated organic compounds identical to those found at the site, have been detected in the ground water (Table C-15). Concentrations of dichloroethane, 1,1,1-trichloroethane, 1,1-dichloroethylene, trans-1,2-dichloroethylene, and trichloroethylene, exceed drinking water standards.

Four extraction wells were installed off-site: two draw from the A-aquifer and two draw from the B-aquifer. The untreated ground water is discharged by permit into the City sanitary sewer system.

TABLE C-15  
ORGANIC CONTAMINANTS IN OFF-SITE MONITORING WELLS

Data are taken from the quarterly monitoring well report, fourth quarter, 1990 (10). The historical range of contaminant concentrations for each aquifer is given with the highest concentration currently measured in that aquifer given in parenthesis.

	Drinking Water Standards	Aquifer Concentration (ppb)		
		A	B	intermediate
1,1- & 1,2-Dichloroethane	0.5 <sup>a</sup>	nd- 330(64)	nd- 310(310)	nd
1,1,1-Trichloroethane	200 <sup>a,b</sup>	nd- 2500(140)	nd- 1100(12)	nd-1.0(nd)
1,1-Dichloroethylene	6 <sup>a</sup>	nd- 420(47)	nd- 350(140)	nd
1,1,2-Dichloroethylene	10 <sup>c</sup>	nd- 580(580)	nd- 550(550)	nd
Trichloroethylene	5 <sup>a,b</sup>	nd- 1599(520)	nd- 320(200)	nd

nd = not detected above detection limits

<sup>a</sup>California MCL

<sup>b</sup>Federal MCL

<sup>c</sup>proposed California MCL

The concentrations of site-related contaminants in ground water are at levels that would be of potential public health concern if domestic use of the contaminated ground water occurred. No municipal wells currently exist near the site. There are several private wells in the area or directly within the contaminated ground-water plume, but most of these are not active. Of those wells that are still active, the water pumped from these wells is not currently used for domestic purposes. At this time, sufficient water for municipal use is available from aquifers having higher quality water and water yield. Additionally, regulatory barriers exist to prohibit installation of shallow private wells.

A theoretical model (Farmer-See Appendix A) was used to estimate the contaminant soil gas flux and the air concentrations within single-family residences located above the contaminated plume. Air concentrations for an "average case scenario", "plausible maximum scenario", and a "most plausible case" were calculated. These scenarios use different



assumptions for area of infiltration (crawl space or crack around perimeter of building), the fraction of air that infiltrates from the crawl space, and/or the air exchange rate of the home or business.

Based on the concentrations of organic contaminants accumulating in a house as developed by this model, the risk of developing cancer from inhaling volatilized organic contaminants for current residents living above the contaminated ground water was calculated. The exposure was assumed to be 24 hours per day, 365 days per year for 40 years for residents. The exposure was assumed to be 8 hours per day, 260 days per year for 40 years off-site workers.

The lifetime excess cancer risk from the inhalation of volatilizing organic contaminants from the shallow ground water was estimated from the addition of the individual risks to the three potential carcinogens, 1,1-dichloroethylene, 1,1-dichloroethane and trichloroethylene.

Lifetime excess cancer risk for off-site residents ranged from  $1.8 \times 10^{-8}$  ("no increased risk") for the least conservative estimate and  $2.9 \times 10^{-5}$  ("no apparent increased risk") for upperbound worst-case conditions. Lifetime excess cancer risk for off-site workers ranged from  $2.1 \times 10^{-9}$  ("no increased risk") for the least conservative estimate and  $3.5 \times 10^{-6}$  ("no increased risk") for upperbound worst-case conditions.

Potential risks were also assessed for the noncarcinogens (trans-1,2-dichloroethylene and 1,1,1-trichloroethane) for residents above the contaminated ground-water plume. The analyses indicated that the inhalation of organic contaminants from off-site ground water would not result in adverse noncarcinogenic effects.

#### C.4.2 Conclusions

Based on information reviewed, ATSDR and CDHS concluded that the site is not an apparent public health hazard. As noted in the human exposure pathways section above, off-site resident and worker exposure is predicted by an air-model but the exposure is at a level below that of health concern.

Future significant exposure to ground-water contaminants is unlikely if the ground-water extraction and treatment system reduces concentrations of site related contaminants to below levels of health

concern, no wells currently in place are used for domestic purposes, and future drinking water wells are not placed in areas of known contamination if ground-water remediation does not clean up contaminants to drinking water standards.

#### C.4.3 Comments on Case Study

As we reviewed this case study, we were struck by the similarity to the preceding case study. The two sites are both located at the southern end of San Francisco Bay and are only a few miles apart. They appear to have similar hydrology and geology. Based on the reported chemical concentrations in the ground water plumes for the two sites, the groundwater appears to be substantially more contaminated at the site discussed in this section. Based on the relative lifetime excess cancer risks for current off-site residents for the two cases, it appears that for this second case indoor air model calculation used a diffusion only method and a flux attenuation factor based on an infiltration area represented by a 0.5 cm crack around the building perimeters. We note that this is extremely more restrictive (yields lower predicted indoor concentrations) than the assumptions used for current residents in the preceding example but is similar to that used for the former elementary school and future residences in that case example. This assumption is likely overly restrictive and insupportable in both case examples.

For illustration purposes only, we have calculated indoor air concentrations for off-site structures above the ground water plume for the current site using the same parameters used for current off-site residences in the previous case example. We also ignore corrections for the capillary fringe (as did the study authors) because only a screening level result is desired. [This correction should be made if a better estimate is needed.] Because we did not have access to sufficient data to calculate the geometric mean concentrations in the ground water, as was used in the previous case, we have used one-half the maximum values

TABLE C-16  
HYPOTHETICAL CALCULATIONS FOR INDOOR AIR  
IN STRUCTURES ABOVE THE GROUND WATER PLUME

Compound	Sunnyvale Off-site conc. (max) in groundwater	Mountain View <sup>(1)</sup> Off-site Conc. (max) in groundwater	Modeled Indoor Air Concentrations (ug/m <sup>3</sup> )			
			Sunnyvale		Mountain View	
			AVG	Plausible Max	AVG	Plausible Max
1,1-Dichloroethylene	4.3	47	4.24	16.4	23	90
Trichloroethylene	120	520	5.50	21.3	12	46
1,1-Dichloroethane	2.5	64	0.087	0.34	1.1	4.3
Trans 1,2-Dichloroethylene	11	580	0.46	1.77	12	47
1,1,1-Trichloroethane	6.3	140	0.87	3.37	9.7	37

(1) - For calculation purposes, one-half this value was used in model

given in Table C-15. The results are in Table C-16. These calculated results indicate that under these modeling assumptions, indoor air near the site would be substantially more contaminated than in the previous case. Thus, it is likely these estimates are much too high.

#### C.5 BUILDINGS OVER GROUNDWATER PLUME (C)

The site is located in a suburb of Casper, Wyoming. A residential subdivision is located approximately one-quarter mile northeast of an industrial park. An oil refinery is located west-southwest of the subdivision on the opposite side of the North Platte River.

In the mid-1980's, a contaminated water plume was discovered underlying part of the residential subdivision. Because the residences all use wellwater, an indoor air study comparing periods with and without showers operating was conducted.

Air sampling was performed in five residences with contaminated wells, five homes with uncontaminated wells and five Casper area homes as controls. Each home was sampled during a 5-hour period with the shower operated at least 10 minutes and on a subsequent day, another 5-hour period without shower operation. In addition, 5-hour basement and 5-hour outdoor air samples were collected. Samples were obtained with low-flow air pumps and Tenax collectors and were analyzed for volatile organics. The study was designed to compare shower vs. non-shower concentrations and to compare results among the three study groups to see if significant differences existed in indoor concentrations.

##### C.5.1 Nature and Extent of Problem

Organic contaminants found in groundwater samples were used to divide the residents into two groups, contaminated (Group 1) and uncontaminated (Group 2). In the residential air study, these two groups were compared to background homes in the Casper area (Group 3).

Residential sampling included indoor air with shower (IAS), indoor air without shower (IA), basement air (BA), and outdoor air (OA) collected in the backyard of each home. In addition, a questionnaire was administered at each home to identify potential alternative sources of airborne contaminants.

The air/Tenax analysis was designed for quantitation of HSL volatile compounds. Tenax tubes were used for sample collection. The Tenax tubes can retain most volatile HSL compounds (lowest boiling, i.e., chloroethane excluded), but do not adequately retain many light hydrocarbons and low boiling compounds, i.e., saturated hydrocarbons  $<C_4$  or  $C_5$ , chloromethane, vinyl chloride, chloromethane, bromomethane.

Tentatively identified compounds (TICs) were requested in case additional compounds were present which could be detected by this method. Also, information about compounds with strong and unpleasant odors, such as phenylmercaptan, benzenethiazol, and methylmercaptan, could help explain apparent odors present. Methylmercaptan is a small volatile molecule, probably not retained by Tenax, and none was found in the air data. Phenylmercaptan and benzenethiazol are large enough molecules to be retained on Tenax, however, they could be subject to decomposition due to analytical system activity and may not elute from the 1% SP 1000 chromatographic column. These compounds were also not found among the VOA/Tenax TICs.

Many samples contained  $C_6$  chain hydrocarbons at estimated levels of 20 ppt. (estimate of unknown dependability due to unknown trapping efficiency for TIC compounds).

The mean and range of contaminant concentration for homes in all three groups are presented in Table C-17. The wide range of values for most contaminants indicated that the sample results were highly variable. The variability in the data may have been due to the small sample sizes (five to seven).

The compounds of primary interest in the indoor air samples were those previously found in well water samples collected in the subdivision. Several of these well water contaminants were detected in residential air: tetrachloroethylene (PCE), trichloroethylene (TCE) and trichloroethane (TCA) were found in measurable concentrations. Benzene, toluene, xylene, ethylbenzene, and 1,1-dichloroethane were found at very low levels in the water supplies of contaminated homes and in residential air. The results for acetone are questionable due to its presence in the laboratory blank. Methylene chloride is also a known contaminant frequently attributed to analytical laboratories.

TABLE C-17

RANGE AND GEOMETRIC MEAN OF AIRBORNE ORGANIC CONTAMINANT CONCENTRATION ng/l

	Group 1					Group 2			
	Person w/Show	Person w/o Show	Basement	Outdoor	Person w/Show	Person w/o Show	Basement	Outdoor	
Acetone	-- --	u-5.8 1.3	u-86.6 1.9	-- --	u-31.2 1.8	u-16.9 1.6	-- --	u-86.3 1.4	
Benzene	1.7-18.1 3.2	u-15.6 7.3	3.6-25.5 8.5	0.5-13.8 1.5	1.6-12.1 6.2	2.3-6.7 3.6	-- --	u-0.6 0.5	
Carbon Tetrachloride	-- --	-- --	-- --	-- --	u-1.2 0.7	-- --	-- --	u-0.6 0.5	
1,1-Dichloroethane	-- --	-- --	u-10.5 1.1	-- --	-- --	-- --	-- --	-- --	
Ethylbenzene	-- --	-- --	u-7.1 1.0	-- --	-- --	-- --	-- --	-- --	
2-Hexanone	u-4.2 1.2	-- --	-- --	-- --	-- --	-- --	-- --	-- --	
Methylene Chloride	u-9.8 0.9	u-26.4 1.1	u-26.4 1.1	-- --	-- --	-- --	-- --	u-10.4 0.7	
Tetrachloroethylene	u-42.9 1.7	u-35.4 1.5	u-66.3 12.3	-- --	u-20.3 3.3	u-11.1 1.3	-- --	-- --	
Trichloroethylene	u-64.6 3.5	u-44.6 5.7	u-31.9 7.0	-- --	u-1.9 0.7	u-10.2 1.8	-- --	-- --	
1,1,1 Trichloroethane	u-68.3 7.4	1.9-35.4 10.3	5.2-37.5 17.4	u-8.2 0.6	u-70.9 4.9	u-95.7 3.8	-- --	u-9.5 1.0	
Toluene	u-75.8 4.9	1.7-59.7 11.4	10.4-60.6 22.0	0.6-9.2 2.4	7.4-51.3 17.0	u-77.7 2.5	-- --	7-12.2 3.5	

-- Undetected

TABLE C-17--continued

	Group 3				Subdivision* 24 Hr.	Casper* 24 Hr.
	Person w/Show	Person w/o Show	Basement	Outdoor		
Acetone	u-398.3 15.6	u-6.2 1.3	u-215.2 11.8	u-164.7 1.5	10.0-257.0 109.7	u-484.3 215.0
Benzene	1.4-4.6 2.7	0.7-6.4 3.0	1.5-7.0 3.3	0.9-32.0 2.5	7-6.1 3.0	u-5.6 2.7
Carbon Tetrachloride	u-0.5 0.5	u-0.8 0.5	u-0.7 0.6	u-0.7 0.5	u-0.6 0.5	-- --
1,1-Dichloroethane	-- --	-- --	-- --	-- --	-- --	-- --
Ethylbenzene	-- --	-- --	-- --	-- --	-- --	-- --
2-Hexanone	u-2.9 1.1	-- --	u-3.7 1.1	-- --	-- --	-- --
Methylene Chloride	u-19.5 1.0	u-87.8 2.2	-- --	-- --	u-5.3 1.7	u-85.7 38.5
Tetrachloro-ethylene	u-17.0 1.1	u-10.5 0.9	u-1.2 0.7	u-1.7 0.6	-- --	-- --
Trichloro-ethylene	u-2.8 0.9	u-3.2 1.0	u-3.9 1.5	-- --	-- --	-- --
1,1,1 Trichloroethane	u-25.7 3.2	u-31.2 3.7	2.9-43.0 11.1	u-23.1 0.5	-- --	-- --
Toluene	u-33.8 13.5	5.2-24.4 10.1	2.5-45.2 10.3	0.4-80.1 3.3	u-21.5 8.5	u-15.6 5.0

-- Undetected

\* Mean values are time weighted 24-hour arithmetic means.

In order to calculate airborne concentration, the flow rates were adjusted to conditions of standard temperature and pressure. The compound weights were blank corrected by subtracting mean weights of all field blank analytes from the reported field sample value prior to dividing by standard liters of air to calculate the flow rate.

Descriptive statistics, including mean and range of concentration were calculated for each sample. When calculating mean values, one-half the instrument detection limit was used for non-reported values. The data were lognormally distributed and samples were randomly selected.

Data were analyzed statistically using the Mann-Whitney (MW) U-Test for independent groups. The data were then logarithmically transformed and analyzed using the more powerful t-test for basement samples and Analysis of Variance (ANOVA) for indoor and outdoor samples. One tailed probability values (p) are reported as an indication of statistical significance.

The MW test converts the original data to ranks and compares two independent groups of data. Ranks are used due to the fact that the small size and high variability of the data do not meet the assumptions of normality or homogeneity of variance necessary to use parametric statistical analysis. The MW test closely approximates the parametric t-test. It is less powerful than the t-test in finding a difference between two means if one exists.

A questionnaire was completed by each participant to identify the following potential sources of airborne organic contaminants: cigarette smoking, use of water operated appliances, use of organic chemicals, house cleaning, and open windows during sampling. The results indicated that Group 2 had more smokers, greater use of appliances, more house cleaning, and more open windows during sampling. Participants were asked not to use chemicals during the sampling period.

## C.5.2 RESULTS

### Shower Compared to Non-Shower Exposure

Samples collected with and without a shower from homes in Group 1 were compared to determine whether groundwater contaminants entered indoor air via showering. As expected, PCE, TCE, and TCA levels were



slightly higher in IAS samples compared to IA samples. A statistical comparison of the data indicated that the results were not significant at the (ANOVA)  $p < 0.10$  level. The highest significance level was found for toluene at (MW)  $p < 0.34$ . IA and IAS samples also contained virtually the same amounts of contaminants when comparisons were made for Groups 2 and 3.

#### Airborne Contaminant with Shower Exposure in the Three Groups

Airborne contaminant exposure in IAS samples were assessed in the three study groups to determine the contribution of contaminants from drinking water to residential air. Mean values were higher in Group 1 homes, compared to Groups 2 and 3, for PCE, TCE, and TCA. However, the values were not found to be statistically significant at the (ANOVA)  $p < 0.10$  level. The highest level of significance was found for TCE between Groups 1 and 2 (MW) ( $p < 0.20$ ). Significance levels for other comparisons ranged from (MW)  $p < 0.27$  to (MW)  $p < 0.42$ . The lowest levels of PCE and TCA were found in Group 3 homes. TCE levels were very similar in Groups 2 and 3.

#### Basement Air Samples

None of Group 2 homes had basements, consequently, comparisons were made between Groups 1 and 3. PCE concentration was higher in the Group 1 samples at a significance level of (t-test)  $p < 0.05$ . Mean TCE concentration was higher in Group 1, but not significantly (t-test  $p < 0.17$ ). The other contaminants were not tested statistically due to the small difference between mean values.

#### Ambient Air Samples

Outdoor air concentrations of all contaminants were consistently lower in Group 1 compared to Group 3 indicating that they did not contribute to indoor levels in Group 1. TCE and PCE were not found in Group 1 outdoor samples, but were found in Group 3 outdoor samples. Toluene and benzene levels were lower in Group 1 samples at significance levels of (MW)  $p < 0.26$  and (MW)  $p < 0.20$ , respectively. TCA levels were slightly lower in Group 1 samples compared to Group 3 samples.

### C.5.3 Conclusion

Contaminants found in previous well water samples from homes in Group 1 were also present in indoor air. Mean levels of PCE, TCE, and TCA were higher in Group 1 homes compared to Group 2 and 3 homes (not statistically significant at  $p < 0.1$  level). The fact that outdoor concentrations of these contaminants were relatively low, even though the primary wind direction was found to be from the southwest emanating from the industrial park toward the subdivision, suggests an indoor source of contaminants. Showering was investigated as a potential source. TCE, PCE, and TCA mean concentrations were found to be slightly, but not significantly higher in IAS as compared to IA samples collected in Group 1 homes.

PCE concentrations in basement samples were significantly higher (t-test;  $p < 0.05$ ) in Group 1 homes compared to Group 3 homes. The source of PCE in basements may have been vapor directly from contaminated groundwater or from appliances that use water, such as hot water heaters or washing machines, located in the basement. If groundwater were the source, TCE levels would also be expected to be elevated. TCE values were higher in Group 1 homes, but not at as significant a level (t-test  $p < 0.17$ ) as PCE. A possible explanation for this result is that PCE partitions from water to air more readily than TCE and, consequently, may volatilize from groundwater and accumulate in residential basements at a higher rate than TCE. The air/water partitioning of the two contaminants was determined using Henry's Law constants at constant atmosphere: PCE,  $1.1 \times 10^3$ ; TCE,  $5.5 \times 10^2$ . The larger of the Henry's Law constant, the greater the equilibrium concentration of the compound in air compared to its concentration in water. It should also be noted that the sample size for the basement sample comparison is quite small, three homes per group. Very small sample size makes a statistical comparison of the data difficult and consequently, makes the data comparison inconclusive.

The influence of other potential sources of airborne contaminants were investigated. Prior to sampling, all participants agreed to avoid use of household or other chemical during the sampling period. Group 2 homes had increased numbers of cigarette smokers, use of water operated

appliances, use of organic chemicals and house cleaning activity during sampling. These factors would be expected to increase the airborne levels of the same volatile organic contaminants found in well water, as well as increased volatile organics from cigarette smoke and organic cleaners and solvents. However, the measured indoor air contaminant levels were not consistently elevated in Group 2 homes compared to Groups 1 and 3.

Cigarette smoking may not have been an important factor in contributing to the airborne contaminant levels presented in Table 2-17. According to the Surgeon General Report, 1981 (Wynder, E. and Hoffman, D.), none of the airborne contaminants identified in the study were found as "major toxic agents" in cigarette smoke. The report does say that the list presented was incomplete and adds that cigarette smoke may contain "such carcinogens as volatile chlorinated olefins". This group may contain PCE and TCE.

The fact that more windows were open during sampling in Group 2 homes may have lowered airborne indoor contaminant concentration. This would negate the effects of the previously discussed factors that tend to increase contaminant levels.

The levels of contaminants found in homes in all three study groups were typical of indoor concentrations found in enclosed living spaces.

Outdoor mean contaminant levels in the three groups and 24-hour samples were also found to be lower than those in the urban areas of four major U.S. cities. (Houston, St. Louis, Denver, and Riverside).

#### C.5.4 Comments on Study

This study was fairly complex in that it monitored at three type homes, with and without showers operating, as well as ambient air. It comes to the conclusion that the indoor air quality in all cases is within the "typical" range for residences. It should be noted that because none of the Group 2 homes had basements, whereas group 1 and Group 3 did, and the possibility of soil gas intrusion from the contaminated groundwater plume existed for Group 1 homes, the Group 2 homes would not appear to be an adequate control group. However, the design

has left open the question whether or not soil gas is infiltrating the homes even at these low levels by presenting an inconclusive statistical result indicating a significant difference from the controls.

Extraction wells were later installed at this site to control groundwater migration.

## C.6 BUILDING NEAR SLUDGE DISPOSAL PIT

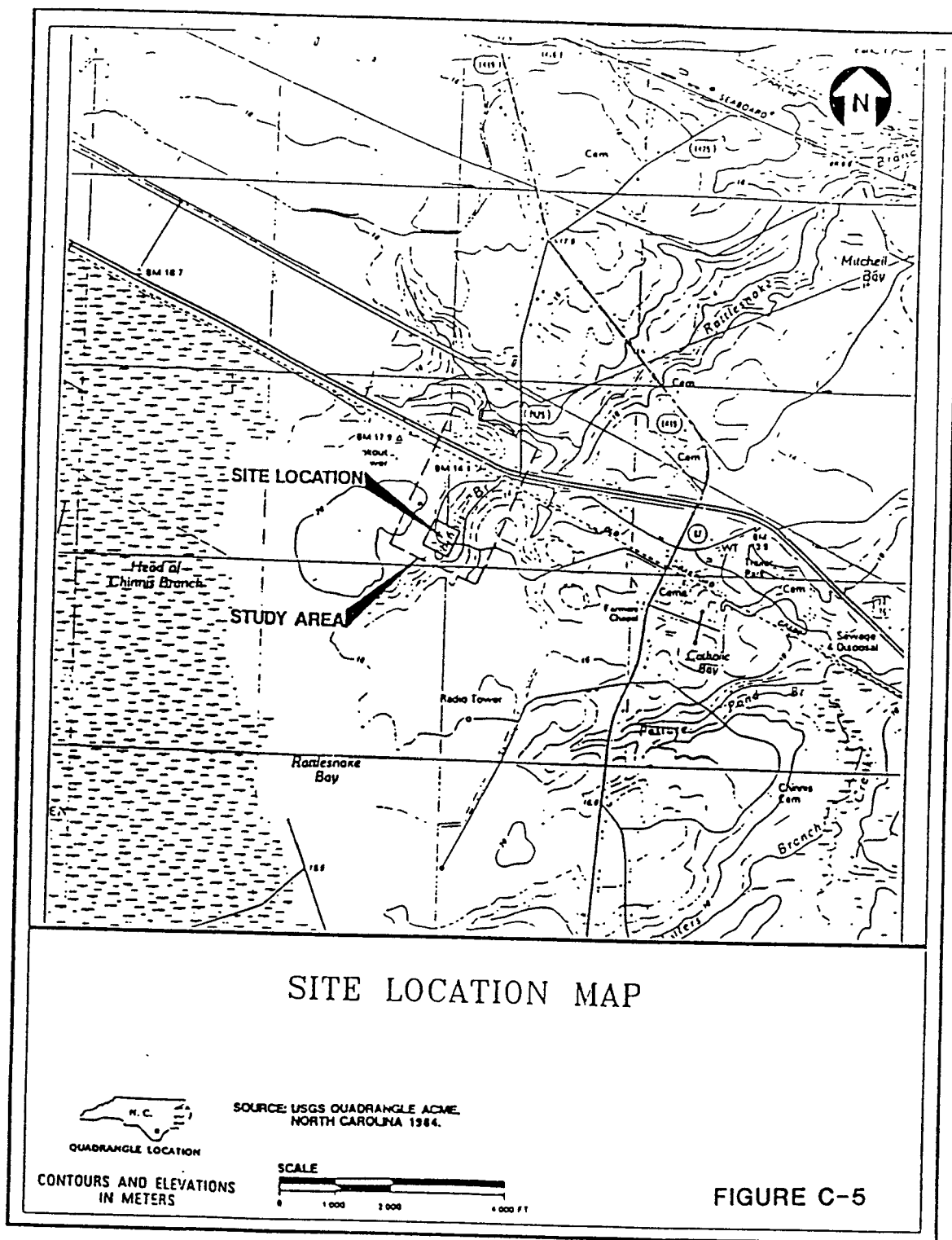
The site is located in a rural section of Brunswick County, North Carolina (Figure C-5).

The site was used by sludge hauling and oil spill cleanup companies for the disposal of septic tank sludge, oil sludge, and other waste materials from 1969 to 1976. These wastes were disposed in shallow (approximately two-to eight-feet deep) unlined pits or directly on the land surface at the site. A residential subdivision now exists in the area of the former disposal areas. Typical dwellings in the subdivision consist of manufactured homes situated on one or two-acre lots, each having a private domestic well. There are approximately 150 residential lots in the area, 70 of which were occupied in 1990.

In May 1976, the owner was informed that an oil disposal pit violated North Carolina statutes and must be cleaned up immediately. This pit was approximately 60 feet long, 20 feet wide, and two to four feet deep. At the time, it was estimated that approximately 2,000 to 3,000 gallons of black oil were contained within the pit. The owner pumped the oil from the pit and then covered the pit with soil. Documentation pertaining to the chemical composition of materials disposed in the pit, the fate of the liquid removed from the pit, and the quantities and characteristics of the material buried on site is not available.

### C.6.1 Nature and Extent of Problem

In August 1976, the failure of an earthen berm allowed approximately 20,000 gallons of black oil to escape from an unlined pit on the property and flow into an on-site creek. The oil remaining in the pit was pumped and transferred to tank trucks and hauled away. The bottom sludges and some oil-stained soils were excavated and disposed in the County Landfill. The remaining thicker sludges, which could not be



pumped, were mixed with sand and buried on site; however, the burial location was not documented.

In 1980, the property changed hands through foreclosure and subdivided for residential development. Family A purchased two lots in the subdivision in 1982 and 1983 and in July 1983, uncovered creosote, oil spill residue, tank bottom sludges, and septic tank sludges in the yard.

State of North Carolina personnel sampled and analyzed soils at the site in response to the discovery. The investigation confirmed the presence of these materials in soil close to the surface at locations on all sides of the house. The well was contaminated with phenols (100 mg/l), dimethyl benzene, methyl phenol, one unknown organic compound, creosote, and septic tank sludge. The shallow well was subsequently condemned and the house was connected to a neighbor's well system.

In September 1983, EPA and the Region IV Field Investigation Team (FIT) conducted an investigation of the property. The investigation included an electromagnetic survey of the area; initial ambient air monitoring under the home; and collection and laboratory analysis of surface water and sediment samples, five subsurface soil samples, and six groundwater samples from off-site and on-site wells. All readings of ambient air were negative. Based on surface water and sediment sampling and analysis, no contamination of Chinnis Branch was detected. Groundwater analysis for inorganic compounds indicated the presence of seven priority pollutant constituents. Groundwater analyses for organic compounds (purgeable, extractable, pesticide/PCBs, and other chlorinated compounds) indicated the presence of 81 different compounds, many of which are commonly associated with creosote or coal-tar derivatives. Soils analyses identified a total of 24 inorganic constituents in the subsurface soil samples, 10 of which are target compound list (TCL) parameters. Soils analyses also indicated the presence of 46 organic compounds in the subsurface samples, 14 of which are TCL parameters, and many of which are polynuclear aromatics associated with asphaltic and coal-tar derivatives.

In February 1984, EPA used ground penetrating radar (GPR) to further delineate the site boundaries. The GPR survey revealed two

anomalous areas that roughly correspond to the location of two surface impoundments illustrated on historical maps. The pits were estimated to be six feet deep toward the center and three feet deep toward the edges.

In March 1984, an Immediate Removal Action (IRA) at the site was requested by the EPA. The IRA at the property consisted of the excavation and removal of approximately 1,770 tons of oil sludge and soils which were transported to a hazardous waste landfill in Pinewood, South Carolina. Soil cleanup activities were completed in April 1984.

In May 1984, EPA installed nine groundwater monitoring wells at the site and conducted sampling and analysis of groundwater samples for volatile organic compounds. Relatively high concentrations (in the ppm range) of benzene, ethyl-benzene, toluene, and xylenes (BETX) were detected in the groundwater samples from the shallow aquifer. Groundwater sampling indicated that the deep aquifer had not been affected by the contamination in the shallow zone. Neither the upgradient nor downgradient deep wells contained detectable volatile organic compounds. EPA recommended that these monitoring wells be regularly monitored.

In 1988, the groundwater monitoring wells were resampled and samples analyzed for purgeable organics and some inorganic parameters (metals, nutrients, etc.). As was the case with the EPA 1984 data, the 1988 monitoring well data indicated that gasoline or waste petroleum product (especially benzene, toluene, and xylenes) were still prevalent at the site. However, the concentration of purgeable organics detected during the two sampling episodes varied significantly. In addition, the 1988 data indicated the possibility of low level benzene, ethyl-benzene, and xylenes in a deep well which would indicate that an aquifer underlying the surficial aquifer had now been affected.

In 1989, EPA determined that the level and extent of on-site contamination warranted a more thorough investigation and assessment. Consequently, a Remedial Investigation (RI) was undertaken through a CERCLA action. The purpose of the initial RI was to assess the nature and distribution of contaminants at the site and to provide the data necessary for developing a Feasibility Study (FS) and ultimately conducting a Remedial Action (RA).



The field investigation of the initial RI was conducted from January 1990 through April 1990, and included soil gas surveys, surface and subsurface soil sampling, monitor well installation, groundwater sampling (of monitor wells and residential wells), hydraulic conductivity testing, and identification of potential ecological and human receptors. Three separate study areas were addressed during the initial RI. Area 1 was comprised of the Family A Property, which is the original site. Area 2, located approximately 1.5 miles from Area 1 in a similar rural residential area, was identified during the document review. Historical records indicated that a waste oil disposal pit existed within Area 2. Area 3, located adjacent to Area 1, was identified in historical records as a potential waste disposal site based on historical aerial photographs of the area. Area 2 was not well documented and could not be located even after extensive interviewing and a thorough reconnaissance of the area. Therefore, no field investigation was initiated. A majority of the field investigation activities subsequently centered in Areas 1 and 3.

The initial RI report concluded that the extent of contamination which poses a risk to human health or potential ecological receptors is limited to the area in the vicinity of the Family A residence. Contamination has impacted surface and subsurface soils, the shallow aquifer, and creek sediments in this area. The predominant media and compounds contributing to public health risk include: benzene and lead in groundwater, and carcinogenic polynuclear aromatic compounds (PAHs) and lead in surface soils.

#### C.6.2 Residential Air Monitoring

Air samples were collected in February 1990 in the crawl space and inside the residences of Family A and Family B. Sampling was conducted at these two residences since they are situated on or near the former waste disposal pits. Unlike the Family A residence, the Family B residence is not located above or adjacent to identified contaminated areas.

A total of five residential air samples were collected using EPA method TO-14 from within the crawl spaces and interiors of the two

homes. The air samples were analyzed for the 34 TCL VOCs listed in Table 2.18. Only three compounds, chloromethane, methylene chloride, and 1,1,1-trichloroethane were detected. Methylene chloride was detected inside the Family B residence at a concentration of 11 ppbv. Low levels of chloromethane (16 ppbv) and 1,1,1-trichloroethane (1.5 ppbv) were detected in the crawl space beneath the Family B residence. No VOCs were detected within or beneath the Family A residence.

Of these three VOCs, 1,1,1-trichloroethane was the only compound detected in sampling in the vicinity of the site and it was only detected in low  $\mu\text{g}/\text{kg}$  concentrations in background soil samples. None of these VOCs were detected in known contaminated areas. These observations suggest that the source(s) of VOCs in the Family B residence are not related to the site.

#### C.6.3 COMMENTS ON INDOOR AIR EFFORT

The fact that no VOCs were detected in or under the Family A residence is counter to published information on typical residential indoor air quality. These data are suspect.

Perhaps of more significance is what was not sampled and analyzed for. The soils analysis demonstrated the site is contaminated with creosote, polynuclear aromatic hydrocarbons, phenols, and other hazardous compounds. Even low concentrations of some of these can result in substantially elevated risk numbers. Vapor pressures are high enough to consider their transport through soil gases especially considering contamination was found in the immediate vicinity of the residence.

TABLE C.18  
TARGET COMPOUNDS

COMPOUNDS	ACETONE
CHLOROMETHANE	CARBON DISULFIDE
BROMOMETHANE	VINYL ACETATE
VINYL CHLORIDE	METHYL ETHYL KETONE
CHLOROETHANE	METHYL ISOBUTYL KETONE
METHYLENE CHLORIDE	METHYL BUTYL KETONE
1,1-DICHLOROETHENE	STYRENE
1,1-DICHLOROETHANE	1,2-DICHLOROETHENE (TOTAL)
CHLOROFORM	
1,2-DICHLOROETHANE	
1,1,1-TRICHLOROETHANE	
1,1,1-TRICHLOROETHANE	
CARBON TETRACHLORIDE	
DIBROMOCHLOROMETHANE	
1,2-DICHLOROPROPANE	
TRANS-1,3-DICHLOROPROPENE	
TRICHLOROETHENE	
BENZENE	
DIBROMOCHLOROMETHANE	
1,1,2-TRICHLOROETHANE	
CIS-1,3-DICHLOROPROPENE	
BROMOFORM	
1,1,2,2-TETRACHLOROETHANE	
TETRACHLOROETHENE	
TOLUENE	
CHLOROBENZENE	
ETHYL BENZENE	
TOTAL XYLENES	

## C.7 FUGITIVE DUST CASE STUDY

Primary zinc smelting operations at this facility (Figure C.6) since the turn of the century emitted large quantities of zinc, cadmium, lead, and copper into the atmosphere in the vicinity of the plant. Significant concentrations of these heavy metals have been measured in the soil within a large area surrounding the plant. The plant area is currently a Superfund and a RCRA site. The facility is currently operating under new ownership as a secondary zinc smelter. A NAMS reference monitor is actively monitoring the area for attainment of the lead NAAQS. The facility has been in compliance with the standard for the past several years.

### C.7.1 Nature and Extent of Problem

Investigations were conducted at two homes by the State in response to citizen requests. Two dust sampling methods used were based on protocols of the Center for Disease Control, Lead Poisoning Prevention Branch, Division of Environmental Hazards and Health Effects, Center for Environmental Health and Injury Control (CDC). The first method used a vacuum pump and filter cassette to pick up dust from a one square foot area. A plastic template was used to measure the area to be sampled - except on window sills where the area was estimated. The second method, based on the Kellogg Dust Protocol Number 2, was wipe sampling. A Whatman Number 42 filter paper dampened with isopropyl alcohol was used, although the original method specified alcohol swabs.

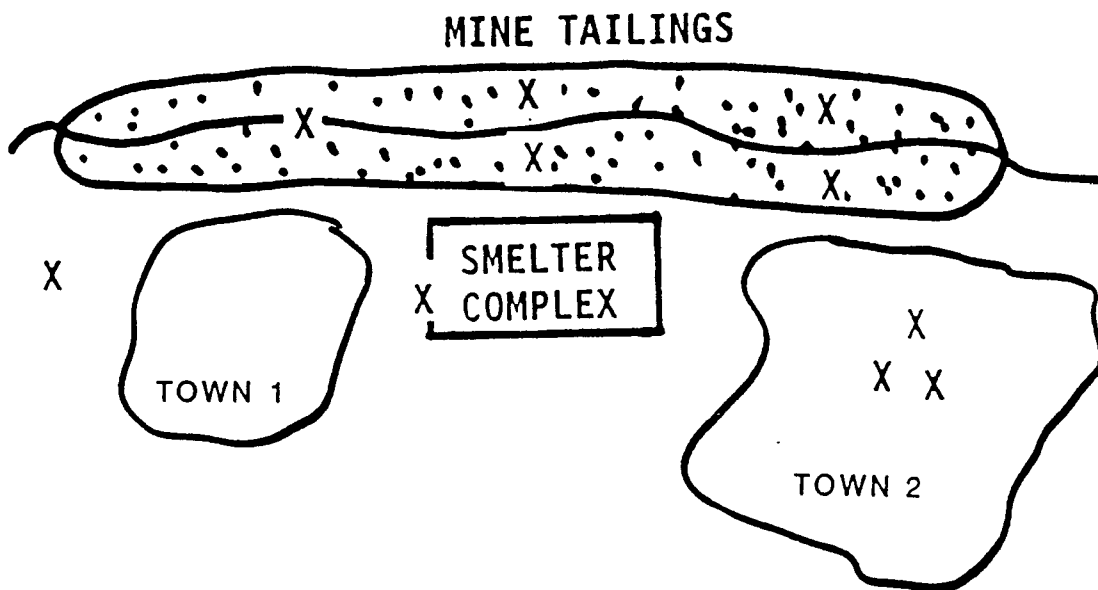
Field blanks were taken at each residence by momentarily opening the cassette. The wipe sample field blank filter was removed from the transport tube, moistened with alcohol, then immediately returned to the transport tube. A new disposable latex glove was used to handle each filter.



PREVAILING WIND



X = AIR MONITORS



LOCATIONAL MAP

FIGURE C-6

The U.S. Public Health Service/EPA Toxicological Profile Document for lead uses a value of 300  $\mu\text{g/g}$  lead in household dust, as a baseline-value to estimate overall population lead exposure from various media. The urban Particulate Standard 1648 from the National Institute for Standards and Technology (NIST), which is a composite urban dust sample, has values of 6,550  $\mu\text{g/g}$  for lead, 75  $\mu\text{g/g}$  for cadmium and 4,760  $\mu\text{g/g}$  for zinc. The lead values obtained from the household dust in the two homes were well above the national averages.

An indoor monitoring study was developed to determine the extent of exposure to lead and heavy metals inside the residents homes. Twenty-five homes were selected randomly in areas where there is a large probability of deposition of airborne lead. Atmospheric dispersion modeling with ISCLT was used to determine these areas. The homes were vacuumed sampled with minirams outfitted with HEPA filters.

Results from the indoor study demonstrated that most of the homes in the area had very high levels of lead. However, since a health threat had not yet demonstrated to exist due to the high levels of lead found in the residential homes, ATSDR was contacted to determine whether the environmental contamination is a public health hazard for the residents.

ATSDR proposed an exposure study to determine the extent of the health hazard, if any, in the town. Although the study has been completed, the results have not yet been reported.

The study:

- Measured blood lead and urinary cadmium levels among a representative group of residents
- Compared the levels of lead and cadmium found in residents to levels found in a comparison community while controlling for other risk factors known to influence exposure to these heavy metals
- Performed a standardized panel of medical tests on both groups

A Superfund Removal Action was scheduled to be performed at those homes in with elevated lead levels. The objective was to clean the homes and eradicate them of lead, thus reducing the probable health

threat. However, Superfund is reluctant to perform this Remedial Action until adequate evidence is available to identify the source of lead dust currently infiltrating the homes so that recurrence can be prevented. Data obtained in the 25 home sampling program showed that lead levels inside the homes were much higher than in the outside soil. Although this suggests an airborne pathway for the indoor air contamination, the data did not conclusively establish whether the contamination was from soil erosion, the smelter, or other sources.

The problem, therefore, has become one of determining the actual current source of lead dust infiltrating the homes. Based on current information, it can be demonstrated with reasonable scientific certainty that:

1. Past primary Zn smelting practices have contributed to the burden of hazardous substances in soil and dust
2. Present secondary Zn recovery processes are adding to the burden of hazardous substances in soil and dust
3. Both 1. and 2. are "non-de minimus"
4. Other common anthropogenic sources are responsible for little of the hazardous substance burden

The problem, thus, becomes one of determining whether the lead dust is from the old primary smelter operations and is being tracked into homes or carried in by wind erosion, or whether it is from wind dispersion of the current secondary smelting operations.

There are five basic identification methods that can be used: geostatistical, elemental composition coupled with multi-variate analysis, chemical speciation, individual particle analysis, and lead isotope ratios. In the geostatistical approach, the spatial variability of the substance of interest is determined and displayed on isoplethic plots. While this provides an easily understandable presentation from which one can infer source locations, a large number of highly representative samples are needed.

The elemental composition method requires determination of multiple elements from both potential sources and receptors. The data are then analyzed using multi-variate techniques such as ratio discriminant

functions and factor analysis. While one can potentially learn a lot from a few samples and infer sources by comparison of source and receptor patterns, the method is not sensitive for subtle sources and post-release chemical transformation can pose analysis difficulties. Also, the method depends on having a fairly complete picture of all potential sources.

Chemical speciation methods depend on determining the actual chemical compound or "species" in source and receptors. Very selective analytical techniques are required. The method suffers significantly if post release transformations take place. For lead, many source compounds may weather to lead sulfate making source identification difficult or impossible.

Individual particles may be analyzed microscopically and by various analytical techniques to determine elemental and chemical composition. This approach appears to combine the best features of the chemical speciation and multi-variate methods. For example, particles from lead-based paint would be associated with carbonates, chromates, titanium, and zirconium whereas lead particles from batteries would contain antimony.

The use of lead isotope ratios can potentially be a very powerful technique, especially for the current problem. Lead ores from different geological ages contain different ratios of the four lead isotopes  $^{206}\text{Pb}$ ,  $^{207}\text{Pb}$ ,  $^{208}\text{Pb}$  to the minor isotope  $^{204}\text{Pb}$ . Because of this, different economically important lead ore bodies have different lead isotope fingerprints as shown in Table 2.19. These ratios can easily be determined using either thermal ionization mass spectroscopy (MS) or inductively coupled argon plasma MS.



TABLE C.19  
LEAD ISOTOPE RATIOS IN WORLD-WIDE LEAD ORES

Source	206/204 Ratio
Rosetta, S. Africa	12.5
Ivigutut, Greenland	14.8
Broken Hill, Australia	16.0 - 16.2
Bunker Hill, Idaho	16.2 - 16.4
Coeur D'Alene Group	16.1 - 16.7
Pine Point, NWT	18.2 - 18.6
Tintic, Utah	18.5 - 18.7
Casapalca, Peru	18.6 - 19.0
Metalline Falls, WA	19.5
Missouri Leads	21.0 -24.0

It is suspected that lead ores used during primary smelter operations were from a limited number of geologically well-defined sources and the secondary smelting operations process lead from a highly average group of world-wide sources. Thus, the lead isotope ratios will be substantially different from these operational periods. If this is the case, then the isotope ratios in household dusts and collected human body fluids will provide convincing evidence for the current source of the lead dust. Furthermore, it is likely the primary Zn smelter emissions were reflective of sulfide ore feedstocks containing Zn, Cd Pb, As, Se, Cu, Ga, In, Ag, and the slag was rich in iron and manganese. Secondary zinc smelter operations, on the other hand, likely reflect compositions of diverse ferrous alloy feed materials and contain high levels of elements not associated with primary zinc smelting such as Be, V, Co, Ni, Mo, Pd, Pt, and lanthanides.

Based on the scientific evidence and available analytical methodologies, the investigative course of action to be taken is:

1. Review existing site characterization data; identify source areas; review site history (what ores were smelted). Review other information such as RCRA records, Air Enforcement records, OSHA records - (the smelter has been cited in the past for worker exposure in the plant and subsequent high blood lead levels).

2. Develop piggyback sampling strategy for residential areas; obtain samples of sources (slag, primary smelter emissions, secondary feed materials, waste piles).

#### Types of Samples Desired

##### Sources

1. Primary Zn smelter stack emissions
2. Slag piles
3. Pre-1980 air filters
4. Post-1980 (present) air filters
5. Fugitive sources of dust from secondary Zn plant (piles, bins, etc.)
6. Raw materials received
7. Products made
8. Present day stack emissions, baghouse dust, etc.

##### Receptors

1. House dust
  2. Soil from yards, public areas, etc.
  3. Hillside soil
  4. Park, etc. dust
3. Apply a combination of the following approaches:
    - a. Elemental composition + MVA
    - b. Lead isotope ratio analysis
    - c. Individual particle analysis

#### C.7.2 Comments on Study

The investigative procedures outlined are currently underway. The value of this case example is that it illustrates that investigative techniques are frequently available to distinguish impacts from specific current sources from other current and past emission sources. Although this is a very specific case involving smelters, the fingerprinting investigative approach may be applicable to other investigations of Superfund site impacts on indoor air quality.

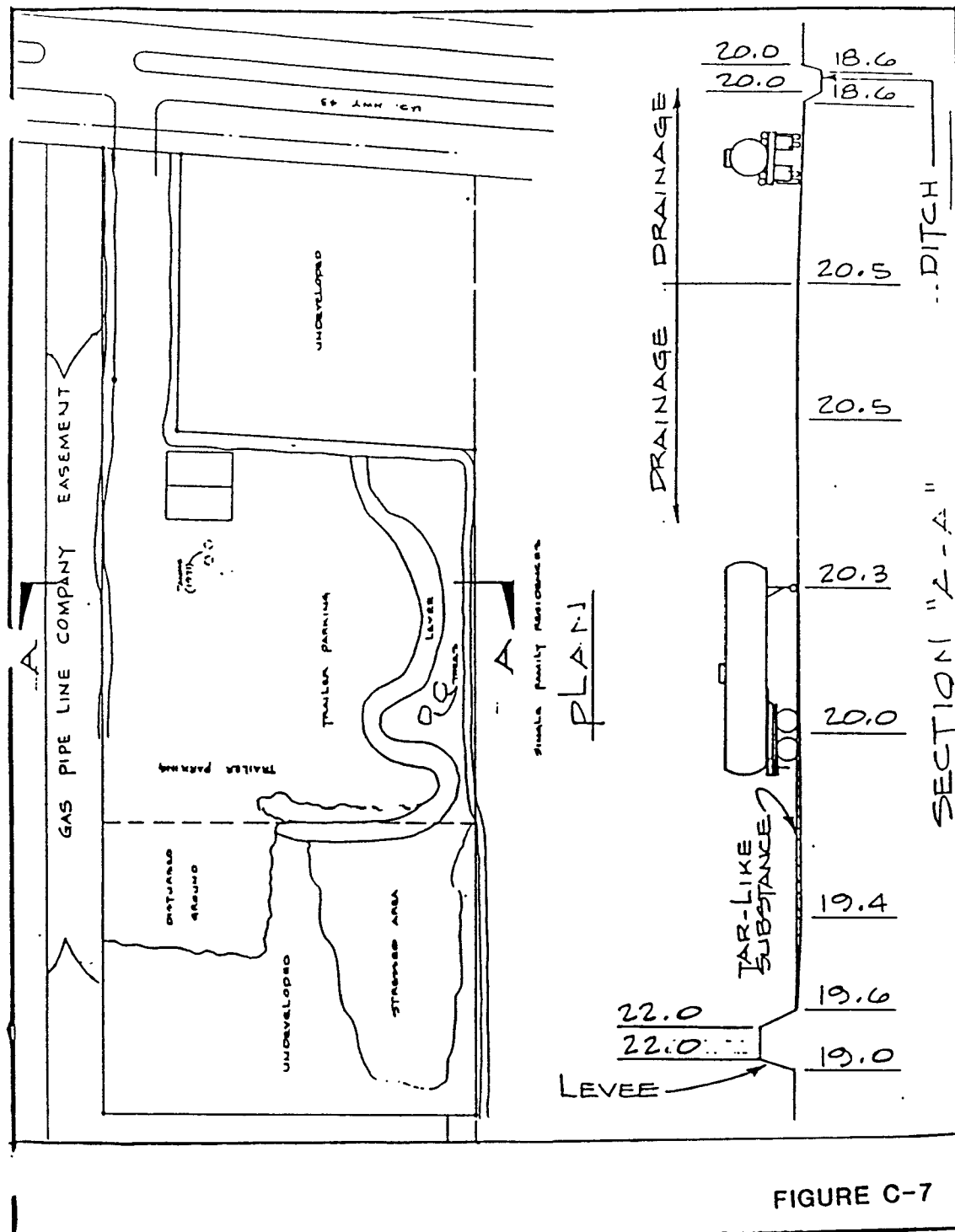
#### C.8 BUILDINGS OVER WASTE OIL PIT

The Site is located in Mobile County, Alabama. The 5.1 acre site, about 11 miles north of Mobile, Alabama, is bounded to the east by U.S. Highway 43, by a gas pipe line easement to the north, an undeveloped lot to the west, and a residential development to the south.

According to available records, in March 1961 a trucking terminal was constructed for intrastate and interstate commercial trucking operations. The Site was used for parking, maintaining, and cleaning trucks and trailers. According to a salesman at the Site, from May 1966 until late 1969, tank trailers were regularly and routinely washed at the Site. The washwater was then discharged in the rear of the terminal property where the ground level was low.

The salesman states that he was told that in late 1965 (before he worked at the Site) levees were built around the terminal to contain materials and an aboveground asphalt tanker on wheels was placed at the back of the property for storing asphalt products to be returned to customers.

In February 1971, the terminal operator was encouraged to move its operations. In March 1971, an offer to buy the property was accepted. Figure C-7 shows the terminal layout as of May 1972, including the configuration of a dike built in 1971. In September 1971, six geotechnical borings, were drilled at the Site to depths ranging from 40 feet to 55 feet. The data collected from these borings were used to design the foundations of the Site. Logs of these borings were compiled on a drawing that was part of the building architectural plans. These boring logs show the stratigraphy underlying the Site consists of a sand stratum, up to 7.5 feet thick, overlying a silty clay stratum, which attains a thickness of up to 34 feet. Underlying the silty clay is another sand stratum of which the thickness was not determined by the borings. To date, a drawing showing the locations of these borings has not been found.

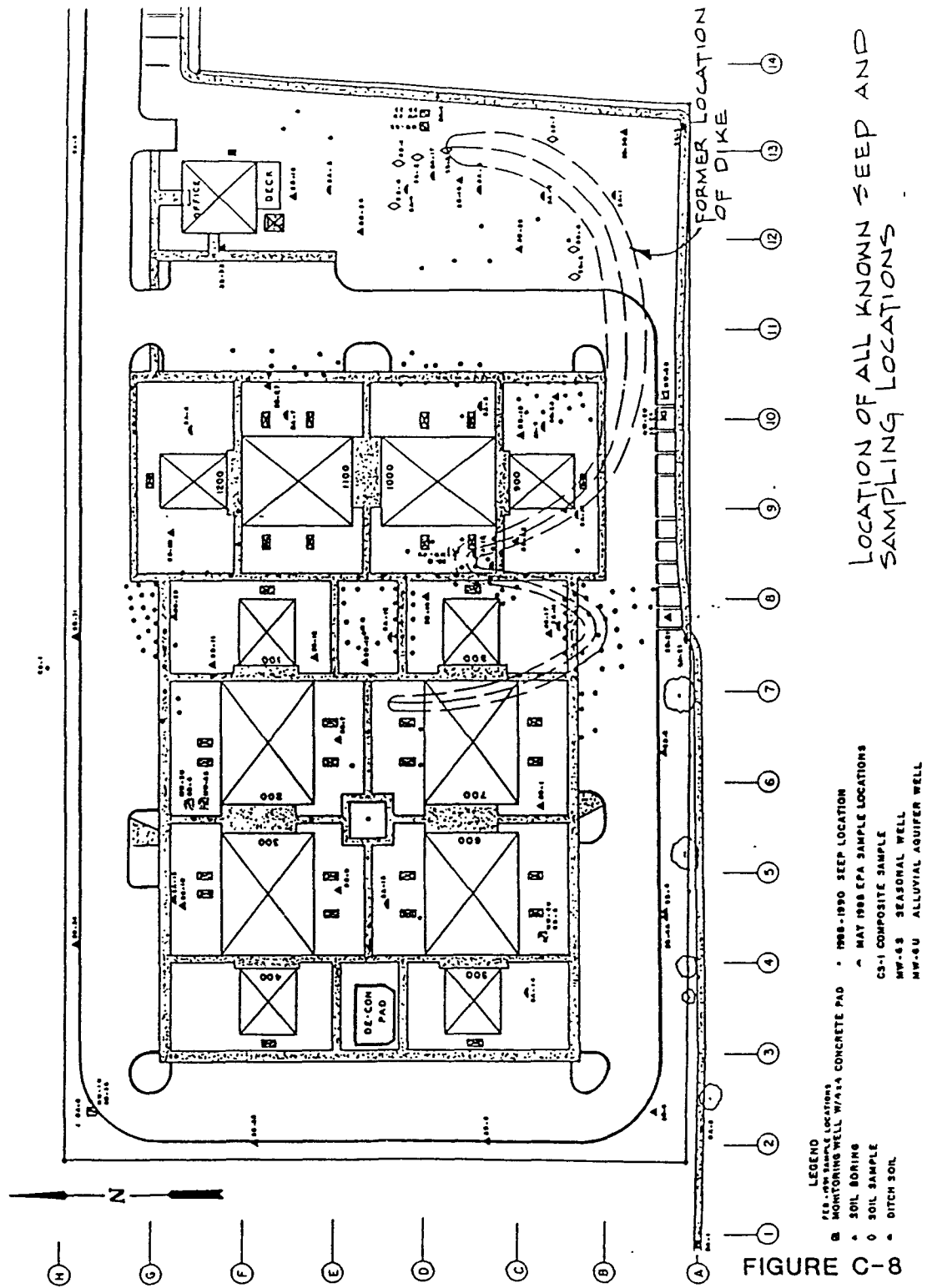


In 1973, the property was sold to the property's current owner which constructed an apartment complex (see Figure C-8) consisting of 13 buildings on the Site. Approximately 160 people live in the apartment complex.

#### C.8.1 Nature and Extent of Problem

In 1977, the owner first became aware of tar-like substances seeping to the surface. The Department of Housing and Urban Development (HUD), which inspected the apartments on an annual basis, inspected the seepage and recommended to the managing agent that the seepage be excavated to a depth of 1½ feet and the area be filled in with sand. This was done periodically as the seepage appeared. HUD continued to inspect the apartments on an annual basis. The managing agent reported the presence of the tar-like substance to the Department of Health. They continued to excavate the property and fill with sand when any seepage occurred. Continued appearance of the tar-like substance prompted the manager of the apartment complex to report the matter to the State in the fall of 1984.

The State investigated the Site and reported the matter to the U.S. Environmental Protection Agency (USEPA) during the same year. The State identified 18 individual seeps where a tar-like substance was oozing to the surface and described the material as a tar or asphalt with a vitreous luster. The material was described as very sticky with a petroleum odor and at cooler temperatures was very plastic and viscous. The investigation included six hand augured holes ranging from 1.1 feet to 5.0 feet in depth. Samples were taken from two holes in the interior grassy courtyard area of the apartments and one hole in the southwest corner of the complex in a grassy area inside the paved driveway. One analysis was taken from these three soil samples although it is unclear



if this was an analysis of a composite sample. The sample contained the following compounds and concentrations:

<u>Compounds</u>	<u>Concentration (<math>\mu\text{g/g}</math>)</u>
Naphthalene	135.4
Acenaphthene	101.9
Fluorene	128.6
Phenanthrene	33.9
Anthracene	53.7
Benzene	0.05

Preliminary sampling by the USEPA in April and May of 1985 detected concentrations of naphthalene, 1,2,4 trichlorobenzene and other compounds in the tar-like material and soil. In February 1990, the USEPA added the Site to the NPL with an HRS score of 30.83.

Compounds reported to have been detected in the subsurface 4 feet from the southeast corner of the courtyard area included butylate (20,000 ppb), vernolate (90,000 ppb) and a mixture of compounds normally found in coal-tar products. Compounds reported to have been detected in the subsurface 4 feet from the east-central courtyard included butylate (2,000,000 ppb), vernolate (300,000 ppb), eptam (30,000 ppb), and coal-tar products at a total concentration of (70,000 ppb).

No organic compounds were reported to have been detected in a composite surface sample of scrapings of white material from nine areas in the complex. However, this sample was reported to contain 37,000,000 ppb sodium, with a Ph of 8.7.

Samples SA-17, SA-18, and SA-20 were surface samples of tar-like seep material. Sample SA-17 from the east side of the Site was reported to contain vernolate (1,000,000 ppb), 1, 2, 4-trichlorobenezene (9,300,000 ppb), coal tar products (total concentration of 380,000 ppb), carbon disulfide (5,000-ppb) and two unidentified terpenes (20,000 ppb). A petroleum based product was also reported to have been detected in this sample. Sample SA-18 in the southeastern corner of the courtyard was reported to contain butylate (70,000 ppb) and vernolate (300,000 ppb) along with some coal products (total concentration of 760,000 ppb). A petroleum based product was also reported to have been detected in this sample. East of the ditch by the playground, Sample SA-20 was

reported to contain coal-tar products at a total concentration of (2,160,000 ppb), xylene (2,000 ppb) and a petroleum product. The USEPA samples of April and May of 1985 found no contamination at the sampling points located outside or downstream of the reported position of the former levee.

A Phase I RI was conducted in February and March of 1991. Phase II was conducted in September of 1991. The investigation was quite thorough and reporting all details is beyond the present scope.

Given in Table C-20 is a summary of the number of compounds found on-site.

TABLE C-20  
SUMMARY OF NUMBER OF CONSTITUENTS DETECTED IN EACH MEDIUM

Media Type/ Sample Location	Total Detected Constituents	Total Constituents with Unqualified Detections	Total Constituents with More than One Unqualified Detection
Alluvial Groundwater	41	27	15
Surficial Groundwater	66	37	24
Soils	110	40	32
Ditches	68	20	13
Tar-like Material	69	34	19

Table C-21 gives organic chemical concentration data from the monitoring wells at the Site.



TABLE C-21

Legend
Well Abbreviations: MW = Monitoring Well U = Upper Alluvial
Aquifer S = Seasonal Watertable RE = Re-extraction DL = Dilution Factor

Water Data -  
Organics

WELL #	COMPOUND	DETECTED CONCENTRATION UG/L
MW-01U	CHLORINATED HYDROCARBON COMP	6.10
MW-01U	ACETONE	53.00
MW-02U	BIS(2-ETHYLHEXYL)PHTHALATE	3.00
MW-02U	ACETONE	23.00
MW-03U	BIS(2-ETHYLHEXYL)PHTHALATE	6.00
MW-03U	CHLORINATED HYDROCARBON COMP	5.30
MW-04U	4,4'- DDT	0.01
MW-04U	BIS(2-ETHYLHEXYL)PHTHALATE	5.00
MW-04U	VERNOLATE	0.44
MW-04U	ACETONE	12.00
MW-05U	4,4'- DDT	0.08
MW-05U	BIS(2-ETHYLHEXYL)PHTHALATE	10.00
MW-05U	BUTYLATE	0.31
MW-05U	CYCLOATE	0.15
MW-05U	VERNOLATE	0.73
MW-05U	ACETONE	25.00
MW-05URE	BIS(2-ETHYLHEXYL)PHTHALATE	26.00
MW-05URE	ETHANOL,2-(2-METHOXYETHOXY	5.80
MW-06U	NAPHTHALENE, DIMETHYL	11.00
MW-06U	ACETONE	19.00
MW-06URE	BIS(2-ETHYLHEXYL)PHTHALATE	20.00
MW-06URE	SULFUR, MOL. (S8)	10.00
MW-3S	2,4,5T	9.60
MW-3S	GAMMA-CHLORDANE	0.01
MW-3S	BIS(2-ETHYLHEXYL)PHTHALATE	11.00
MW-3S	BUTYLATE	10.00
MW-3S	CYCLOPENTANOL,2-METHYL	230.00
MW-3S	BUTYLATE	2.30
MW-3S	EPTC	0.24
MW-3S	VERNOLATE	4.90

TABLE C-21-Continued

Water Data -  
Organics

Legend  
Well Abbreviations: MW = Monitoring Well | U = Upper Alluvial  
Aquifer | S = Seasonal Water Table | RE = Re-extraction | DL = Dilution Factor

WELL #	COMPOUND	DETECTED CONCENTRATION UG/L
MW-3S	2-HEXANONE	4.00
MW-3S	ACETONE	33.00
MW-SS	2-CYCLOHEXEN-1-ONE	4.70
MW-SS	BUTYLATE	0.74
MW-SS	VERNOLATE	1.70
MW-SS	ACETONE	89.00
MW-6S	4 METHYPHENOL	130.00
MW-6S	BENZOIC ACID	66.00
MW-6S	BICYCLO(22.1)HEPTAN-2-ONE	33.00
MW-6S	BIS(2-ETHYLHEXYL)PHTHALATE	11.00
MW-6S	DI-N-BUTYLPHTHALATE	3.00
MW-6S	SULFUR, MOL. (S8)	11.00
MW-6S	BUTYLATE	2.10
MW-6S	VERNOLATE	5.10
MW-6S	2 BUTANONE	72.00
MW-6S	2 HEXANONE	16.00
MW-6S	4 METHYL-2-PENTANONE	16.00
MW-6S	ACETONE	550.00
MW-6S	CARBON DISULFIDE	190.00
MW-6S	CHLOROFORM	2900.00
MW-6S	METHYLENE CHLORIDE	330.00
MW-6S	TOLUENE	4.00
MW-6SDL	ACETONE	4900.00
MW6SDL	CHLOROFORM	18000.00
MW-6SDL	METHYLENE CHLORIDE	530.00
MW-6SRE	4-METHYLPHENOL	180.00
MW-6SRE	BENZOIC ACID	47.00
MW6SRE	BICYCLO(22.1) HEPTAN-2-ONE	23.00

### Indoor Air Modeling

No actual monitoring was conducted inside the structures. All estimates are based on modeling. [The modeling approach for soil gas intrusion is described in Appendix A, Sections A.1.5 and A.1.6].

In this case, the modeling approach to estimate soil gas flux was based on the assumption that the contaminants are initially uniformly distributed vertically and horizontally throughout the soil. The model then allows equilibrium to be established among chemicals adsorbed on soil, chemicals dissolved in soil water, and chemicals in the soil gas. The soil gas diffuses to the surface resulting in an ever-expanding zone of clean soil from the soil surface downward. It appears that the model assumptions result in an average flux over a ten year period. These source modeling equations were based on and conform to those given in EPA/600/6-86-002, "Development of Advisory Levels for Poly-chlorinated Biphenyl (PCB) Cleanup."

The above calculation yields only the flux (mass of chemical exiting the soil surface per unit area per unit of time, eg.  $\text{g/m}^2\text{-s}$ ). To calculate the rate of entry into the structures, it was necessary to make estimations of:

- the ratios of diffusive to convective flow of soil gas,
- the area of the structure through which soil gas could enter,
- the air exchange rate for the structure.

The ratios of convective to diffusive flow was calculated from the Peclet number, a dimensionless parameter, that considers the diffusivity, soil permeability, and vacuum created by the structure. The calculation indicated the diffusion mechanism dominated (see comments section below). The area through which gas could enter the structure was estimated as 0.1 percent of the floor area, based on literature data for homes on slabs. The structure air exchange rate was estimated to be about 0.7 air exchanges per hour, based on average wind speeds and indoor-outdoor temperature difference.

In addition, outdoor air concentrations can contribute to indoor air concentrations. Since the buildings are surrounded by the Grassy Area, indoor air concentrations can be affected by vapors from the Grassy Area. Thus, the total indoor air concentration was estimated by

summing the modeled indoor air and 100% of the Grassy Area air concentrations (indoor exposure, excluding seeps). Seeps of tar-like material may also contribute to the indoor air concentrations. Thus, total indoor air concentration including vapor emissions from seeps was estimated by summing modeled indoor air concentrations, Grassy Area air concentrations (99.66%), and emissions from seeps of tar-like material (0.34%) (indoor exposure, including seeps). This conservatively assumes that all tar seeps are located in the Grassy Area and contribute 100% to indoor air. The results, excluding contribution from seeps, are given in Table C-22.

Data from all sources was used to complete a risk assessment. The results for the current exposure are summarized in Tables C-23 and C-24. (Risks for future exposure scenarios, which assume use of on-site wells, are not included in the table, but are discussed below.

Total current cancer risks *including* exposure to seeps were estimated to be between  $7 \times 10^{-5}$  and  $2 \times 10^{-4}$  for the various receptor populations. The most important pathway contributing to the risk is indoor inhalation of vapors containing PAHs from seeps of tar-like materials. In particular, benzo(a)anthracene, benzo(b)fluoranthene, and chrysene contribute about 90% of the risk from indoor inhalation.

Under the Future I scenario *including* seeps, the cancer risks range between  $4 \times 10^{-4}$  and  $2 \times 10^{-3}$ . Ingestion of water from the alluvial aquifer accounts for most of the cancer risk, approximately 75% of the total risk. Arsenic and beryllium constitute the greatest proportion of the risk, with aldrin, BEHP and dieldrin also contributing to the total risk.

The Future II scenario *including* seeps poses risks ranging from  $3 \times 10^{-3}$  to  $1 \times 10^{-2}$ . Inhalation of indoor air vapors during showering account for approximately 100% of the risk, and the risk is primarily due to chloroform from the on-site surficial aquifer.

TABLE C-22  
MODELED INDOOR AIR CONCENTRATIONS

Contaminants	Molecular Weight (g/mole)	Koc (cm <sup>3</sup> /g)	Henry's Law Constant (unitless)	Kd (cm <sup>3</sup> /g)	Diffusivity In Air (m <sup>2</sup> /s)	Soil Concentration				Indoor Air Concentration (g/m <sup>3</sup> )
						All Depths (ug/kg)	Tar-like Material (ug/kg)	Average (ug/kg)	Total Vapor Emission (g/m <sup>2</sup> ·s)	
ACENAPHTHENE	152	6.17e+03	6.07e-02	45.50471	6.24e-06	2.00e+02	1.08e+03	6.41e+02	2.45e-09	5.01e-09
ACETONE	58	1.76e+01	8.58e-04	0.130183	1.24e-05	4.54e+01	1.26e+02	8.57e+01	1.03e-09	2.10e-09
ALDRIN	365	1.82e+04	6.10e-04	134.3558	4.50e-06	4.10e+00	4.00e+00	4.05e+00	7.65e-13	1.57e-12
ANTHRACENE	178	1.74e+04	4.18e-02	128.2497	5.77e-06	1.78e+02	1.22e+03	7.01e+02	1.27e-09	2.61e-09
BENZO(A)ANTHRACENE	228	2.45e+05	4.83e-05	1811.575	5.10e-06	1.65e+02	2.88e+03	1.52e+03	2.35e-11	4.81e-11
BENZO(A)PYRENE	252	7.08e+05	6.46e-05	5224.64	4.30e-06	1.65e+02	6.71e+02	4.18e+02	4.03e-12	8.26e-12
BENZENE	78	8.13e+01	2.29e-01	0.599846	8.80e-06	0.00	3.04e+00	1.52e+00	1.21e-10	2.48e-10
BENZO(B)FLUORANTHENE	252	7.08e+05	4.88e-04	5224.64	4.30e-06	0.00	3.17e+03	1.59e+03	4.20e-11	8.62e-11
BENZO(GH)PERYLENE	276	2.00e+06	2.00e-06	14725.04	4.10e-06	0.00	3.21e+02	1.61e+02	1.58e-13	3.25e-13
BIS(2-ETHYLHEXYL)PHTHALATE	391	1.43e+04	1.20e-05	105.9001	3.51e-06	1.87e+02	1.79e+02	1.83e+02	4.83e-12	9.90e-12
BUTYLATE	217	5.38e+02	3.38e-04	3.969997	5.00e-06	1.81e+02	2.75e+03	1.47e+03	1.26e-09	2.59e-09
CARBON DISULFIDE	76	2.92e+02	5.03e-01	2.153041	1.05e-05	4.40e+00	0.00	2.20e+00	1.48e-10	3.03e-10
CHLORDANE, ALPHA	410	1.27e+06	3.94e-04	9384.613	4.80e-06	3.91e+01	4.00e+01	3.96e+01	7.42e-13	1.52e-12
CHLORDANE, GAMMA	410	4.01e+04	3.94e-04	295.7852	4.80e-06	3.93e+01	4.00e+01	3.97e+01	4.19e-12	8.59e-12
CHLOROBENZENE	113	4.27e+02	1.53e-01	3.14816	7.30e-06	0.00	8.47e+00	4.24e+00	1.06e-10	2.17e-10
CHLOROFORM	119	2.81e+02	2.00e-01	2.073632	1.04e-05	2.70e+00	3.78e+01	2.02e+01	8.56e-10	1.76e-09

TABLE C-22 (Continued)

## MODELED INDOOR AIR CONCENTRATIONS

Contaminants	Molecular Weight (g/mole)	K <sub>oc</sub> (cm <sup>2</sup> /g)	Henry's Law Constant (unitless)	K <sub>d</sub> (cm <sup>2</sup> /g)	Diffusivity in Air (m <sup>2</sup> /s)	Soil Concentration				Indoor Air Concentration (g/m <sup>3</sup> )
						All Depths (ug/kg)	Tar-like Material (ug/kg)	Average (ug/kg)	Total Vapor Emission (g/m <sup>2</sup> -s)	
CHRYSENE	228	2.45e+05	4.30e-05	1811.575	5.00e-06	1.65e+02	2.66e+03	1.41e+03	2.03e-11	4.17e-11
DI-N-BUTYL PHTHALATE	278	2.65e+04	1.15e-05	195.6394	4.38e-06	1.65e+02	0.00	8.25e+01	1.75e-12	3.59e-12
DICAMBA	221	3.14e+01	3.75e-05	0.231363	3.40e-05	4.99e+02	0.00	2.50e+02	7.75e-10	1.59e-09
4,4'-DDD	320	5.62e+04	3.26e-04	414.8168	5.34e-06	9.70e+00	8.00e+00	8.65e+00	7.59e-13	1.55e-12
4,4'-DDE	318	1.53e+05	2.79e-03	1129.943	4.80e-06	7.90e+00	0.00	3.95e+00	5.69e-13	1.17e-12
4,4'-DDT	354	5.55e+04	2.10e-02	409.6532	5.10e-06	1.29e+01	9.40e+00	1.12e+01	7.54e-12	1.54e-11
DIETHYL PHTHALATE		5.46e+02		4.027709		3.32e+02	0.00	1.66e+02	5.27e-11	1.08e-10
DIELDRIN	381	1.91e+03	1.88e-05	14.09469	4.40e-06	7.90e+00	8.00e+00	7.95e+00	8.05e-13	1.65e-12
ENDOSULFAN I	207	2.03e+03	1.67e-03	15.00568	4.70e-06	4.00e+00	0.00	2.00e+00	1.91e-12	3.92e-12
ENDRIN	381	7.21e+03	2.08e-05	53.17364	5.00e-06	8.20e+00	8.95e+00	8.58e+00	5.01e-13	1.03e-12
EPTC	189	1.69e+02	3.58e-05	1.246113	5.00e-06	5.88e+01	2.03e+02	1.31e+02	6.57e-11	1.35e-10
ETHYLBENZENE	106	8.32e+02	2.63e-01	6.138389	7.55e-06	0.00	3.31e+01	1.65e+01	3.95e-10	8.10e-10
FLUORANTHENE	202	4.90e+04	2.64e-04	361.4568	4.80e-06	2.03e+02	7.25e+03	3.73e+03	2.92e-10	5.99e-10
FLUORENE	168	9.77e+03	2.68e-03	72.12009	5.00e-06	2.06e+02	3.97e+03	2.09e+03	1.19e-09	2.44e-09
HEPTACHLOR	374	5.90e+03	3.36e-02	43.51676	4.90e-06	3.90e+00	4.00e+00	3.95e+00	1.02e-11	2.08e-11
HEPTACHLOR EPOXIDE	389	7.01e+02	1.80e-02	5.174339	4.80e-06	0.00	4.54e+00	2.27e+00	1.23e-11	2.52e-11

TABLE C-22 (Continued)

## MODELED INDOOR AIR CONCENTRATIONS

Contaminants	Molecular Weight (g/mole)	Koc (cm <sup>2</sup> /g)	Henry's Law Constant (unitless)	Kd (cm <sup>3</sup> /g)	Diffusivity In Air (m <sup>2</sup> /s)	Soil Concentration				Indoor Air Concentration (g/m <sup>3</sup> )
						All Depths (ug/kg)	Tar-like Material (ug/kg)	Average (ug/kg)	Total Vapor Emission (g/m <sup>2</sup> -s)	
BHC, ALPHA	291	3.15e+03	2.40e-04	23.2625	5.34e-06	4.00e+00	4.00e+00	4.00e+00	1.24e-12	2.54e-12
BHC, BETA	291	3.15e+03	3.05e-05	23.2625	5.34e-06	5.00e+00	4.87e+00	4.94e+00	5.46e-13	1.12e-12
BHC, GAMMA (LINDANE)	291	3.15e+03	3.20e-04	23.2625	5.34e-06	4.40e+00	0.00	2.20e+00	7.88e-13	1.62e-12
INDENO(1,2,3-CD)PYRENE	276	1.95e+06	2.80e-06	14389.85	5.00e-06	0.00	3.55e+02	1.78e+02	2.31e-13	4.75e-13
METHOXYCHLOR	345.7	5.20e+03	2.28e-01	38.39342	5.17e-06	4.07e+01	4.15e+01	4.11e+01	3.01e-10	6.17e-10
METHYL ETHYL KETONE	72	3.30e+01	1.91e-03	0.243466	8.05e-06	7.90e+00	0.00	3.95e+00	4.15e-11	8.52e-11
METHYLENE CHLORIDE	85	1.21e+02	1.31e-01	0.895858	1.04e-05	5.80e+00	3.40e+00	4.60e+00	2.40e-10	4.93e-10
MOLINATE	187	1.04e+02	0.000057	0.764199	5.00e-06	3.85e+01	0.00	1.92e+01	1.56e-11	3.19e-11
NAPHTHALENE	128	1.41e+03	1.98e-02	10.42455	5.90e-06	2.21e+02	1.52e+03	8.69e+02	3.84e-09	7.88e-09
PEBULATE	203	3.63e+02	0.0065	2.679014	5.00e-06	7.22e+01	1.93e+02	1.33e+02	6.12e-10	1.25e-09
PHENOL	94.11	1.48e+02	1.86e-05	1.094675	8.20e-06	1.67e+02	0.00	8.37e+01	4.13e-11	8.47e-11
PYRENE	202	4.68e+04	2.06e-04	345.1885	5.42e-06	1.88e+02	5.61e+03	2.90e+03	2.18e-10	4.47e-10
2,4,5-T	255.49	1.98e+02	3.62e-07	1.458214	0.000005	3.00e+01	0.00	1.50e+01	6.68e-13	1.37e-12
TOLUENE	92	3.31e+02	2.80e-01	2.443739	8.70e-06	3.20e+00	2.28e+01	1.30e+01	5.48e-10	1.12e-09
1,2,4-TRICHLOROBENZENE	181	4.15e+03	9.63e-02	30.64338	5.00e-06	0.00	1.56e+03	7.82e+02	4.10e-09	8.40e-09
VERNOLATE	203	3.34e+02	0.00108	2.465437	5.00e-06	3.59e+02	1.03e+04	5.32e+03	1.04e-08	2.14e-08

TABLE C-22 (Continued)

## MODELED INDOOR AIR CONCENTRATIONS

Contaminants	Molecular Weight (g/mole)	K <sub>oc</sub> (cm <sup>3</sup> /g)	Henry's Law Constant (unitless)	K <sub>d</sub> (cm <sup>3</sup> /g)	Diffusivity in Air (m <sup>2</sup> /s)	Soil Concentration			Indoor Air Concentration (g/m <sup>3</sup> )
						All Depths (ug/kg)	Tar-like Material (ug/kg)	Average (ug/kg)	
XYLENE	106	1.12e+03	2.93e-01	8.280508	7.00e-06	0.00	3.60e+02	1.80e+02	3.76e-09
									7.71e-09

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TABLE C-23

SUMMARY OF PATHWAY-SPECIFIC CARCINOGENIC RISKS

Exposure Scenario	RME Receptor (Worst-Case Scenario)			
	Sum of Adult Cancer Risk	Sum of 9-Year-Old Cancer Risk	Sum of 4-Year-Old Cancer Risk	Sum of 9-and 4-Year-Old Cancer Risk
<b>CURRENT EXPOSURE: No known documented cases of exposure at these levels</b>				
<b>Target Area E</b>				
Ingestion of soil	$7 \times 10^{-7}$	$2 \times 10^{-6}$	$5 \times 10^{-6}$	$6 \times 10^{-6}$
Dermal contact with soil	$7 \times 10^{-6}$	$2 \times 10^{-6}$	$2 \times 10^{-6}$	$4 \times 10^{-6}$
Inhalation of vapor	$6 \times 10^{-6}$	$6 \times 10^{-6}$	$7 \times 10^{-6}$	$1 \times 10^{-5}$
Inhalation of particulates	$1 \times 10^{-8}$	$1 \times 10^{-8}$	$2 \times 10^{-8}$	$3 \times 10^{-8}$
<b>Grassy Area</b>				
Ingestion of soil	$1 \times 10^{-7}$	$6 \times 10^{-8}$	$5 \times 10^{-7}$	$6 \times 10^{-7}$
Dermal contact with soil	$1 \times 10^{-6}$	$7 \times 10^{-7}$	$2 \times 10^{-6}$	$3 \times 10^{-6}$
Inhalation of vapors	$9 \times 10^{-8}$	$1 \times 10^{-8}$	$1 \times 10^{-8}$	$2 \times 10^{-8}$
<b>Total Indoor Exposure</b>				
Inhalation of vapors (including seeps)	$5 \times 10^{-6}$	$5 \times 10^{-6}$	$6 \times 10^{-6}$	$1 \times 10^{-4}$
Inhalation of vapors (excluding seeps)	$2 \times 10^{-7}$	$2 \times 10^{-7}$	$2 \times 10^{-7}$	$3 \times 10^{-7}$
<b>Ditch</b>				
Ingestion of sediments	0	$2 \times 10^{-7}$	$6 \times 10^{-7}$	$8 \times 10^{-7}$
Dermal contact with sediments	0	$3 \times 10^{-8}$	$2 \times 10^{-6}$	$5 \times 10^{-6}$
<b>EXPOSURE TO SEEPS OF TAR-LIKE MATERIAL: Assumes no removal of seeps for RME Receptors</b>				
Ingestion of tar-like material	$4 \times 10^{-8}$	$5 \times 10^{-8}$	$2 \times 10^{-7}$	$3 \times 10^{-7}$
Dermal contact with tar-like material	$7 \times 10^{-7}$	$1 \times 10^{-6}$	$2 \times 10^{-6}$	$3 \times 10^{-6}$
Inhalation of vapors	$5 \times 10^{-6}$	$5 \times 10^{-6}$	$5 \times 10^{-6}$	$1 \times 10^{-5}$
<b>TOTAL CURRENT EXPOSURE (EXCLUDING SEEPS)</b>		$3 \times 10^{-6}$	$4 \times 10^{-6}$	$7 \times 10^{-6}$
<b>TOTAL CURRENT EXPOSURE (INCLUDING SEEPS)</b>	$7 \times 10^{-6}$	$9 \times 10^{-6}$	$1 \times 10^{-4}$	$2 \times 10^{-4}$

TABLE C-24

## SUMMARY OF PATHWAY-SPECIFIC TOTAL HAZARD INDICES

Exposure Scenario	RME Receptor (Worst-Case Scenario)		
	Adult	Nine-Year Old	Four-Year Old
<b>CURRENT EXPOSURE: No known documented cases of exposure at these levels</b>			
<b>Target Area E</b>			
Ingestion of soil	$4 \times 10^{-2}$	$1 \times 10^{-1}$	$4 \times 10^{-1}$
Dermal contact with soil	$3 \times 10^{-1}$	$1 \times 10^0$	$2 \times 10^0$
Inhalation of vapor	$2 \times 10^{-3}$	$3 \times 10^{-3}$	$4 \times 10^{-3}$
Particulate inhalation	$9 \times 10^{-6}$	$1 \times 10^{-6}$	$2 \times 10^{-6}$
<b>Grassy Area</b>			
Ingestion of soil	$3 \times 10^{-3}$	$3 \times 10^{-3}$	$2 \times 10^{-2}$
Dermal contact with soil	$6 \times 10^{-3}$	$7 \times 10^{-3}$	$2 \times 10^{-2}$
Inhalation of vapor	$5 \times 10^{-6}$	$9 \times 10^{-6}$	$1 \times 10^{-4}$
Particulate inhalation			
<b>Northern Ditch</b>			
Ingestion of sediments	0	$3 \times 10^{-3}$	$7 \times 10^{-3}$
Dermal contact with sediments	0	$1 \times 10^{-2}$	$1 \times 10^{-2}$
<b>Indoor Exposure</b>			
Inhalation of vapors, total indoor (including seeps)	$1 \times 10^{-2}$	$2 \times 10^{-2}$	$2 \times 10^{-2}$
Inhalation of vapors, total indoor (excluding seeps)	$1 \times 10^{-3}$	$2 \times 10^{-3}$	$3 \times 10^{-3}$
<b>EXPOSURE TO SEEPS OF TAR-LIKE MATERIAL: Assumes no removal of seeps for RME Receptor</b>			
Ingestion of tar-like material	$9 \times 10^{-6}$	$2 \times 10^{-4}$	$9 \times 10^{-4}$
Dermal contact with tar-like material	$7 \times 10^{-4}$	$2 \times 10^{-3}$	$3 \times 10^{-3}$
Inhalation of vapors	$1 \times 10^{-3}$	$2 \times 10^{-3}$	$2 \times 10^{-3}$
<b>TOTAL CURRENT EXPOSURE (EXCLUDING SEEPS)<sup>1</sup></b>	$4 \times 10^{-1}$	$1 \times 10^0$	$2 \times 10^0$
<b>TOTAL CURRENT EXPOSURE (INCLUDING SEEPS)<sup>2</sup></b>	$4 \times 10^{-1}$	$1 \times 10^0$	$2 \times 10^0$