Public Health Consultation

Vapor Intrusion Assessment: Taku Gardens

Fort Wainwright, Alaska

January 31, 2012

"The findings and conclusions in this report have not been formally disseminated by [the Centers for Disease Control and Prevention/the Agency for Toxic Substances and Disease Registry] and should not be construed to represent any agency determination or policy."

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Foreword

The Agency for Toxic Substances and Disease Registry, ATSDR, was established by Congress in 1980 under the Comprehensive Environmental Response, Compensation, and Liability Act, also known as the Superfund law. This law set up a fund to identify and clean up our country's hazardous waste sites. The Environmental Protection Agency (EPA) and the individual states regulate the investigation and clean up of the sites.

Since 1986, ATSDR has been required by law to conduct a public health assessment at each of the sites on the EPA National Priorities List. The aim of these evaluations is to find out if people are being exposed to hazardous substances and, if so, whether that exposure is harmful and should be stopped or reduced. If appropriate, ATSDR also conducts public health assessments when petitioned by concerned individuals. Public health assessments are carried out by environmental and health scientists from ATSDR and from the states with which ATSDR has cooperative agreements. The public health assessment process allows ATSDR scientists and public health assessment cooperative agreement partners flexibility in document format when presenting findings about the public health impact of hazardous waste sites. The flexible format allows health assessors to convey to affected populations important public health messages in a clear and expeditious way.

Exposure: As the first step in the evaluation, ATSDR scientists review environmental data to see how much contamination is at a site, where it is, and how people might come into contact with it. Generally, ATSDR does not collect its own environmental sampling data but reviews information provided by EPA, other government agencies, businesses, and the public. When there is not enough environmental information available, the report will indicate what further sampling data is needed.

Health Effects: If the review of the environmental data shows that people have or could come into contact with hazardous substances, ATSDR scientists evaluate whether or not these contacts may result in harmful effects. ATSDR recognizes that children, because of their play activities and their growing bodies, may be more vulnerable to these effects. As a policy, unless data are available to suggest otherwise, ATSDR considers children to be more sensitive and vulnerable to hazardous substances. Thus, the health impact to the children is considered first when evaluating the health threat to a community. The health impacts to other high-risk groups within the community (such as the elderly, chronically ill, and people engaging in high risk practices) also receive special attention during the evaluation.

ATSDR uses existing scientific information, which can include the results of medical, toxicologic and epidemiologic studies and the data collected in disease registries, to evaluate the possible health effects that may result from exposures. The science of environmental health is still developing, and sometimes scientific information on the health effects of certain substances is not available.

Community: ATSDR also needs to learn what people in the area know about the site and what concerns they may have about its impact on their health. Consequently, throughout the evaluation process, ATSDR actively gathers information and comments from the people who live or work near a site, including residents of the area, civic leaders, health professionals, and community groups. To ensure that the report responds to the community's health concerns, an early version is also distributed to the public for their comments. All the public comments related to the document are addressed in the final version of the report.

Conclusions: The report presents conclusions about the public health threat posed by a site. Ways to stop or reduce exposure will then be recommended in the public health action plan. ATSDR is primarily an advisory agency, so usually these reports identify what actions are appropriate to be undertaken by EPA or other responsible parties. However, if there is an urgent health threat, ATSDR can issue a public health advisory warning people of the danger. ATSDR can also recommend health education or pilot studies of health effects, full-scale epidemiology studies, disease registries, surveillance studies or research on specific hazardous substances.
Comments: If, after reading this report, you have questions or comments, we encourage you to send them to us.

Letters should be addressed as follows:

Attention: Manager, ATSDR Record Center Agency for Toxic Substances and Disease Registry, 1600 Clifton Road (F-09), Atlanta, GA 30333.

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Acronyms

ADEC	Alaska Department of Environmental Conservation
ATSDR	Agency for Toxic Substances and Disease Registry
CEL	cancer effect levels
CREG	cancer risk evaluation guide
DHHS	Department of Health and Human Services
DRO	diesel-range organic
EMEG	environmental media evaluation guide
EPA	U.S. Environmental Protection Agency
FCS	Former Communications Site
GRO	gasoline-range organic
IARC	International Agency for Research on Cancer
LOAEL	Lowest Observed Adverse Effect Level
$\mu g/m^3$	microgram per meter cubed
mg/kg	milligrams per kilogram
mg/kg/day	milligrams per kilograms per day
MRL	minimal risk level
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PCE	tetrachloroethylene
RCRA	Resource Conservation and Recovery Act
RfD	reference dose
RMEG	reference dose media evaluation guide
RRO	residual-range organic
SSD	sub-slab depressurization
SVOC	semi-volatile organic compound
TCE	trichloroethylene
TCP	1,2,3-trichloropropane
USACE	United States Army Corps of Engineers
VOC	volatile organic compound

I. Summary

INTRODUCTION	The Agency for Toxic Substances and Disease Registry (ATSDR) recognizes your need for more information about potential future exposures to vapor intrusion in the Taku Gardens housing development. Our primary objective in writing this health consultation is to provide you with the information you need to protect your health.
BACKGROUND	In April 2005, construction of the 54-acre Taku Gardens housing development began. In June 2005, workers noted a solvent-like odor when excavating the foundation for Building 52. During subsequent 2005 and 2006 site investigations, a "hot spot" of polychlorinated biphenyl (PCB)-contaminated soil was identified near the footprint of Building 52. In 2010, ATSDR finalized a health consultation focused on the PCB contamination at Taku Gardens. In 2011, the U.S. Army asked ATSDR to provide a health consultation focusing on the potential for vapor intrusion in the completed Taku Gardens housing development. The purpose of this consultation is to evaluate the potential for public health effects to future residents who may come into contact with subsurface contaminants and hazardous vapors at the site. The 55-building development was constructed on the Former Communications Site of Fort Wainwright. Former operations at the site used solvents and heating oil tanks and performed a variety of other operations. Remedial activities to address residual contamination from these operations have included removal of contaminated soil and salvage debris. Some of the volatile organic compound (VOC), semi-volatile organic compound (SVOC) and petroleum compounds have leached into the groundwater under the site and can serve as a continuing source of vapors that may migrate up and into houses at the development. In an attempt to characterize the nature and degree of contamination that would impact residents' health, ATSDR reviewed all of the data available from sources such as the U.S. Army and the State of Alaska. Through the health assessment process, ATSDR determined that future residents of the housing development are the main receptor populations who will potentially be exposed to vapor intrusion at Taku Gardens.
CONCLUSION 1	ATSDR concludes that breathing vapors that have migrated into housing from residual soil and groundwater contamination at Taku Gardens is not expected to harm people's health. Sampling and modeling show that the maximum estimated indoor air levels are not expected to result in hazardous levels of contamination from vapor intrusion.

BASIS FOR CONCLUSION 1	Sub-slab sampling has been performed at least twice in each duplex, and indoor air samples gathered from the units with the highest sub-slab gas levels did not find hazardous levels. Indoor air sampling and modeling using empirical, radon-derived attenuation factors and sub-slab gas levels does not predict indoor air levels sufficient to cause harm to people's health from vapor intrusion.
NEXT STEPS FOR CONCLUSION 1	ATSDR recommends at least three sub-slab samples for a representative number of residences to improve knowledge about the spatial variability of vapors in the sub-slab space. ATSDR supports land use controls (LUCs) and institutional controls (ICs) indicating that residents should immediately report odors to the Ft Wainwright Army Garrison Directorate of Public Works (DPW) and vacate the area. Digging is also restricted. Uncertainties are inherent in sampling and predicting the sub-slab vapor intrusion pathway. The pathway may need to be reevaluated if the buildings are modified, the hydrogeological setting is altered, or if new information reveals unexpected risks in the future. ATSDR supports plans for sampling of sub-slab gas over the next 5 years to continue evaluation of temporal variability.
CONCLUSION 2	ATSDR cannot conclude whether or not harm may occur from vapors migrating to indoor air from subsurface containers that may harbor hazardous substances and become compromised by aging or physical disturbance.
BASIS FOR CONCLUSION 2	Five buildings are present with observed buried material beneath, and another six buildings remain with possible buried material beneath. Materials observed to be present under buildings include drums, lead-acid batteries, paint cans, transformers, rockets, gas cylinders, fire extinguishers and discarded military munitions that could contain or produce toxic, asphyxiant, flammable or explosive gases. Jet Assisted Take-Off bottles were also found near the buildings. Most of the recovered material did not contain sufficient material to result in a health hazard. However, even a small chance of events occurring that could have a high consequence effect should be addressed.
NEXT STEPS FOR CONCLUSION 2	ATSDR supports continued periodic sampling up to and perhaps after five years, as long as containers possibly holding hazardous waste remain beneath buildings and contaminant sources remain at the site. ATSDR has reviewed the sub-slab depressurization (SSD) system pilot study. ATSDR supports the conclusion that a double suction point SSD system can serve as an initial design for units with observed or possible hazardous containers beneath and that the SSD may need to be modified for effectiveness. Lines of evidence that could evaluate performance of

	the system include evaluating the depressurization extension field's ability to achieve the recommended pressure differential (4 Pascals) below the entire slab. If the desired performance is not achieved, further investigation may be warranted to ensure health hazards to residents of those units do not occur. ATSDR may be available to assist in the design and evaluation process, if requested.
FOR MORE INFORMATION	If you have questions or comments, you can call ATSDR toll-free at 1-800-CDC-INFO and ask for information on the Fort Wainwright: Taku Gardens site.

II. Background

Taku Gardens is a housing development located between Alder and Neely roads, east of White Street, and west of the Fort Wainwright Power Plant (see **Figure 1**) (CH2MHILL 2008). The 54-acre construction site is located in an area known as the Former Communication Site (FCS) within the main post of Fort Wainwright (OASIS 2007). Fort Wainwright is an active Army installation in Fairbanks, North Star Borough, Alaska.

> ATSDR completed a public health assessment on Fort Wainwright in September 2003, and a public health consultation on Taku Gardens in April 2010 (see http://www.atsdr.cdc.gov/HAC/PHA/HCPHA.asp?State=AK).

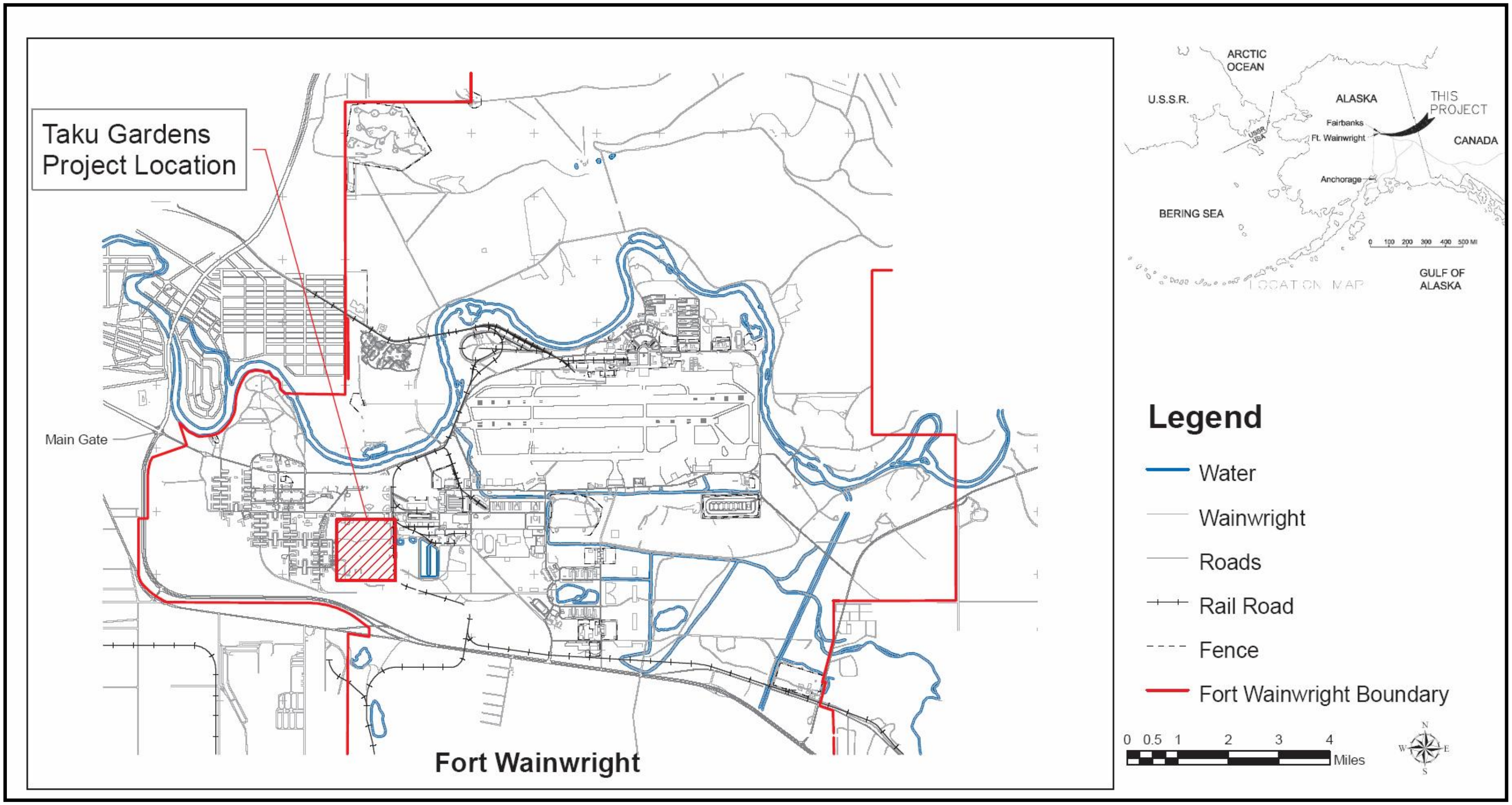
In 2002–2003, the Former Communication Site was selected as a future military family housing area. Before construction began, an Environmental Assessment, two Geophysical Surveys, two Geotechnical Surveys, and two Chemical Surveys were performed by the Army, United States Army Corps of Engineers (USACE), and their contractors (OASIS 2007).

Prior to the construction of the housing units in April 2005, the Former Communication Site was in a relatively natural state (OASIS 2007). The northern portion of the site was cleared and used to store snow. The remainder of the site was vegetated with a dense cover of second or third growth alder, aspen, scattered spruce, and birch. Several trails passed through the site and a community garden was located in the southwest corner (USACE 2004).

In June 2005, during the excavation of the foundation for Building 52 (located within Subarea E), workers noted a solvent-like odor. Ensuing investigations discovered high levels of polychlorinated biphenyls (PCBs) in the soil. Construction activities were halted and environmental investigations began, followed by removal actions.

Historical information reveals that debris, drums and heating oil tank spills have impacted the environment at the Taku Gardens family housing development. Large volumes of metal debris and 1,058 drums, of which 1,050 had no apparent residue, were removed from the site following housing construction. Under some circumstances, volatile and semi-volatile organic compounds (VOCs, SVOCs) and petroleum compounds have been found in the subsurface at the Taku Gardens housing development. Under some circumstances, volatile compounds in the subsurface can migrate into indoor air where residents may breathe the contaminants.

Figure 1. Location of Taku Gardens



Source: North Wind 2007

III. ATSDR's Vapor Intrusion Evaluation Process

Studies have shown that vapor intrusion varies widely over time and space (EPA 2008). Since the variability is not always predictable, ATSDR and other agencies recommend the use of many sources of information (termed multiple lines of evidence) when assessing the vapor intrusion pathway (ATSDR 2008; AFIOH 2008; ITRC 2007; ADEC 2009c). Current vapor sampling and modeling methodologies each have limitations precluding any single one of them from satisfactorily assessing the variability of vapor intrusion (EPA 2005).

ATSDR has a 14 step approach (Table 1) that includes gathering information on multiple lines of evidence. The major parts of a public health evaluation are Pathway Analysis, Exposure Evaluation, Health Implications and Conclusions and Recommendations.

Table 1. ATSDR 14 Step Approach to Evaluate the Vapor Intrusion Pathway	
1	Are there subsurface volatile chemicals reported or suspected?
2	Are there occupied buildings within 100 feet laterally or vertically of volatile subsurface contaminants?
3	Are reported concentrations of volatile subsurface contaminants near the buildings documented to be, or plausibly above applicable screening levels?
4	Begin developing and improving a Conceptual Site Model.
5	Search for evidence of any urgent public health hazards.
6	Evaluate distance between contaminants and occupied buildings.
7	Evaluate environmental information, environmental concentrations of contaminants in nearby soil, groundwater, and soil gas, and potential background sources.
8	Evaluate building construction characteristics.
9	Check for any preferential pathways from contaminated soil or groundwater toward occupied buildings.
10	Are there valid indoor air measurements to use for dose calculation?
11	If there are no valid indoor air measurements, are there sub-slab soil gas measurements or other site specific information that can be used to estimate indoor air concentrations using reasonable but conservative attenuation factors from observations?
12	Request further site specific information and measurements if the answer to items 10 & 11 above is negative.
13	If a valid exposure dose can be estimated from information discussed in Part II, proceed to evaluate the public health implications as described in the Public Health Assessment Guidance Manual.
14	Follow the Public Health Guidance Manual

III.A. Pathway Analysis

1. Are there subsurface volatile chemicals reported or suspected?

Since 1938, Fort Wainwright operations have resulted in disposal and releases of construction materials, waste oils, asphalt, solvents, fuels, pesticides, PCBs, lubricants, battery fluids, painting waste, coal fly ash, batteries and low-level radioactive materials in the FCS area (CH2MHILL 2010b). In 2005, construction of the Taku Gardens family housing development began. 110 residential units (55 duplexes) are located at the site. PCBs, petroleum related chemicals, polycyclic aromatic hydrocarbons, chlorinated VOCs, SVOCs, pesticides, herbicides, and explosives have been detected in subsurface environmental media at the Taku Gardens family housing development. Two subsurface soil hot spots of diesel-range organics (DRO) at 12 and 16 feet and one of 1,2,3-trichloropropane at four feet were identified, in addition to a wide variety of containers and debris and widely scattered lower levels of contamination. Drums were found that contained 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, DRO, naphthalene, gasoline-range organics (GRO), residual-range organics (RRO), benzene, cyclohexane, polycyclic aromatic hydrocarbons (PAH), pesticides and metals. Soil gas sampling detected over 50 chemicals (CH2MHILL 2010b).

2. Are there occupied buildings within 100 feet laterally or vertically of volatile subsurface contaminants? If the answer is no, are preferential pathways (such as mining shafts, utility conduits, fractures of karst features) present that may result in transport over unusually long distances to occupied buildings?

Surface soil, subsurface soil, soil gas and groundwater samples have detected historically related contaminants in close proximity to buildings at the Taku Gardens housing complex. The contamination may serve as vapor sources in the groundwater, soil, and soil gas and could migrate to indoor air from the vadose zone, capillary fringe or phreatic (saturated) zone of the subsurface by advective, convective or diffusive mechanisms. The heterogeneous nature of the contaminant sources and complex environmental history of the site indicate that low level contamination may be present at a variety of depths within the soil column, at discontinuous areas of groundwater contamination, and, possibly, within drums or containers underneath structures at the site. Groundwater at the site averages around 15 feet and ranged from approximately 11 to 20 feet below ground surface (CH2MHILL 2010b). Sub-slab gas and indoor air samples have demonstrated vapors are in direct contact with buildings on-site, but that vapor migration is very scattered and variable (CH2MHILL 2010b).

3. Are reported concentrations of volatile subsurface contaminants near the buildings documented to be, or plausibly above applicable screening levels? Appendix H of the ITRC guide discusses the development and application of screening levels.

ATSDR's screening process ATSDR's screening levels are called comparison values and include the cancer risk evaluation guides (CREGs), environmental media evaluation guides (EMEGs), reference dose media evaluation guides (RMEGs), and reference concentrations (RfCs). CREGs are estimated contaminant concentrations that would be expected to cause no more than one excess cancer in a million (10^{-6}) for persons exposed during their lifetime (70 years). ATSDR's CREGs are calculated from EPA's cancer slope factors for oral exposures or unit risk values for inhalation exposures. These values are based on EPA evaluations and assumptions about hypothetical cancer risk at low levels of exposure. EMEGs are estimated contaminant concentrations that are not expected to result in adverse noncarcinogenic health effects based on ATSDR evaluation. EMEGS are based on ATSDR Minimal Risk Levels (MRLs) and conservative assumptions about exposure, such as intake rate, exposure frequency and duration, and body weight. ATSDR derives RMEGs from EPA's oral reference doses, which are developed based on EPA evaluations. RMEGs represent the concentration in water or soil at which daily human exposure is unlikely to result in adverse noncarcinogenic effects (ATSDR

2005). A RfC is an estimate of a continuous inhalation exposure concentration to people (including sensitive subgroups) that is likely to be without risk of health effects during a lifetime. These guides are non-enforceable, health-based comparison values developed by ATSDR and other government agencies for screening environmental contamination for further evaluation.

While concentrations at or below the relevant comparison value can reasonably be considered safe, it does not automatically follow that any environmental concentration exceeding a comparison value would be expected to produce adverse health effects. Comparison values are not thresholds for harmful health effects, rather they are screening tools. Typically, the lowest comparison value consistent with the conditions at or near the site is selected for screening purposes (ATSDR 2005). ATSDR comparison values represent contaminant concentrations that are many times lower than levels at which no effects were observed in studies on experimental animals or in human epidemiologic studies (No Observed Adverse Effect Levels or NOAELs). The NOAEL and Lowest Observed Adverse Effect Level (LOAEL) values are found in ATSDR's Toxicological Profiles (see http://www.atsdr.cdc.gov/toxprofiles/index.asp).

Soil and Groundwater Concentrations

The maximum detected subsurface levels for VOCs and SVOCs above ATSDR screening levels (or alternate screening levels, when ATSDR comparison values (CVs) are not available) are shown in Table 2. The soil and groundwater levels are not used here to determine exposures, but are indicators of the nature and extent of contamination. The health assessment process will later focus on indoor air levels as the point of exposure to future residents.

Soil investigations at the Taku Gardens area were initiated in 2003 to evaluate PCB contamination in site soils (CH2MHILL 2010b). Groundwater was investigated beginning in 2005 following the discovery of petroleum contamination in site soils (CH2MHILL 2010b). Even if the compounds are not that volatile, as with PCBs, if they are relatively insoluble, they may be forced into the vapor state if water competes for the soil pore space.

Therefore ATSDR uses a screening approach that focuses on the measured concentrations as well as the potential equilibrium concentrations –and compares them with various of health screening values.

As can be seen in Table 2, a variety of contaminants, including petroleum related hydrocarbons, polycyclic aromatic hydrocarbons, chlorinated VOCs, and SVOCs, were found to exceed screening levels. 1,2,3-trichloropropane had the highest exceedance, with levels in groundwater 1,200 times the screening level. Fuel range organics, 1,2-dibromo-3-chloropropane, 1,1,2,2-tetrachloroethane, tetrachloroethylene and vinyl chloride exceeded screening levels by greater than a factor of 10.

Table 2. Maximum Soil and Groundwater Concentrations for Contaminants Exceeding Screening Levels*

Contaminant		Surface Soil (mg/kg)	Subsurface Soil (mg/kg)	Soil Screening Level (mg/kg)	Ground water (µg/L)	Ground water Screening Level (µg/L)
Petroleum Hydrocarbons	GRO	850	630	140 ADEC	200	220 ADEC
	DRO	360	15,000	1025 ADEC	29,000	150 ADEC
	RRO	860	3,500	1000 ADEC	1,490	110 ADEC
	Benzene	0.4	0.34	10 CREG	2.6	0.6 CREG
Polycyclic Aromatic Hydrocarbons	Benzo(a)pyrene	0.091	0.17	0.1 CREG	0.0385	0.005 CREG
	Dibenzo(a,h) Anthracene	0.019	0.099	0.049 ADEC	0.0787	0.012 ADEC
Chlorinated VOCs	1,2-dibromo-3-chloropropane	-	0.26	0.0054 ADEC	-	-
	1,1,2,2-tetrachloroethane	0.017	0.017	4 CREG	9.8	0.2 CREG
	tetrachloroethene	0.088	0.71	1 CREG	1	0.06 CREG
	1,1,2-trichloroethane	-	0.13	10 CREG	0.89	0.6 CREG
	Trichloroethene	0.081	0.33	20 CREG	14	5 MCL
	1,2,3-trichloropropane	-	0.5	0.02 CREG	1.2	0.001 CREG
	Vinyl chloride	-	0.02	0.5 CREG	0.84	0.02 CREG
SVOCs	n-Nitroso-dimethylamine	-	0.061	0.016 ADEC	-	-
	n-Nitrosodi-n-propylamine	-	0.28	0.1 CREG	-	-
	Bis-(2-Ethyl hexyl)phthalate	0.52	4.4	22 ADEC	2.7	0.6 ADEC

* Screening levels are ATSDR comparison values or, in the absence of ATSDR comparison values, ADEC screening levels or EPA maximum contaminant levels (MCLs). Highlighted values are greater than the lowest comparison value. Chemical concentrations are from CH2MHILL 2010b.

If the answer to any of the 3 questions above is no, then human exposure to harmful levels of contaminants from vapor intrusion is unlikely. If the answer to all three questions is yes, continue the evaluation process with the following steps.

4. Begin developing and improving Conceptual Site Model (described below).

The three main components of a conceptual site model are characterization of (1) the contaminant sources, (2) the contaminant migration pathways and (3) the point of exposure to human receptors.

(1) **Contaminant sources** The contaminant sources at the Taku Gardens site were generated over decades of military use of the Former Communications Facility. Former features located at the site that have been removed include (CH2MHILL 2010b, 2011):

- Communications and radar operations
- Garden plot(s)
- Equipment salvage and reclamation
- Barracks and company headquarters
- Fire training area(s)
- Possible ammunition storage
- Debris and salvage material disposed in prior Hoppe's slough (a previous loop of the Chena river), trenches and possibly other local depressions

Large and dense geophysical anomalies that consisted of large volumes of buried debris and/or drums were detected at the FCS by magnetometry, electromagnetic and ground penetrating radar surveys. Exploratory excavations based on magnetometry, historical operations, topographic features and observation resulted in the removal of buried debris, drums and containers during the course of the remedial investigation. Remedial actions also included excavation of surface stains and soil contaminated with residual solvents, heating oil, PCBs, DRO, PAHs, and petroleum, oil and lubricant (POL).

Five buildings remain with observed buried debris (that may or may not include chemical-containing items) beneath the foundation, where removal was terminated due to structural stability concerns. Six buildings have indications that debris may remain beneath the foundation. Containers that could release VOCs, such as drums, oil-burning furnaces (one of approximate dimensions 20 by 30 feet), transformers, lead-acid batteries, heating oil tanks, fuel lines, paint cans, gas cylinders, fire extinguishers, rocket motors with propellant, hydraulic cylinders, fuel bladders, discarded military munitions, and other debris were observed in excavation side walls adjacent to buildings. Buried materials, including construction debris, empty drums, cylinders, lead battery plates, creosote-soaked timbers, ash, and jet assisted take-off JATO bottles, were also found in the vicinity of buildings. The debris tended to be concentrated in former low-lying areas and pits that were filled and covered before the FCS was developed (CH2MHILL 2010b).

Petroleum fuel and related chemicals, solvents, PAHs, and SVOCs were found in shallow aquifer groundwater monitoring wells and soil at the site.

- Petroleum fuel (DRO and RRO) was found to most heavily contaminate the northwestern area groundwater and soil where a prior fuel line was removed in 2008 and heating oil and tar containing drums were remediated. Lower levels of petroleum related contaminants in groundwater were also observed scattered around the site.

- Chlorinated VOCs were found in groundwater around the Hoppe's slough area with highest concentrations near where previous drums and paint cans were excavated from beneath one of the buildings onsite. Lower concentrations of chlorinated VOCs in groundwater were scattered across the site, but do not correlate well with the low level soil detects scattered across the site.
- 1,2,3-trichloropropane in groundwater is present in highest concentrations along the eastern edge of the site, with a few lower detects in other areas. Only one soil sample detected 1,2,3-trichloropropane, which was in subsurface soil amongst the scattered groundwater detections.
- Pesticides, herbicides, SVOCs and explosives were scattered at low levels across the site in subsurface soil and groundwater, but there was no apparent relation in contamination between soil and groundwater detections.

(2) **Contaminant migration pathways** Factors affecting the contaminant migration pathways from subsurface to indoor air have been identified for the duplex structures at Taku Gardens. Groundwater was found to vary from about 10 to 20 feet below ground surface, with an average depth of about 15 feet (CH2MHILL 2010b). Seasonal changes in groundwater flow directions of up to 180 degrees and changes in groundwater level are not uncommon adjacent to the rivers because of the effects of changing river stages in the Tanana and the Chena Rivers (CH2MHILL 2010b). River and groundwater levels rise in spring and summer due to snow and ice melt runoff and decrease in fall and winter when melting ceases and rain decreases. Chemicals of concern at the Taku Gardens complex include VOCs and SVOCs. Typically environmental health scientists are most concerned with VOCs; however, regions with large-scale variability in the water cycle (rain, drought, and ice) provide greater opportunity for SVOCs to intrude. SVOCs can exist as vapors in equilibrium with the groundwater near the water table. The vapors can be flushed up into buildings if the groundwater rises or water fills the soil pore spaces rapidly. Understanding the presence and distribution of chemicals in the groundwater and soil and how those change in different conditions will provide clues for assessing subsurface vapor migration pathways.

The native geology and soils at the site consist of soil and unconsolidated sediment with varying proportions of silt, sand and gravel which are commonly layered (CH2MHILL 2010b). More porous sand and gravel are present below about 8 to 10 feet (CH2MHILL 2010b). Subsurface soils at the site consist of heterogeneous fill materials resulting from the extensive relandscaping, filling, excavation and geoengineering of the Taku Gardens housing complex for construction. Soil sections from beneath the slab reveal large cobble in some areas, to fines in others. The heterogeneity of soil and groundwater contamination is consistent with the historical presence of scattered soil contamination that has leached into groundwater and then been excavated and replaced with clean fill. Stratified and varied soil conditions in the subsurface can result in preferential routing of vapors through zones of high-porosity, low-moisture material. Such vapor migration behavior would be consistent with the spatial heterogeneity of sub-slab gas between units and duplexes, i.e. the tendency for soil gas data to show very low levels of sub-slab gas at units adjacent to units with high sub-slab gas levels.

(3) **Point of exposure to human receptors** Indoor air concentration is the point of exposure to human receptors. Vapors that migrate into buildings from the subsurface can become

concentrated in indoor air. Factors affecting the EPC can include heating, ventilation and air conditioning (HVAC) system performance and exhaust systems, such as the kitchen hood and dryer exhaust vents included in the Taku Gardens housing plans (CH2MHILL 2010b). Exposures may depend on the time spent in different rooms and levels of the home. Upper floors tend to have more dilution and attenuation of vapors as they migrate farther up into the home, unless preferential pathways are present to upper floors. No studies on upper levels have been performed at Taku Gardens because the ground level indoor air concentrations have been low. Considerable variability generally occurs in indoor air concentrations on an hourly, daily and monthly basis. Chronic effects depend on the long term average exposures. Background concentrations are also widely documented in generic studies and often confound vapor intrusion analyses.

5. Search for evidence of any urgent public health hazards such as fire and explosion hazards or potential exposures to free product.

Site overview and residual contamination All identified hot spots and areas with drums and debris that are accessible have been remediated. Over 1000 drums (mostly crushed and empty) and over 7.5 acres of land were excavated down to groundwater. Photoionization detector sampling was used to confirm that soil removal achieved delineation during removals of heating oil contamination and POL (CH2MHILL 2010b). Measured levels of residual contamination in groundwater, soil, soil gas and air have not exceeded ATSDR acute comparison values for screening against immediate or short term exposure hazards.

Potential for VOC release from subsurface containers Containers of hazardous substances, possibly containing free product, could feasibly remain underneath some structures at the site. The remedial investigation report noted 5 buildings with observed buried material and 6 buildings with possible debris remaining beneath (CH2MHILL 2010b). A maximum of 4 feet of engineering aggregate separates slabs and pre-construction ground conditions (JEG 2011). Containers, equipment and debris that could not be excavated were observed in excavation side walls adjacent to buildings. Examples of such items found that could possibly release toxic, asphyxiating, flammable or explosive vapors include drums, oil-burning furnaces, heating oil tanks, fuel lines, paint cans, gas cylinders, fire extinguishers, rockets, hydraulic cylinders, fuel bladders and discarded military munitions (CH2MHILL 2010b). Buried materials, including construction debris, empty drums, cylinders, lead battery plates, creosote-soaked timbers, ash, and JATO bottles, were also found in the vicinity of buildings and tended to be concentrated in former low-lying areas and pits that were filled and covered before the FCS was developed (CH2MHILL 2010b). The likelihood of remaining containers holding enough vaporous material and releasing it in a way that can cause an urgent hazard is low, but cannot be ruled out.

The following events could contribute to the possibility of an urgent hazard. The integrity of one or more containers containing hazardous material could become compromised by processes such as corrosion, aging, physical disturbance, freeze thaw, or seismic events. The liquid or vapor could be released by a slow leak or rapid expulsion of the contents under pressure. The ability of vapors from a subsurface release to migrate to and accumulate in air at acutely hazardous levels would depend on factors such as soil porosity, preferential pathways, pressure differentials and the nature of the contaminant. Fairbanks is located in an area with considerable potential for earthquake activity (USGS 2007), which could rupture containers, create subsurface preferential pathways, or increase cracking in the slabs.

NOTE: It is beyond the scope of this focused health consultation to evaluate physical hazards from explosives at the site. The evaluation herein is specifically focused on inhalation hazards from subsurface vapors migrating to breathing zones. The remedial investigation report states that "It is extremely unlikely that any explosive ordnance is present at the site and, furthermore, the probability of encounter by residents with any buried munitions that might be present is unlikely."

6. Evaluate distance between contaminants and occupied buildings.

A variety of residual contaminants exist in the immediate vicinity of the housing structures of Taku Gardens. Remedial actions found potentially contaminated debris beneath duplexes in excavation side walls where removal was terminated due to structural stability concerns. Additionally, though all identified hot spots and debris have been remediated when practical, residual contamination still remains in soil and groundwater across the site. Groundwater is less than 20 feet deep and soil gas sampling has confirmed that contaminant vapors are migrating into sub-slab gas beneath the duplexes at the site.

7. Evaluate environmental information, environmental concentrations of contaminants in nearby soil, groundwater, and soil gas, and potential background sources.

Over 3,500 soil samples have been collected from 77 soil borings, 87 surface soil samples, and excavation confirmation samples. Over 80 groundwater wells screened in the upper part of the aquifer were sampled one to five times each. Open area vadose zone gas, sub-slab soil gas, indoor air and outdoor air were sampled for contaminant vapors in the Taku Gardens housing area (Table 3).

Passive soil gas sampling in fall 2006 found petroleum contamination in most areas sampled, and chlorinated VOCs near buildings (Appendix N of CH2MHILL 2010b). Soil gas sampling events took place in late summer, fall and winter at least once per year from 2006 to 2010. Sub-slab gas sampling was performed under live-in conditions (thermostat set to 68^{o} F) in each of the 110 residential units in Dec 2008 and in one unit of each duplex in Aug 2009 (CH2MHILL 2010b). Soil gas samples were collected from beneath the garage areas over 30 minutes with a representative number of samples undergoing leak-testing using helium tracer gas. Outdoor air was sampled as a potential background source of indoor air contamination (CH2MHILL 2010b).

Table 3: Chronology of Soil Gas and Outdoor Air Sampling Events

	Soil Gas	Outdoor Air
Fall 2006	35 passive vadose zone (8' deep, near 2 units)	
Fall 2007	110 sub-slab, 49 vadose zone (5' deep, insufficient detection levels)	4
October 2008	10 sub-slab (HVAC off)	1
December 2008	110 sub-slab (68^{o}F)	6
August 2009	6 sub-slab (all duplexes sampled) (68^{o}F)	2

July 2010	12 sub-slab (68°F)	10

The complex history of activities causing contamination at the Taku Gardens development, in combination with targeted excavations, has resulted in a very heterogeneously contaminated site. Recent sampling has found exceedances of screening levels with considerable spatial and temporal variability. All but one of the units chosen for indoor air sampling in July 2010 were different than those chosen in December 2008 due to changing contaminant patterns. Discussion of the nature and extent of contamination is organized by the different types of sources below.

Chlorinated VOCs There was poor correlation between high chlorinated VOC concentrations in soil, groundwater, and soil gas. Additionally, the contamination was very scattered and discontinuous within each media (CH2MHILL 2010b). This spatial variability and lack of correlation between media may reflect residual contamination from sources already removed during excavations at the site, the presence of small discrete source areas, and/or variable vapor or source migration patterns. The temporal variability could be explained by variation in migration patterns as conditions such as temperature, barometric pressure, precipitation, ground cover by snow and ice, and groundwater levels fluctuate.

Comparison of maximum site soil gas and outdoor air concentrations with ATSDR's comparison values for air are shown in Table 4 with values exceeding screening levels highlighted. ATSDR does not have soil gas screening values, but indoor air levels are likely an attenuated portion of the soil gas values. Since preferential pathways could possibly transport soil gas into indoor air, direct comparison of soil gas levels to comparison values for direct contact with air is a protective method of screening chemicals for further evaluation. As can be seen in Table 4, almost half of the chemicals exceeded screening levels in outdoor air, but not by more than about a factor of 10.

Table 4: Maximum Soil Gas Concentrations (μg/m³) for Chlorinated Contaminants Exceeding Screening Levels*

Chemical	Maximum Soil Gas	Maximum Outdoor Air	Screening Level
Bromomethane	34	0.31	5 RfC
Carbon tetrachloride	38	0.61	0.2 CREG
Chloroform	280	0.24	0.04 CREG
1,2-Dibromo-3–chloropropane	5.8	1.1	0.2 RfC
1,2-Dichloroethane	1.1	0.42	0.04 CREG
1,1-Dichloroethylene	200	0.047	80 EMEG
1,2-Dichloropropane	8.8	0.26	4 RfC
Hexachlorobutadiene	2.3	Not listed	0.05 CREG
Methylene chloride	16	3.4	2 CREG
1,1,2,2-Tetrachloroethane	0.25	Not listed	0.02 CREG
Tetrachloroethylene	110	1.9	0.2 CREG
1,2,4-Trichlorobenzene	7.5	Not listed	4.2 ADEC
1,1,2-Trichloroethane	0.34	0.048	0.06 CREG
Trichloroethylene	110	0.19	0.5 CREG
1,2,3-Trichloropropane	1	Not listed	0.3 RfC
Vinyl chloride	0.15	0.025	0.1 CREG

* Screening levels are ATSDR comparison values, or ADEC screening levels in the absence of ATSDR comparison values. Chemical concentrations are from the remedial investigation and 2010 Technical Memorandum (CH2MHILL 2010a,b). Maximum soil gas and outdoor air values greater than screening levels are highlighted.

Several different types of chlorinated VOCs (and one brominated VOC) were present at the site. The chlorinated ethylenes, PCE and TCE, are commonly used solvents that degrade into dichloroethylenes and vinyl chloride. The presence of dichloroethylenes and vinyl chloride indicate that natural attenuation by microorganism reductive dechlorination is occurring. PCE was found to be widespread in soil gas and exceeded screening levels in groundwater, but not in soil. TCE was detected most widely across the site and exhibited significant temporal variability.

VOC samples differed markedly between the August 2009 and July 2010 sampling events. In August 2009 significantly higher levels of chlorinated VOCs were found in sub-slab gas than in prior surveys in colder seasons (CH2MHILL 2010b). Sub-slab VOCs were reevaluated for 12 units in July 2010 but the elevated chlorinated VOCs seen in the Aug 2009 sub-slab sampling were not corroborated as a seasonal (summer) effect in the July 2010 sampling. The occurrence of elevated chlorinated VOCs in August 2009 sub-slab gas followed by low chlorinated VOC sub-slab levels in July 2010 underscores the wide degree of temporal variability that can occur within a season. The one-time, elevated sub-slab gas levels could be due to less temperature suppression on the volatility of subsurface VOCs in the warmer month of August, i.e. a seasonal effect, in combination with other factors increasing susceptibility to vapor intrusion. Factors such as soil moisture, barometric pressure, and groundwater level and flow patterns can cause such variation in subsurface vapor flow. Radon attenuation factors (to be discussed in Step 11) for August 2009 were similar to March 2009 and Jan 2010, evidence supporting that the effect causing elevated sub-slab gas chlorinated VOCs in August 2009 was likely due to phenomenon related to the subsurface, not migration of sub-slab gas to indoor air.

Table 5: Sub-slab Gas Data Showing Temporal Variability in Late Summer

Sampling Data	TCE (µg/m^3)	Chloroform (µg/m^3)
August 2009	Range: 49-110	Range: 140-200
July 2010	Range: nondetect-2.9	Range: nondetect-48

In addition to temporal variability, spatial variability at the site is extreme. For example, none of the 12 duplexes with chlorinated VOC levels of concern in soil gas were adjacent. The TCE well with the highest concentration was near the center of the site. The closest building to the well did not exhibit high sub-slab soil gas levels, but the next building over (to the west) had the highest sub-slab gas TCE level measured. This is an example where vapor migration from groundwater to indoor air is not necessarily spatially direct and predictable.

Two types of halogenated propanes, 1,2,3-trichloropropane and 1,2-dibromo-3-chloropropane, were also detected at the site. The 1,2,3-trichloropropane was found in one subsurface soil sample and scattered groundwater samples with the highest groundwater levels clustered in the east-central portion of the site. The single soil gas detection of 1,2,3-trichloropropane was not in the area of highest groundwater contamination. The 1,2,3-trichloropropane could have been used as a solvent or cleaning reagent (ATSDR 1992). USGS lists a predominant commercial use of

1,2,3-trichloropropane as a fumigant (USGS 2006). The volatile chemical 1,2-dibromo-3-chloropropane, a nematocide fumigant banned in 1977, was detected in three soil samples and two sub-slab gas samples, but has not been detected in groundwater. Concern over laboratory practices has suggested that the presence of 1,2-dibromo-3-chloropropane in laboratory analysis could be an artifact. However, prior use of the FCS area for garden plots (CH2MHILL 2010b) and the documented presence of parasitic plant nematodes in the region (Bernard 1986) indicate that prior use of fumigants could possibly have occurred at the site.

Other chlorinated VOCs used as solvents were found at elevated levels in the soil gas. Chloroform, carbon tetrachloride and methylene chloride were not detected in soil or groundwater above screening levels but were relatively elevated in scattered samples of soil gas.

Petroleum and Petroleum-related Compounds Fuel grade hydrocarbons, benzene and PAHs were detected above groundwater and soil screening levels across the site. The highest concentrations were for fuel grade hydrocarbons in groundwater and soil within the Hoppe's slough area. Fuel grade hydrocarbons are a mixture of gasoline, diesel or other fuel range hydrocarbons of which benzene is often considered the most toxic. Though fuel grade hydrocarbons were over 100 times screening levels, benzene was less than ten times screening levels in soil and groundwater (CH2MHILL 2010b), with the highest exceedances occurring in earlier sampling events. Soil gas detections were widespread and levels appear to be decreasing over time. Hydrocarbons are typically less persistent in the environment than chlorinated volatile organics because hydrocarbons often undergo natural attenuation processes (Tri-Services 2008). The maximum detected level of benzene in outdoor air was found to be higher than that in soil gas. Benzene and 1,2,4-trimethylbenzene soil gas were found to exceed screening levels by slightly more than a factor of ten, with the remaining contaminants below ten times screening levels in soil gas.

Table 6: Maximum Soil Gas Concentrations (µg/m^3) for Petroleum Related Contaminants Exceeding Screening Levels*

Chemical	Maximum Soil Gas	Maximum Outdoor Air	Screening Level
Benzene	1.1	3.6	0.1 CREG
Naphthalene	12	1.9	3 RfC
1,2,4-trimethylbenzene	160	1.7	7.3 ADEC
1,3,5-trimethylbenzene	56	0.49	7.3 ADEC
Xylenes	600	4.6	100 RfC

* Screening levels are ATSDR comparison values or ADEC screening levels (in the absence of ATSDR comparison values). Chemical concentrations are from the remedial investigation and 2010 Technical Memo (CH2MHILL 2010a,b). Levels higher than air screening values are highlighted.

Background In addition to evaluating historical contamination sources at the site, background sources of indoor air contamination should also be considered. Table 7 shows indoor air background levels that are based on 15 indoor air studies conducted between 1990 and 2005 in North American residences (EPA 2011a). Levels detected in indoor air at Taku Gardens are below these background levels for benzene, carbon tetrachloride and chloroform, and slightly higher for 1,2-dichloroethane. Indoor air background sources in the Taku Gardens duplexes are expected to be limited in comparison with typical household residences, because the units have not been occupied and the usual household products have not been brought into the homes. Therefore, background sources in the Taku residences are building materials, maintenance supplies, chemicals associated with utilities, and VOCs that may be associated with the workers' presence in the units, such as vehicles in the garage, personal care products, or cigarette smoke.

Table 7. Select Data from *Background Indoor Air Concentrations of Volatile Organic Compounds in North American Residences (1990-2005): A Compilation of Statistics for Assessing Vapor Intrusion* (EPA 2011a) (µg/m^3)

Chemical	N*	RL Range*	Range of 50th%*	Range of 95th%*	% Detects
1,2-dichloroethane	1,432	0.08-2.0	<RL	<RL-0.2	13.8
Benzene	2,615	0.05-1.6	<RL-4.7	9.9-29	91.1
Carbon tetrachloride	1,248	0.15-1.3	<RL-0.68	<RL-1.1	53.5
Chloroform	2,278	0.02-2.4	<RL-2.4	4.1-7.5	68.5

* N = number of samples, RL = laboratory reporting limit

A study of residential homes in Fairbanks, AK (ABSN 2002) found benzene levels were highest in homes with garages and no centralized ventilation system. Higher benzene levels were found when older vehicles were stored in garages. Homes with tuck-under garages, such as several of the Taku Garden configurations, showed higher indoor benzene levels than those with one-wall-attached garages. Configurations with furnaces located within garages also exhibited higher indoor benzene levels. Fifty five percent of the homes in the Fairbanks study were projected to exceed 11 µg/m^3, with a maximum detected level of 140 µg/m^3. Levels detected in the Taku Gardens indoor air study are well below these typical background levels in Fairbanks.

8. Evaluate building construction characteristics, such as basements, sumps, drainage, ventilation systems, relative elevation, and other critical features.

The following building specific factors were identified at the Taku Gardens complex that could affect the susceptibility of the buildings to vapor intrusion:

- Slab: Extensive cracking was observed in the test duplex slabs (JEG 2011). The garage slab in each duplex unit was poured separately from that under the main living space (JEG 2011). Vapors can migrate through the expansion joint between slabs when a monolithic slab is not used (EPA 2008b).
- Exhaust systems: Lower indoor pressure can be transiently created from operation of kitchen fume hoods or dryers vented to the outside, such as seen in the housing plans for the Taku Gardens duplexes (Appendix S of CH2MHILL 2010b).
- Sub-slab heterogeneity:

- Sub-slab aggregate tended to be more compact under the garage storage rooms than the middle of the duplexes (JEG 2011). This indicates that gas flow may be less restricted to the area beneath the living space.
- During testing, subsurface support beams were found to impede sub-slab vapor connectivity between the depressurization point and locations where pressure differential was measured, i.e. depressurization was minimal when footings interceded between the venting well and the port where pressure differential was measured. The support beams provide support for the 2^{nd} floor duplexes and consist of thickened slab up to 10 inches with placement varying amongst floor plans (JEG 2011).
- While support beams decreased vapor connectivity, sub-slab pipe chases and porous materials surrounding internal footings were observed to increase the radius of influence of the SSD system by dissipation (JEG 2011).
- Garage space may be closed off from the ventilated indoor air section of the house. This would likely result in different pressure influence on the subsurface than under the ventilated portion of the homes. Subsurface wall footings between the garage and living space could also result in the sub-slab gas samples under the garage not reflecting soil gas under the main living area of the buildings.

Construction Features Architectural documents for the site show a variety of different floor plans (A through F) with options for enlarged kitchens and laundry rooms (CH2MHILL 2010b). Plans for other structures at the site include warming huts/picnic pavilions, mechanical and communication buildings, though people would not be expected to spend much time in these ancillary buildings. Foundation slabs at the site are approximately 4" thick with up to 4' of engineering aggregate beneath. Slabs of at least 3 1/2 inches are recommended (EPA 2008b). Similar construction methods will likely result in less variability in vapor migration from sub-slab to indoor air from building-to-building (for a given floor plan) than between buildings constructed by different contractors.

Information from Sub-Slab Depressurization Pilot Testing The *Former Communications Site Active Sub-Slab Depressurization Pilot Test* was performed from January to March 2011 and revealed a significant amount of information regarding fate and transport of soil gases beneath duplexes at Taku Gardens. The tests were initiated to assess the installation and performance of active sub-slab depressurization (SSD) systems at four "worst-case" duplexes (JEG 2010). The worst-case duplexes were chosen based on observations of subsurface metal debris beneath and in the vicinity of the buildings. According to the Remedial Investigation (CH2MHILL 2010b), five buildings have residual debris observed beneath the foundation and six buildings may have debris beneath. If subsurface remains contain hazardous volatile material and became compromised, vapors could be emitted that could enter overlying buildings by vapor intrusion.

The sub-slab depressurization system pilot study evaluated the difference between baseline subsurface vapor migration patterns and patterns with the sub-slab depressurization systems active. The spatial variability of sub-slab gases and the rate at which sub-slab gases dissipate were assessed. The pressure differences between sub-slab and indoor air were also measured. For the SSD performance testing:

- A tracer (sulfur hexafluoride) was introduced into the subsurface
- Migration and dissipation was then monitored in remote test holes with and without the SSD system being active
- Pressure field extension tests were performed

Similarities in pressure communication trends were seen with similar placement of six remote test holes amongst three different floor plans evaluated in the SSD pilot study. Foundation footings appeared to impede sub-slab gas flow, but resulted in more preferential pathways. RTHs 20-35 feet from the suction point had essentially no pressure differential from sub-slab to indoor air. However, sulfur hexafluoride was still removed within two hours during active testing, which is 2-20 times faster than in baseline studies. ITRC generally recommends a pressure differential of 4 Pascal for SSD systems to protect against sub-slab gas infiltration to indoor air (ITRC 2007). The SSD pilot report recommended double suction point sub-slab depressurization systems in duplexes with potential subslab debris, and ATSDR concurs with this approach (JEG 2011). The performance of the systems should be evaluated and adjusted as necessary to achieve 4 Pascals of depressurization across the slab to prevent sub-slab vapors from intruding into the living space.

9. Check for any preferential transport pathways from contaminated soil or groundwater toward occupied buildings (i.e. buried utility lines, known shallow fracture flow zones, or solution channels).

The following features are considered to increase the potential for preferential gas flow through the subsurface:

- Utility lines and corridors
- Surface cover adjacent to buildings by snow and ice
- Heterogeneous subsurface
- Permafrost

Utility Lines Utility line beds tend to be lined with porous materials that allow drainage. Such porous channels provide a path of least resistance relative to more tightly packed native soils. Pre-manufactured direct-bury pipes were used at Taku Gardens. In the Taku Gardens SSD pilot study, pressure differential patterns indicated that sub-slab utility line corridors served as preferential pathways.

In addition to the typical plumbing, electric and gas utility lines that may supply residences, a system of glycol heating, steam and condensation lines run from mechanical buildings to duplexes on site and within the sub-slab aggregate. Manholes with insulated covers allow access to isolation valves for maintenance. Glycol lines were found to warm the sub-slab space during the SSD pilot study (JEG 2011), which could result in a mini-stack-effect, i.e. the tendency for heated air in the sub-slab to rise into the building. As Henry's law shows that volatility is dependent on temperature, heated conduits that traverse the site and connect directly to buildings provide ideal preferential pathways for vapors to migrate across site and to duplexes. This pathway could be responsible for much of the spatial variability at the site. For example, the building closest to the highest TCE groundwater well did not exhibit elevated sub-slab gas, but the adjacent duplex had the highest sub-slab gas level. Soil gas data have shown multiple instances where sub-slab gas was elevated in one unit of a duplex, but sub-slab gas beneath the adjacent unit was low (CH2MHILL 2010b). No soil gas samples from the utility conduits were available for review.

Surface Cover During SSD testing, depressurization failed in a location where snow melt exposed the external French drain adjacent to the building. French drains were found to possibly serve as a vent of sub-slab gas to the outdoor air. Such behavior has been modeled where subsurface permeability and the presence or absence of impervious surface cover surrounding a building affected atmospheric dilution below the slab (Pennell 2009). Subsurface venting to the outside can serve to decrease sub-slab gas concentrations by dilution, but it can also prevent depressurization of the slab by a sub-slab depressurization system decreasing the system's protectiveness against sub-slab gases.

Subsurface Heterogeneity The heterogeneous nature of the contamination and hydrogeology on-site indicate the potential for significant variability in preferential pathways for vapor intrusion across the site. During digging of the SSD pilot test suction pits, subsurface materials were found to be very heterogeneous and vary from large rounded stone with little to no fines to sections with mostly fines and few stones (JEG 2011). The presence of such zones with higher and lower permeability can result in irregular patterns of vapor flow.

Permafrost The Taku Gardens duplexes were generally constructed on porous (gravel/sand) foundations to help prevent frost/heave from occurring underneath the structures. Permafrost may complicate subsurface vapor flow. Permafrost in the Fairbanks region varies between 0.5 and 50 meters (ATSDR 2003). Aquifers may exist above, within and below permafrost. Porous permafrost may allow contaminant migration, or solid subsurface ice wedges may route water or vapor flow. Soil fissures can be created by soil freezing and thawing events. Permafrost may be affected by the freezing point depression of groundwater by contaminants. Additionally, developed land tends to be less susceptible to permafrost and can result in thaw-bulb regions that may serve as an areal pathway for vapor flow. Soil borings onsite have only detected permafrost in the SE area (CH2MHILL 2010b).

III.B. Exposure Evaluation (Dose Estimation)

10. Are there valid indoor air measurements to use for dose calculation?

The health assessment process focuses on indoor air levels as the point of exposure to future residents. The most direct approach to evaluating exposure is to directly measure indoor air. Valid indoor measurements are available for a select number of units at Taku Gardens.

Selection of Units for Indoor Air Testing Structures found to have the highest sub-slab gas levels were chosen for indoor air sampling, in attempts to directly identify indoor air problems. Two rounds of indoor air sampling were performed under live-in conditions. Ten of the 110 units were chosen for indoor air sampling based on sub-slab gas contaminant levels in Dec 2008 and twelve units were chosen in July 2010. Concurrent indoor and outdoor air samples were collected over 24 hours in summa canisters and sub-slab vapor samples were collected over 30 minutes.

Indoor Air Results and Discussion The results of the indoor air testing are shown in Table 8. Samples with indoor air concentrations above outdoor and background levels, and below sub-slab gas levels are likely from vapor intrusion. 1,2-dibromo-3-chloropropane (DBCP) was the only chemical found to have an indoor air level below sub-slab gas and above outdoor air, background, and the lowest comparison value. Only one unit found DBCP in indoor air and resampling of this unit in March 2009 found no DBCP when analyzed by two separate labs. Another hit of DBCP occurred in sub-slab gas at a separate unit in July 2010, but indoor air levels were below outdoor air levels.

Table 8. Maximum Indoor Air and Corresponding Soil Gas Concentrations for Contaminants Exceeding Screening Levels for Indoor Air in µg/m^3 (maximum value highlighted)*

Chemical	Dec 2008		July 2010		Maximum Outdoor Air/ Background¥	Screening Levels
	Maximum Indoor Air	Sub-slab Gas‡	Maximum Indoor Air	Sub-slab Gas‡		
Benzene	3.3	0.13U	0.5	0.007 U	3.6 / 1.6	0.1 CREG
Carbon tetrachloride	0.55	0.17 J	0.54	0.32	0.61 / 1.3	0.2 CREG
Chloroform	0.63	1.2	0.072 J	3.8	0.24 / 2.4	0.04 CREG
1,2-Dibromo-3-chloropropane	Not listed	Not listed	1.4 UJ	1.6 UJ	1.1	0.2 RfC
1,2-Dichloroethane	0.96	0.013 U	0.37 U	0.035 U	0.42 / 2	0.04 CREG
Methylene Chloride	7.7	0.39 U	1.8	0.41 U	3.4	2 CREG
Tetrachloroethylene	0.95	0.61	0.088 J	0.47	1.9	0.2 CREG
Trichloroethylene	0.64	0.015 U	0.014 U	0.007 U	0.19	0.5 CREG

* Chemical concentrations are from the remedial investigation and 2010 Technical Memo (CH2MHILL 2010a,b).

‡ The "J" qualifier in the table indicates that there is uncertainty in the value due to analytical limitations. The "U" qualifier in the table indicates that this value is below the analytical detection limit.

¥Maximum outdoor air concentrations and/or reference background levels were greater than indoor air concentrations for benzene, carbon tetrachloride, 1,2-dichloroethane, and tetrachloroethylene, indicating that indoor levels may be influenced by outdoor air and/or reference background and that sub-slab gas may not be the dominant source of indoor air contamination. Methylene chloride and trichloroethylene both exhibited maximum indoor air levels greater than the maximum sub-slab gas levels, indicating that the range of these contaminants in indoor air is outside the range of what should be expected from vapor intrusion alone. The isolated and sporadic nature of low-level 1,2-dibromo-3-chloropropane detections in indoor air and the relatively low levels of all other indoor air constituents indicates that vapor intrusion is not expected to be a health concern at the site. However, the limited data set and evidence of spatial and temporal variability in vapor migration at the site indicate that continued sampling should include 1,2-dibromo-3-chloropropane to reduce uncertainty regarding this contaminant.

11. If there are no valid indoor air measurements, are there sub-slab soil gas measurements and other site specific information that can be used to estimate indoor air concentrations using reasonable but conservative attenuation factors from observations (Dawson, Hers, & Truesdale, 2007) or from appropriate models, such as the Johnson and Ettinger model? (http://www.epa.gov/oswer/riskassessment/ainnodellpdfl2004_0222_3phase_user s~de.pdf).

The following data sets were gathered to estimate attenuation factors and characterize sub-slab gas and indoor air at the site:

- VOC samples: Paired sub-slab gas, indoor and outdoor air in select residences
- Radon samples: Paired sub-slab gas, indoor and outdoor air in select residences
- Comprehensive sub-slab gas sampling for VOCs at duplexes

Sub-slab VOCs were sampled for each duplex, sometimes for each unit, for application of site specific attenuation factors to model indoor air levels. Sub-slab gas may be less variable than indoor air levels and less susceptible to background effects, thus making it an indicator of the potential for indoor air problems. VOCs did not provide sufficient information to estimate site-specific attenuation factors. The site-specific attenuation factors determined by radon measurements were used to provide estimates of indoor air for all units based on sub-slab gas data.

VOCs Most of the VOCs detected in indoor air were not present at levels significantly over outdoor air or typical background levels. During indoor and sub-slab air sampling, two of the ten samples yielded chemical concentrations sufficient to calculate attenuation factors: indoor/sub-slab = 0.12J/190 μg/L = 0.00063 for chloroform, and indoor/sub-slab = 0.58/110 μg/L = 0.0053 for tetrachloroethylene. Smaller attenuation factors correspond to more attenuation of vapors from sub-slab to indoor air; conversely larger attenuation factors assume less dilution or attenuation of vapors migrating indoors from the sub-slab. The two attenuation factors calculated from VOCs are not sufficient to assess the spatial and temporal variability in attenuation for all 110 units. Therefore radon sampling was used as a surrogate.

Radon Radon gas sampling has been shown to be an effective method of evaluating the attenuation of sub-slab gases upon migration into indoor air (ITRC 2007). Radon was found to be present at reliably measurable levels in the Taku Gardens duplexes and samples were collected in March and August 2009 and January and July 2010 to evaluate indoor air attenuation factors for representative buildings (CH2MHILL 2010b). The radon samples targeted units with the highest chlorinated VOC exceedances in soil gas and evaluated each style of floor plan. The initial samples tested five units, then the January 2010 radon sampling event was expanded to 19 units representing about ~18% of the units (CH2MHILL 2010b). A summary of the results is shown in Table 9 below.

Table 9: Temporal analysis using radon sampling and attenuation factors*

	Mar 09 (5 units)	Aug 09 (5 units)	Jan 10 (19 units)	Jul 10 (12 units)
Range	0.0008 - 0.0016	0.0006 - 0.0024	0.0006 - 0.0034	0.000003 - 0.0011

Mean	0.0013	0.0011	0.0018	0.0006

* Table N-5 of App N showed data for all 19 units in Jan 2010 **(**CH2MHILL 2010a,b**)**

Temporal analysis of the initial five units by radon sampling did not show a remarkable difference in attenuation factors between Mar 2009, Aug 2009, and Jan 2010 sampling, though significantly more attenuation was noted in the July 2010 radon sampling event. These four sampling events over two years showed temporal variability spanning a factor of 1000, from 0.000003 to 0.0034. The most protective assumption for the attenuation factor would be to use the highest value of 0.0034.

Comprehensive Analysis Maximum detects in sub-slab gas and an attenuation factor of 0.0034 were used to model maximum expected indoor air values. Table 10 shows the modeled values side-by-side with the measured indoor and outdoor air values and the screening values. The modeled indoor air values were less than the detected indoor air values for all chemicals except chloroform and 1,1-dichloroethylene, which were slightly less than modeled values (Appendix C). This comparison shows that the modeled values are not reflective of measured indoor air levels in most cases. Actual indoor air levels are the result of the combined influence of all indoor, outdoor and sub-slab sources.

When measured indoor air contamination is present above levels predicted by the model, one of the following two situations may be occurring:

(1) Higher indoor air levels may be caused by background contributions.
(2) The model is under-predicting the extent of vapor intrusion. The preferential pathways in the sub-slab space could result in subsurface migration from localized sources of VOCs that behave differently from the dispersed radon emissions measured.

Indoor air concentrations, regardless of contaminant source, are the most important factor in assessing potential health effects at sites. Estimating indoor air levels at vapor intrusion sites is challenging due to the considerable fluctuation that occurs in indoor air levels and the variability of vapor entry by the vapor intrusion pathway. The most prudent approach to evaluating health effects is to choose a representative indoor air concentration and evaluate whether or not that value is protective of human health. The choice of representative indoor air concentration at Taku Gardens depends on conclusions from multiple lines of evidence that include measured indoor air concentrations; indoor air concentrations extrapolated from subsurface media and background; and information about the influence that variability and uncertainty may have on the adequacy of the chosen indoor air concentration. As a health protective approach, ATSDR will evaluate the higher of the modeled and sampled indoor air levels of VOCs in relation to levels found to cause health effects in Step 13.

Table 10: Comparison of Modeled and Sampled Indoor Air and Outdoor Air for Chemicals Exceeding Screening Levels in Sub-slab Gas (µg/m^3)*

Chemical	Maximum Subslab Gas	Maximum Modeled Indoor Air‡	Maximum Sampled Indoor Air	Maximum Outdoor Air	Screening Level
Benzene	1.1	0.0037	3.3	3.6	0.1 CREG
Bromomethane	34	0.12	0.85	0.31	5 RfC
Carbon tetrachloride	38	0.13	0.55	0.61	0.2 CREG
Chloroform	280	0.95	0.63	0.24	0.04 CREG
1,2-Dibromo-3 -chloropropane	5.8	0.020	1.4 UJ	1.1	0.2 RfC
1,2-Dichloroethane	1.1	0.0037	0.96	0.42	0.04 CREG
1,1-Dichloroethylene	200	0.68	0.048 U	0.047	80 iEMEG
1,2-dichloropropane	8.8	0.030	0.35 U	0.26	4 RfC
Hexachlorobutadiene	2.3	0.0078	Not listed	Not lised	0.05 CREG
Methylene Chloride	16	0.054	7.7	3.4	2 CREG
Naphthalene	12	0.041	0.096 U	1.9	3 RfC
1,1,2,2-tetrachloroethane	0.25	0.00085	Not listed	Not listed	0.02 CREG
Tetrachloroethylene	110	0.37	0.95	1.9	0.2 CREG
1,2,4-trichlorobenzene	7.5	0.026	Not listed	Not listed	4.2 ADEC
1,1,2-trichloroethane	0.34	0.0012	0.036 U	0.048	0.06 CREG
Trichloroethylene	110	0.37	0.64	0.19	0.5 CREG
1,2,3-trichloropropane	1	0.0034	Not listed	Not listed	0.3 RfC
1,2,4-Trimethylbenzene	160	0.54	1.4	1.7	7.3 ADEC
1,3,5-trimethylbenzene	56	0.19	0.42 J	0.49	7.3 ADEC
Vinyl chloride	0.15	0.00051	0.021 U	0.025	0.1 CREG
Xylenes	600	2.0	28.1	6.0	100 RfC

* The maximum of the three indoor air predictors (maximum modeled indoor air, maximum sampled indoor air and maximum outdoor air) are highlighted, and screening values are highlighted when exceeded by any of the three indoor air predictors. The "J" qualifier in the table indicates that there is uncertainty in the value due to analytical limitations. The "U" qualifier in the table indicates that this value is below the analytical detection limit.

‡ Modeled from maximum sub-slab gas data and a radon based attenuation fator of 0.0034.

12. Request further site specific information and measurements if the answer to the items 10 & 11 above is negative.

Monitoring Program The Ft Wainwright Army Garrison land use control/institutional control policy provides specific guidance and general recommendations which call for the reduction in potential for health hazards from environmental exposure at the Taku Gardens complex (CH2MHILL 2011). The Ft Wainwright Army Garrison Directorate of Public Works (DPW) shall monitor sub-slab soil gas for all buildings in the Taku Gardens Family Housing area at each change of occupancy, but not less than every three years or until the US Army, EPA and ADEC agree the monitoring is no longer required (CH2MHILL 2011). The proposed sub-slab gas monitoring program (Appendix D of CH2MHILL 2011) included a set schedule for monitoring sub-slab gas for the next five years, with discontinuation after five years contingent on stable sampling results that indicate that there is no health hazard from sub-slab vapor. Quarterly sub-slab sampling is proposed for the first two years in 12 select residences with all 110 units being sampled at the beginning and end of the first two year period. For the next three years annual sampling is proposed for the 12 select residences each February.

ATSDR supports considering continued periodic sampling after five years. If the degradation of debris or drums remaining in place results in the release of contaminants over time, there could be vapor intrusion issues that do not arise until after five years. Given the wide variety of subsurface containers and debris identified in the past at the site, such as drums, paint cans, containers of rocket propellant, hydraulic cylinders and fuel bladders, estimating how long the degradation of containers may take is a complex problem. Difficulty also arises in estimating the potential rate of release from such sources and whether or not such releases directly below a building may result in an acute hazard to the indoor occupants without an effective sub-slab depressurization system. Shifting patterns in wind, rain, temperature, barometric pressure, and contaminant plumes could also shift soil vapor migration patterns over periods greater than 5 years.

Future Use If potentially hazardous material or debris is discovered, the base land use control/institutional control policy directs that all activity in the area should cease, individuals should move away and the DPW or emergency responders should be contacted (CH2MHILL 2011). Future construction shall consider the potential for vapor intrusion of hazardous materials into indoor air and incorporate facility designs to protect health (CH2MHILL 2011). Alternatives for addressing contamination should consider the potential to affect vapor intrusion at the Taku Gardens complex. Particularly, attenuation, natural or in situ chemical oxidation may lead to the presence of toxic degradation products from chlorinated VOCs, such as vinyl chloride. The progress of attenuation should be monitored at an appropriate rate to ensure that any shifting of the suite of chemicals present should not endanger health from individual or combined chemical effects. The unpredictable migration patterns of contaminants resulting from temporal and spatial variability should be taken into consideration in designing and evaluating remedial alternatives.

Sub-slab Depressurization System ATSDR supports the conclusion from the SSD pilot study that a dual suction point setup is an appropriate starting point in system design. For a sub-slab depressurization system to be protective against migration of sub-slab contamination into indoor air, a 4 Pascal pressure differential between sub-slab space and corresponding indoor air is suggested in the ITRC Vapor Intrusion Pathway document (ITRC 2007). Performance measured by tracer and pressure field extension testing has been shown effective for removing sub-slab gas and evaluating the pressure differential. Testing performed under conditions that may impart different internal pressures, i.e. seasonal HVAC influence and during operation of exhaust systems, such as the kitchen hood and dryer, would provide more confidence in consistent performance during occupancy. Periodic indoor air radon measurements over the initial 5-year evaluation period would be a practical method to assure long-term operation of the system. Should any combustion appliances be used, performance testing of the SSD should include evaluation of the potential for back-drafting of hazardous vapors, such as carbon monoxide, into indoor air. Periodic inspection of SSD equipment and the surrounding conditions could be added to the 5-year monitoring protocol to determine the need for modifications.

Continue Studies of Spatial and Temporal Variability During the previous focused indoor air sampling events, 10 of the 110 units were selected for sampling in Dec 2008 based on higher VOC exceedances of target levels detected during comprehensive sub-slab gas sampling. In July 2010, 12 units were selected based on the August 2009 comprehensive sub-slab gas sampling. However, only one of the units found to have the highest exceedances from the Dec 2008 event was reselected in July 2010. Based on this history, a large degree of temporal variability seems to dictate the sub-slab gas levels spatially. ATSDR supports continued studies of temporal and spatial variability in sub-slab gas and indoor air.

- Spring sampling could reveal groundwater and soil gas changes due to snow melt. Drainage swales on the west direct heavy spring runoff and summer storm-water to the north (CH2MHILL 2010b).
- Soil gas samples collocated with subsurface utility lines and within manholes could reveal preferential pathways and how far contamination is being transported, such as along the heating line conduits that traverse the site.
- The Alaska Department of Environmental Conservation (ADEC) draft vapor intrusion guidance indicates that at least three sub-slab locations should be sampled per building with one in the area of the highest soil or groundwater contamination near or beneath the building (ADEC 2009c). Such sampling could provide information on spatial variability under slabs, including whether differences occur beneath the slabs of the garage and the living space.

Analyte List The proposed five year samples will be analyzed for VOCs. Analysis for SVOCs could detect naphthalene, which has been detected at one of the locations, and Aroclor 1232, a VOC which sometimes occurs in hydraulic fluids (ATSDR 2000). ATSDR supports plans for continued 1,2-dibromo-3-chloropropane monitoring (CH2MHILL 2010b) to provide evidence as to whether or not previous detects were the result of lab errors or the result of spatial or temporal variability.

III.C. Public Health Implications

13. If a valid exposure dose can be estimated from information discussed in Part II, proceed to evaluate the public health implications as described in the Public Health Assessment Guidance Manual

Comparison of air levels with health based criteria The estimated indoor air concentrations for duplexes at Taku Gardens are presented in Table 11 below, in addition to ATSDR's comparison values, and the actual levels at which adverse health effects have been observed in scientific studies—LOAELs. LOAELs are defined as the lowest tested dose of a substance that has been reported to cause harmful (adverse) health effects in people or animals. Outdoor air levels measured at the Taku Gardens complex and odor thresholds are also provided for comparison.

Table 11 shows that the indoor air levels of the VOCs are far below LOAELs, which are the levels actually shown to cause non-cancer and cancer health effects in scientific studies. Seven of the chemicals' indoor air values exceeded CREGs or EPA's lowest threshold for acceptable excess lifetime cancer risk (ELCR = 1 in 1,000,000), but fell within EPA's risk management range of cancer risk (ELCR = 1 in 10,000 to ELCR = 1 in 1,000,000). Additionally, the hypothetical cancer risk from breathing these chemicals is very low compared to the lifetime probability that residents of the United States will develop some type of cancer during their lifetime: 44% (almost 1 in 2) for men and 38% (just over 1 in 3) for women (ACS 2008). 1,2-dibromo-3-chloropropane exceeded a non-cancer screening value, but appeared to be particularly isolated and sporadic in the sampling events and was only detected on two occasions. Additionally, 1,2-dibromo-3-chloropropane was well below the LOAEL and not likely to result in noticeable health effects if infrequently breathed at the levels detected.

Table 11. Maximum Air Exposure Point Concentrations, Health Based Levels, and Odor Thresholds (all values in μg/m^3)*

Chemical	Maximum Estimated Indoor Air‡	Maximum Outdoor Air	Comparison Values (type)	LOAEL (type, subject of study)¥	Odor Threshold¥
Benzene	3.3	3.6	0.1 CREG	974 (chronic, human)	200,000
Carbon tetrachloride	0.55	0.61	0.2 CREG	63,950 (acute, rodents)	10,000
Chloroform	0.95	0.24	0.04 CREG	9,930 (chronic, human)	422,000
1,2-Dibromo-3 - chloropropane	1.4	1.1	0.2 RfC	5802 (chronic, rodent)	96,500
1,2-Dichloroethane	0.96	0.42	0.04 CREG	411,390 (acute, rabbit & guinea pig)	49,400
Methylene Chloride	7.7	3.4	2 CREG	88,270 (intermediate, rodent)	540,000
Tetrachloroethylene	0.95	1.9	0.2 CREG	47,500 (chronic, human)	7,000
Trichloroethylene	0.64	0.19	0.5 CREG	55,000 (intermediate, rodent)	537,000

* The higher of indoor and outdoor air highlighted

‡ Maximum estimated indoor air values are the higher of the: (1) maximum sampled indoor air concentration, or (2) maximum modeled indoor air concentration.

¥ LOAELs and odor thresholds were obtained from ATSDR's toxicological profiles (http://www.atsdr.cdc.gov/toxprofiles/index.asp).

Benzene, carbon tetrachloride and tetrachloroethylene were detected at higher concentrations in outdoor air at Taku Gardens than the highest estimated indoor air levels. However, these outdoor air levels were well below LOAELs. Some chemical groups may change over time due to natural or accelerated biodegradation processes, such as vinyl chloride creation from chlorinated solvents. However, vinyl chloride has not been detected in air above health based screening levels thus far.

Healthy approach to reducing exposures to VOCs in air Though air contaminants at the site are estimated to be below levels expected to cause observable health effects, a slight theoretical increased risk of cancer exists. EPA advises that individuals be aware of their indoor and outdoor air exposures to VOCs and reduce exposures when practical. VOC levels in homes may accumulate to levels 2 to 5 times higher than outdoor air (EPA 2011b). The main indoor sources of VOCs are environmental tobacco smoke (secondhand smoke), stored fuels and paint supplies, household cleaning and maintenance products, commercial air fresheners, and automobile emissions in attached garages. Actions that can reduce VOC exposure include eliminating smoking within the home, providing for maximum ventilation while using VOC-containing household products (NLM 2010), and discarding VOC-containing household products that will not be used immediately (EPA 2011b).
Odors can be an indicator that air contaminants may be at levels that can affect health. In some cases odor thresholds are greater than chronic LOAELs and shouldn't be relied upon to determine health hazards. Regardless, odors have identified contamination source areas at Taku Gardens in the past and notice of chemical odors in indoor or outdoor air should be reported to the Ft Wainwright Army Garrison Directorate of Public Works (DPW) and investigated.

Spatial and temporal variability of indoor air vapors compound uncertainties in sampling contaminant levels and estimating human exposures. Additionally, human-to-human differences in susceptibility to chemical exposures and uncertainties in estimating toxicological effect levels from controlled or epidemiological studies contribute to overall uncertainty in estimating health effects. The variability and uncertainty in evaluating environmental exposures makes a comprehensive approach to reducing exposures all the more important to maintaining a healthy lifestyle.

IV. Conclusions

ATSDR concludes that breathing vapors that have migrated into housing from residual soil and groundwater contamination at Taku Gardens is not expected to harm people's health because sampling and modeling show that the maximum estimated indoor air levels are not expected to result in hazardous levels of contamination from vapor intrusion. Sub-slab sampling has been performed at least twice in each duplex, and indoor air samples gathered from the units with the highest sub-slab gas levels did not find hazardous levels. Indoor air sampling and modeling using empirical, radon-derived attenuation factors and sub-slab gas levels does not predict indoor air levels sufficient to cause harm to people's health from vapor intrusion. Further sampling of sub-slab gas is planned for the next 5 years to continue evaluation of temporal variability.

ATSDR cannot conclude whether or not harm may occur from vapors migrating to indoor air from subsurface containers that may harbor hazardous substances and become compromised by aging or physical disturbance. Five buildings are present with observed buried material beneath and another six buildings remain with possible buried material beneath. Materials observed to be present under buildings include drums, lead-acid batteries, paint cans, transformers, rockets, gas cylinders, fire extinguishers and discarded military munitions that could contain or produce toxic, asphyxiant, flammable or explosive gases. Jet assisted take-off bottles were also found in the vicinity of buildings. Most of the recovered material in the Taku Gardens area did not contain sufficient material to result in a health hazard. However, even a small chance of events occurring that could have a high consequence effect should be addressed.

V. Recommendations

Based upon review of the Taku Gardens data, ATSDR offers the following recommendations for protection of the health of future residents:

<u>Site characterization to further decrease uncertainty in spatial and temporal variability</u>

- Sampling of sub-slab gas in at least three locations is recommended for a representative number of residences to characterize the spatial variability of vapors in the sub-slab space.
- A comprehensive sampling of sub-slab soil gas during spring for all residences is recommended.
- Soil gas sampling collocated with utility lines and sampling of utility line access ports (manholes) may provide evidence for or against this preferential pathway.
- ATSDR supports continued periodic sampling up to and perhaps after five years, as long as containers possibly holding hazardous waste remain beneath buildings and contaminant sources remain at the site. Monitoring at appropriate intervals following any changes to the site for remedial action, such as degradation of chlorinated VOCs, is recommended.
- Monitoring should include analysis for SVOCs, such as naphthalene and aroclor 1232, as well as all other chemicals of concern found thus far, such as 1,2-dibromo-3-chloropropane.

<u>Future changes to conceptual site model</u>

- Future alterations to the hydrogeological setting or structures at the site may result in the need to reevaluate the potential for vapor intrusion. For example, installation of a new sewer line might provide new preferential pathways into the buildings that will need to be sealed and checked.
- ATSDR supports planned efforts to install sub-slab depressurization systems for duplexes over observed or possible residual debris. Installation of sub-slab depressurization systems in these buildings could prevent vapor intrusion of acutely hazardous vapors released rapidly from subsurface containers by drawing them from the space and venting them to outdoor air a safe distance from the house to allow dispersal and prevent exposure to hazardous levels. Performance of such a system would depend on sufficient depressurization beneath the entire slab in the areas of release.

Information for future residents

- ATSDR supports land use controls/institutional controls indicating that residents should immediately report odors to the Directorate of Public Works or emergency responders and vacate the area. Digging is also restricted.
- Individuals are advised to be aware of past operations in the Taku Gardens area and provided information to make wise decisions regarding LUCs/ICs and operation and maintenance of any mitigation systems that may be installed. ATSDR supports efforts of health education regarding:
    - the historical operations and nature of contamination at Taku Gardens
    - the nature and location of subslab depressurization systems or other remedial/exposure mitigation measures implemented
    - what to do if odors or visible contamination are noted
    - monitoring procedures, schedules and what to expect during and following monitoring events

VI. Public Health Action Plan

The public health action plan for the site contains a description of actions that have been or will be taken by ATSDR and other government agencies at the site. The purpose of the public health action plan is to ensure that this public health consultation both identifies public health hazards and provides a plan of action designed to mitigate and prevent harmful human health effects resulting from breathing, drinking, or touching hazardous substances in the environment.

<u>Public health actions that have been taken include:</u>

- The U.S. Army and its contractors
  - performed field screening, soil excavations, and debris removal during housing construction activities,
  - performed air, sub-slab soil gas, soil gas, and groundwater sampling,
  - conducted sub-slab depressurization system pilot testing on a select number of duplexes.
- ATSDR reviewed
  - existing historical information on FCS activities, waste disposal practices and environmental investigations,
  - proposed land use controls, institutional controls, and future monitoring plans
  - results and analysis of sub-slab depressurization system pilot testing.

<u>Public health actions that have been or will be implemented:</u>

- Completion of the ATSDR health consultation
- ATSDR may be available for technical assistance upon request
  - to review work-plans for future site characterization, remediation and mitigation and make recommendations to protect public health,
  - to review sampling data from follow-up environmental investigations and make recommendations to protect public health,
  - to review design and performance information for sub-slab depressurization systems.
- ATSDR may be available to assist in addressing health concerns upon request
  - by providing fact sheets on
    - past, present and future conditions,
    - the nature of environmental investigations and remedial actions,
    - protocols to follow should individuals encounter suspicious materials or odors;
  - by holding public availability sessions to discuss individuals' concerns and/or site related issues;
  - by collaborating with local physicians and medical infrastructures to help medical professionals interpret the potential for health effects from site-related environmental exposures, should any occur.

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Appendix A. ATSDR Glossary of Environmental Health Terms

The Agency for Toxic Substances and Disease Registry (ATSDR) is a federal public health agency with headquarters in Atlanta, Georgia, and 10 regional offices in the United States. ATSDR's mission is to serve the public by using the best science, taking responsive public health actions, and providing trusted health information to prevent harmful exposures and diseases related to toxic substances. ATSDR is not a regulatory agency, unlike the U.S. Environmental Protection Agency (EPA), which is the federal agency that develops and enforces environmental laws to protect the environment and human health. This glossary defines words used by ATSDR in communications with the public. It is not a complete dictionary of environmental health terms. If you have questions or comments, call the agency's toll-free number, 1-800-CDC-INFO (1-800-232-4636).

Absorption
The process of taking in. For a person or an animal, absorption is the process of a substance getting into the body through the eyes, skin, stomach, intestines, or lungs.

Acute
Occurring over a short time [compare with chronic].

Acute exposure
Contact with a substance that occurs once or for only a short time (up to 14 days) [compare with intermediate duration exposure and chronic exposure].

Adverse health effect
A change in body function or cell structure that might lead to disease or health problems

Ambient
Surrounding (for example, ambient air).

Attenuation
The decrease in concentration that typically occurs by dispersion, dilution, and other factors as vapors move from the subsurface into indoor air.

Background level
An average or expected amount of a substance or radioactive material in a specific environment, or typical amounts of substances that occur naturally in an environment.

Biologic uptake
The transfer of substances from the environment to plants, animals, and humans.

Biota
Plants and animals in an environment. Some of these plants and animals might be sources of food, clothing, or medicines for people.

Body burden
The total amount of a substance in the body. Some substances build up in the body because they are stored in fat or bone or because they leave the body very slowly.

Cancer
Any one of a group of diseases that occur when cells in the body become abnormal and grow or multiply out of control.

Cancer risk
A theoretical risk for getting cancer if exposed to a substance every day for 70 years (a lifetime exposure). The true risk might be lower.

Carcinogen
A substance that causes cancer.

Chronic
Occurring over a long time [compare with acute].

Chronic exposure
Contact with a substance that occurs over a long time (more than 1 year) [compare with acute exposure and intermediate duration exposure]

Comparison value (CV)
Calculated concentration of a substance in air, water, food, or soil that is unlikely to cause harmful (adverse) health effects in exposed people. The CV is used as a screening level during the public health assessment process. Substances found in amounts greater than their CVs might be selected for further evaluation in the public health assessment process.

Completed exposure pathway [see exposure pathway].

Concentration
The amount of a substance present in a certain amount of soil, water, air, food, blood, hair, urine, breath, or any other media.

Contaminant
A substance that is either present in an environment where it does not belong or is present at levels that might cause harmful (adverse) health effects.

Dermal
Referring to the skin. For example, dermal absorption means passing through the skin.

Dermal contact
Contact with (touching) the skin [see route of exposure].

Detection limit
The lowest concentration of a chemical that can reliably be distinguished from a zero concentration.

Dose
The amount of a substance to which a person is exposed over some time period. Dose is a measurement of exposure. Dose is often expressed as milligram (amount) per kilogram (a measure of body weight) per day (a measure of time) when people eat or drink contaminated water, food, or soil. In general, the greater the dose, the greater the likelihood of an effect. An "exposure dose" is how much of a substance is encountered in the environment. An "absorbed dose" is the amount of a substance that actually got into the body through the eyes, skin, stomach, intestines, or lungs.

Dose-response relationship
The relationship between the amount of exposure [dose] to a substance and the resulting changes in body function or health (response).

Environmental media
Soil, water, air, biota (plants and animals), or any other parts of the environment that can contain contaminants.

Environmental media and transport mechanism
Environmental media include water, air, soil, and biota (plants and animals). Transport mechanisms move contaminants from the source to points where human exposure can occur. The environmental media and transport mechanism is the second part of an exposure pathway.

EPA
United States Environmental Protection Agency.

Epidemiology
The study of the distribution and determinants of disease or health status in a population; the study of the occurrence and causes of health effects in humans.

Exposure
Contact with a substance by swallowing, breathing, or touching the skin or eyes. Exposure may be short-term [acute exposure], of intermediate duration, or long-term [chronic exposure].

Exposure assessment
The process of finding out how people come into contact with a hazardous substance, how often and for how long they are in contact with the substance, and how much of the substance they are in contact with.

Exposure pathway
The route a substance takes from its source (where it began) to its end point (where it ends), and how people can come into contact with (or get exposed to) it. An exposure pathway has five parts: a source of contamination (such as an abandoned business); an environmental media and transport mechanism (such as movement through groundwater); a point of exposure (such as a private well); a route of exposure (eating, drinking, breathing, or touching), and a receptor population (people potentially or actually exposed). When all five parts are present, the exposure pathway is termed a completed exposure pathway.

Geographic information system (GIS)
A mapping system that uses computers to collect, store, manipulate, analyze, and display data. For example, GIS can show the concentration of a contaminant within a community in relation to points of reference such as streets and homes.

Groundwater
Water beneath the earth's surface in the spaces between soil particles and between rock surfaces [compare with surface water].

Hazard
A source of potential harm from past, current, or future exposures.

Hazardous waste
Potentially harmful substances that have been released or discarded into the environment.

Health consultation
A review of available information or collection of new data to respond to a specific health question or request for information about a potential environmental hazard. Health consultations are focused on a specific exposure issue. Health consultations are therefore more limited than a public health assessment, which reviews the exposure potential of each pathway and chemical [compare with public health assessment].

Indeterminate public health hazard
The category used in ATSDR's public health assessment documents when a professional judgment about the level of health hazard cannot be made because information critical to such a decision is lacking.

Incidence
The number of new cases of disease in a defined population over a specific time period [contrast with prevalence].

Ingestion
The act of swallowing something through eating, drinking, or mouthing objects. A hazardous substance can enter the body this way [see route of exposure].

Inhalation
The act of breathing. A hazardous substance can enter the body this way [see route of exposure].

Intermediate duration exposure
Contact with a substance that occurs for more than 14 days and less than a year [compare with acute exposure and chronic exposure].

In vitro
In an artificial environment outside a living organism or body. For example, some toxicity testing is done on cell cultures or slices of tissue grown in the laboratory, rather than on a living animal [compare with in vivo].

In vivo
Within a living organism or body. For example, some toxicity testing is done on whole animals, such as rats or mice [compare with in vitro].

Lowest-observed-adverse-effect level (LOAEL)
The lowest tested dose of a substance that has been reported to cause harmful (adverse) health effects in people or animals.

Metabolism
The conversion or breakdown of a substance from one form to another by a living organism.

Metabolite
Any product of metabolism.

mg/kg
Milligram per kilogram.

Migration
Moving from one location to another.

Minimal risk level (MRL)
An ATSDR estimate of daily human exposure to a hazardous substance at or below which that substance is unlikely to pose a measurable risk of harmful (adverse), noncancerous effects. MRLs are calculated for a route of exposure (inhalation or oral) over a specified time period (acute, intermediate, or chronic). MRLs should not be used as predictors of harmful (adverse) health effects [see reference dose].

No apparent public health hazard
A category used in ATSDR's public health assessments for sites where human exposure to contaminated media might be occurring, might have occurred in the past, or might occur in the future, but where the exposure is not expected to cause any harmful health effects.

No-observed-adverse-effect level (NOAEL)
The highest tested dose of a substance that has been reported to have no harmful (adverse) health effects on people or animals.

No public health hazard
A category used in ATSDR's public health assessment documents for sites where people have never and will never come into contact with harmful amounts of site-related substances.

Pica
A craving to eat nonfood items, such as dirt, paint chips, and clay. Some children exhibit pica-related behavior.

Point of exposure
The place where someone can come into contact with a substance present in the environment [see exposure pathway].

Population
A group or number of people living within a specified area or sharing similar characteristics (such as occupation or age).

Prevalence
The number of existing disease cases in a defined population during a specific time period [contrast with incidence].

Prevention
Actions that reduce exposure or other risks, keep people from getting sick, or keep disease from getting worse.

Public health hazard
A category used in ATSDR's public health assessments for sites that pose a public health hazard because of long-term exposures (greater than 1 year) to sufficiently high levels of hazardous substances or radionuclides that could result in harmful health effects.

Public health hazard categories
Public health hazard categories are statements about whether people could be harmed by conditions present at the site in the past, present, or future. One or more hazard categories might be appropriate for each site. The five public health hazard categories are no public health hazard, no apparent public health hazard, indeterminate public health hazard, public health hazard, and urgent public health hazard.

Public health statement
The first chapter of an ATSDR toxicological profile. The public health statement is a summary written in words that are easy to understand. The public health statement explains how people might be exposed to a specific substance and describes the known health effects of that substance.

Public meeting
A public forum with community members for communication about a site.

Receptor population
People who could come into contact with hazardous substances [see exposure pathway].

Reference dose (RfD)
An EPA estimate, with uncertainty or safety factors built in, of the daily lifetime dose of a substance that is unlikely to cause harm in humans.

Remedial investigation
The CERCLA process of determining the type and extent of hazardous material contamination at a site.

Risk
The probability that something will cause injury or harm.

Risk reduction
Actions that can decrease the likelihood that individuals, groups, or communities will experience disease or other health conditions.

Risk communication
The exchange of information to increase understanding of health risks.

Route of exposure
The way people come into contact with a hazardous substance. Three routes of exposure are breathing [inhalation], eating or drinking [ingestion], or contact with the skin [dermal contact].

Safety factor [see uncertainty factor]

Sample
A portion or piece of a whole. A selected subset of a population or subset of whatever is being studied. For example, in a study of people the sample is a number of people chosen from a larger population [see population]. An environmental sample (for example, a small amount of soil or water) might be collected to measure contamination in the environment at a specific location.

Sample size
The number of units chosen from a population or an environment.

Source of contamination
The place where a hazardous substance comes from, such as a landfill, waste pond, incinerator, storage tank, or drum. A source of contamination is the first part of an exposure pathway.

Special populations
People who might be more sensitive or susceptible to exposure to hazardous substances because of factors such as age, occupation, sex, or behaviors (for example, cigarette smoking). Children, pregnant women, and older people are often considered special populations.

Statistics
A branch of mathematics that deals with collecting, reviewing, summarizing, and interpreting data or information. Statistics are used to determine whether differences between study groups are meaningful.

Substance
A chemical.

Surface water
Water on the surface of the earth, such as in lakes, rivers, streams, ponds, and springs [compare with groundwater].

Toxic agent
Chemical or physical (for example, radiation, heat, cold, microwaves) agents that, under certain circumstances of exposure, can cause harmful effects to living organisms.

Toxicological profile
An ATSDR document that examines, summarizes, and interprets information about a hazardous substance to determine harmful levels of exposure and associated health effects. A toxicological profile also identifies significant gaps in knowledge on the substance and describes areas where further research is needed.

Toxicology
The study of the harmful effects of substances on humans or animals.

Uncertainty factor
Mathematical adjustments for reasons of safety when knowledge is incomplete. For example, factors used in the calculation of doses that are not harmful (adverse) to people. These factors are applied to the lowest-observed-adverse-effect-level (LOAEL) or the no-observed-adverse-effect-level (NOAEL) to derive a minimal risk level (MRL). Uncertainty factors are used to account for variations in people's sensitivity, for differences between animals and humans, and for differences between a LOAEL and a NOAEL. Scientists use uncertainty factors when they have some, but not all, the information from animal or human studies to decide whether an exposure will cause harm to people [also sometimes called a safety factor].

Urgent public health hazard
A category used in ATSDR's public health assessments for sites where short-term exposures (less than 1 year) to hazardous substances or conditions could result in harmful health effects that require rapid intervention.

Other glossaries and dictionaries:
Environmental Protection Agency (http://www.epa.gov/OCEPAterms/)
National Library of Medicine (NIH) (http://www.nlm.nih.gov/medlineplus/mplusdictionary.html)

Appendix B. Vapor Intrusion Screening Checklist

This is a list of several factors that identify the potential for vapor intrusion. This checklist is not an exhaustive list of all the factors that suggest vapor intrusion, but includes the most common factors identified within ATSDR's work as of 2/11/2011. This checklist identifies the potential for the pathway, not the magnitude or the risk. Check a box if the factor exists or use: No, NA (Not Applicable), and UK (unknown).

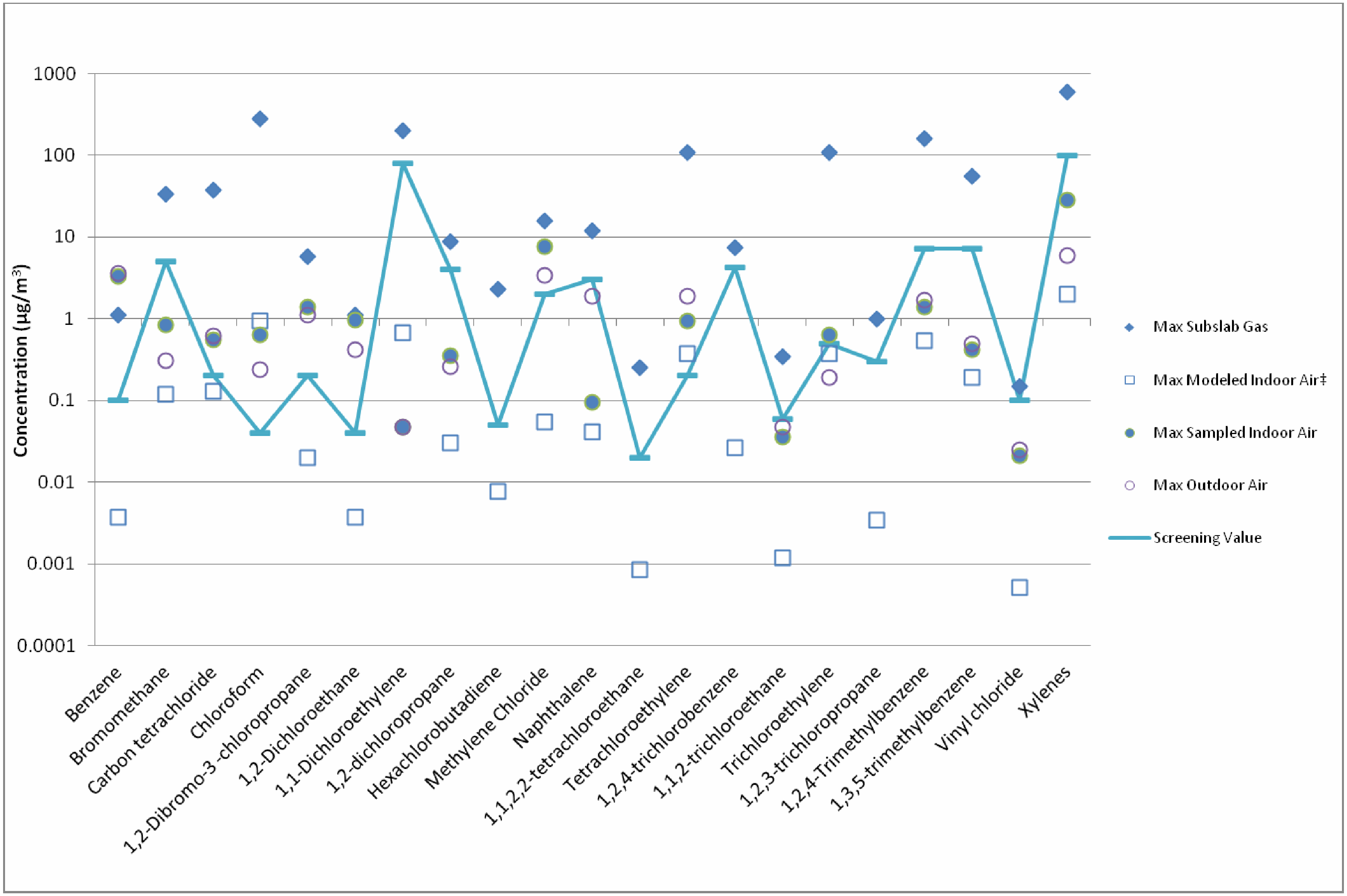
1) Sources on the property or nearby
   - X Contaminated groundwater (measurement if available) see CH2MHILL 2010b
   - X Contaminated soil (soil vapors detected, measurement) see CH2MHILL 2010b
   - ❑ USTs on or near property –(circle one) with without product
   - X Indoor air vapors detected
2) Pervious foundation
   - ❑ No foundation
   - ❑ Post and beam construction
   - ❑ Cracks in foundation
   - ❑ Basement
   - ❑ No moisture barrier
3) Conveyance to/into building
   - ❑ Unsealed electrical conduits
   - ❑ Unsealed plumbing
   - ❑ Lack of water trap
   - X Pressure gradient flow is enhanced (decomposing material, landfill, etc) extremely cold and icy climate
   - ❑ Fractured bedrock
   - X Heterogeneous fill (note kind if available) frost/heave, possible ice shelves, localized source & debris excavation followed by fill that may differ from native subsurface
   - ❑ Tree roots into building
   - X Other preferential pathways observed ice cap in the surrounding area with possible neighborhood-wide permafrost melt bulb created under buildings
4) Stack effect
   - X Heated building (2-story)
   - ❑ HVAC influence (positive pressure, fresh air supply, intake/exhaust location, etc)
   - ❑ Tall building
   - ❑ Adjacent buildings are not as warm in winter
5) Sub-surface influence (hydrologic pumping)
   - ❑ Intense drought followed by high rain events (wet dog effect)
   - X Tidally-influenced groundwater – rapid river rise due to snow melt may translate to rapid rise in groundwater
   - ❑ Shallow groundwater (less than 15 ft) below lowest level – depth to groundwater averages about 15 ft; potable wells are screened at 60-80'
   - X Property adjacent to building is impervious (circle: ice, concrete, pavement, or other building) – seasonal solid ice/snow
   - X Soil Type – gravel, sand, permafrost in region, but ruled out under housing

6) Conditions during inspection or during sampling
- ❑ Weather conditions (rainy/clear/recently rained)____________________
- ❑ Soil moisture __________________________
- ❑ Soil Grain Observation __________________

Notes: Place any sampling data or additional information here that helps to validate or refute the pathway. For example: common chemicals in subsurface and indoor air.

1) Sources on the property or nearby – leakage from heating oil tanks, operational solvent releases, soil excavations were performed (where PCBs were detected and for subsurface debris detected by magnetometry around housing), soil gas not correlated with groundwater contamination
2) Pervious foundation
3) Conveyance to/into building - possible utility conduit migration
4) Stack effect
5) Sub-surface influence (hydrologic pumping) snow melt into adjacent river may cause rapid groundwater rise, buried debris known or suspected beneath bldg 15, 17, 22, 24, 48, 49
6) Conditions during inspection or during sampling
   - Sampling events in December and August span seasonal extremes.
   - Conditions 68 degrees indoors, except the Oct 2008 sampling event.
   - See CH2MHILL 2010b for many more details

Appendix C - Figure: Comparison of Air and Soil Gas Values for Chemicals Exceeding Screening Values in Sub-slab Gas



Appendix D - Evaluating Vapor Intrusion Pathways at Hazardous Waste Sites

Agency for Toxic Substances and Disease Registry (ATSDR), 2008. *Evaluating Vapor Intrusion Pathways at Hazardous Waste Sites,* Atlanta: US Department of Health and Human Services, Feb 6, 2008.
Available online at: http://www.atsdr.cdc.gov/document/evaluating_vapor_intrusion.pdf

Introduction

Volatile organic chemicals (VOCs), such as solvents, are among the most common contaminants released into the environment from hazardous waste sites. In addition to contaminating groundwater and soils, these chemicals may off-gas from soils and groundwater and seep into the air of homes and commercial buildings. Asphyxiating and flammable gases can also behave similarly to VOCs, in addition to some non-organic volatiles, such as mercury, radon, carbon dioxide, hydrogen sulfide and sulfur dioxide. This movement of volatile chemicals and gases from soil and groundwater into indoor air is known as the vapor intrusion pathway.

Designed for environmental health professionals, this document focuses on how to evaluate the public health implications of vapor intrusion. This document is being issued as a technical supplement to the January 2005 Public Health Assessment Guidance Manual (PHAGM) prepared by the Agency for Toxic Substances and Disease Registry (ATSDR). As a supplement, the discussion will not repeat the basic concepts and processes of the public health assessments found in the PHAGM (http://www.atsdr.cdc.gov/HAC/PHAManual/index.html) (1).

Although sometimes associated with VOC contaminated groundwater, landfill gas will not specifically be addressed in this document. For a discussion of landfill gas, readers should review the ATSDR Landfill Gas Primer at http://www.atsdr.cdc.gov/HAC/landfill/htm/intro.html (2).

Since the 1980s, vapor intrusion has been the subject of increasing research and scientific discussion. However, the research and discussion did not yield a national consensus on methods of evaluation until 2002. Problems in consistent characterization of vapor intrusion at hazardous waste sites led the U.S. Environmental Protection Agency (EPA) to issue draft guidelines in 2002 (http://www.e.pa.gov/epaoswer/hazwaste/ca/eis/vapor.htm) (3). Many state health and environmental agencies have also issued their own guidelines for evaluating vapor intrusion. The majority of the state guidelines appear to follow the approach proposed by EPA with the addition of state-specific screening levels for contaminants. Many states are developing vapor intrusion guidance, and a frequently updated list of state guidance documents is available at http://www.envirogroup.com/links.php (4). Recently, a comprehensive guidance document on vapor intrusion was prepared by scientists and engineers from 19 state and four federal agencies and members of the regulated community and released by the Interstate Technology and Regulatory Council (ITRC; http://www.itrcweb.org) (5).

This document does not attempt to duplicate the in-depth information provided by EPA, state agencies, or the ITRC. Instead, the guidance documents prepared by other agencies are used as references and springboards for discussion of public health practices when evaluating vapor intrusion. In particular, the ITRC document, *Vapor Intrusion: A Practical Guideline* (http://www.itrcweb.org/Documents/VI-l.pdf) (5) is recommended for use by health assessors as a reference for vapor intrusion issues. The ITRC vapor intrusion guidance is intended to aid regulatory agencies in their investigation and remediation of vapor intrusion problems. The ITRC guidance also includes a discussion (Appendix H) of how screening levels are created and used by state agencies.

As a document intended for internet publication, links to appropriate references and source documents, such as the ITRC guidance noted above, will be provided throughout this document. Readers are forewarned that these links may not be updated. If a link fails, readers are encouraged to use appropriate search programs to find the updated web address, assuming the document is still available on the internet.

ATSDR recognizes that many environmental and health organizations have developed excellent resources to evaluate vapor intrusion fate and transport. ATSDR uses the information gained from vapor intrusion fate and transport analyses to determine if exposure to a contaminant poses a health hazard. This evaluation requires a tool that provides dependable information for making health conclusions. ATSDR finds that some guidances serve ATSDR's mission better for some site-specific criteria. Therefore, this document was developed to assist health assessors with choosing from the many available policies for their site-specific needs.

What are the health risks from the vapor intrusion pathway?

As discussed in the Wisconsin Department of Health guidance on chemical vapor intrusion and residential air (http://dhfs.wisconsin.gov/eh/Air/pdf/VI guide.pdf) (6), vapor intrusion into indoor air can be of public health concern because volatile organic compounds (VOCs) in air are readily absorbed by the lungs. If groundwater is contaminated with VOCs, inhalation of VOCs from groundwater may pose a greater hazard than drinking the water. Intrusion of contaminated soil gases into indoor air may lead to the following health and safety issues: fire, explosion and acute, intermediate and chronic health effects. Asphyxiation is a possible but less likely problem.

Fire and explosion

Vapors from leaking buried fuel tanks and fuel pipelines may enter nearby occupied buildings; creating the potential for fire and explosion if they accumulate to sufficient concentration in a confined space such as a basement room or a utility room. If carried by shallow groundwater, the fuels tend to stay at the top of the saturated zone in relatively high concentrations and thereby increase the potential for entry into any building basement or a buried utility system (i.e. storm sewers) that might intercept a high water table.

Acute health effects

Acute (short term) health effects from VOCs include headaches, nausea, eye and respiratory irritation. Such health effects are sometimes associated with petroleum-based air contaminants, such as diesel fuel and heating oils. Benzene is a chemical associated with fuel vapors that may be acutely irritating at low levels (http://www.epa.gov/ttn/atw/hlthef/benzene.html) (7). People with pre-existing respiratory problems (such as asthma and chronic obstructive pulmonary disease) and children may be affected more than healthy adults.

Intermediate health effects

Health effects from intermediate duration exposures (14 days to 364 days) to VOCs can include liver, neurological and reproductive effects. Few studies involving human exposures have been performed for intermediate duration exposures. However, effect levels observed in animal studies are modified by safety factors to give conservative values for screening. If these screening values are exceeded, ATSDR's Toxicological Profiles (http://www.atsdr.cdc.gov/toxpro2.html) (8) and current toxicological literature should be consulted to evaluate potential health effects. Chapter 8 of ATSDR's PHAGM provides guidance on the in-depth analysis of health effects.

Chronic health effects

Health effects associated with long-term inhalation of air contaminants include both cancer and non-cancer health effects. The non-cancer health effects most frequently associated with inhalation of relatively high levels of chlorinated VOCs are damage to the liver, kidneys, and nervous system.

Cancer health effects

Many VOCs are classified as known human carcinogens or reasonably anticipated to be a human carcinogen. For many carcinogenic chemicals, there is no clear threshold below which there is no increased risk of cancer. Therefore, even though most indoor air concentrations of chemicals from vapor intrusion are not likely to result in observable increases in cancer rates for exposed populations, prudent public health practice is to minimize exposures to cancer causing chemicals.

Asphyxiation

Infiltrating vapors, particularly heavier than air gases such as carbon dioxide, can displace and reduce the oxygen in occupied spaces to below life sustaining levels. Though low indoor air oxygen levels have resulted from infiltration of landfill and petroleum derived gases, the asphyxiation hazard has not been associated with infiltration of chlorinated VOCs.

When should a vapor intrusion pathway be evaluated?

There are two basic criteria for determining if it is necessary to evaluate vapor intrusion at a hazardous waste site. First, volatile contaminants must be present in the subsurface, and second, buildings must be laterally and vertically close enough to the subsurface contaminants for concentrations above health concern levels to reach indoor breathing zones. The 2005 California Department of Toxic Substances Control guidance at http://www.dtsc.ca.gov/loader.cfm?url=/commonspot/security/getfile.cfm&pageid=11492. (9)

discusses these criteria in more detail. Future use of contaminated areas should also be considered.

Why is it so difficult to assess the public health hazard posed by the vapor intrusion pathway?

Vapor intrusion is a complex problem with multiple variables (factors) and often too few measurements. Determining the environmental health hazards from air contaminants in homes and commercial buildings is often difficult because of the dynamic nature of the media and the need to assess the entire period of time people are inhaling the contaminants.

The concentrations of contaminants entering the indoor air from subsurface are dependent upon site and building specific factors such as building construction, number and spacing of cracks and holes in foundation, and the impact of the heating and air conditioning system on increasing or decreasing flow from the subsurface. Soil type and moisture between the building and source area, time of year, and tidal effects also affect vapor migration to indoor air.

Health assessors are seldom provided with adequate information to discriminate the contribution of vapor intrusion contaminants from other sources of indoor air contamination. Common sources of indoor air contaminants include household products, stored fuels, furniture, flooring products, dry cleaned clothing, and outdoor air contaminants. In addition, indoor air is a dynamic media with frequent changes in air flow and air composition. Concentrations of air contaminants may change significantly over the course of a single day as a result of air exchange with outside air or the introduction of a temporary source of contaminants, such as furniture polish or paint.

What is the best approach for a public health evaluation of the vapor intrusion pathway?

Many experienced investigators, including those who produced the ITRC guidance, believe that a multiple lines of evidence approach provides the best means of evaluating the vapor intrusion pathway. Such an approach is used in the public evaluation steps described in the following section.

Public Health Evaluation

The EPA and ITRC guidance documents and most of the state guidance documents establish a multiple lines of evidence approach to evaluating vapor intrusion. For example, the ITRC guidance has a 13 step approach that includes gathering information on multiple lines of evidence such as subsurface samples, preferential pathways, geology, soils, and building conditions. This document recommends a very similar approach with several steps that parallel the ITRC guidance. The major parts of a public health evaluation are Pathway Analysis, Exposure Evaluation, Health Implications, and Conclusions and Recommendations.

Outline of Evaluation Process (detailed explanation of evaluation steps starting with Step 4 follows outline)

I. Pathway Analysis

1. Are there subsurface volatile chemicals reported or suspected?
2. Are there occupied buildings within 100 feet laterally or vertically of volatile subsurface contaminants? If the answer is no, are preferential pathways (such as mining shafts, utility conduits, fractures or karst features) present that may result in transport over unusually long distances to occupied buildings?
3. Are reported concentrations of volatile subsurface contaminants near the buildings documented to be, or plausibly above applicable screening levels? Appendix H of the ITRC guide discusses the development and application of screening levels.

If the answer to any of the 3 questions above is no, then human exposure to harmful levels of contaminants from vapor intrusion is unlikely. If the answer to all three questions is yes, continue the evaluation process with the following steps.

4. Begin developing and improving Conceptual Site Model (described below).
5. Search for evidence of any urgent public health hazards such as fire and explosion hazards or potential exposures to free product.
6. Evaluate distance between contaminants and occupied buildings.
7. Evaluate environmental information, environmental concentrations of contaminants in nearby soil, groundwater, and soil gas, and potential background sources.
8. Evaluate building construction characteristics, such as basements, sumps, drainage, ventilation systems, relative elevation, and other critical features.
9. Check for any preferential transport pathways from contaminated soil or groundwater toward occupied buildings (i.e. buried utility lines, known shallow fracture flow zones, or solution channels).

II. Exposure Evaluation (Dose Estimation)

10. Are there valid indoor air measurements to use for dose calculation?
11. If there there are no valid indoor air measurements, are there sub-slab soil gas measurements and other site specific information that can be used to estimate indoor air concentrations using reasonable but conservative attenuation factors from observations (Dawson, Hers, & Truesdale, 2007) (17) or from appropriate models, such as the Johnson and Ettinger model

(http://www.epa.gov/oswer/riskassessment/ainnodellpdfl2004_0222_3phase_user s~de.pdf) (18)?

12. Request further site specific information and measurements if the answer to the items 10 & 11 above is negative.

III. Public Heath Implications

13. If a valid exposure dose can be estimated from information discussed in Part II, proceed to evaluate the public health implications as described in the Public Health Assessment Guidance Manual.

IV. Public Health Conclusions and Recommendations, and Public Health Action Plan

14. Follow the Public Health Assessment Guidance Manual

Detailed Explanation of Evaluation Steps-starting with Step 4.

Step 4) Conceptual Site Model:

Develop and improve a conceptual model of the site and the pathway as you gather, review, and evaluate site specific information. Depending on the need for detailed analyses and reporting, the conceptual site model (CSM) may only be a mental visualization or may be a written or graphic description of the site and the vapor intrusion pathway.

As discussed in the New Jersey Department of Environmental Protection Vapor Intrusion Guidance (http://www.nj.gov/dep/srp/guidance/vaporintrusion/) (10), the basic components of a CSM are: known or suspected contaminant sources, contaminant migration pathways, potential human receptors, and the exposure routes by which these receptors may come in contact with contaminants on a site specific basis.

Sometimes the source of the VOCs reported in private and monitoring groundwater wells is not known or multiple sources are suspected rather than a single source. Even without a specific source, a CSM can still be constructed that provides a visualization of contaminant movement from groundwater toward indoor air.

Spatial information, both vertical and horizontal, such as maps, aerial photography, borehole logs, and regional or local stratigraphy, is very useful for formulating a CSM. For sites involving several buildings spread over more than a city block area geographic information systems (GIS) provide extremely useful analytical and visualization tools for CSMs and pathway analyses.

In developing the CSM, pay particular attention to the lateral and vertical distances between sample locations of contaminants and the locations of occupied buildings and subsurface work areas (i.e. buried utilities with man-hole access). For example, determine the lateral and vertical distance from a monitoring well with reported concentrations of a VOC and the basement of a nearby residence. For additional information on CSM, health assessors are referred to section 2.1 (page 12) of the ITRC guidance titled Developing a Conceptual Site Model.

Step 5) Evaluate Presence of Urgent Public Health Hazards:

When reviewing information on the site, first check for any urgent public health hazards such as fire, explosion, oxygen depletion or the presence of free product. For example, ATSDR found flammable levels of methane and Threshold Limit Value (TLV) levels of hydrogen sulfide while investigating indoor air impacted by groundwater at Cady Road, Ohio (http://www.atsdr.cdc.gov/NEWS/cadyroad pr 082902.html) (11). If residents or building occupants report unexplainable (no known indoor sources such as fuel tanks or leaking fuel lines), persistent and pervasive fuel odor within the home or building, local fire officials should be contacted to check for possible flammable or explosive conditions. Also local fire officials should be contacted to check oxygen levels in homes or buildings if occupants voice combined complaints about headaches or dizziness and problems such as pilot lights going out. Seeping carbon dioxide or other gases might be replacing the oxygen in the same portion of the building. The National Institute for Occupational Safety and Health (NIOSH) Pocket Guide to Chemical Hazards lists safety hazards associated with specific chemicals from exposures in an occupational setting (http://www.cdc.gov/niosh/npg/)(12).This topic is also discussed in section 2.3 (page 15) of the ITRC guidance titled Step 1: Does the Site Represent an Acute Exposure Concern?

Step 6) Evaluate Subsurface Environment:

Evaluate the distance between subsurface sources of VOCs (e.g., contaminated groundwater and soil gas) and occupied buildings. According to EPA and state guidance documents, buildings 100 feet beyond the edge of groundwater or soil-gas with concentrations of contaminants above applicable screening levels are less likely to be affected by harmful levels of contaminated gases entering by vapor intrusion than buildings within 100 feet of screening levels. A vertical distance of 100 feet between bottom floor of a building and the top of a contaminated groundwater zone is also often considered an adequate buffer. Both distances assume no preferential pathways are present and other factors such as fluctuations in groundwater levels are minimal. For further discussion of distance between source and buildings, health assessors should review section 2.6 (page 16) of the ITRC guidance titled Step 4: Are Buildings Located in Close Proximity to Volatile Chemicals in Soil, Soil Gas, or Groundwater?

Step 7) Evaluate Environmental Information:

Evaluate the reported contaminant concentrations in groundwater, soil gas and indoor air and the sample locations. As with all environmental health issues (see PHAGM), evaluate the applicability of the sampling and analytical methodology before using the reported results for further public health evaluation. Review Chapter 2 (Investigation of the Soil Vapor Intrusion Pathway) and Chapter 3 (Data Evaluation and Recommendations for Action) from the New York State Department of Health guidance document for more detailed information (http://www.health.state.ny.us/nysdoh/gas/svi guidance/docs/svi main.pdf) (13).

Please note that the presence of indoor air contaminants does not always indicate a completed pathway from the subsurface to indoor air. Always evaluate the presence and concentrations of indoor air contaminants in relation to all sources of contaminants, including the range of background concentrations found in surveys of indoor air contaminants. The New York State Department of Health guidance provides several tables of background concentrations for indoor air contaminants in Appendix C.

Evaluating the applicability of background data to individual sites is recommended on a site-by-site basis. If background sources are present, the EPA Introduction to Indoor Air Quality website (http://www.epa.gov/iaq/ia-intro.htmJ)(15) can be consulted for general information about indoor air pollutants and improving indoor air quality. Data evaluation and background concentrations are discussed in Section 2.4 (page 15) and Section 3.5.4 (page 28) of the ITRC guidance. The Minnesota Department of Health also provides a useful guidance entitled Indoor Air Sampling at VOC Contaminated Sites: Introduction, Methods, and Interpretation of Results at the following website:
http://www.health.state.mn.us/divs/eh/hazardous/topics/iasampling0l06.pdf(14).

Step 8) Evaluate Building Construction:

Evaluate building construction characteristics, such as foundation type (e.g., basement, slab, crawl-space), foundation condition (e.g., cracks or other openings in basement floors and walls; blocked crawlspace vents), sumps, ventilation systems, drainage, relative elevation, and other critical features. Some construction (post and beam) is largely variable with respect to retarding vapor intrusion. Tightly sealed buildings commonly found in cold climates are more prone to vapor intrusion than houses with vented crawl spaces found in warmer regions. For more information see the building features discussion on page 2 of the Wisconsin Department of Health guidance at the following website: http://www.dhfs,wisconsin.gov/eh/Air/pdf/VI guide.pdf. Also, the ITRC guidance contains (Appendix G) the building checklist developed by the New York Department of Health.

Step 9) Preferential Pathways:

Check for any preferential transport pathways from contaminated soil or groundwater toward occupied buildings. Drains, trenches, and buried utility corridors (such as tunnels and pipelines) can act as conduits for gas movement The natural geology often provides underground pathways, such as fractured rock, porous soil and buried stream channels, where the gas can migrate. Fluctuations in groundwater levels from flooding or tidal influence may hydraulically flush soil gases to the surface. During the winter time, frozen soils may impede VOCs from escaping from open ground surfaces, thereby increasing the migration of VOCs through unfrozen soil under buildings.

Step 10) Are there valid indoor air measurements to use for dose calculation?

Health Assessors should review the indoor air sampling plan and *QNQC* plan to determine if the analytical results are adequate for making public health decisions. The sampling plans can be compared with the recommendations for indoor air sampling in the New York State Health Department guidance for indoor air (http://www.health.state.ny.us./nysdoh/indoor/docs/guidance.pdf) and the New York State Health Department guidance for vapor intrusion (http://www.health.state.ny.us/enviromnental/investigations/soil gas/svi guidance/docs/svi main.pdf). As noted in the NYSDOH guidance, the health assessor should check the analytical methods used to determine validity and compatibility with EPA analytical methods.

As a reminder, the indoor air samples cannot distinguish whether the source is from vapor intrusion, ambient air, or transient sources such as commercially dry cleaned clothing stored in a closet. Therefore the indoor air results should be compared with ambient air samples and soil gas samples (particularly sub-slab soil gas samples) taken at the same location and time to evaluate the potential for these media to be the source of indoor air contamination. If possible, information should include more than a single point in time sampling. Low confidence is generally attributed to decisions based on one sampling event, unless there is clear evidence that this will result in a health protective decision. Outdoor air monitoring that reflects seasonal variations for the site should provide a better basis for an exposure estimate. The California guidance recommends at least a late summer/early fall sample in addition to a late winter/early spring sample. Page D-22 of the ITRC guide also discusses indoor air sample locations and frequency.

Step 11) What if no valid indoor air measurements are available?

If no valid indoor air measurements are available, determine if there is sufficient site specific information (such as sub-slab soil gas samples, or crawlspace air samples) to estimate indoor air measurements. When using results from sub-slab gas samples, crawlspace air samples, or groundwater samples, reasonable but conservative attenuation factors should be used in estimating indoor air concentrations. The ITRC guidance document provides more information on using sub-slab gas samples on pages 24 and 39 and more information on attenuation factors on pages H-2, B-3, H-9 and H-10. A recent compilation by EPA of measured attenuation factors from groundwater and sub-slab to indoor air reported a 95^{th} percentile attenuation factor of about 0.02 for sub-slab vapor to indoor air (Dawson, Hers, & Truesdale 2007) (17). This database is expected to become publicly available in the near future for review of the information by all interested parties.

When no sub-slab gas, soil gas or crawlspace air measurements are available, an environmental transport model, such as the Johnson and Ettinger vapor intrusion model, can be used with conservative assumptions to estimate indoor air concentrations of VOCs moving from groundwater through the soil column and into an occupied building. However, even the best model can lead to erroneous estimates if input parameters do not correctly characterize site specific conditions, such as depth to groundwater, soil type, soil moisture, and structure characteristics; as well as building features such as sump pumps, earthen floors, fieldstone walls, crawlspaces, etc. Please review the ATSDR Division of Health Assessment and Consultation (DHAC) guidance on use of fate and transport models at http:/intranet.cdc.gov/nceh-atsdr/dhac/hac modeling.pdf. Also carefully review the guidance provided by USEPA (http://www.epagov/athens/publications/reports/Weaver600R05106ReviewRecentResearch.pdf) before using any model to estimate indoor air concentrations.

Cases where groundwater monitoring results were below detection limits have been found to exhibit elevated soil gas contaminant levels. Consequently, groundwater results alone may not accurately predict susceptibility of buildings to the vapor intrusion pathway. Field verification sampling is strongly encouraged to confirm model results, particularly when the model suggests the site poses no risk.

Also consider whether collecting additional environmental measurements might be a better use of resources instead of modeling if too many site specific parameters, such as soil moisture and soil type, are unknown or if there is too much variability across the site for other parameters, such as building construction. Supplemental measurements might also be wise if previous sampling was performed after recent precipitation or unusual meteorological events (ITRC guidance, D-27 and D-28).

Before using a model or requesting additional environmental measures, check requirements of state specific guidance for vapor intrusion. Some state guidelines require additional investigation if groundwater and/or soil gas measurements exceed published screening values.

Step 12) Request further site specific information and measurements if there are no indoor air data and sufficient information is not available to estimate indoor air concentrations based on observed attenuation factors or modeling.

When requesting additional information, consider both the quantity and quality of environmental measurements needed to estimate an exposure dose. If multiple occupied buildings may be impacted, how many and which buildings should be sampled? Consider the cost and intrusiveness of both sub-slab sampling and indoor air sampling. For additional information on alternatives for additional environmental measurements, health assessors should review Chapter 3 of the ITRC vapor intrusion guidance.

Step 13) If a valid exposure dose can be estimated from information discussed in Part II, proceed to evaluate the public health implications as described in the Public Health Assessment Guidance Manual.

Step 14) Follow the PHAGM to provide the appropriate Public Health Conclusions, Recommendations, and Public Health Action Plan.

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[ATSDR 2008] Appendix A.

Lessons learned from health assessments of Ohio vapor intrusion sites

From Robert Frey, Ph.D., Ohio Department of Health

~ Current vapor intrusion models have limited utility with regard to predicting impacts of vapor intrusion on residential and commercial structures

~ Vapor intrusion sites have to be investigated and evaluated on a site specific basis -Ohio sites have indicated numerous exceptions to some of the generalities that have been made to date with regard to the vapor intrusion pathway

~ These evaluations are only as good as the data collected to support these investigations -more accurate diagnoses come when you have all of the data groundwater, deep soil gas, sub-slab soil gas, and indoor air -not just one or two pieces of the puzzle

~ Soil gas levels are often an order of magnitude or more higher than groundwater concentrations (ex. Springfield Street site: maximum PCE in groundwater =257 ppb versus PCE in soil gas at 7,700 ppb/v; Behr-Dayton site: maximum TCE in groundwater = 16,000 ppb versus TCE in soil gas at 160,000 ppb/v)

~ Residences with crawl spaces and dirt floors may actually have lower levels of vapor-phase VOCS indoors than homes with concrete basements (homes with crawl spaces are often vented to the outside and typically are less "energy efficient" than homes with finished basements)

~ Important to establish a public health team (including the local health department) to support the environmental protection agencies enforcement activities and establish good contacts and communications with the impacted communities to better facilitate the investigations and corrective actions that might be taken

[ATSDR 2008] Appendix B.

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