Colorado Department Of Public Health And Environment

Hazardous Materials And Waste Management Division

Colorado Department of Public Health and Environment

DRAFT

INDOOR AIR GUIDANCE

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1.0 INTRODUCTION

At sites where soil or ground water contain volatile organic compounds (VOCs), there is the potential for chemical vapors to migrate through subsurface soils or along underground utility lines and into the indoor air spaces of overlying buildings. In some cases, these vapors may accumulate at concentrations that pose short-term safety hazards (e.g., fire and explosion, or acute health effects) or aesthetic problems such as odors. More commonly, the chemical concentrations are lower, and the main concern is whether the building occupants are experiencing health effects due to longer term chronic exposures to chemical vapors. The intended purpose of this document is to provide guidance to those facilities needing to determine whether chemical releases to soil or ground water have the potential to contribute to indoor air contamination, and what actions are necessary if this exposure pathway is determined to be complete.

The indoor air exposure pathway is different from other pathways for several reasons. First, assessment of the vapor intrusion pathway has a much shorter history than the assessment of other pathways, such as ingestion of ground water. Consequently, the key issues and technical challenges are not as well understood. Second, available response actions are more limited in number. Eliminating the exposure is not as simple as offering bottled water to residents. Third, the assessment of this pathway is more complex because of the many variables that influence the movement of vapors through the subsurface into buildings. This is further complicated by the fact that, in some instances, ambient background levels can exceed health-based air concentrations for some commonly used chemicals. There are typically dozens of detectable chemicals in indoor air from sources such as cleaners, paint, glues, etc., even in the absence of subsurface contributions. Vapors attributable to ambient indoor and outdoor sources need to be considered when assessing the completeness of this pathway.

1.1 USE OF THIS GUIDANCE DOCUMENT

The purpose of this document is to provide predictable and consistent, yet flexible guidance for evaluating and responding to the intrusion of hazardous vapors into buildings overlying chemical waste materials and/or contaminated environmental media. Although a process is outlined to assist users of this document, it must be understood that this issue is complex and its resolution cannot be determined using a rigid formula in every instance. Flexibility is warranted, based on 1) consideration of site-specific factors and 2) incorporation of new information, procedures, and technology as they develop in this rapidly changing field of science. As knowledge of this exposure pathway evolves with the collection of new data, so too should our response actions. As our collective experience working on this exposure pathway increases, the expectation is that this guidance document will be updated to incorporate new information and techniques learned from evaluating and responding to indoor air impacts and the associated risk.

It is assumed that the reader is versed in general procedures and protocols associated with environmental sampling and analysis since this document is not a primer on scientific method, but rather a guide for acquiring and evaluating acceptable indoor air data in Colorado. It should be used by knowledgeable persons using sound scientific techniques.

Considering the importance of adequate data collection and analysis, evaluation of the vapor intrusion pathway should be conducted in direct consultation with Department representatives in

accordance with the normal review and approval process established by the program responsible for overseeing the work being performed. A collaborative approach employed early in the process will ensure that the work will be conducted in an efficient and effective manner, yielding test results that will support any necessary short or long-term risk management activities. Therefore all work plans and reports prepared during an indoor air assessment should be reviewed and approved by the Department prior to implementing any proposed activities to ensure that all are in agreement as to the goals, methods and analysis of the resulting data. The program under which remediation is being performed, and its statutory and regulatory requirements, will ultimately decide on a case-by-case basis the acceptability of any proposal made to assess this pathway, including: the minimum level of data collection; design of the investigation and any background studies that may be conducted; adequacy of the site investigation and evaluation of the resulting data; use of the data to support proposed remedial action decisions, including recommendations to exit the process; remedy selection; and post remediation monitoring requirements.

This guidance does not modify, replace, or pre-empt any existing statutory or regulatory requirements, enforcement actions, agreements, policies or other legal mechanisms that may govern actions within the Department's various remedial programs. This guidance is simply meant to inform the regulated community of their responsibilities in assessing the indoor air exposure pathway: it is not regulation, nor does it constitute an enforceable standard that must be complied with. In the event of a conflict between this guidance and existing programmatic requirements, this guidance defers to various legal and operating mechanisms of those remedial programs.

2.0 EVALUATING THE INDOOR AIR EXPOSURE PATHWAY

If there are volatile organic compounds (VOCs) in subsurface soil, ground water or in non-aqueous phase liquids (NAPL), then the potential for an indoor air problem exists. Indoor air contamination is not typically a problem associated with semi-volatile organic compounds or metals, except mercury. A pathway must exist between the source and the receptor before an exposure can occur.

The potential receptors in this pathway scenario are the occupants of buildings overlying or adjacent to the ground water or soil contamination. Both residential and commercial buildings should be evaluated for possible indoor air impacts. There has been no observed pattern of measured indoor air chemical concentration between styles of building foundations. For example, indoor air chemicals from the subsurface have been observed in homes with basements, homes with crawl spaces, and those with slab-on-grade construction.

Using all the information available about a site, the responsible party can evaluate the need for collecting indoor air samples. The Department will make the final determination as to whether, and to what extent, an indoor air assessment will be required for site characterization.

An indoor air exposure assessment generally consists of three separate phases that are performed sequentially:

Phase I – determine the potential for vapors to be present
Phase II – determine if the exposure pathway is complete and risk levels are exceeded
Phase III – determine the extent and degree of exposure

This section of the guidance discusses each of the major parts of an indoor air exposure assessment. Figure 1 is a decision tree flowchart that outlines the entire soil vapor intrusion evaluation process. It should be used as a guide to determine the need for an indoor air exposure assessment, evaluation of the resulting data, and possibly trigger the remediation of affected properties. An answer of "no" to a number of questions on the flowchart may be an indication that the subsurface source may have little to no impact on air quality within a building. Parties performing an indoor air investigation have the option of pursuing one or more of the multiple pathways provided. They also have the flexibility to modify the flowchart to evaluate lines of evidence earlier in the process than is indicated, potentially avoiding having to collect data that building occupants may find disruptive (sub-slab or indoor air testing). Any modification to the flow chart should be discussed with and approved by the Department in advance of collecting the data to ensure that resources are not expended unnecessarily.

2.1 PHASE I: INDOOR AIR EXPOSURE POTENTIAL

The first phase of the indoor air exposure assessment is to determine whether the potential exists for vapors to be present in the subsurface that could migrate and enter nearby structures. This assessment may be conducted using data that is normally generated during an investigation to determine extent and magnitude of a release (e.g., characterization of the source area and any associated ground water plume). Four basic questions are asked to determine whether there is a potential for the ground water/soil to indoor air exposure pathway exists.

1. Are VOCs present in soil, ground water or as a non-aqueous phase liquid (NAPL)? (If yes, continue; if no, an indoor air assessment is probably not necessary).

2. Are buildings currently located (or proposed to be located) above or within approximately 100 feet of the edge of this contamination? (If yes, continue; if no, an indoor air assessment is probably not necessary).

3. Are VOCs present in ground water at concentrations that exceed any of the values provided in Table 1? (If yes, an indoor air assessment is probably necessary; if no, an indoor air assessment is probably not necessary. In either case continue on to question 4).

4. Are VOCs present in the soil or NAPL at concentrations that could potentially volatilize and migrate into nearby structures? This is primarily a concern near source areas. (If yes, an indoor air assessment is probably necessary; if no, an indoor air assessment is probably not necessary because of either the soil or NAPL contamination).

If buildings are over or close to ground water contamination that exceed Table 1 values, then an indoor air assessment needs to be considered. Table 1 is not a complete list of chemicals that could cause a vapor problem, but is a list of those chemicals most likely to cause a vapor exposure problem. These commonly encountered chemicals, when present as a dissolved phase in ground water, pose the highest probable risk for vapor intrusion based on their physical properties. When NAPL is present, the number and concentration of chemicals that may cause a

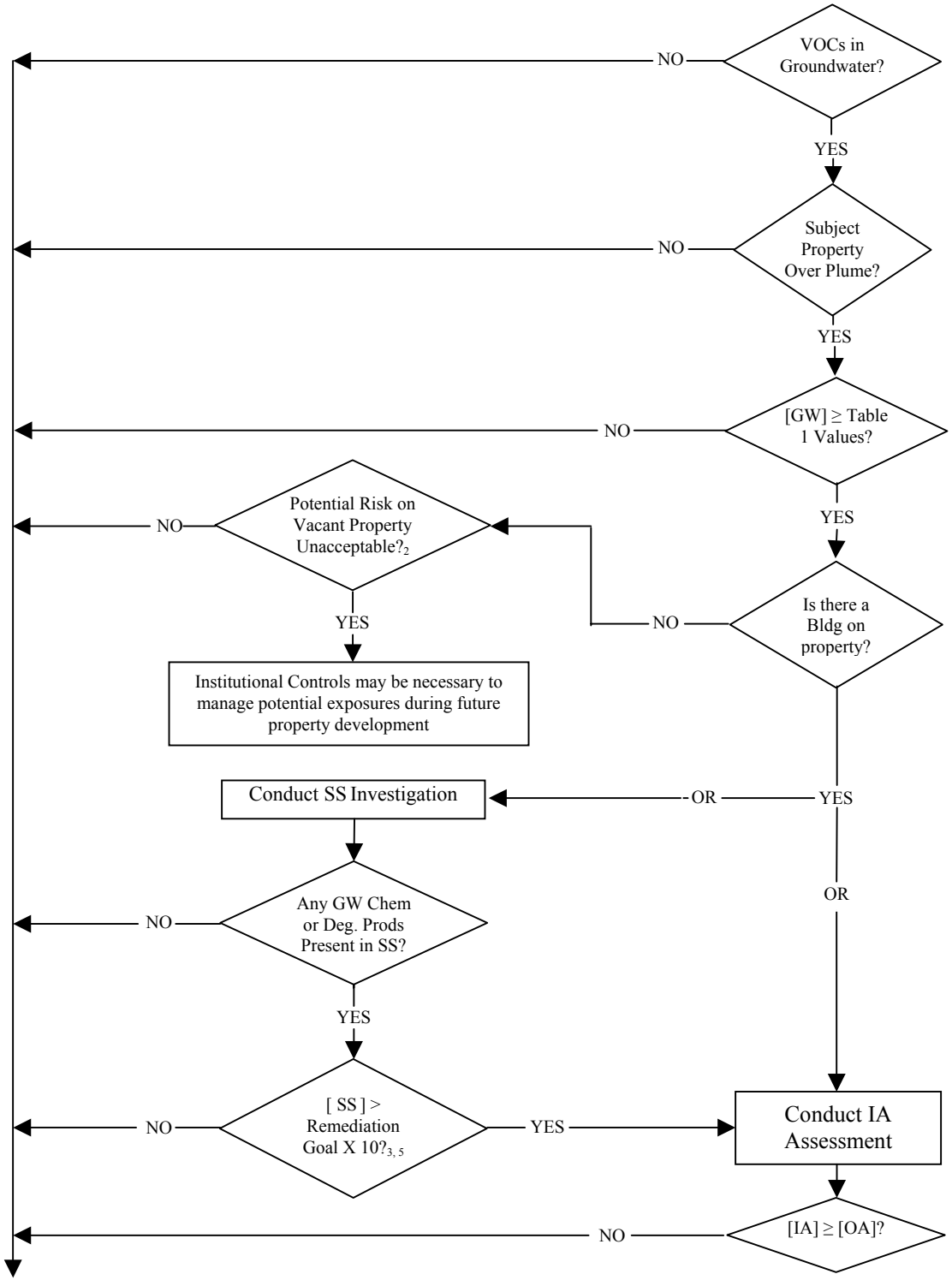


FIGURE 1

INDOOR AIR DECISION PROCESS GUIDANCE

This figure represents a generalized outline of the indoor air decision process. Site-specific conditions may warrant its modification, with Department approval. Additional lines of evidence evaluations may be introduced at any time into this process, or they may be performed earlier/later than are indicated on the flowchart.

NOTES

1) All evaluations based on representative data set reported to CDPHE
   - a) [IA]: Indoor Air Chemical Concentrations
   - b) [OA]: Outdoor Air Chemical Concentrations
   - c) [SS]: Subslab Chemical Concentrations
   - d) [GW]: Groundwater Chemical Concentrations
   - e) [BG]: Background Chemical Concentrations
2) Based on the presence of subsurface contamination, as determined through a process similar to what is illustrated on this flowchart or through a lines of evidence evaluation discussed in the guidance.
3) Remediation goal = $1X10^{-6}$ risk or Hazard Index (HI) ≤ 1
4) Decision based on single chemical evaluation of risk
5) a) Crawlspace attenuation factor = 1

   b) Basement / slab on grade attenuation factor = 10
6) The following lines of evidence are final determinations. Other lines of evidence may be used to eliminate the need for additional indoor air assessments or continued indoor air characterization.
7) If [SS] for any one chemical is > 100 times the remediation goal, then conduct periodic seasonal verification sampling within the building, even if SS chemicals or degradation products are not found in indoor air.

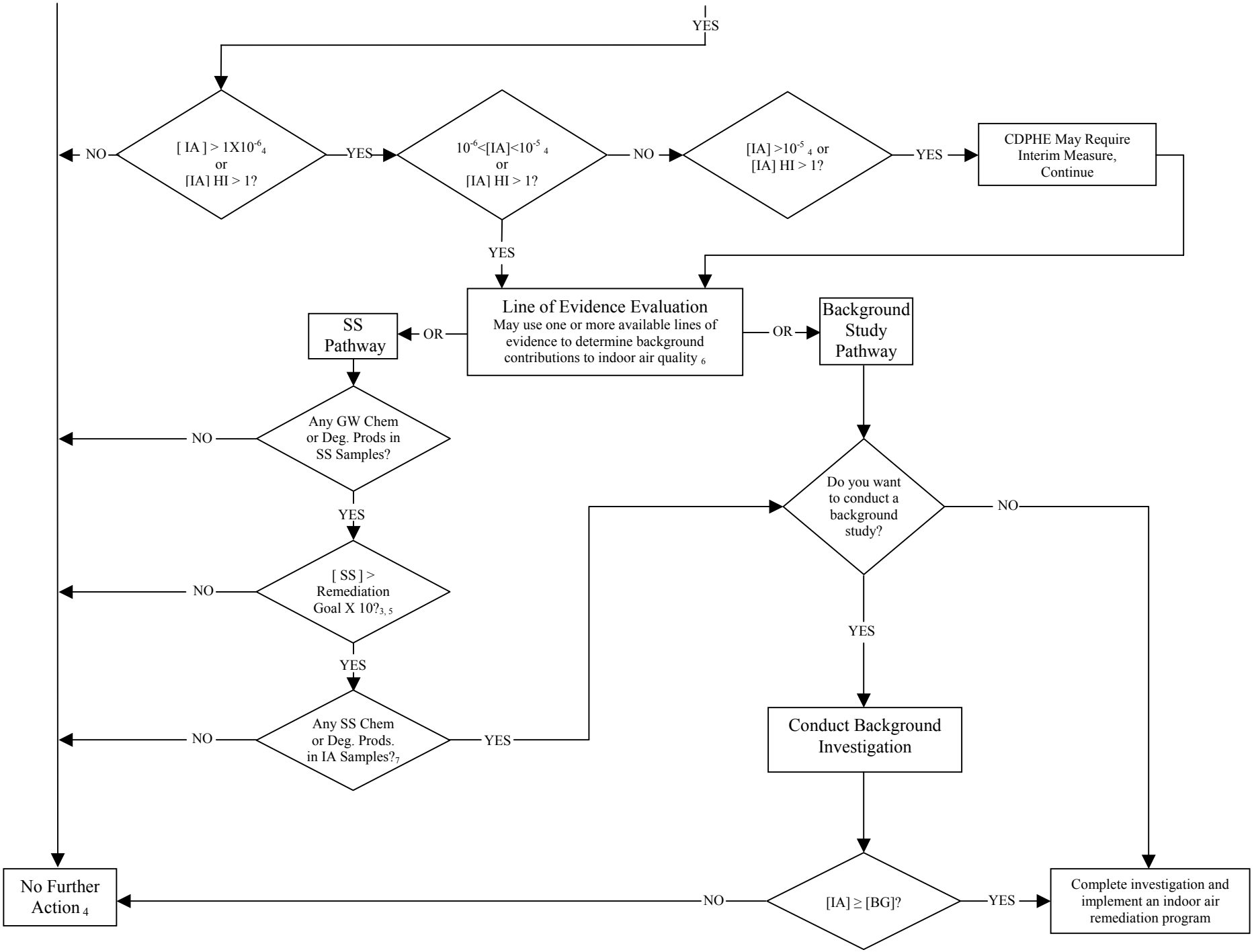

YES
[IA] > 1X10-6 4 or [IA] HI > 1?
NO
YES
10-6<[IA]<10-5 4 or [IA] HI > 1?
NO
[IA] >10-5 4 or [IA] HI > 1?
YES
CDPHE May Require Interim Measure, Continue
YES
Line of Evidence Evaluation
May use one or more available lines of evidence to determine background contributions to indoor air quality 6
OR
SS Pathway
OR
Background Study Pathway
Any GW Chem or Deg. Prods in SS Samples?
NO
YES
[SS] > Remediation Goal X 10?3, 5
NO
YES
Any SS Chem or Deg. Prods. in IA Samples?7
NO
YES
Do you want to conduct a background study?
NO
YES
Conduct Background Investigation
[IA] ≥ [BG]?
NO
YES
No Further Action 4
Complete investigation and implement an indoor air remediation program

TABLE 1
Ground Water Screening Concentrations (Based on a 10^{-6} risk or HQ $\leq$ 1)

Volatile organic compounds are chemicals that have a high vapor pressure (Henry's Law Constant > 10^{-5} atm m^3/mol) and easily form vapors at normal temperature and pressure. This definition applies to a large number of organic compounds, many of which are human-made chemicals such as solvents, paint additives, refrigerants, aerosol spray can propellants, fuels, petroleum distillates, dry cleaning products and many other industrial and consumer products ranging from office supplies to building materials. From this long list of chemicals, the Department has chosen those typically found in the environment at chemical release sites that can be analyzed using the TO-15 low resolution SCAN method.

Ground water screening concentrations for those chemicals not included on this list may be found in Table 2c of EPA's November 2002 "Draft Guidance For Evaluating The Vapor Intrusion To Indoor Air Pathway From Groundwater And Soils". Consult with Department staff before basing any decisions on the need for further work using concentrations found in EPA's table.

Chemical Abstracts No.	Chemical Name (IUPAC)	Risk Basis C=Cancer NC=Noncancer	CGWS µg/Liter	Ground Water Screening Concentration µg/Liter	Source of the Ground Water Screening Concentration[1]
71-43-2	Benzene	C	5	15	DOPS
56-23-5	Carbon tetrachloride	C	0.27	5	USEPA
108-90-7	Chlorobenzene	NC	100	390	USEPA
67-66-3	Chloroform	C	6	80	USEPA
156-59-2	Cis-1,2-dichloroethene	NC	70	210	USEPA
95-50-1	1,2-dichlorobenzene	NC	600	2600	USEPA
106-47-7	1,4-dichlorobenzene	NC	75	8200	USEPA
107-34-3	1,1-dichloroethane	NC	----	2200	USEPA
107-06-2	1,2-dichloroethane	C	0.38	5	USEPA
75-35-4	1,1-dichloroethene	NC	7	10	CDPHE
78-87-5	1,2-dichloropropane	NC	0.52	35	USEPA
100-41-4	Ethylbenzene	C	700	18,000	DOPS
75-09-2	Methylene chloride	C	4.7	58	USEPA
100-42-5	Styrene	NC	100	8900	USEPA
79-34-5	1,1,2,2-Tetrachloroethane	C	0.18	3	USEPA
127-18-4	Tetrachloroethene[2]	C	5	5	USEPA
108-88-3	Toluene	NC	1000	6900	DOPS
71-55-6	1,1,1-Trichloroethane	NC	200	1400	USEPA
79-00-5	1,1,2-Trichloroethane	C	3	5	USEPA
79001-6	Trichloroethene[3]	C	5	5	USEPA
75-01-4	Vinyl chloride	C	2	2	USEPA
1330-20-7	Xylene, total	NC	10,000	14,000	DOPS

IUPAC – International Union of Pure and Applied Chemists
CGWS – Colorado Ground Water Standards, as found in Regulation #41 (5 CCR 1002-41)
DOPS – Department of Labor and Employment's Division of Oil and Public Safety
USEPA - Derived from EPA's November 2002 "Draft Guidance For Evaluating The Vapor Intrusion To Indoor Air Pathway From Groundwater And Soils". Except for those values based on Maximum Contaminant Levels, the screening numbers assume water/vapor equilibrium and an attenuation coefficient of 1000.
CDPHE – Colorado Department of Public Health and Environment. The posted value was extrapolated from the USEPA value.
[1] The Ground Water Screening Concentrations are derived from a variety of sources. Parties using this table should periodically check these sources to verify that the posted values are still current.
[2] Tetrachloroethene's ground water screening concentration was chosen using an indoor air target concentration based on California EPA's (CalEPA) toxicity value. Until EPA's toxicity review process is complete, the Department will use the CalEPA inhalation and oral slope factors for tetrachloroethene.
[3] Trichloroethene's ground water screening concentration was chosen using an indoor air target concentration based on the upper bound cancer slope factor identified in EPA's draft risk assessment for trichloroethylene (US EPA, 2001). The slope factor is based on state-of-the-art methodology, however the TCE assessment is still undergoing review.

vapor intrusion impact is much greater than those chemicals dissolved in water, and therefore Table 1 is not an appropriate screening guide.

If it is determined that the potential exists for subsurface vapors to be present at concentrations that could impact indoor air quality, an indoor air assessment is probably necessary, triggering the need to move on to Phase II of the assessment process. Be sure to report the findings of this initial phase to the Department, even if the results are negative.

2.2 PHASE II: INDOOR AIR EXPOSURE PATHWAY COMPLETION / MAGNITUDE ASSESSMENT

The next step of the process is to determine whether VOCs present in the subsurface have migrated into overlying buildings, possibly at concentrations that exceed established action levels or remediation goals. Additional data will need to be collected beyond what is typically gathered during a routine site investigation, for the purpose of either directly or indirectly determining whether the vapor intrusion pathway is complete.

It is the Department's preference that air samples be collected from potentially affected buildings closest to the contaminant source area to measure actual indoor air quality and precisely determine what vapor concentrations its occupants may be exposed to. With this in mind, the following sections focus exclusively on procedures and other considerations for conducting indoor air testing in buildings overlying areas of subsurface contamination, listed in the order they are generally performed. Other indirect lines of evidence that may be useful for evaluating the potential of vapors to migrate into buildings is discussed in the Section 4.0 (Indoor Air Background) of this document.

2.2.1 Community Involvement

The Department's experience has been that when preparing to conduct an indoor air assessment, it is necessary to first implement a sound Community Involvement Plan. Public interest in potentially affected communities is very high, their concerns ranging from the health effects associated with exposure to vaporous chemicals to impacts on property values. Failure to plan for communicating vapor intrusion risks to the public will almost certainly result in strong negative reactions upon learning of the exposure, even if the risk is considered to be acceptable by the Department. Consequently, a site-specific Community Involvement Plan should be prepared for and implemented at every site at which indoor air samples are taken. The basic outline of these plans can be found in the *RCRA Public Involvement Manual* (EPA 530-R-93-06). Since communicating with the public should be a joint effort, the Department will help the facility conducting the investigation prepare and execute a Community Involvement Plan.

Before performing an indoor air assessment, clear lines of communication and points of contact for both the facility and the regulatory agency need to established early in the process in order to respond to questions that may arise from the public or news media. The facility should inform the impacted community that an indoor air assessment will be performed using a combination of information flyers, fact sheets, homeowner association newsletters, general mailings and/or public meetings. The information shared with the community should include, but not be limited to, a history of the situation, what is being done to address the problem, the chemicals of concern and their health effects, the purpose of the indoor air testing, reporting of the data, and the phone

numbers of contacts at the facility and the state where more information can be obtained. For larger problems, the services of a qualified community relations specialist is encouraged.

In addition, local elected officials and health departments should be contacted and kept informed of the progress and findings of the indoor air assessment. Their input on how best to communicate with the public should be sought. If possible, seek their assistance and their direct involvement in the communication and assessment process.

As part of the process for developing a Community Involvement Plan, members of the local community are interviewed and asked how they would like to receive information about the facility's progress dealing with environmental matters. There are a number of useful tools for keeping the public informed about activities at the facility, including newsletters, fact sheets, information repositories at local libraries, websites, and public meetings. The methods used to share information with the public should be tailored to the specific needs and desires of the community.

2.2.2 Setting up the Assessment

The details of performing an indoor air assessment must be submitted in a work plan prepared by the facility to be reviewed and approved by the Department. Communication with the Department is highly recommended during work plan development to ensure that proposed testing will result in the collection of adequate data necessary to determine whether vapor intrusion has occurred.

An indoor air assessment is a site-specific evaluation to ascertain if the indoor air exposure pathway is complete. The assessment is initially focused over the area of highest contamination in soil and/or ground water where an indoor air exposure pathway is most likely to exist. It should initially be limited in scope and area. For example, a small group of residences located above the area of maximum ground water concentration would have indoor air samples taken at least twice, once in summer and once in winter (this assumes the initial test showed no significant exposures, otherwise quarterly monitoring may be required). If this "worst-case" study finds no impact to indoor air quality as a result of subsurface contamination, it is reasonable to conclude that vapor intrusion problems are unlikely to exist elsewhere within the area where contaminant concentrations are anticipated to be lower. In this example, the Department may conclude that no further action is required with regard to the vapor intrusion pathway. The Phase II indoor air test results will be used to decide if, and what, additional indoor air assessment is needed, possibly triggering the need for a Phase III investigation.

2.2.3 Gaining Access and the Chemical Survey

The facility must notify and attempt to gain access for indoor air sampling at all buildings in the study area. If access negotiations fail and indoor air sampling is denied, then the next closest building, if not otherwise scheduled for sampling, should be sampled.

It has been the Department's experience that personal contact is the best way to get permission to sample a person's home or business. Giving people a telephone number to call to set up a sampling episode has not been as effective but is a viable alternative. Explain the situation and ask if they would like to participate. The Department cannot force a building owner to grant

access permission. Access denial should be documented in written correspondence to the Department.

Once access is granted, a comprehensive chemical survey should be conducted within the building as close to or on the day the indoor air samples are to be collected. The purpose of the survey is to determine if there are any activities, products or chemicals kept in the building that may interfere with the proposed testing, making it difficult to distinguishing the source of measured contamination (subsurface contamination vs. household products). As was mentioned in the introduction to this guidance document, there are multiple products and/or activities that could by themselves be sources of indoor air contamination. New carpet, freshly painted walls, recently dry-cleaned clothes, storage of petroleum products including gasoline operated equipment, and hobby supplies are a few of the potential sources of VOCs. Newer construction typically has more interference chemicals. The presence of these chemicals could lead to erroneous conclusions regarding the degree and completeness of subsurface contributions to indoor air impacts. Therefore, a complete interview with the property owner about chemical usage and storage in the building and a physical survey of the building for potential chemical sources and vapor intrusion pathways should be conducted and documented. Portable organic vapor monitoring equipment (i.e., photoionization detectors (PIDs)) can be used to help evaluate potential interferences. Based on the results of the chemical interview, indoor air testing may proceed, be delayed, or be deferred. An example survey form is provided in Attachment A. The contents of the survey form should be updated as needed during subsequent sampling events.

If results of the initial chemical interview determine that a property does not qualify for a sampling program, the elimination of interfering vapor sources may allow for it to be sampled at a later date. If vapor producing products or materials are identified inside the building during the survey (e.g., a container of gasoline, can of solvent, etc.), then consideration should be given to removing the interfering vapor sources, if practical, and delaying indoor air sampling for at least 2 weeks. The inability to eliminate potential interferences may be justification for not testing (this decision is chemical dependent).

Once a property owner agrees to grant access, and the property passes the chemical survey, have the access agreement ready to sign. Then set up the times to drop off and pick up of the sample device. Use of products or activities that may contribute to indoor air contamination should be discouraged for 24 hours prior to collecting the sample (operation of ventilation fans, painting, use of petroleum or oil-based cleaning products, engaging in hobbies which use materials containing volatile organic chemicals, application of pesticides, etc.).

Contact with the public during the access and sampling process involves both scientific and community relations efforts. It has been the Department's experience that the community will form its strongest impression of the work being done based on the experience they have with the people doing the interviews and the sampling.

2.2.4 Choosing a Laboratory

The analytical method presently being used to determine the concentrations of VOCs in indoor air is the *Compendium Method TO-15*, selected ion monitoring (SIM) mode, as specified in EPA document EPA/625/R-96/010b (Appendix C of this document) using the specific *Colorado Guidance for Analysis of Indoor Air Samples* (April 2000) (Appendix B of this document). The laboratory must demonstrate to the Department its ability to perform this analysis with

quantitatively reliable results down to levels that equate to health-based concentrations for the chemicals of concern. The Department determines acceptability of the resulting data.

Laboratories currently performing indoor air analyses are solvent free and have a section that specializes in low-concentration air analyses. Because of the limited number of laboratories in the country capable of performing the required analyses, the Department will, upon request, provide a list of laboratories that have demonstrated the capability to deliver acceptable analyses.

2.2.5 Sample Collection

Indoor air samples should be collected in either a six-liter or ten-liter Summa canister. The Summa canister is a vacuum bottle with a slow release valve. It fills with air over a pre-set period, usually 24 hours. The initial and final pressure reading of the Summa canister should be recorded. The samplers need to be confident that the canisters are initially clean. Use of canisters that have previously contained high concentrations of vapors should be avoided because of the potential for cross-contamination. If a lengthy investigation involving numerous sample locations is anticipated, use of project-dedicated canisters should be considered.

The Summa canister is placed in the lowest occupied floor of the structure, away from areas of increased air movement like vents, fans, windows, or outside doors. The canister should be placed at a height that would simulate the breathing space of the occupants of the specific room (approximately three feet above the floor). A 24-hour sample should be collected during each indoor and outdoor sampling event. The relative pressure to atmosphere of Summa canisters needs to be measured at the beginning and end of the sample period, and at the laboratory. Once samples are collected, they should be stored according to the method protocol and delivered to the analytical laboratory as soon as possible.

Every indoor air sampling event has quality control samples (duplicates and blanks) taken along with a group of regular samples. There should be no more than 20 samples in a group. Detailed sampling procedures must be specified in the Sampling and Analysis Plan or Quality Assurance Project Plan. Failure of quality control samples to meet analytical requirements or sampling goals may invalidate the sample group associated with those quality control samples. Quality control samples are used to demonstrate the quantitative reliability of a sample group, and to locate sampling and analysis problems. The Department determines the acceptability of data.

The use of Tedlar bags is not appropriate for sampling indoor air, except in instances where high chemical concentration impacts have been documented and the use of field analytical techniques to monitor soil gas or indoor air quality is determined to be appropriate. Tedlar bag samples need to be analyzed within 12 hours of collection.

2.2.5 Analytical Method

Samples are transported under strict chain of custody to the analytical laboratory. The relative pressure of air in the Summa canister is checked before an aliquot is taken for analysis. Pressure measurements are necessary to make the conversion from volumetric to mass per unit volume units, and to check the operation of the Summa Canister. An aliquot of the Summa canister contents is taken and analyzed using Gas Chromatography/Mass Spectrometry (GC/MS) techniques as specified in EPA *Compendium Method TO-15* described in document EPA/625/R-

96/010b. *EPA Compendium Method TO-14* is often referenced in the TO-15 document. The results are initially reported in volumetric terms, such as parts per million by volume.

The Department's *Guidance for Analysis of Indoor Air Samples* April 2000 (Attachment B) should be followed strictly by the laboratory. Any deviation needs written approval by the Department. Otherwise, the Department may not accept the analytical results.

Quantitation limits shall be less than the residential risk concentration for the chemicals of concern as established by the Department.

2.2.6 Data Analysis

Once the analytical instrument is correctly set up and operating in the high-resolution Selected Ion Monitoring (SIM) mode, the data output needs to be carefully analyzed by an experienced chemist. Because both primary and secondary ion fragments are considered during the identification process, computer selection of identified chemicals is less reliable. Not only are the elution times critical, but also the primary ion to secondary ion abundance ratio is very important to proper chemical identification. The Department's *Guidance for Analysis of Indoor Air Samples* (April 2000) covers the process for properly selecting and quantifying chemical vapors in air.

2.2.7 Reporting the Results

Air analysis results can be reported both as volumetric measurements and as a mass per unit volume. The mass per unit volume result ($\mu g/m^3$) is used to assess risk. This means that the atmospheric pressure and temperature must be known at the sample time. In the Denver area, atmospheric pressure is approximately 640 Torr. At sea level, atmospheric pressure is approximately 760 Torr. (1 Torr = 1 mm of Hg at 0^oC = 133.3 Pascals)

If necessary, preliminary results can usually be received from the laboratory within seven days of receipt. The preliminary results should undergo a quality review by the consultant before release to the public and the Department. Preliminary results should be clearly labeled as such. The schedule for releasing preliminary results is part of the process negotiated with the Department.

The preliminary results should be faxed or delivered to the Department and to the owner/resident of the sampled building. The Department needs to be aware of analytical results to be able to answer questions and/or take appropriate action.

Final, validated results should be delivered to the Department within 60 days of the sampling event.

2.2.8 Risk Communication

Copies of indoor air sample test results must be provided to the building occupants as soon as they become available, along with some explanation of what the test results indicate. Similarly, news of indoor air contamination affecting a community downgradient of a release site should be communicated to the public, community leaders, and other stakeholders, particularly if their cooperation is necessary with future sampling efforts. The difficulty will be in communicating

the concept of vapor intrusion risks and other complicated details in a clear and easily understood manner that results in an informed public. This communication strategy should be outlined in the Community Involvement Plan, tailored to the findings of the investigation with the help of Department staff.

A variety of outreach strategies can be used to provide information to the community and gain feedback in making decisions. These may include public meetings, newsletters and/or informational fact sheets that may accompany individual test results. The use of technical terms and concepts should be avoided, as they may be confusing to stakeholders who are unfamiliar with this jargon. For this reason, it is important to design any presentation with the intended audience in mind.

2.3 PHASE III: DETERMINATION OF EXTENT AND DEGREE OF EXPOSURE

Once it is confirmed that vapors derived from the subsurface source have migrated into overlying buildings at concentrations that may pose a risk to the occupants (e.g., a hazard quotient greater than 1 or above a $1x10^{-6}$ cancer risk), a comprehensive indoor air investigation needs to be conducted to define the extent and degree of the exposure. Depending on the Phase II test results, it may be necessary to immediately implement interim measures to deal with unacceptable exposures that have been identified (e.g., above the hazard quotient >1 or $1x10^{-5}$ action level). These same initial test results will also determine the pace of the investigation to define the full extent of the vapor intrusion exposure area is conducted: test results that trigger the need for interim measures will necessitate the rapid identification of all other buildings with similar unacceptable levels of exposure.

The methodology for conducting this phase of the indoor air assessment is identical to what was done under Phase II: the only thing that changes is the scope of the investigation. A work plan describing the investigation methods should be provided to the Department for review and approval. Defining the extent of the vapor intrusion exposure is an iterative process beginning at and moving away from the location where elevated readings were initially observed (select a number of buildings, sample, review results, sample next line of buildings). The work plan should therefore propose an iterative decision process whereby the course of the investigation will be specified based on predetermined criteria. Such a dynamic work plan would lay out the decision logic that will be followed in determining data needs, and describe how the proposed approach for collecting and analyzing samples will support the decision logic. This dynamic characterization process will quickly and efficiently characterize the indoor air exposure from its beginning to end, thereby eliminating the need for multiple interim reports and work plans. It is the Department's preference that such an iterative sampling approach be used to define the nature and extent of indoor air exposures since it allows for the rapid acquisition of data, provides flexibility, and focuses the facility's resources on data collection, not document preparation.

The standard approach to characterizing the extent of indoor air contamination using this iterative process is referred to as the step-out method. One or two rows of buildings around the location where indoor air exceeds allowable risk levels found during the Phase II investigation are targeted for sampling. If the analysis of air samples at these locations continue to exceed established risk-based concentrations, the party conducting the investigation should step-out another one or two rows of buildings and target these new locations for air sampling. The exact locations of the new sampling points may be adjusted based on site-specific circumstances. This

process should be repeated until the full horizontal extent of the indoor air contamination has been defined. In this instance, the Department would approve the initial set of sample points and the decision tree for selecting new sample locations. No other interim plans or reports would need to be prepared or reviewed prior to completing the investigation. This approach has the potential to save considerable time and money for all parties involved.

3.0 EXPOSURE CONCENTRATIONS

The hazards associated with vapors that have migrated into indoor spaces are based on the duration of the exposure and the concentration and toxicity of the contaminant. The concentration is measured at each location during the indoor air assessment described in the preceding section. EPA has established cancer slope factors and reference doses for many different chemicals. Standard EPA methodologies and exposure assumptions are used for calculating the risk associated with the inhalation of one or more chemicals that may be present in indoor air. For the purpose of evaluating the health risks posed by indoor air contamination, the focus of the risk assessment is on the inhalation pathway. This document does not specifically address acute hazards, which are rare but can happen under certain circumstances. Such high concentrations will typically be indicated by a strong chemical odor that will usually be apparent and responded to early in the corrective action process. In most cases, there is no odor associated with low concentration vapors that have migrated into a building from a subsurface source, remaining undetected until an indoor air assessment is conducted by the facility. The following calculations for risk-based air concentrations focus on long-term exposures to low-level vapor concentrations.

The Department considers both carcinogenic and non-carcinogenic health effects caused by exposure to a chemical of concern. In those instances where a chemical may have both a cancer slope factor and a non-cancer reference dose, the Department uses the lower of the two health-based concentrations for making risk management decisions. In cases where the vapor consists of a mixture of different chemicals, the risk posed by individual constituents may be added together to evaluate the total risk of the vapor a person may be exposed to. The Department can choose a more conservative health-based concentration for indoor air contaminants than EPA if our independent review of the toxicological data suggests that this is warranted.

The exposure assumptions for different exposure scenarios can change, for example in terms of: hours per day, days per year, and years of exposure. The residential exposure scenario is generally the most conservative. It assumes a 70-year lifetime, 30 years of exposure, 350 days per year, and 24 hours per day and is generally considered to be protective of sensitive subpopulations as well as average adults. The commercial/industrial scenario exposure assumptions are generally less conservative than the residential exposure scenario. It assumes a 25-year exposure, 250 days per year, and 24 hours per day. Exposure assumptions may be modified, with documented justification, to account for site-specific circumstances. Considering the highly variable population of individuals who may be exposed, the reasonably conservative default exposure assumptions noted below must be employed in order to protect the greatest number of people.

3.1 CALCULATIONS FOR RISK-BASED AIR CONCENTRATIONS

Currently, the Department calculates indoor air risk-based concentrations using the Inhalation Cancer Slope Factor, inhalation rate, and receptor-specific body weight because it takes into account the higher exposure of children based on body weight and inhalation rate of the receptor. The Department has adopted the EPA Region 3 methodology for calculating risk-based concentrations. We recognize that, toxicologically, scaling to child's body weight and inhalation rate is not considered an accurate method to address inhalation risks for children. Therefore, this approach may result in under- or over-estimation of risks to children in some cases. It is, however, believed that the uncertainty associated with the adjustment of inhalation rate per body weight is outweighed by the non-conservative uncertainty of not evaluating the child receptor altogether. The failure to do so will leave this vulnerable subpopulation unprotected. The Department will revise the methodology when alternative methods are available to better characterize a child's inhalation risk.

Carcinogenic risk-based concentration (RBCc):

$$\text{RBCc } \mu g/m^3 = (\text{TR x ATc x 1000 } \mu g/mg) / (\text{EFr x IFAadj x CSFi})$$

Non-carcinogenic risk-based concentration (RBCnc):

$$\text{RBCnc } \mu g/m^3 = (\text{THQ x RfDi x BWa x ATn x 1000 } \mu g/mg) / (\text{EFr x EDtot x IRAa})$$

Symbol[1]	Definition (units)[1]	Value[1]
CSFi	Inhalation cancer slope factor (risk per/mg/kg/d)	chemical specific
RfDi	Reference dose inhaled (mg/kg/d)	chemical specific
TR	Target cancer risk	1×10^{-6}
THQ	Target hazard quotient	1
ATc	Averaging time –carcinogen (days)	25,550
ATn	Averaging time –non-carcinogen (days)	ED x 365
EFr	Exposure frequency (days/year)	350
EDtot	Exposure duration, total (years)	30
EDc	Exposure duration – child (years)	6
IFAadj	Inhalation factor, age adjusted (m^3-yr/kg-d)	11.66
IRAa	Inhalation rate – adult (m^3/day)	20
IRAc	Inhalation rate – child (m^3/day)	12
BWa	Body weight – adult (kg)	70
BWc	Body weight – child (kg)	15

[1] Values obtained from EPA Region 3 Risk-Based Concentration Table (last updated on March 10, 2004).

[2] $$\text{IFAadj } (m^3\text{-yr/kg-d}) = \frac{\text{IRAa x (EDtot – Edc)}}{\text{BWa}} + \frac{\text{IRAc x EDc}}{\text{BWc}}$$

Examples

Methylene chloride has a CSFi = 1.65 X 10^{-3} 1/mg/kg/d. Using the above stated exposure and residential duration assumptions, the carcinogenic risk-based concentration is:

RBCc (methylene chloride) = ((1 x 10^{-6}) x (70 years x 365 days/year) x 1000 ug/mg) / ((350 days/year) x 11.66 m^3-yr/kg-d x 1.65 X 10^{-3} 1/mg/kg/d = 3.8 µg/m^3.

For non-cancer risk methylene chloride has an RfDi = 0.86 mg/kg/d. This yields a non-cancer risk concentration of:

RBCnc = (1 x 0.86 mg/kg/day x 70 kg x 30 years x 365 days/year x 1000 ug/mg) / (350 days/year x 30 years x 20 m^3/day) = 3.1 mg/m^3.

In this example, methylene chloride's health-based concentration due to cancer risk, being approximately one thousand times more protective than the non-cancer threat, becomes the residential exposure concentration for the inhalation pathway.

3.2 REMEDIATION GOALS AND ACTION LEVELS

Remediation goals are chemical concentrations in the affected media that a final remedy should strive to ultimately achieve. These numeric targets should be protective of human health and the environment and may take into consideration the current and proposed future uses of the site. Remediation goals for human health should be developed based on the degree of actual or potential exposure to a contaminant (resulting in an estimate of dose) and the toxicity of the contaminant resulting in an estimate of risk.

In general, health-based remediation goals are calculated as follows:

- For known or suspected carcinogens, the cleanup level should be at concentrations that represent an excess upper bound lifetime risk to an individual of 1x10^{-6}. For sites with multiple contaminants, cleanup levels should be set so that the risk posed by individual constituents does not exceed a 1x10^{-6} <u>and</u> where the cumulative (total) excess upper bound lifetime risk from all contaminants does not exceed a 1x10^{-5}.

- For constituents associated with adverse effects other than cancer, cleanup levels should be established at concentrations to which human populations, including sensitive subgroups, could be exposed on a daily basis without appreciable risk of negative effect during a lifetime. Such levels are interpreted as being equal to or below a hazard quotient of one. For sites with multiple contaminants or exposure pathways, cleanup levels should result in a cumulative hazard quotient equal to or less than one for all those constituents with similar critical endpoints.

Action levels are health-based concentrations that, when exceeded, trigger interim measures to minimize or eliminate the continued exposure to vaporous contamination derived from a subsurface source. For known or suspected carcinogens, the action level is set at a concentration that represent an excess upper bound lifetime risk is greater than 1x10^{-5} for either individual or

multiple chemicals. For non-carcinogens, such levels are interpreted as being greater than a hazard quotient of one.

3.3 OSHA CONSIDERATIONS

The Occupational Safety and Health Act of 1970 (OSHA) states that "the standards contained in [OSHA] shall apply with respect to employments performed within a workplace in a State…" 29 CFR §1910.5(a). OSHA uses Permissible Exposure limits (PELs) to regulate the exposure to chemicals in the work place. The PELs are based on an 8-hour day, and 40-hour workweek for an average, healthy worker. OSHA PELs are not based solely on risk, but are adjusted to account for factors including economic feasibility. This approach is different than that of the Department, which considers only human health when calculating its risk-based numbers. Because of the fundamentally different approaches used to calculate "acceptable" risk, OSHA's permissible exposure to virtually any given constituent is higher than the Department's.

The key to understanding the difference between the way the Department and OSHA regulate exposure to hazardous vapors is knowing whether the exposure is voluntary or not and whether the employees are informed and afforded the appropriate personal protection. The Department will generally defer to OSHA's numbers and forego corrective action in occupational settings where 1) the facility workers have voluntarily accepted the known risks associated with exposure to chemicals during their employment, 2) the exposure concentrations are within OSHA's standards, 3) reasonably safe controls (clothing, respiratory gear, periodic health monitoring, etc.) are in place to limit foreseen exposures to hazardous chemicals and 4) the workers are informed of the environmental contamination and have access to the results of OSHA-mandated monitoring which shows the increased contamination, if any, caused by the subsurface source. The Department will employ its own risk-based numbers in all other instances where employees within buildings have not voluntarily accepted a risk associated with environmental contamination in connection with their employment.

The following examples illustrate those scenarios where either OSHA standards or the Department's risk-based numbers apply.

1) If a person works at a job site where they are exposed to vapor from a subsurface source of contamination regulated by the Department (regardless of whether that contamination is derived from that facility or another) and are simultaneously exposed to the same hazardous vapors as part of the normal operating conditions of the work place (e.g., a vapor degreaser) and is knowledgeable of their exposures, then the exposure is regulated under OSHA.

2) If, on the other hand, a person works at a job site where they are exposed to vapors from subsurface contamination and are exposed to different hazardous chemicals as part of the normal operating conditions of the work place that they protect themselves against, but not those associated with the subsurface contamination, then the exposure associated with the RCRA release will be regulated by the risk protocols established in this guidance. The employer has the option of incorporating these environmental exposures into its employee protection program, in which case all OSHA requirements and numbers would apply.

3) If a person exposed to subsurface contamination works in a non-industrial work environment at a site where exposure to a hazardous vapor is part of the normal operating conditions at a different location within the work place (i.e., office staff associated with manufacturing operations), that employee's exposure is determined by the Department's risk-based numbers. Again, the employer has the option of incorporating the environmental exposure into their employee protection program (inform staff of their exposure and provide appropriate monitoring and/or protection), in which case all OSHA requirements and numbers would apply.

4) If the exposure to vapors from environmental contamination is not associated with the normal operating conditions of the work place (e.g., a retail operation or daycare center), then the Department's risk-based numbers apply.

Examples 1 through 3 above pertain primarily to the combination of environmental and occupational exposures within industrial workplaces where the release into the subsurface occurs. The Department will generally use its own risk-based numbers in all other scenarios, particularly in workplaces downgradient of the subject facility.

4.0 INDOOR AIR BACKGROUND

Facilities that have had a release of hazardous constituents, wastes, pollutants, or other regulated contaminants (herein referred to as hazardous substances) into the environment are obligated to characterize and remediate the impacts of the release(s). While the responsible parties are obligated to remediate releases at or from their facility, they do not have to remediate chemicals that are not associated with releases from their facility. Therefore, it is important to determine which hazardous substances found in the environment are attributable to releases from the facility and which occur naturally and/or from anthropogenic sources unrelated to activities at the facility.

Hazardous substances found in the environment that are not associated with releases from a particular facility are, in this guidance, referred to as background. Background concentrations may result from two sources: 1) naturally occurring components derived from soil or rock (e.g., methane, radon) and 2) anthropogenic releases not related to a hazardous waste site. The anthropogenic background concentrations of a chemical in indoor air may originate from three categories of sources: chemical sources within the building, outdoor air contamination associated with socially accepted or permitted activities within an urban environment, and soil and ground water contamination originating from a facility other than the one being investigated for the release of the hazardous substance. Sources of indoor air contamination originating from within a building could include carpets, paints, adhesives, plastics, cleaning chemicals, office chemicals, gasoline from cars or lawn equipments, fingernail polish remover, chemicals used in remodeling, refinishing, woodworking, or dry cleaning. Indoor air impacts derived from outdoor sources could include air emissions from nearby manufacturing operations, dry cleaners, gas stations, refineries, wood treating facilities, automobile exhausts along nearby roadways, or a multitude of other permitted sources. Subsurface contamination derived from other unrelated chemical release sites may commingle with and contribute to indoor air contamination being cleaned up by the party working with the Department.

4.1 MULTIPLE LINES OF EVIDENCE

The primary concern of this guidance is with evaluating and responding to vapors impacting indoor air that are derived from a known release of a hazardous substance. Since there may be multiple unidentifiable sources of air contamination not associated with a known release (ambient outdoor air and indoor sources), careful consideration must be given to determining which constituents are derived from subsurface contamination (soil and/or ground water) that the responsible party is required to remediate. Attribution of observed constituents can become a very complex and difficult task. In some instances this may be unnecessary because the measured concentrations of indoor air contaminants all fall below the established remediation goals: in this example it is unimportant whether the hazardous substances are derived from subsurface, indoor or outdoor sources. In other instances, the measured concentrations of indoor air contaminants might be above action levels at multiple locations, suggesting that the air contaminant is derived from a subsurface source.

In those instances where hazardous substances with multiple potential sources are measured in air at concentrations above defined action levels or remediation goals, it may be necessary to gather multiple lines of evidence to support a remedial decision either to include or exclude certain constituents. The premise is that if it can be demonstrated to the Department through multiple lines of evidence that an indoor air constituent concentration above a remediation goal is not derived from a subsurface source, the party performing the cleanup is not responsible for this background contamination. The more evidence gathered to support such a conclusion, the stronger the justification for the Department to approve a request to limit a party's responsibility to only those constituents attributable to its release. Site-specific decisions should be made as to the number and types of information employed: use of many lines of evidence may not be required if only a few or even one provide clear evidence of either background or soil vapor intrusion sources. The Department recognizes that there will be some uncertainty associated with such an assessment, regardless of the number of lines of evidence considered: decisions will be made based on what professional judgment deems to be reasonable and logical.

The following lines of evidence, listed in no particular order, may be used to determine whether measured indoor air contamination is derived from subsurface contamination or background sources. Other lines of evidence may be available depending on the site-specific circumstances. The party performing the investigation has the option of what data to collect and which lines of evidence it will pursue in order to support a particular determination with regard to indoor air measurements.

- Subsurface Source: Constituents – One of the initial steps of conducting an indoor air investigation is to define what hazardous substances have been released into the subsurface (soil and ground water), and which are constituents of concern (COC) with regard to the indoor air pathway. These COCs may be both the primary chemical constituents released into the environment as well as their degradation products. Defining the COCs will determine the analytical suite for indoor air samples. It may be safe to conclude that if indoor air measurements identify constituents other than those on the COC list, these non-COC constituents are probably derived from background sources. Testing for these other constituents may not be necessary, unless the data can be used to help fingerprint this background source of indoor air contamination for the purpose of distinguishing it from subsurface derived contamination.

- Subsurface Source: Extent – It may be assumed that if a building is not located directly over or immediately adjacent to a subsurface source of contamination (i.e., within one or two properties of the plume boundary or approximately 100 feet), any indoor air contamination within that structure is probably not attributable to that release. Buried utility corridors that may act as preferential pathways and/or the lateral diffusion of vapors may complicate this assumption. This line of evidence will require the collection of adequate data to precisely define the horizontal extent of the subsurface contamination. There is much less uncertainty associated with a well characterized release, and therefore less need to rely on a conservative perspective when performing a multiple lines of evidence assessment. It should not be automatically presumed that vapor intrusion is occurring at a building located over a contaminant plume: other lines of evidence may be used to demonstrate otherwise.

- Subsurface Source: Magnitude – The primary source of soil vapors affecting the largest number of buildings is contaminated ground water that migrates through the subsurface. Our experience shows that contaminant concentrations must exceed a certain threshold before off-gassing vapors have the potential to migrate through the soil column above the water table and accumulate in overlying structures at concentrations that may pose a risk. The physical properties of both the contaminants and the formation through which the vapors travel, along with the characteristics of the structure, all influence the degree of attenuation that occurs during its migration through the subsurface. Table 1 provides minimum ground water concentrations that must be exceeded before there can be any opportunity for vapors to accumulate in an overlying structure at levels that begin posing a risk. Any compounds that do not exceed these conservatively calculated threshold-screening levels may be eliminated as COCs with respect to soil vapor intrusion. This conservative screening step should not be inferred to mean that ground water concentrations that exceed these threshold-screening levels would cause soil vapor intrusion. As was noted above, lateral diffusion of vapors from areas of higher levels of contamination may complicate this assumption.

- Physical Properties of the COCs –Only volatile organic compounds (VOC) have the ability to readily enter the vapor phase and migrate through the soil column, eliminating from further consideration those constituents that do not exhibit this behavior, such as metals (with the exception of mercury) and organic compounds with low vapor pressures (semivolatile organic compounds). However, the presence of VOCs in the subsurface does not automatically imply that they will be found in overlying structures. VOC concentrations in the subsurface source area may need to exceed a certain threshold in order to produce vapors that can accumulate in overlying structures at concentrations that exceed action levels or remediation goals. Such a threshold can only be determined using actual site-specific data, although mathematical approaches using accepted principals might provide an indication of what that theoretical threshold concentration may be (e.g., using Henry's Law to calculate the partitioning of a constituent between the water and vapor phases).

- Sub-Slab Soil Vapor Data – Vapor measurements collected from beneath a building will provide an indication of what constituents could potentially migrate into and accumulate within it. If COCs are not observed in the sub-slab or crawlspace vapor samples, it is

reasonable to conclude that any measured contamination in the indoor air samples is derived from other background sources. The difficulty with this line of evidence is ensuring that representative vapor samples are collected from beneath the structure. Also, since vapors to some degree naturally attenuate in their migration from the subsurface into the overlying building, a detection in the sub-slab vapor sample does not necessarily mean that all contamination observed in the indoor air sample is attributable to the subsurface source. For the purpose of evaluating the subsurface contribution of vapors to a home, one can use an attenuation factor of 10 for structures with basements or built on concrete slabs, while no attenuation factor should be considered for structures with crawlspaces or with features that allow for the uninhibited movement of vapor from the subsurface into the structure (water collection sumps, openings through the floor exposing underlying fill or native soil, etc.). Vapor samples collected below well sealed liners in crawl spaces may be valid alternatives for sub-building tests representative of concrete slabs. Alternate attenuation factors may be proposed for COCs based either on site-specific or comparable data that is likely to accumulate over the next few years. EPA's draft sub-slab vapor sampling procedures are provided in Attachment C. The Department recommends that the latest versions of that draft document be looked for prior to conducting a sub-slab soil vapor investigation.

- Constituent Ratios – Evaluating the ratio of COCs between ground water, soil gas, and indoor air may be a way to identify potential vapor intrusion contributions, or to screen out background sources. For many VOCs, the background VOC ratios are quite distinct from ground water derived VOC ratios. This characteristic allows the VOC ratios from other media to be used to eliminate indoor air COCs. If the indoor air VOC ratios are significantly different from the soil vapor or ground water ratios, it can be presumed that background contributions are dominant and the chemical may not be an indoor air COC. Even if the ratio analysis suggests that indoor or ambient sources are likely responsible for some of the measured indoor air concentrations, subsurface sources may still be contributing to indoor air concentrations. Conversely, if the ratio of constituents in the indoor air sample is similar to the ratio observed in the sub-building vapor sample, one may conclude that the two are linked and there is a significant contribution from the subsurface sources. Chemical data collected at the system influent of remediated residences can be considered the same as sub-slab soil vapor data for the purposes of determining ratios to predict indoor air chemical ratios. If a "marker" chemical (a chemical with little to no background concentrations, see below) is found in indoor air, the ground water derived concentration of other chemicals can be estimated by multiplying the concentration of the marker chemical by the ratio of the second chemical. If the indoor air concentrations of the second chemical are above that predicted by the ratio method, the additional amounts found in indoor air may be due to background contributions.

  Comparison of compound ratios in ground water to ratios in indoor air may also be considered, however, these ratios should be adjusted for different relative volatilities of the COCs (their Henry's Law Constants) and, if significant, different rates of retardation and/or biodegradation in the vadose zone. The comparison of soil vapor ratios to Henry's Law adjusted ground water ratios may be another line of evidence for determining background contributions. It should be recognized that background sources might fortuitously result in ratios that fall within the range predicted for ground water or

measured in soil vapor data. Therefore, ratios can screen out obvious background sources, but will not necessarily confirm soil vapor intrusion or eliminate the potential for background contributions.

- Spatial Correlations – The use of spatial correlations is another tool for differentiating soil vapor intrusion sources from background. For example, use of COC ratios might eliminate a number of background outliers, but still leave buildings with ratios that are consistent with either soil vapor intrusion or background source. Spatial analysis might show that a cluster of such ratios is consistent with a ground water plume, whereas in other area buildings the ratios appear to be randomly distributed and are more likely associated with background levels. The spatial distribution of contaminants measured within a building may also shed light on the source of the vapors: concentration gradients or hot spots may indicate indoor emission sources.

- Soil Vapor Measurements: Not from beneath the Structure – Although experience suggests that soil vapor measurements are an unreliable means of predicting vapor concentrations that may exist within a building, it may be one line of evidence that can be used to evaluate the likelihood for soil vapor contamination to enter a building. Use of this technique is dependent upon the collection of reliable and representative site-specific soil vapor measurements (multiple measurements may be required). The problem with this tool is that considerable variability may be observed in measurements obtained from a relatively small area (questionable reliability and representativeness of the results) and it does not account for the attenuation that occurs when vapors move from the subsurface into the overlying building. It can be correctly assumed that if high levels of vapors exist in the soil (greater than the health-based concentration multiplied by the conservative default attenuation factors noted in the discussion on Sub-Slab Soil Vapor Data above), it is probable that vapors are migrating into the building and are contributing to the indoor air contamination. The converse assumption is not necessarily true, although it may further support the findings of other lines of evidence. Although the absolute value of soil vapor concentrations measured outside the structure may not be representative of conditions below the building, compound ratios may be a useful line of evidence for evaluating background sources. If given the choice, the Department would prefer that the responsible party collect the more reliable sub-slab soil vapor samples, not soil vapor samples collected outside and away from the structure.

- Knowledge Regarding the Impacted Structure – Information regarding the construction and operation of a building may be used to establish the likelihood of subsurface vapors to enter and accumulate within it. For example, if a building's heating, ventilation and/or air conditioning system generates a positive air pressure within the structure, it may be reasonable to conclude that this system will minimize or prevent vapors from migrating into the building from a subsurface source. Other information regarding the building construction may help determine the potential for soil vapor contamination to migrate into and accumulate within the building (e.g., wood floor over an unlined crawl space-high potential for entry, installation of a vented gravel bed covered with an impermeable sheet of plastic beneath the concrete floor slab-minimal to no opportunity for entry, etc.).

- Chemical / Remodeling Activities Survey – A thorough chemical and remodeling activities survey may identify background sources of COCs within the building. If these

sources can be removed and the indoor air of the residences re-sampled after sufficient ventilation time, then the results can be compared to help determine if the ancillary sources were the origin of measured indoor air concentrations. If these potential sources cannot be removed, it would be difficult to attribute measured concentrations to a particular source or sources. It may be appropriate to eliminate a candidate residence from sampling if known chemical sources exist (e.g., from a background study). However, in many cases, consumer products do not identify all of the chemicals contained in the product. Chemicals contained in the products, furniture, and other items may not be identified by a survey. Surveys should be considered a potential means of identifying, but not ruling out, background sources.

- Background Air Measurements – Claims that observed indoor air contamination is attributable to background sources unrelated to the subsurface source (located within and/or outside the structure being tested) can be supported with data showing that these same constituents are present in air samples collected from locations that are not affected by the subsurface contamination. These may include samples collected from similar locations/structures outside the affected area (and not affected by contaminant plumes of their own), post-remediation data from within the plume area, local air toxics monitoring stations or other reliable and comparable data derived from Department approved sources. Use of post-remediation test results is contingent upon demonstrating the effectiveness of remediation systems to prevent the continued infiltration of soil vapor contamination into the building (typically done with a tracer compound or marker chemical that is unique to the ground water contamination, such as 11-DCE, the assumption being that if this marker chemical is not detected in the home being remediated, it is reasonable to assume that no other volatile compounds are entering the building to any great extent). Post-mitigation testing data may also be useful on an individual basis, i.e., if concentrations of certain compounds drop (due to mitigation) but others do not, the other compounds can be assumed to be due to background sources. Assuming that a reasonable background threshold value is established (indoor or outdoor air quality), measured indoor air concentrations below the threshold are presumed to be background. Concentrations above the threshold might still be due to background (depending on how background was calculated), but would require a line of evidence evaluation to make this determination. When conducting a background study, particularly for outdoor air, one should be careful not to allow plume-derived vapors to bias the resulting data set (e.g., contributions from operating sub-slab depressurization air emission systems or the transport of vapors from a subsurface source directly into the overlying atmosphere).

- Absence/Presence of Marker Chemicals – As was noted in the example above, the presence of marker chemicals (those constituents that are associated with the subsurface contamination, but not background air sources) in indoor air measurements is a good indication that infiltration is occurring and the observed constituents are derived from the subsurface. The converse assumption may also be true, i.e., the absence of a marker chemical in indoor air measurements is a good indicator that little to no contamination is coming from the subsurface, suggesting that any air contaminants observed are from background sources. This second assumption, however, is dependent upon all COCs behaving in a similar fashion, i.e., the volatility and infiltration potential of the marker chemical is equal to or greater than the other COCs.

- Indoor Air Models – Although the Department does not rely on computer models to determine whether or not to sample indoor air in a potentially affected structure, models can be used as a line of evidence to evaluate the likelihood that contamination will migrate into a building. If a model suggests that the potential for soil vapor to accumulate within a structure is high, it is very probable that hazardous substances measured in indoor air are coming from the subsurface. On the other hand, if the model suggests that it is unlikely vapors derived from the subsurface will accumulate within the structure in excess of allowable limits, it may not always be reasonable to conclude that the measured constituents are derived from a background source. The many uncertainties associated with modeling a complex and poorly understood physical system results in predictions that may be off by an order of magnitude or more, limiting the usefulness of this tool to attribute vapor measurements to either background or subsurface contaminant sources. Where possible, the model should be calibrated with site-specific data, or run with conservative default parameters. Experience using actual data will lead to better calibration of soil vapor intrusion models that may, in the future, allow for their use as a more reliable predictive tool.

There are at least two other potential sources of background contamination that should be considered, not as a line of evidence per se, but during the data validation process to determine the reliability and quality of the analytical data. These sources are: 1) residual concentrations remaining in a clean sampling system (i.e., canister and associated inlet and flow controller), and 2) residual concentrations in the laboratory analytical system. These sources of contamination may be identified using routine field and laboratory blanks after which the data is appropriately qualified. Although the residual concentrations may be quite small, they may be a significant contributor to measured concentrations near the screening level risk criteria, particularly if the risk is summed. As risk-based screening levels become smaller, these residual concentrations become more important. The Department should be consulted in order to decide how to qualify these results and evaluate data usability. In those situations where the screening level concentration is close to the method detection limit, the confidence of the estimated values should be factored into the risk management decision.

Although large uncertainty may be associated with the results of each individual line of evidence, the findings of multiple lines of evidence may support a determination as to the relative contributions from both subsurface contaminant sources and background-derived sources. While there is no exact formula for factoring the multiple lines of evidence, determinations based on direct lines of evidence carry more weight than those that rely on indirect means. For example, a claim that measurements represent background is more easily supported using data collected during a comprehensive background study, as opposed to reliance on the combination of a chemical survey, operational characteristics of the building and modeling. Fewer lines of evidence employing direct, quantifiable methods are required to support attribution to background, while multiple lines of evidence using indirect methods or assumptions would be required before such a claim would be considered by the Department.

The Department will consider all data presented during such an evaluation to decide whether the weight of evidence supports a determination one way or the other.

4.2 WHEN BACKGROUND BECOMES A CONSIDERATION

Background must be considered when making remedial decisions in cases where: there are no marker chemicals to distinguish sources of contamination; the COCs are commonly found in background measurements; the COCs are found in commonly used household products; the indoor air measurements fall within the range of background readings, and/or; the COC action level and/or remediation goal falls within the range of observed background readings. In these instances it may be difficult to impossible to distinguish between vapors derived from a subsurface source, which the facility is responsible for remediating, and those coming from a variety of undefined, unrelated background sources. The dilemma of distinguishing between background and facility related sources of indoor air contamination is not only a problem in structures above or near a subsurface source where contributions would be expected, it is also a problem when a) trying to define the lateral limits of the area requiring monitoring and/or remediation and b) when evaluating the effectiveness of an operating indoor air remediation system. Each of these cases is discussed in the sections below.

Lines of evidence have been incorporated into the Figure 1 decision tree flowchart that outlines the entire soil vapor intrusion evaluation process. Figure 1 should be used to evaluate the need for monitoring and/or remediation in areas where background sources may be significant contributors to indoor air contamination, not only in areas above a subsurface source, but along its margins as well. An answer of "no" to a number of questions on the flowchart may be an indication that the subsurface source may have little to no impact on air quality within the building, the indoor air readings possibly being due entirely to background sources. Parties performing an indoor air investigation have the option of pursuing one or more of the multiple pathways provided. They also have the flexibility to modify the flowchart to evaluate lines of evidence earlier in the process than is indicated in the chart, potentially avoiding having to collect data that building occupants may find disruptive (sub-slab or indoor air testing). Any modification to the flow chart should be discussed with and approved by the Department in advance of collecting the data to ensure that resources are not expended unnecessarily.

4.2.1 Background: Over The Plume

The presence of background contamination complicates the task of determining the source of and responsibility for COCs measured in indoor air samples in structures located directly above a subsurface source area (e.g., the ground water plume). Unless convincing data is provided using multiple lines of evidence justifying reasons to the contrary, it is the Department's expectation that indoor samples will be collected from structures above a subsurface source area containing volatile COCs in order to begin the process of assessing whether or not a problem exists.

4.2.2 Background: Lateral Limits Of An Impacted Area

The presence of background contamination may also make it difficult to determine the lateral limits of an impacted area. The challenge is in identifying the crossover point on the margins of a subsurface source where vapor contributions are minimal to nonexistent and where the indoor air readings are dominated by unrelated background sources. In this situation, it may not be feasible to define the lateral extent of the area impacted by vapors coming off a subsurface source relying solely on action levels or remediation goals, potentially triggering the unnecessary requirement to either monitor indoor air and/or install remediation systems.

The party responsible for remediating the contamination may propose to do one of two things. They may elect to extend the boundaries of the area they are responsible for monitoring and remediating to include areas that are reasonably expected to be outside the influence of their subsurface source. Experience indicates that a two-house buffer zone (or approximately 100 feet) beyond the edge of a well-defined ground water plume is adequate to encompass homes potentially subject to soil vapor intrusion. Site-specific considerations may justify adjusting the size of this buffer zone. The alternative is to gather additional data (e.g., sub-building soil vapor samples) and other lines of evidence to define the lateral limits of the affected area, thereby supporting a proposal to restrict remedial activities to a limited area near the margins of the subsurface source of vapors. Data gathered from all applicable lines of evidence will be carefully reviewed before the Department will approve a decision to limit or exclude the building from the responsible party's corrective action process.

4.2.3 Background: Post-Remediation Sampling

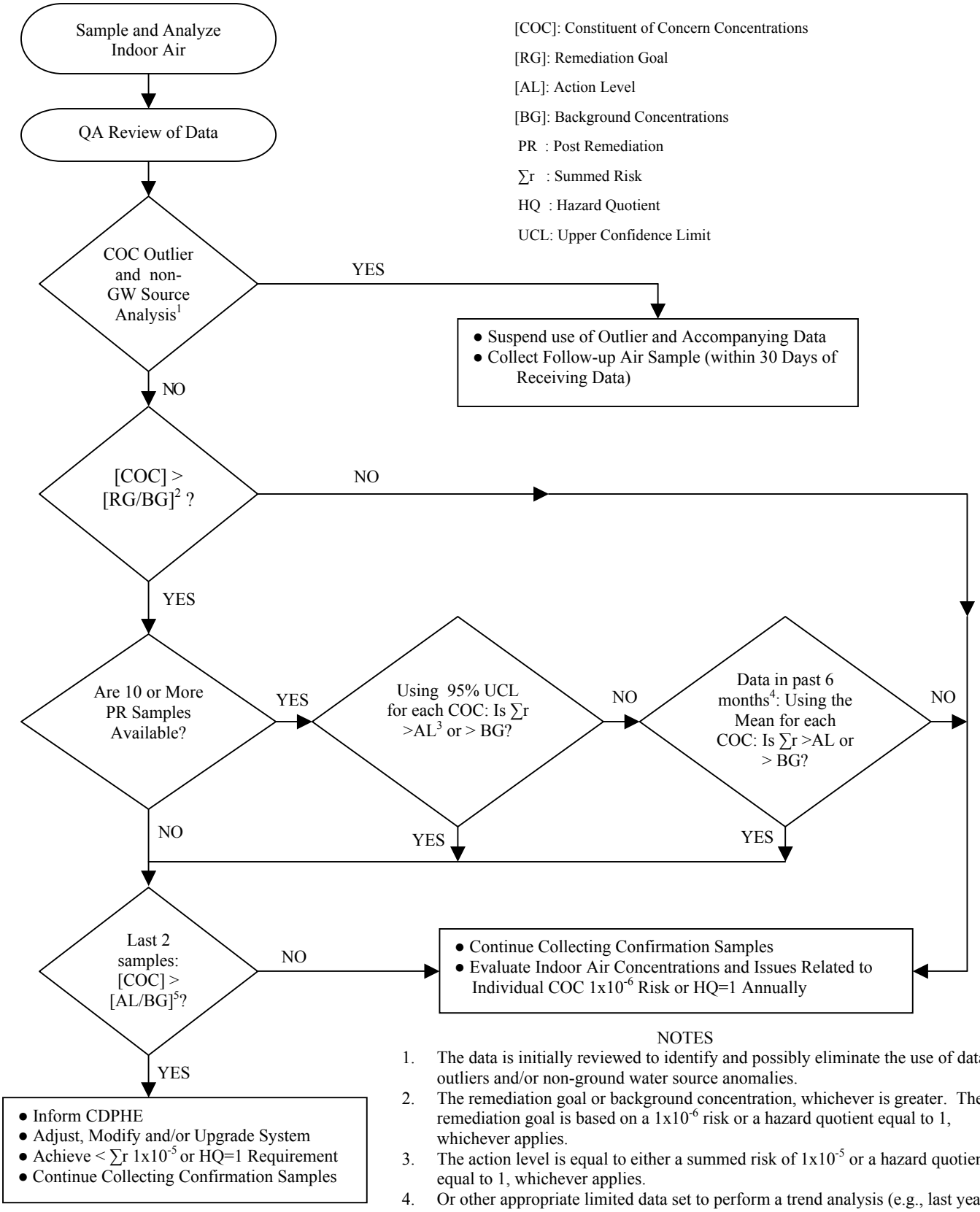
The presence of background contamination may make it difficult for the facility to achieve the remediation goal in buildings where indoor air remediation systems are operating (buildings with readings above the action level), and/or where the remediation of the subsurface source is determined to be the primary method of eliminating the COCs that are contributing to the indoor air contamination (buildings with concentrations less than the interim action level but where measured values are above the final remediation goal). There may be situations where a constituent's action level/remediation goal falls within the range of background values, complicating the task of determining whether additional action is necessary to respond to measured concentrations. In these instances, the action levels or remediation goal may be unachievable if the remedy does not factor in background contributions. This is particularly true in cases where the combination of background sources, elevated reporting limits and false positives (e.g., due to residual contamination in canisters or in laboratory analytical systems) may quickly cause exceedence of the 10^{-5} risk action level if COCs are summed.

In these situations, the Department recommends that the air sampling data once again be evaluated in an effort to determine the source of the measured COCs. A line of evidence evaluation may need to be performed a second time to make the determination that the post-remediation sampling results are attributable to background sources. The second half of the decision tree flowchart illustrated in Figure 1 may once again be used to evaluate background contributions of COCs to indoor air quality. Another approach to evaluating post-remediation data is outlined in Figure 2. This flowchart can also be used to determine whether the post-remediation data is indicative of a background source or continuing vapor intrusion (requiring that the performance of a building's remediation system be enhanced to further reduce indoor air concentrations). An alternate decision process may be proposed to allow a facility to exit from post-remediation monitoring for locations with "anomalously high" background. Any modification to this flowchart should be negotiated with and approved by the Department in advance of collecting any data that may be used to attribute measured contamination to lingering background sources.

The above questions should be answered for each of the COCs at the site, one or more of which may influence a decision on whether or not background is a concern. All available information should be carefully reviewed before a conclusion is reached that the observed COC levels are attributable to background sources and no further action is required on the part of the facility to remediate these residual, background contributions.

FIGURE 2

POST-REMEDIATION DATA EVALUATION



NOTES

1. The data is initially reviewed to identify and possibly eliminate the use of data outliers and/or non-ground water source anomalies.
2. The remediation goal or background concentration, whichever is greater. The remediation goal is based on a $1x10^{-6}$ risk or a hazard quotient equal to 1, whichever applies.
3. The action level is equal to either a summed risk of $1x10^{-5}$ or a hazard quotient equal to 1, whichever applies.
4. Or other appropriate limited data set to perform a trend analysis (e.g., last years worth of data, last 4 sampling events, etc.)
5. The action level or background concentration, whichever is greater. The action level is based on a $1x10^{-5}$ risk or a hazard quotient equal to 1, whichever applies.

4.3 BACKGROUND AND RISK ASSESSMENT

COC concentrations attributable to background sources should be included in the baseline risk assessment, even though the party performing the cleanup is not responsible for these contributions and the incremental risk due to soil vapor intrusion is small. Even minimal background contributions have the potential to cause indoor air quality to exceed risk-based concentrations that may trigger remedial actions. At the very least, the responsible party may be required to implement remedial actions in areas where subsurface sources of contamination are present to achieve either background levels (in cases where the risk-based concentration is below background) or risk-based concentrations (in cases where these are above background). Decisions regarding the mitigation of soil vapor intrusions should be based on the results of the risk assessment, factoring in the background contributions. Please consult other guidance documents on the subject of risk assessment to perform this evaluation and assist in making those decisions.

4.4 METHODS FOR DETERMINING BACKGROUND

There are two primary methods being used to determine background indoor air concentrations. One methodology compares the indoor air at a specific location to ambient conditions surrounding a given structure, at a specific time. In other words, compare the inside air quality data to the outside ambient air quality data. The other approach attempts to determine an areal indoor air background concentration near a location whose indoor air has been impacted by contaminated ground water. In other words, compare indoor air concentrations in buildings over subsurface contamination to buildings not affected by this environmental contamination. Each approach has advantages and disadvantages that will be discussed below. However, determining background indoor air concentrations may be unnecessary if the indoor air chemical concentrations are below the prescribed health-based unrestricted use indoor air concentrations.

The number and locations of background indoor air samples associated with a project will depend on the site-specific characteristics and variability of site conditions. Establishing background concentrations for indoor air may be very time consuming and resource intensive due to the number of parameters and their spatial and temporal variability. Physical conditions that can affect ambient indoor air chemical concentrations include temperature, barometric pressure, wind speed, building construction, building ventilation, and surrounding external air contaminant sources (busy streets with automobile emissions, manufacturing operations with air emissions, etc.).

Background concentrations should be defined using methods that result in measurements that are as representative of the site conditions as possible. Therefore, background vapor concentrations must be evaluated in areas with similar settings as the study area. One of the key aspects to procuring meaningful background data is to reduce or eliminate, to the extent practicable, the variability in each of the parameters between the site and the background locations that affects vapor measurements. Every effort should be made to normalize these conditions.

Background samples should be collected contemporaneously with the actual study area samples. This will help to normalize the metrological/ambient conditions and minimize the differential impacts of temperature, wind speed, barometric pressure, soil moisture, soil saturation, and soil temperature.

There are several advantages to collecting the background indoor air samples near the study area. The hydrogeologic setting may be similar in both areas. Hopefully the geology, depth to ground water, and ground water chemistry will be similar or have negligible differences. Nearby homes and business constructed during the same general time period are often built using similar construction techniques and materials.

If possible, background locations should be selected that best represent the various types of structures that are impacted by indoor air. These buildings may include single-family homes, apartments, office buildings, manufacturing facilities, and commercial establishments. The background locations should have similar construction characteristics. Single-family homes should be evaluated to determine if they are slab-on-grade, have a crawl space, or basement.

Prior to collecting the background samples, each structure should be surveyed. The purpose of the survey is to collect information regarding the building status that may impact the chemicals identified in the samples. The evaluations should assess: 1) the age of building; 2) the structural integrity of the building (do the walls and floors appear to be sealed and tight); 3) potential vapor migration pathways (elevator sumps, utility chases, open stairways); 4) chemicals used and, stored, or managed in the building (household, home business, and business cleaners and chemicals, chemical used with hobbies such as woodworking, modeling, painting); and 5) the type of ventilation system(s) (central heat and air that induces a positive pressure within the structure). This information will be used to determine if the proposed background sample location is representative of the structures impacted with contaminated indoor air, and whether they will have potential interferences that should cause them to be eliminated from the background study.

Once suitable structures are identified for the background study, then the number of samples per structure and the timing of the sampling events should be determined. The minimum number of background samples needed will vary and depend on many factors including how many background sample locations are available. The goal is to obtain a confidence of ninety (90%) percent. The samples should be analyzed for the pre-selected chemicals of concerns related to hazardous waste/hazardous constituents released from the facility. If the chemicals of concern have not been determined prior to implementing the background study, then a broader suite of chemicals must be analyzed. While the more exhaustive chemical analysis may be more burdensome, it may preclude missing a chemical of concern in the background study.

The Department typically recommends quarterly sampling events. Quarterly sampling affords collection during each of the major seasonal periods. This methodology will capture data that can be used to help evaluate seasonal trends, in addition to background evaluations. Monitoring specifics will be detailed in a site-specific work plan. The duration of a monitoring program depends on the type of survey or assessment being conducted.

Accurately determining the background concentrations of the chemicals of concern is key in the remediation decision process. Facilities must remediate the indoor air contamination associated with releases from their facilities down to health-based or background concentrations, whichever is greater. If the background concentration of a chemical of concern is greater than the health-based concentration, then the indoor air will only have to be remediated down to the background concentration.

5.0 REMEDIAL ACTIONS

Decisions regarding the need for mitigation will be made on the basis of a demonstrated, discernable impact to indoor air quality caused by the migration of vapors from subsurface contamination derived from a release at the responsible party's facility. The health threat associated with the measured concentration of a chemical shall determine what that remedial action will consist of. Responses may range from doing nothing, other than remediating the source area, all the way to relocating building occupants while an indoor air mitigation system is installed. These remedial actions, along with their trigger criteria, are outlined in Table 2. This approach is rarely modified by the site-specific situations. It is assumed that adequate data is available (both representative concentrations and toxicological data) to calculate the threat posed by exposure to measured indoor air contaminants upon which risk management decisions can be based. Site-specific decisions will dictate whether actions are based on single sample results or multiple samples collected over a period of time to account for seasonal variations. Similarly, remedial actions may be based on site-specific factors that influence decisions on how to manage the threat and/or the speed with which the facility responds to elevated vapor readings (building construction, building occupants, vapor concentrations, projected time for the remediation of contamination, etc.). Although specific activities have been identified the following sections, the Department recognizes the need for flexibility when responding to issues that may arise during the course of these complex and high profile situations. Other equally protective abatement strategies may be available and better suited to site-specific circumstances. The use of alternate techniques should be discussed with and approved by the Department prior to their implementation.

5.1 NO FURTHER ACTION

No additional air sampling is required at locations where test results show that measured concentrations do not exceed chemical specific remediation goals. Site-specific conditions will dictate whether this decision is based on a single sample or multiple samples collected over a set period of time. Few samples would be required if lines of evidence suggest that there is a low probability that vapors will intrude a particular location. Renewed testing at these same locations may be warranted if data becomes available indicating that subsurface conditions have changed and there is an increased likelihood that vapors may now be migrating into the building (e.g., contaminant concentrations in nearby ground water monitoring wells increase).

5.2 MONITORING ONLY

Readings that fall within this range of concentrations may necessitate testing indoor air periodically to ensure that concentrations remain below action levels. Site-specific factors will be considered when deciding the frequency and length of such monitoring. Although air monitoring may be all that is required to assess this exposure pathway, the Department's expectation is that actions to remediate the subsurface source of these vapors will ultimately reduce their concentration to the extent that the remediation goal is achieved in all affected media, including indoor air.

5.3 INTERIM MEASURE: INSTALLATION OF MITIGATION SYSTEMS

In those instances where constituent specific action levels are exceeded in indoor air, interim measures may be required to quickly control or eliminate threats to human health. Interim measures are actions performed to reduce risk as quickly and effectively as practicable. It may be an action that is either proposed by the facility or required by the Department. When evidence demonstrates impact to people above a 1×10^{-5} excess cancer risk or a hazard quotient of 1, and effective action can be taken before a long-term remedy can be implemented, then an interim measure will be considered by the Department.

The installation of a sub-slab depressurization system has proven effective in reducing soil or ground water derived indoor air vapors. This involves creating a low-pressure zone beneath the building and venting the vapors to the outside atmosphere. Installation of this mitigation systems consists of drilling through the floor slab, placement of piping into a small space excavated beneath the floor slab, sealing the pipe in place, then connecting this pipe to an exhaust blower outside the building. Experience indicates that this is usually effective in reducing indoor air concentrations to below action level concentrations. For larger buildings, multiple points of pipe installation, or horizontal perforated pipe installed beneath the building have been effective reducing vapor intrusion. Buildings with crawl spaces may be remediated using a synthetic membrane that acts as a blanket to block the migration of transient vapors. Suction is applied below the membrane and the resulting gasses are discharged to the atmosphere.

5.4 INTERIM MEASURES: TEMPORARY RELOCATION OF BUILDING OCCUPANTS

Measurements with calculated risks greater than $1x10^{-4}$ may require that the facility offer the building occupants the option of being temporarily relocated while a mitigation system is installed. The speed with which such a system can be installed will determine whether or not it is necessary to inconvenience the building occupants in this fashion (rapid actions to eliminate the exposure will result in a minimal incremental risk).

5.5 LONG-TERM REMEDIAL ACTIONS

Contaminated indoor air must be remediated to final sustained concentrations that are either 1) equal to or below a hazard quotient of one (non-carcinogens) or 2) do not present an excess cancer risk greater than $1x10^{-6}$ per chemical for each chemical of concern, with a maximum of $1x10^{-5}$ for more than ten constituents. A facility may propose the use of an alternative cleanup level based on site-specific background concentrations. The Department believes that this long-term risk goal will be protective of human health for unrestricted use. The $1x10^{-6}$ individual chemical risk goal for indoor air is generally consistent with health-based cleanup levels derived for other media including the State and Federal ground water maximum contaminant levels (MCLs) and soil as outlined in Department's *Proposed Soil Remediation Objectives Policy Document* (December 1997).

Achievement of the long-term goal for indoor air will rely heavily on the cleanup of soil and/or ground water to reduce or eliminate the contamination source: source reduction should result in minimizing or eliminating the generation of vapors that can migrate into overlying buildings. Thus, soil/ground water remediation must be part of the preferred long-term remedy for the indoor air pathway, and this integration should be clearly stated and described in the corrective

measures work plan prepared for the site. Long-term monitoring to demonstrate movement towards and ultimately achieving the remediation goals, in both the contaminated environmental media and indoor air, should also be described in that plan for the site.

TABLE 2 - REMEDIAL RESPONSE ACTIONS

HEALTH-BASED TRIGGER CRITERIA	REMEDIAL ACTION
Remediation Goal: Carcinogens: $\leq 1x10^{-6}$ Non-Carcinogens: HQ $\leq$ 1	No Further Action – Concentrations that fall below these risk levels are deemed to pose no significant threat to the public and no additional testing would be required, unless a change in subsurface conditions (e.g., increasing ground water concentrations) trigger the need for renewed testing.
Carcinogens: $>1x10^{-6}$ and $<1x10^{-5}$	Monitoring Only – Sample locations that yield concentrations that fall within this range should be monitored periodically to verify that natural variation in vapor concentrations will not increase to the point where interim measures are required. It is assumed that timely actions to remediate the sources of the vapors will be implemented to eventually achieve the remediation goal, triggering no further action.
Action Level: Carcinogens: $\geq 1x10^{-5}$ and $<1x10^{-4}$ Non-Carcinogens: HQ > 1	Interim Measures – Indoor air mitigation systems will need to be installed, within a reasonable period of time after discovery, at those sample locations with vapor measurements that fall within this range.
Action Level: Carcinogens: $\geq 1x10^{-4}$ Non-Carcinogens: HQ > 10	Interim Measures – Occupants of buildings with indoor air concentrations that exceed these criteria will be offered temporary relocation while remedial systems are installed.

6.0 MONITORING REQUIREMENTS

Indoor air monitoring will be conducted for several reasons. It can be performed as part of an initial study to see if a problem exists (Phase II exposure assessment). It can be performed to define the extent and degree of known contamination (Phase III exposure assessment). It is also conducted to gauge the performance of mitigation system that may have been installed (compliance monitoring) and to verify that buildings along the known edge of the impacted area remain below the action level concentration (verification monitoring). Monitoring results are used to judge the performance of systems that may have been installed to remediate soil and ground water contamination and the resulting changes they may have with regard to the vapor intrusion pathway in the impacted area. They are also used to determine when monitoring frequency can be changed. The various forms of indoor air monitoring, their recommended frequency and criteria for modifying the location and frequency of monitoring are summarized in Table 3.

During the characterization phase of an indoor air assessment, buildings are monitored quarterly, and sometimes more often. Testing moves from building to adjacent building until the impacted area is defined, plus a buffer zone. This buffer zone is used to monitor for emerging impacts and future movement of contamination.

Buildings with indoor air mitigation systems should be routinely monitored to verify the effectiveness of a mitigation system. This type of monitoring starts on a quarterly frequency, but may decrease as more data becomes available and confidence is gained that conditions will either remain the same or improve with the passage of time. Changing the frequency to semi-annual can be proposed to the Department after at least a year of monitoring below the action level, and exhibiting no trend of increasing concentration. The Department will also take into consideration the historical data for the monitoring locations and their position relative to ongoing corrective actions, before deciding to accept the proposal or not.

Buildings adjacent to properties with mitigation systems are also routinely monitored to verify that they too don't exceed action levels in the future that may trigger the need for an interim measure. The frequency of monitoring depends on the phase of the mitigation process for a particular building, and on the location of the building within the zone of contamination, and its potential to be impacted.

Any active ground water or soil remediation system that has the potential to affect soil vapor concentrations should take into account potential impacts to indoor air, especially during the startup phase. Chemical oxidation, air sparging, bioremediation, hydrofracturing, bioventing, and other remedial technologies may initially mobilize or elevate concentrations of contaminants, or result in the generation of potentially volatile and toxic breakdown daughter products that were not previously monitored in the indoor air at the site. Design precautions must be taken to control these effects and to identify and prevent potential impacts to indoor air. Increased frequency of indoor air monitoring, soil gas, and indoor air remediation system influent during the startup phase of source remediation should be considered, and may be required.

6.1 EFFECTIVENESS MONITORING OF DEPRESSURIZATION SYSTEMS

The post-remediation test results should be evaluated not only to determine whether action levels or remediation goals have been achieved, but also to determine the effectiveness of the mitigation system to halt the continued migration of vapors into buildings. This becomes especially important in situations where background sources may be contributing to indoor air contamination.

The effectiveness of depressurization systems can be evaluated by comparing the concentrations in samples collected prior to the installation of the system (i.e., initial, step-out, confirmatory, and pre-ventilation sampling episodes) to the results of samples collected after the installation of a mitigation system. For each building, the concentrations of VOCs measured before system installation should be averaged, and the result compared to the average concentration measured during the post-mitigation sampling events. The percent decline in individual contaminant concentrations is an indication of the remediation systems effectiveness intercepting vapors before they have the opportunity to migrate into the building.

For those constituents whose appearance fluctuates from non detect to some measurable value from one sampling episode to another, a value of one-half the laboratory reporting limit should be substituted for samples in which the VOC was not detected when calculating an average pre- or post-mitigation concentration for that particular constituent.

Varying levels of effectiveness removing chemical-specific vapors may be an indication that there are other sources of these compounds in buildings not attributable to subsurface contamination. If the contaminants exist entirely as vapors below the buildings, the mitigation systems should be equally effective at preventing vapor entry. If different rates of removal are observed, a background study may be needed to determine whether some of the compounds are derived from indoor sources or ambient outdoor air.

TABLE 3 – RECOMMENDED INDOOR AIR MONITORING FOR EXISTING CONSTRUCTION

TYPE OF MONITORING	FIRST YEAR	SECOND YEAR	THIRD YEAR AND BEYOND	CRITERIA FOR A CHANGE IN MONITORING
Horizontal Extent Monitoring - To define the extent of vapor impacted homes above the remediation goal ($1x10^{-6}$ or an HQ of 1).	Indoor air sampling continues until all homes above the remediation goal are identified.	Not applicable.	Not applicable.	If vapor concentrations exceed the remediation goal (cancer risk greater than $1x10^{-6}$ or HQ greater than 1), one of the monitoring programs noted below should be implemented. Otherwise, a decision can be made to terminate monitoring.
Post-Remediation Monitoring – To monitor the performance of installed indoor air remediation systems.	Quarterly monitoring	Semiannual monitoring	Annual monitoring	Frequency of monitoring may decrease if the following conditions are met: 1) indoor air remediation systems are operating continuously and without problem, 2) vapor concentrations are stable, 3) vapor concentrations are consistently below the action level (cancer risk less than $1x10^{-5}$ or HQ$\leq$1) and, 4) ground water conditions are stable. Testing may be terminated when measured concentrations are consistently below the remediation goal ($1x10^{-6}$ or HQ$\leq$1) without the use of active indoor air abatement systems.
Verification Monitoring I– To monitor indoor air quality in homes along the perimeter of the vapor impacted area, just outside the area requiring active remediation.	First line of homes: Quarterly monitoring Second line of homes: Semiannual monitoring	First line of homes: Semiannual monitoring Second line of homes: Annual monitoring	First line of homes: Annual monitoring	Frequency of monitoring may decrease if the following conditions are met: 1) vapor concentrations are stable, 2) vapor concentrations are consistently below the action level (cancer risk less than $1x10^{-5}$ or HQ$\leq$1), 3) ground water conditions are stable, and 4) similar conditions are observed in those nearby homes being remediated. Testing may be terminated when measured concentrations are consistently below the remediation goal ($1x10^{-6}$ or HQ$\leq$1).
Verification Monitoring II– To monitor indoor air quality in homes downgradient of a facility, where vapor concentrations are less than the action level but still above the remediation goal ($1x10^{-5}$ to $1x10^{-6}$ risk range or HQ$\leq$1), where no active remediation systems are required. Homes closest to the source are selectively targeted for sampling.	**Quarterly monitoring**	Semiannual monitoring	Annual monitoring	Frequency of monitoring may decrease if the following conditions are met: 1) vapor concentrations are stable, 2) vapor concentrations are consistently below the action level (cancer risk less than $1x10^{-5}$ or HQ$\leq$1), 3) ground water conditions are stable, and 4) similar conditions are observed in those nearby homes being remediated. Testing may be terminated when measured concentrations are consistently below the remediation goal ($1x10^{-6}$ or HQ$\leq$1).
Performance Evaluation Monitoring - To monitor the effects of site-wide remedial activities on indoor vapor concentrations.	Monitoring frequency and location is dependent on the remedy to eliminate the source of the vapors from the environment	Monitoring frequency and location is dependent on the remedy to eliminate the source of the vapors from the environment	Monitoring frequency and location is dependent on the remedy to eliminate the source of the vapors from the environment	Sampling frequency may decrease based on the test results of all media being monitored

ATTACHMENT A

Example Chemical Interview Form

EXAMPLE INDOOR AIR SAMPLING BUILDING SURVEY

DATE:_____ ID #_____

ADDRESS _____
_____
_____

Residential Contact _____

Phone: Home ( )_____ Work: ( )_____

Move in date _____

Length of residence in area: _____

List of Current Occupants/Occupation

AGE (IF UNDER 18)	SEX (M/F)	OCCUPATION

BUILDING CONSTRUCTION CHARACTERISTICS

What type of building do you have? (Please circle appropriate type)

Single Family	Multiple Family	School	Commercial
Ranch	2-family		
Raised Ranch	Duplex		
Cape	Apartment house		
Colonial	# of units _____		
Split Level	Condominium		
Adobe	# of units _____		
Mobile Home	Other (please specify) _____		
Other (Please specify) _____			

General description of building construction methods

_____

_____

_____

How many occupied stories does the building have? _____

Has the building been weatherized with any of the following? (please circle all that apply)

Insulation Storm Windows Energy-efficient Windows
Other (specify)_____

What type of foundation does the building have?

Full basement crawl space Slab-on-Grade
Other (please specify)_____

What are the basement characteristics? (please circle all that apply)

	Basement Floor:	Foundation Walls:	Moisture:
Finished	concrete	poured concrete	wet
Unfinished	Dirt	block	damp
	Other_____	stone	dry

Is a basement sump present? YES NO

Heating & Ventilation System(s) Present:

What type of heating system(s) are used in this building? (Please circle all that apply)

Hot air circulation Heat pump Steam radiators Wood stove
Hot air radiation Unvented kerosene heater Electric baseboard

Other (please specify) _____

What type(s) of fuel are used in this building? (please circle all that apply)

Natural gas Electric Coal Other (specify)_____
Fuel oil Wood Solar

What types of mechanical ventilation systems are present and/or currently operation in the building? (please circle all that apply)

Central air conditioning Mechanical fans Bathroom vent fan
Individual air conditioning units Kitchen range hood Air-to air heat exchanger
Open windows Other (please specify) _____

SOURCES OF CHEMICAL CONTAMINANTS:

Which of these items are present or recently present in the building? (Please check all that apply)

Potential Chemical Source	Location of Chemical	Was Removed 48 hours prior to sampling? (Y/N)
Paints or thinners		
Gasoline-powered equipment		
Gasoline storage cans		
Cleaning solvents		
Air fresheners		
Oven cleaners		
Carpet/upholstery cleaners		
Hairspray		
Nail polish or remover		
Bathroom cleaner		
Appliance cleaner		
Furniture/floor polish		
Moth balls		
Fuel tank		
Wood stove		
Fireplace		
Hobby Supplies like solvents, paints, lacquers, glues, photographic darkroom supplies, etc.		
Scented trees, wreaths, potpourri, etc		
Other		
Other		

Do one or more smokers occupy this building on a regular basis?

Has any body smoked in the building in the last 48 hours?

Does the building have an attached garage?

If so, is a car usually parked in the garage?

Do the occupants of the building frequently have their clothes dry-cleaned?

Was there any recent remodeling of painting done in the building?

Are there any pressed wood products in the building e.g., hardwood plywood wall paneling, particle board, fiber board?

Are there any new upholstery, drapes, shower curtains, or other textiles in the building?
Has the building been treated with any insecticides/pesticides? If so, what chemicals are used and how often are they applied.

Do any of the occupants apply pesticides/herbicides in the yard or garden? If so, what chemicals are used and how often are they applied?

WEATHER CONDITIONS DURING SAMPLING

Outside Temperature (^{o}F) _____
Prevailing wind direction and speed _____
Describe the general weather conditions (i.e. sunny, cloudy, rain, snow) _____
Was there any significant precipitation (0.1 inches) within 12 hours of the sampling event? ____
Type of ground cover (e.g. grass, asphalt, concrete, dirt, etc.) outside building. _____

GENERAL COMMENTS

Is there any other information about the structural features of this building, the habits of its occupants or potential sources of chemical contamination to the indoor air that may be of importance in facilitating the evaluation of the indoor air quality of the building?

ATTACHMENT B

Guidance for Analysis of Indoor Air Samples

GUIDANCE FOR ANALYSIS OF INDOOR AIR SAMPLES

Colorado Department of Public Health and Environment

Hazardous Materials and Waste Management Division
(303) 692-3300

Revised April 2000

Purpose of this Guidance

This is intended as general guidance for generators of hazardous waste and is meant to assist in compliance with the hazardous waste regulations. The guidance is not meant to modify or replace the promulgated regulations which undergo periodic revisions. In the event of a conflict between this guidance and promulgated regulations, the regulations govern. Some portions of the hazardous waste regulations are complex and this guidance does not go into details of these complex situations. If a regulatory situation is not described in the guidance or clarification is desired, an official interpretation of a specific hazardous waste regulation can be requested by writing to the Hazardous Materials and Waste Management Division at the address on page 7.

We would appreciate any comments or suggestions for making improvements in future editions. Suggestions or comments can be sent to the address on page 7.

This document was revised to correct the isotope ratios on page one, paragraph three.

GUIDANCE FOR ANALYSIS OF INDOOR AIR SAMPLES

The Hazardous Materials and Waste Management Division ("HMWMD") of the Colorado Department of Public Health and Environment, in consultation with US EPA Region VIII, have evaluated analysis protocols being employed to ascertain the inhalation exposure pathway for domiciles impacted by volatile organic compounds (e.g., chlorinated solvents and their degradation products) released to the environment, and specify minimal acceptable requirements.

The impact to residential communities by volatile organic compounds via the respiratory exposure pathway is being assessed by regulated industries with oversight from the agency. The purpose of these investigations is to acquire data to be used as inputs into a risk assessment process employed by agency toxicologists, and to provide a tool with which to establish remediation and response activities. These types of investigations are Category 1 Projects which the agency considers to be the highest priority effort with potentially large negative public health impacts. In order to maximize the usability of these data and minimize the cost of these investigations, the agency is here defining the minimal acceptable technical thresholds and attributes for these data.

The minimal acceptable tuning requirements for GC/MS-SIM instruments

GC/MS instruments operated to meet Compendium Methods TO-14, TO-14a, TO-15, and TO-16 Scan mode, must meet specified tuning requirements for operation. SIM tuning and data acquisition requirements are not specified. Presently, instruments may be tuned in any manner at the discretion of the laboratory, and may include tuning to Scan mode requirements with an accompanying loss in sensitivity. The agency notes that tuning algorithms which are designed to maximize the 69 atomic mass unit ("amu") ion for the tuning compound perfluorotributylamine ("PFTBA") inherently produce a better signal to noise ratio, and a lower detection limit. These tuning algorithms are typically referred to as the "Autotune" instrument option. The agency will require that tuning be accomplished by way of Autotune protocols, and the following conditions must be met: (1) The operator must confirm that the 69/70, 219/220, and 502/503 isotope ratios occur at the proper ratios of 1 percent (+/- 50 %), 5 percent (+/-25 %), 10 percent (+/- 10 %) respectively; (2) The peak width at half height for the 502, 219, and 69 PFTBA isotopes be 0.5 amu +/- 0.2 amu: and (3) The operator must confirm the correct mass assignment of these isotopes to a tolerance of 0.1 amu (e.g., 69.0 amu +/- 0.1 amu).

Once tuned, these instruments have acceptable electronic drift; such that, operators must verify that the tuning is stable at a minimum of once per operating day to insure correct mass axis alignment, and eliminate data accumulated with contaminated ion sources. These instrument tuning requirements specify the minimum acceptable performance goals which are easily verified.

The minimal acceptable data acquisition requirements for GC/MS-SIM instruments

GC/MS instruments operated to meet Compendium Methods in the SIM mode must be tuned and operated to acquire data with 1 amu of resolution. Presently, there are no tuning criteria for the SIM mode in these methods. The agency evaluated data produced with low resolution (between 1.4

and 1.8 amu) and high resolution (1 amu) approaches on a linear quadrapole instrument. The data produced with high resolution show a demonstrable improvement in signal to noise ratio, fewer interferences, and a lower detection limit for all compounds of interest. Furthermore, actual data accumulated for an indoor air quality assessment was examined, and all samples analyzed by a low resolution approach exhibited detrimental interferences. Only two samples demonstrated the absence of interference. These samples were found to have been acquired with a high resolution approach (1 amu of resolution). Data acquired with 1 amu of resolution met required detection limits for the compounds of interest.

The agency requires that GC/MS-SIM data be acquired with 1 amu of resolution, and that the following conditions must be met: (1) the operator must demonstrate compliance with the tuning specifications; (2) the operator must confirm that the software method used to collect calibrant and sample data be set to the high resolution option (1 amu); (3) the ion dwell times must have been optimized to obtain a minimum of 10 scans per peak; and (4) the electron multiplier voltages must be set to meet the detection limits of the project (conveniently accomplished by setting EM voltages at +300 volts relative to the tune voltage).

The minimal acceptable requirements for ion selection for GC/MS-SIM and GC/MS-Scan

GC/MS instruments operated to meet Compendium Methods in the SIM and Scan modes report the air concentration of contaminants by using prominent and unique fragmentation ions in the contaminant's mass spectra. The magnitude of these so called "characteristic" ions, operate in both the SIM and Scan modes as the means to measure the concentration of the contaminant present in the sample. In the SIM mode, the characteristic ions function additionally to provide the identity to the contaminant found in the sample. The Compendium Methods are an assemblage of known analytical approaches which are peer reviewed, documented, and made available for general use. These methods are not offered as absolute, or infallible approaches. There is an assumption that knowledgeable and proficient scientists will operate on data resulting from these methods, and will take actions to meet the data quality objectives of specific projects.

The Compendium Methods have tabular attachments which list the contaminant and its characteristic ions. EPA and HMWMD chemists have independently come to the identical conclusion that the chlorinated solvents characteristic ions used in these methods are substantially different from those tabular lists in methods for other EPA programs (water and hazardous waste). For the typical suite of nine solvent contaminants and degradation products accumulated for indoor air samples, four of these targets have different characteristic ions in equivalent methods (EPA method 8260B, EPA method 624, and EPA method 524). The agency is aware that a significant amount of thought and consultation occurred for the adoption of the characteristic ions for these contaminants into these equivalent methods, and there is no discernible distinction for the media sampled for these contaminants because all analytical approaches ultimately utilize a gas phase for analysis. The Agencies believe that the selection of characteristic ions for this analysis is another critical element for the correct application of indoor air sampling. The agency desires to point out that the selection of characteristic ions is not a simple matter of consulting water and waste analytical methodologies, but is driven by the careful consideration of library mass spectra for the

contaminant of interest, and the presence/influence of interference. Absolutely, all available information should be consulted, but sampling and analysis to illuminate environmental impacts must include a minimal iterative performance examination of the data resulting from a particular technique. If early data sets demonstrate intolerable interference on particular ions, then subsequent analysis certainly ought to recognize other more appropriate characteristic ions which eliminate, and minimize the influence of interference.

Interferences occur in Scan and SIM data, and if these interferences occur in conjunction with characteristic ions of target contaminants, the actual concentrations may be overestimated. The agency has detected that characteristic ions used quantitatively in either mode with interference may significantly overestimate the air concentration of contaminants, regardless of the risk assessment objective (chronic or acute exposure). A dogmatic selection of quantitation ions and the presence of coeluting interferants can cause overestimates of the actual risk to impacted populations. Obviously, overestimating the impact involves unnecessarily alarming citizens to the impact of these solvent releases, and the over commitment of resources to dubious problems. More importantly, the agency's toxicologists rely on accurate data to generate a reasonable risk assessment. Funding for these remedial activities rely on private and public money, and the agency prefers to expend resources based upon the best available information to achieve needed remediation, when it is necessary. The agency prefers to use characteristic ions found in equivalent EPA methodology for GC/MS-Scan applications, and has formulated suggested ions for GC/MS-SIM based upon best professional judgment, after accounting for detrimental interferences observed in three projects, as follows:

Contaminant	Compendium Characteristic Ions[1]	Agency preferred GC/MS-Scan Equivalent Method Characteristic Ions[2]	GC/MS-SIM Suggested Ions
1,1-DCE	61[3], 96	96, 61, 63	96, 98[5]
1,2-DCA	62, 64	62, 98	62, 98[5] or 62, 64
Methylene Cl	49[3], 84[4], 86	84, 86, 49	84, 86
TCE	130, 95[4]	95, 130, 132	130, 132

(1) EPA Air Compendium Methods T0-14, T0-14a,T0-15, and TO-16 . Primary (quantitation ion) listed first.

(2) EPA method(s) 8260B (SW-846), 624 (Clean Water), and 524 (Drinking Water). Primary ion listed first.

(3) Interference detected on the primary (quantitation) ion, evaluation of 3 projects. Data from two laboratories using GC/MS-Scan and GC/MS-SIM.

(4) Interference detected on the secondary (confirming) ion, evaluation of 3 projects. Data from two laboratories using GC/MS-Scan and GC/MS-SIM.

(5) The selection of the 98 ion reflects the prominence of this ion for this compound, and observed interferences.

Interferences that have occurred in SIM data tend to obscure the identity of target compounds. The SIM approach uses a combination of retention time for characteristic ions and the characteristic ion abundance ratio to identify a contaminant. If interferences occur with target contaminants, both identification criteria may fail, and have failed. Laboratories operating this technique are reduced to "estimating" the identity and the concentration of the suspect contaminant where interferants occur in these data. This has been accomplished by assigning a "J" qualifier to the reported result. These actions are justified by the chromatographic retention time of a single characteristic ion in a single chromatographic column. The Agencies understand this approach, but are concerned about the potential for misidentification by relying solely upon a one dimensional datum.

Chromatographic behavior is a useful tool in the determination of solvent contaminants because this behavior provides a probability that a particular contaminant is present, but chromatographic behavior also includes a finite probability that the identification is incorrect. The agency is also concerned about the manner in which these qualifications apply to these data. By convention, the "J" qualification applies only to the quantitative result for the contaminant, not the identity of the contaminant. The agency will allow this approach only if such identifications additionally report that the contaminant was detected but not confirmed, along with the reason for this determination (retention time for characteristic ions, or ion ratio out of range). The agency firmly believes that the frequency of occurrence for this problem will become minor when appropriate tuning, data acquisition, and selection of characteristic ions are fully and completely implemented with a timely, iterative performance evaluation on the resulting data.

The agency and regulated facilities should not feel unreasonably constrained by Compendium methods to accomplish prudent and necessary steps to insure the adequacy of data. EPA's Office of Solid Waste and Emergency Response ("OSWER"), has established a performance based

approach to the collection of data for all of its programs, and HMWMD has likewise announced, in the preamble to the adoption of Update III to SW-846, its commitment to allow, or require analytical methodology with performance which meets the data quality objectives of a project.

The agency is aware that there are ongoing projects affected by this decision. Because of this, the agency will allow data previously accumulated that does not meet these minimal requirements, but will examine these data to determine if the data quality objectives were met. Based on these examinations, the agency may require additional sampling and analysis. Projects which require this type of sampling and analysis, proceed only by approval of the agency, and the agency will only approve of plans which specify those minimum requirements discussed here. Regulated facilities involved in sampling indoor air should amend their sampling and analysis plans immediately to reflect these minimal requirements.

To assist in this endeavor, Attachment 1 to this document specifies in tabular form the minimal acceptable requirements for analysis of indoor air samples.

Attachment 1
Minimal acceptable requirement for analysis of indoor air samples

Activity	Specifications	Documentation needed
GC/MS-SIM Tuning	Autotune or equivalent. Acceptable Isotopic ratios (1, 5, 10 %) Peak width at half height (0.5 amu +/- 0.2) Correct mass assignment (+/- 0.1 amu)	Printout of tune report.
GC/MS-SIM Data Acquisition	Meet tune specifications. Optimize ion dwell time.	Printout of instrument method. 10 scans/peak minimum. Printout of Extracted Ion Chromatogram.
	Set electron multiplier voltage to achieve required detection limits.	Data Quality Objectives.
	Collect calibrant and sample analysis data with the high resolution option. (1 amu)	Printout of instrument method. Raw Sample Data
Ion Selection		**Reference**
GC/MS-SIM	Select primary ions from 8260B tabular data, or at least two ions, justified from Library Spectra, that meet data quality objectives. (Free from interferences)	Method 8260B, Library Spectra
	Consecutively evaluate ion selection. Adjust as necessary.	Library Spectra, Raw Sample Data
GC/MS-SCAN	Select primary ions from 8260B tabular data, or at least two ions, justified from Library Spectra that meet data quality objectives. (Free from interferences)	Method 8260B, Library Spectra
	Consecutively evaluate ion selection. Adjust as necessary.	Library Spectra, Raw Sample Data

GC/MS-SIM Reporting Requirements

Confirmed Positive detections: (REPORT: Concentration, qualify quantitative estimates with a "J")

- ion relative retention time tracks that of standards ***(+/- 0.10 RRT)***
- characteristic ion abundance ratio tracks ratio of standards (+/- 25 %)
- characteristic ions maximize within +/- one scan

Unconfirmed detections: (REPORT: Detected not confirmed, specify reason. Qualify quantitative estimates with a "J")

- ion relative retention time tracks that of standards ***(+/- 0.10 RRT)***
- characteristic ion abundance ratio fails to track ratio of standards (+/- 25 %)
- characteristic ions do not maximize within +/- one scan

CONTACT INFORMATION

24-hour Emergency Response Line	(877) 518-5608
***New* state-wide toll-free**	
Colorado Department of Public Health and Environment	(303) 692-2000
(CDPHE) toll-free	(800) 886-7689
Hazardous Materials and Waste Management Division	(303) 692-3300
(HMWMD) toll-free	(888) 569-1831
HMWMD Technical Assistance Line	(303) 692-3320

CDPHE Website	http://www.cdphe.state.co.us/
HMWMD Website	http://www.cdphe.state.co.us/hm/
Downloadable Regulations	http://www.cdphe.state.co.us/regulate.asp
HMWMD Internet e-mail	comments.hmwmd@state.co.us

Other Phone Numbers:

National Response Center	(800) 424-8802
RCRA/Superfund Hotline	(800) 424-9346

Send questions in writing to:

Colorado Department of Public Health and Environment
Hazardous Materials and Waste Management Division
Technical Assistance
4300 Cherry Creek Drive South
Denver, CO 80246-1530

OR

FAX (303) 759-5355

Please provide as much detail as possible regarding your question and the waste or process to which it applies.

ATTACHMENT C

Draft Standard Operating Procedure (SOP) for Installation of Sub-Slab Vapor Probes and Sampling Using EPA Method TO-15 to Support Vapor Intrusion Investigations

Draft

Standard Operating Procedure (SOP) for Installation of Sub-Slab Vapor Probes and Sampling Using EPA Method TO-15 to Support Vapor Intrusion Investigations

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Background

Vapor intrusion is defined as vapor phase migration of volatile organic and/or inorganic compounds into occupied buildings from underlying contaminated ground water and/or soil. Until recently, this transport pathway was not routinely considered in RCRA, CERCLA, or UST investigations. Therefore the number of buildings or homes where vapor intrusion has occurred or is occurring is undefined. However, considering the vast number of current and former industrial, commercial, and waste processing facilities in the United States capable of causing volatile organic or inorganic ground-water or soil contamination, contaminant exposure via vapor intrusion could pose a significant risk to the public. Also, consideration of this transport pathway may necessitate review of remedial decisions at RCRA and CERCLA sites as well as implementation of risk-reduction technologies at Brownsfield sites where future development and subsequent potential exposure may occur. EPA's Office of Solid Waste and Emergency Response (OSWER) recently (2002) developed guidance to facilitate assessment of vapor intrusion at sites regulated by RCRA and CERCLA where halogenated organic compounds constitute the bulk of risk to human health. EPA's Office of Underground Storage Tanks (OUST) is considering modifying this guidance to include underground storage tank sites where petroleum compounds primarily determine risk and biodegradation in subsurface media may be a dominant fate process.

The OSWER guidance recommends indoor air and sub-slab gas sampling in potentially affected buildings at sites containing elevated levels of soil-gas and ground-water contamination. To support the guidance and improve site-characterization and data interpretation methods to assess vapor intrusion, EPA's Office or Research and Development is developing a protocol for sub-slab gas sampling. When used in conjunction with indoor air, outdoor air, and soil gas and/or ground-water sampling, sub-slab gas sampling can be used to differentiate indoor and outdoor sources of volatile organic and/or inorganic compounds from compounds emanating from contaminated subsurface media. This information can then be used to assess the need for sub-slab depressurization or other risk-reduction technologies to reduce present or potential future indoor air contamination due to vapor intrusion.

Sub-Slab Vapor Probe Construction and Installation

1. Prior to drilling holes in a foundation or slab, contact local utility companies to identify and mark utilities coming into the building from the outside (e.g., gas, water, sewer, refrigerant, and electrical lines). Consult with a local electrician and plumber to identify the location of utilities inside the building.

2. Prior to fabrication of sub-slab vapor probes, drill a pilot hole to assess the thickness of a slab. As illustrated in **Figure 1**, use a rotary hammer drill to create a "shallow" (e.g., 2.5 cm or 1 in) "outer" hole (e.g., 2.2 cm or 7/8 in diameter) that partially penetrates the slab. Use a small portable vacuum cleaner to remove cuttings from the hole if penetration has not occurred. Removal of cuttings in this manner in a competent slab will not compromise sampling because of lack of pneumatic communication between sub-slab material and the source of vacuum.

3. Then use the rotary hammer drill to create a smaller diameter "inner" hole (e.g., 0.8 cm or 5/16 in) through the remainder of the slab and some depth (e.g., 7 to 8 cm or 3 in) into sub-slab material. **Figure 2** illustrates the appearance of "inner" and "outer" holes. Drilling into sub-slab material will create an open cavity which will prevent obstruction of

probes during sampling by small pieces of gravel.

4. The basic design of a sub-slab vapor probe is illustrated in **Figure 3**. Once the thickness of the slab is known, tubing should be cut to ensure that probes “float” in the slab to avoid obstruction of the probe with sub-slab material. Construct sub-slab vapor probes from small diameter (e.g., 0.64 cm or 1/4 in OD x 0.46 cm or 0.18 in ID) chromatography grade 316 stainless steel tubing and stainless-steel compression to thread fittings (e.g., 0.64 cm or 1/4 in OD x 0.32 cm or 1/8 in NPT Swagelok female thread connectors) as illustrated in **Figure 4**. Use of stainless-steel materials to ensure that construction materials are not a source of VOCs.

5. Set sub-slab vapor probes in holes. As illustrated in **Figure 5**, the top of the probes should be completed flush with the slab and have recessed stainless steel or brass plugs so as not interfere with day-to-day use of buildings. Mix a quick-drying portland cement which expands upon drying (to ensure a tight seal) with water to form a slurry and inject or push into the annular space between the probe and outside of the “outer” hole. Allow cement to cure for at least 24 hours prior to sampling.

6. Install at least 3 sub-slab vapor probes in each residence. As illustrated in **Figure 6**, create a schematic identifying the location of each sub-slab probe.

Sub-Slab Sampling

1. Connect dedicated a stainless-steel fitting and tubing (e.g., 1/8 in NPT to 1/4 in tube Swagelok fitting and 30 cm or 1 ft of 1/4 in I.D. Teflon tubing to a sub-slab vapor probe as illustrated in **Figure 7**. Use of dedicated fitting and tubing will avoid cross-contamination issues.

2. Connect the Teflon tubing to 1/4" ID Masterflex (e.g., 1.4 in ID high performance Tygon LFL) tubing and a peristaltic pump and 1-L Tedlar bag as illustrated in **Figure 8**. Use of a peristaltic pump will ensure that sampled air does not circulate through a pump causing potential cross contamination and leakage.

3. Purge vapor probe by filling two dedicated 1-L Tedlar bags. The internal volume of sub-slab probes is insignificant (< 5 cm^3). A purge volume of 2 L was chosen based on the assumption of a 0.64 cm (1/4") air space beneath a slab and an affected sample diameter of 0.61 m (2 ft).

4. Use a portable landfill gas meter to analyze for O_2, CO_2 and CH_4 in Tedlar bags as illustrated in **Figure 9**.

5. Collect sub-slab vapor samples in evacuated 10% or 100% certified 1-L Summa polished canisters and dedicated particulate filters as illustrated in **Figure 10**. Check vacuum in canisters prior to sampling. Sampling will cease when canister pressure reaches atmospheric pressure. Submit canisters to a commercial laboratory for analysis by EPA Method TO-15.

6. Collect at least one duplicate sub-slab sample per building using dedicated stainless-steel tubing as illustrated in **Figure 11.**

Figure 1. Drilling through a slab

Figure 2. “inner and “outer

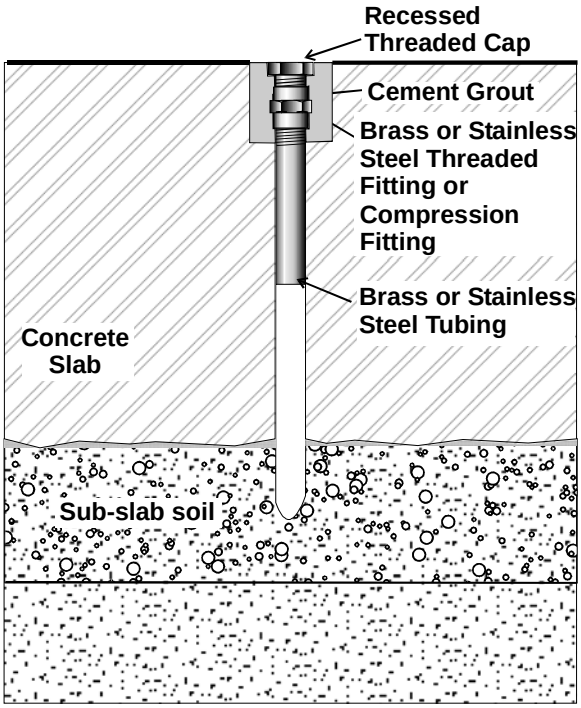

Figure 3. General schematic of sub-slab vapor probe

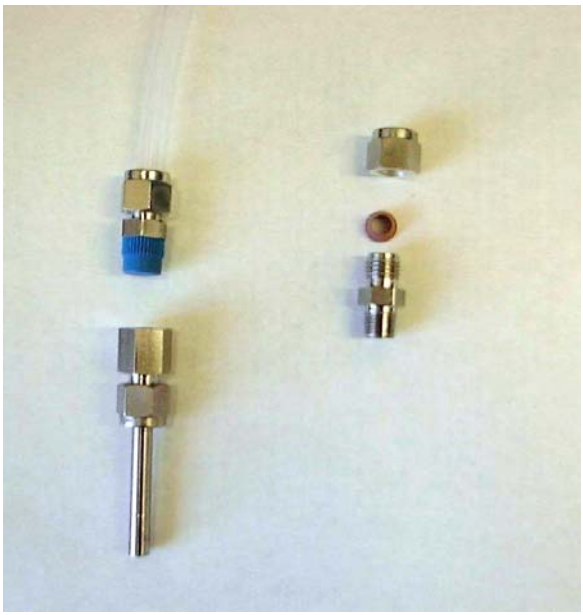

Figure 4. Stainless steel sub-slab vapor probe components

Figure 5. Competed vapor probe installation

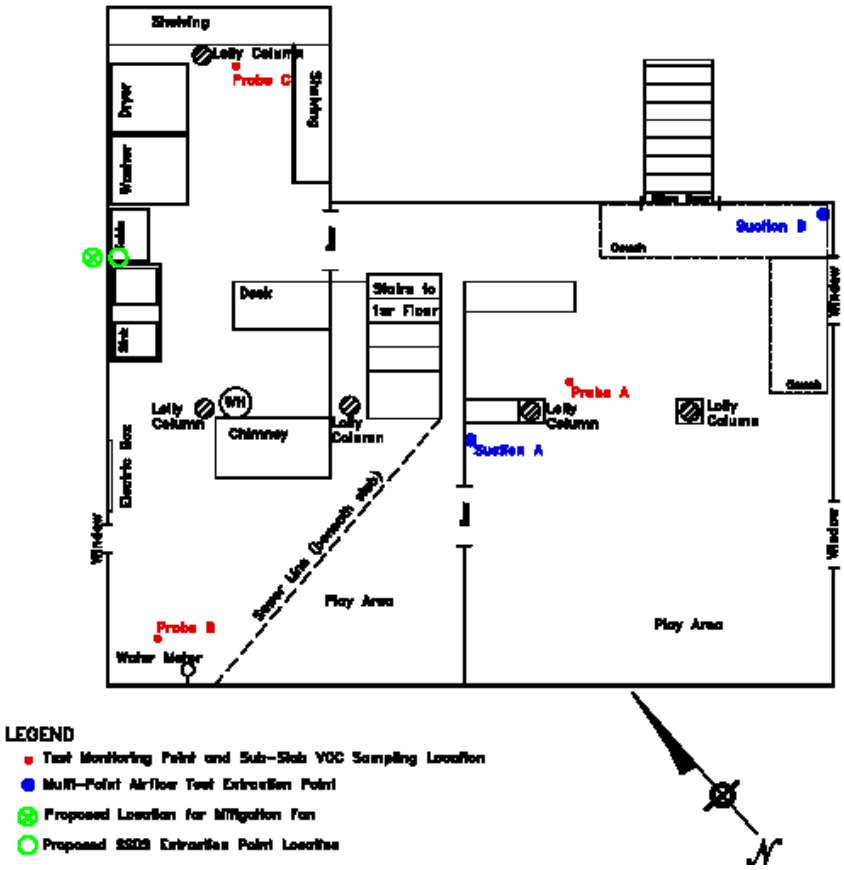

Figure 6. Schematic illustration location of vapor probes in a basement

Figure 7. Compression fitting to probe

Figure 8. Purge prior to sampling

Figure 9. Analysis of O2, CO2, and CH4

Figure 10. Sampling in 1-L evacuated canister for TO-15 analysis

Figure 11. Collection of duplicate sample