

**SOCIETY OF BROWNFIELD RISK ASSESSMENT**

**Vapour Intrusion –  
Guidance Notes for Assessment in  
Contaminated Land Scenarios in the UK**

Note 1C: Vapour intrusion data collection considerations

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## **PUBLICATION**

This series of reports and tools is published by the Society of Brownfield Risk Assessment (SoBRA). It presents work undertaken by a SoBRA sub-group composed of volunteers listed in the acknowledgments below. This publication is part of a series of work packages designed to address various issues in data collection and evaluating risks associated with vapour intrusion.

The Society of Brownfield Risk Assessment (SoBRA) has produced a series of accessible and concise practitioners' guides to support informed decision making with respect to vapour intrusion (VI) risk assessment within the UK. In the context of these papers, "VI" is defined as:

"Vapour intrusion occurs when there is a migration of vapor-forming chemicals from any subsurface source into an overlying building" (US EPA).

These guides follow on from the publication of the SoBRA Groundwater Vapour Generic Assessment Criteria ( $GAC_{gwwap}$ ) and from the recommendations of the SoBRA Summer 2017 workshop.

It is acknowledged that there is already an extensive portfolio of existing industry guidance available both within the UK and internationally in relation to VI risk assessment, nevertheless, these practitioners' guides aim to provide high level summaries of the existing guidance, covering key aspects of VI risk assessment and include signposting to the relevant published industry documents for more detailed information, where required.

The topics covered by the SoBRA practitioners' guides published so far comprise:

- 1A. Conceptual site model development for the assessment of VI contaminant linkages in the UK (this publication);
- 1B. Benefits of soil vapour sampling for assessment of VI risks; and
- 1C. VI data collection considerations.

This third document in the series considers the benefits and limitations of data collection in relation to VI risk assessment, including field sampling strategy and methodologies, associated laboratory analysis and quality assurance (QA) and quality control (QC) drivers for robust vapour sampling data collection.

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## 1. INTRODUCTION

This guidance document summarises the various benefits and limitations of vadose zone, sub-slab and internal space vapour sampling for consideration in the context of VI risk assessment. The document also provides a synopsis of the various vapour sampling methodologies available and highlights the requirement for appropriate laboratory method detection limits relative to Reference Concentrations, as well as considering quality assurance (QA) and quality control (QC) drivers for robust vapour sampling data collection.

Designing an appropriate data collection strategy and subsequent analytical approach, with due consideration of QA/QC measures throughout, is fundamental to producing a robust assessment of potential VI risks.

This note discusses the following aspects of data collection:

- Sampling strategy – Vapour sampling in vadose zone, sub-slab and internal areas;
- Sampling methodology – Available options (active, passive and onsite analysis);
- Sample analysis – Consideration of method detection limits relative to reference concentrations; and
- Drivers for robust vapour sampling data collection – QA / QC considerations.

## 2. SAMPLING STRATEGY – SOIL VAPOUR SAMPLING IN VADOSE ZONE, SUB-SLAB AND INTERNAL AREAS

When designing a soil vapour sampling strategy to assess VI risks, it is important to consider the conceptual site model (CSM), as discussed in more detail within the associated SoBRA CSM guide (1A).

Depending on the specific site in question, there are several options available for soil vapour sampling, and each one can be considered to target different points along the potential VI migration pathway from source through to the end receptor.

Sampling can target the vadose zone in the soils overlying a soil vapour source, or in the case of onsite buildings, sampling can also be designed to target the sub-slab or the building's internal airspace.

The information contained within Table 1 summarises the perceived benefits and limitations of each soil vapour sampling strategy with respect to obtaining robust data for subsequent assessment of potential VI linkages.

**Table 1. Soil vapour sampling in vadose zone, sub-slab and internal areas – benefits and limitations**

Benefits	Limitations
Soil Vapour Sampling Location: Vadose zone	
<ul style="list-style-type: none"> <li>• Various methods of monitoring well installation are available including window sampler boreholes, and driven probes. These methods allow a number of installations to be constructed quickly with minimal disturbance, and also allow installation in areas where access is restricted.</li> <li>• Provides data for both proposed and existing developments.</li> <li>• Either continuous data or point data can be collected from monitoring wells.</li> <li>• Monitoring wells can be targeted to anticipated vapour source locations, in proposed receptor locations and/ or along boundaries to assess risks from offsite sources – however – well design does need to consider more permeable horizons that may be present within the subsurface.</li> <li>• Can target monitoring wells at various depths and strata within the vadose zone to identify vertical variations and investigate preferential pathways.</li> <li>• No requirement to enter buildings - Can obtain data with minimal disturbance of site users.</li> <li>• Data will not be influenced by external sources (ambient air, traffic, cleaning products etc) as long as well installation is competent (although wells will require purging prior to collection of a representative soil vapour sample).</li> </ul>	<ul style="list-style-type: none"> <li>• Good monitoring well construction with sufficient seals is essential for reliable data collection. Monitoring wells are required to be vapour specific and fully screened within the vadose zone rather than utilising groundwater monitoring wells that intercept the underlying groundwater<sup>1</sup>. Use of groundwater monitoring wells will not be representative of soil vapour, as dissolved volatile contaminants in groundwater can influence the soil.</li> <li>• Well design needs to consider the stratum that the well is installed in, diameter of the well and the response zone of that well. If there is a small response zone e.g. low permeability strata, then the radius of influence needs carefully considering which may mean a large number of wells being required.</li> <li>• This method will not identify potential vapour migration along preferential pathways such as around utility pipe entries etc.</li> <li>• If groundwater levels are high (i.e. shallow groundwater) it may prove difficult to install suitable monitoring wells in the vadose zone.</li> <li>• Potential for wells to be destroyed or tampered with if in public areas or within a construction site, compromising data continuity and integrity.</li> <li>• Potential water ingress from surface if monitoring well installation is not completed competently, or if headworks are damaged.</li> <li>• Sufficient gas tight seals (minimum 2m length) are required if using nested wells. Nested wells are more prone to error than single well installations as they are dependent on competency of the seals, which can be difficult to achieve and validate. Contaminant appropriate materials for monitoring well installations are required. For instance, use of stainless-steel wells rather than HDPE may be required to sample for certain volatile organic compounds (VOCs) (such as vinyl chloride) to maintain data integrity.</li> </ul>

<sup>1</sup> The term “groundwater” is used generically throughout this document to denote all sub-surface water – e.g. either perched water or groundwater. The distinction between these is a critical consideration for the CSM.



Benefits	Limitations
	<ul style="list-style-type: none"> <li>• Potential for leakage out of, or into, monitoring wells through headworks, thus impacting on sample quality and reliability of results. Leakage testing is required at the monitoring well prior to sampling.</li> <li>• If driven probes are used to install monitoring wells, this may cause smearing of cohesive materials which could restrict soil vapour flow and impact on reliability of the results.</li> <li>• Whilst access to buildings is not required, depending on the context of the site assessment (i.e. access to a residential property garden as part of a Part 2A investigation), presence on site may require communication of risk to residents/site users.</li> </ul>
<b>Soil Vapour Sampling Location: Sub-floor void (utilising existing void/ airbrick)</b>	
<ul style="list-style-type: none"> <li>• Useful if the source is beneath a building as it targets the migration pathway between the source and the receptor.</li> <li>• Results are unlikely to be influenced by sources within the building (e.g. cleaning products).</li> <li>• No building access required - Can obtain continuous monitoring results with minimal disturbance of site users and samples will not be disturbed by building occupants</li> </ul>	<ul style="list-style-type: none"> <li>• May not be appropriate for all building types as this method requires a sub-floor void to be present.</li> <li>• Only applicable if building currently present on site, not appropriate for future development.</li> <li>• May over or underestimate concentrations if influenced by ambient air. Ambient air concentrations may contain a background level of vapours, dependant on the site location, for instance if in close proximity to large roads, railways, airports or an industrial source etc.</li> <li>• Ambient air samples will be required for comparison - obtaining representative samples and analysis with appropriate laboratory method detection limits (LMDL) relative to the health criteria value (HCV) or a reference concentration (RfCc) is often challenging.</li> <li>• Requires working near to buildings (which may include residential properties) and associated communication of risk to residents/site users.</li> <li>• Other data quality limitations related to vapour sampling via airbricks can include uncertainty regarding foundation structure design (i.e. whether there are blockages or areas which are in a different air regime beneath the building) and also how far beneath the foundation the sampling probe would need to reach to provide reliable results.</li> </ul>

Benefits	Limitations
Soil Vapour Sampling Location: Sub slab (installation through existing slab) <i>(Could also apply to sampling below suspended wooden floors)</i>	
<ul style="list-style-type: none"> <li>• Useful if the source is potentially beneath a building as can target the migration pathway between the source and the receptor.</li> <li>• Allows the vapour conditions immediately below the slab to be monitored.</li> <li>• Will not be influenced by ambient air conditions if installed competently.</li> <li>• Allows for permanent installations, enabling repeat monitoring (although permanent installations are not necessarily required as the sampling point can easily be blocked and carpet etc. replaced if required).</li> <li>• Reduces uncertainty in modelling the VI pathway.</li> <li>• Useful if preferential pathways in natural geology are known/suspected and can be targeted in the vadose zone beneath the potential receptor.</li> </ul>	<ul style="list-style-type: none"> <li>• Access for monitoring well installation within an existing building may be restricted in terms of headspace and is unlikely to be appropriate if the building is occupied.</li> <li>• Ease of installation will be dependent upon the slab construction.</li> <li>• Potential to damage gas membranes or damp-proof membranes beneath the slab.</li> <li>• Potential to create a preferential pathway into the building if monitoring wells are not installed correctly.</li> <li>• Requires access to buildings (which may include residential properties) and associated communication of risk to residents/site users.</li> <li>• Only applicable if building currently present on site, not appropriate for future development.</li> </ul>
Soil Vapour Sampling Location: Internal space	
<ul style="list-style-type: none"> <li>• Provides data on the concentrations within indoor air and therefore reduces uncertainty otherwise associated with modelling indoor air concentrations based on vadose zone or sub-slab monitoring.</li> <li>• Allows monitoring in a range of locations within the building to confirm if preferential pathways are present and to target potential vapour entry points (e.g. service conduits, cracks in building slab, gaps in floorboards etc.).</li> <li>• Confirms if the foundation construction of the specific building is providing a sufficient barrier to VI or not.</li> <li>• May provide more comfort to site users that risks have been adequately assessed.</li> </ul>	<ul style="list-style-type: none"> <li>• Other sources within the building, regardless of occupation and use of the building, could affect the results including presence and use of cleaning products, smoking / vaping, paint and storage of chemicals.</li> </ul> <p><u>Occupied buildings:</u></p> <ul style="list-style-type: none"> <li>• If the building is occupied there is potential for disturbance of equipment during the monitoring period. This could cause damage to equipment and loss of samples. Some monitoring equipment is also sensitive to water ingress and humidity (sorbent tubes).</li> <li>• The time of year could influence how representative the data is of worst-case conditions, i.e. dependant on the level of heating in use at the time of monitoring, frequency of windows being opened etc. which will vary between summer and winter.</li> <li>• Limited access to occupied buildings may mean that it is difficult to ensure the monitoring locations always represent worst case conditions (i.e. small rooms maintaining closed doors and windows etc.).</li> <li>• Monitoring frequency and therefore the type of sampling which can be carried out (passive rather than active) may also be restricted by access.</li> <li>• Requires access to buildings (which may include residential properties) and associated communication of risk to residents/site users.</li> </ul>

Benefits	Limitations
	<p><u>Unoccupied buildings:</u></p> <ul style="list-style-type: none"> <li>• Internal space monitoring in unoccupied buildings can present additional limitations:</li> <li>• Unoccupied buildings are often unheated, and this influences the way air is drawn into the building.</li> <li>• An unoccupied building can also have different levels of humidity and different air exchange rates (as doors/windows are not opened) compared to an occupied building.</li> <li>• If monitoring internal space within an unoccupied building, careful consideration is required as to whether the results are reflective of if there was a receptor actually in the building, and of how different end occupant's lifestyles could alter the CSM.</li> </ul>

### 3. SAMPLING METHODOLOGY – AVAILABLE OPTIONS (ACTIVE, PASSIVE AND ONSITE ANALYSIS)

#### 3.1 Active sampling methods

##### Vacuum canisters (TO-15 methodology)

Silonite vacuum canisters are stainless steel containers with a fused silica coating which are sent under vacuum from the analytical laboratory (US EPA, 1999a). A sample train is also provided, which restricts the flow of sample uptake into the canister and ensures that vapour samples are collected at a controlled flow rate. The assembly also includes a vacuum gauge that indicates when the canister is close to atmospheric pressure. "Bottle Vacs" can be collected in place of canisters, but these are more typically used for samples known to have higher concentration VOCs present. The volume collected is normally less than is collected by canisters, so the equivalent detection limits cannot be achieved.

Because a whole sample is collected, total petroleum hydrocarbons (TPH), permanent gases, odorants and other compounds that also fall into carbon band range C1 to C7 and can be determined. This is one of the key advantages of canisters over sorbent tubes as well as the fact that you do not need to know which specific contaminant(s) of concern might be detected prior to sampling (as is required for soil vapour sampling via sorbent tubes).

Sampling via canisters is particularly useful for very volatile compounds as well as more reactive compounds because these compounds that are not quantitatively retained by sorbent tubes. In addition, the use of vacuum canisters allows for repeat analysis and does not require additional power supply like a pump would (i.e. as required for

sampling via sorbent tubes). Laboratories in the UK have produced in-house stability data for TO-15 analysis, indicating holding times are in the region of 25 days.

Canister sizes vary and can therefore be chosen on the basis of required detection limit and/or period over which sampling is required to take place. Flow restrictors can be placed in-line in the sampling train to control the sampling rate and therefore vary the time over which the sampling takes place. Times can typically be varied from less than 1 minute to up to 24 hours.

#### Sorbent tubes (TO-17 methodology)

Active sampling using sorbent tubes for subsequent thermal desorption (TD) analysis involves drawing a volume of soil vapour through a TD tube packed with specific sorbents known to be suitable for the collection of the contaminant(s) of concern (US EPA, 1999b). These sorbents may be used singly or in multi-sorbent packings. Tubes with more than one sorbent, packed in order of increasing sorbent strength, are used to facilitate quantitative retention and desorption of VOCs over a wide volatility range. The higher molecular weight compounds are retained on the front, least retentive sorbent. The more volatile compounds are retained further into the packing, on a stronger absorbent.

Sorbent tubes allow for the capturing of compounds with boiling points above 220°C (i.e. compounds that fall into carbon banding ranges greater than C12), which is outside the capability of Silonite vacuum canisters.

The tubes are sent with brass caps; when sampling is required the cap is removed from the sample end (the side of the tube marked with a groove) and replaced with the diffusion cap. The original brass cap is then replaced when sampling is complete. When sampling, the pump is placed at the end of the sampling train and forces soil vapour through the sorbent tube at a low flow rate. The flow rate and sampling period combined dictate the laboratory detection limit which can be achieved. If an insufficient flow rate or sampling time is used, there is the potential that insufficient sorption of VOCs to the sorbent medium will occur, and there will be a corresponding increase in the laboratory detection limit. Conversely, if too great a flow rate or sampling time is used, the sorbent medium might become saturated early in the sample collection process and the full range of contaminant(s) of concern and associated soil vapour concentrations may not be determined. This can be mitigated by using tubes in series to evaluate and/or protect against sample sorbent breakthrough. The pump rate needs to be checked using a flow meter before and after sampling. Holding times are similar to those for Silonite canisters (~25 days). Sampling times for pumped sorbent tubes are

typically in the order of 1 hour, but the sampling duration can be shortened or extended by varying the pump rate.

#### Other active sampling methodologies

Active sampling methodologies often used for bulk gases, such as Tedlar bags and Gresham cylinders are not typically suitable for sampling VOCs because of the stability of the target compounds.

Gresham cylinders are simply a steel or aluminium tube with no passivated coating so are not suited to volatile analytes. The disadvantages of Tedlar bags are well documented (i.e. within CIRIA C682; CIRIA, 2009) and include very short holding times (48 hours or less), high detection limits and permeation of VOCs through the bag which will compromise sample integrity. These bags are also fragile and easily punctured.

### **3.2 Passive sampling methods**

A key concern with active indoor air sampling is that temporal variability leads to uncertainty in whether active sampling methods conducted over typically shorter time periods (24 hours or less) are suitably representative of longer-term, time-weighted average concentrations.

An alternative technique for indoor air and subsurface characterisation is passive sampling, which can be implemented over longer durations, thereby minimising the impacts of temporal variability, and obtaining more representative measures of longer-term average concentrations. This can be much more cost-effective than obtaining sequential active 24-hour samples.

Passive soil vapour samples are collected by exposing a sorbent to the environment being sampled and allowing passive diffusion of contaminant(s) onto the sorbent. The British Standard

BS EN 16007-2 provides further guidance on the sorbent to be used. The sorbent is contained in a specific sampling tube, typically a stainless-steel sorbent tube or other sampler body which determines the 'uptake rate' or rate of diffusion from the environment being sampled onto the sorbent.

The uptake rate, combined with sampling data including exposure period, temperature and pressure, can be used to convert the amount of contaminant(s) sorbed into a concentration. Uptake rates are specific for each target compound as well as specific to the sorbent being used and are not yet available for all potential contaminant(s) of concern, i.e. TPH fractions.

Samples are typically collected using a sorbent tube, in which one end of the tube is fitted with an open mesh diffusion cap. The tubes are sent with brass caps; when sampling is required the cap is removed from the sample end (the side of the tube marked with a groove) and replaced with the diffusion cap. Passive sorbent tubes can be deployed for two weeks or less, depending on the specific project and limit of detection requirements. The diffusion sampler is replaced with the original brass cap when sampling is complete.

Potential sources of bias for passive samplers include starvation, poor recovery, turbulence, high humidity and blank contamination. Starvation occurs if the passive sampler withdraws target compounds from the surrounding media faster than they are replenished causing a negative bias. Usually this is not an issue for indoor or outdoor sampling but needs to be further considered for soil vapour and sub-slab sampling.

Some compounds are challenging to measure using passive samplers and additional research is needed to demonstrate the capabilities and limitations of various passive samplers. Challenging compounds include vinyl chloride, chloromethane and possibly other low boiling point, low molecular weight compounds that tend to be weakly sorbed and poorly retained. Analysis of passive sampling method results is also limited to compounds that have published uptake rates for the period of sampling chosen in each case, which is a significant restriction in the overall applicability of the method.

Sample blank contamination is another source of positive bias and can occur with the sorbents used in passive sampling are that are inadvertently contaminated during sample preparation, storage, shipping or handling and would lead to a positive bias if unidentified.

### **3.3 Onsite analysis**

Real-time analysers can be used to collect data to locate preferential pathways and VOC sources inside structures as well as confirm the VI pathway. A variety of real-time analysers exist including photoionisation detectors (PID), flame ionisation detectors (FID), membrane interface probes (MIP) and portable gas chromatography–mass spectrometry (GC-MS) machines.

The applicability of these instruments is determined by their sensitivity and cost. Larger data sets allow trends in the results to be correlated to other variables such as pressure differentials, wind speed and heating, ventilating and air conditioning (HVAC) systems. However, most field screening instruments in use in the UK currently are limited to the parts per million (ppm) range and do not provide sufficient sensitivity for VI investigations.

A summary of the various on-site analysis techniques available is presented in Table 2.

**Table 2. Comparison of on-site analysis techniques**

Field Technique	Commentary
<p><b>Potable GC-MS</b>  (Portable gas chromatography – mass spectrometry)</p>	<ul style="list-style-type: none"> <li>• The gas chromatography technique separates compounds, and the mass spectrometer quantifies their mass.</li> <li>• The sensitivity of the analysis is enhanced if a pre-concentrator is used, which comprises a sorbent trap through which air is drawn for a period of time to trap a larger mass of the target compounds. Because of the time required to pre-concentrate with the trap and separate the compounds with the GC, the GC-MS usually requires 10-15 minutes per measurement to achieve reporting limits but can run continuously in a scan-mode with higher detection limits for background or reconnaissance monitoring.</li> <li>• High frequency analysis systems such as VaporSafe™ provide quantitative results and can reach sufficiently low detection limits for the key chlorinated solvents, but they do not offer the same scope of analysis as conventional laboratory techniques and there has been limited use and validation of such approaches in the UK. The methods require a high-level of training for correct operation. The rapid interpretation of results greatly improves the ability to locate the source(s) of VOCs detected in indoor air as well as optimise mitigation measures.</li> <li>• This technique has significant advantages for sites where the potential for acute exposure requires a rapid response to minimise risk to human health, for example where trichloroethene (TCE) may be present.</li> </ul>
<p><b>PID</b>  (Photoionisation detector)</p>	<ul style="list-style-type: none"> <li>• The PID ionises all VOCs with ionisation potentials lower than the size of the lamp being used, so the reading represents total VOCs.</li> <li>• Each compound has a unique response factor, so separate calculations are then required to correlate PID reading to laboratory analysis results.</li> <li>• Moisture in the sample can pose interference, particularly if the instrument is cold and condensation occurs on the lamp.</li> <li>• Some PIDs can measure to parts per billion (ppb) levels, but accuracy and precision are less reliable below about 100 ppb.</li> </ul>
<p><b>FID</b>  (Flame ionisation detector)</p>	<ul style="list-style-type: none"> <li>• The FID can be used in preference to a PID as some hydrocarbons are not ionised by the PID (notably methane).</li> <li>• Readings are taken through a carbon filter to discern the proportion of the total instrument response attributable to methane (methane is not absorbed appreciably by activated carbon filters, whereas other petroleum hydrocarbons are).</li> <li>• If the oxygen levels are low (for example when hydrocarbon concentrations are high), the FID flame may extinguish.</li> </ul>
<p><b>MIP</b>  (Membrane interface probe)</p>	<ul style="list-style-type: none"> <li>• The MIP is deployed via either direct-push methods or via a cone penetrometer system.</li> <li>• The tool comprises a probe containing a small gas permeable membrane, that in turn flows into a stream of inert carrier gas within a trunkline that flows up to the analysis instrumentation at the ground surface.</li> </ul>

Field Technique	Commentary
<p><b>MIP</b> (Membrane interface probe) (contd.)</p>	<ul style="list-style-type: none"> <li>• The MIP is driven to the desired depth and a sample of the soil vapour collected and recovered back to the ground surface via the carrier gas within the trunkline for subsequent analysis.</li> <li>• The surface instrumentation element of the MIP comprises a gas chromatograph that contains three gas phase detectors (i.e. a PID, an FID and a halogen-specific detector), each of which responds differently to the various VOC analytes that could be encountered. The probe also houses an electrical conductivity (EC) probe.</li> <li>• The MIP generates a real-time graphic log of the detector response(s) with depth, that can allow identification of potential areas of petroleum hydrocarbons (PHCs) and / or chlorinated hydrocarbons (CHCs) contamination as required.</li> <li>• The MIP is rarely used as a standalone tool, but its value lies in the ability to characterise relative concentrations of PHCs and CHCs and their distribution in heterogeneous ground conditions.</li> </ul>

**Note:** Throughout the subsequent sections of this paper CHCs and PHCs are identified by the colours purple and orange to assist the reader.

Real-time monitors are often subjected to changes in temperature, moisture, or other factors that could cause interference or drift compared to fixed laboratory analytical instruments. It is, therefore, beneficial to include some inter-method duplicate samples as a QA/QC step. If, for example, a portable GC-MS is used for indoor air quality monitoring, a percentage of samples should be collected as duplicates for analysis by a different method (TO-15 or TO-17) to document the accuracy of the portable/transportable instrument. The results of the inter-method comparison will not be available for real-time decisions but will support the decisions regarding data quality following analysis.

Selection and use of real-time monitors should consider the capabilities and limitations of each line of evidence. Combining approaches helps overcome the limitations of one with the strengths of another. In the UK, a platform incorporating a field PID with a co-located canister has been designed to trigger sampling when the results from the sensor reach a predetermined level. This approach combines the advantages of continuous monitoring with laboratory quality data.

### 3.4 Sampling methodology – Conclusions

No single approach to vapour sampling should be considered as definitive in all situations. Increasing use of complementary techniques is becoming more common in order to determine whether the VI pathway is complete.

Passive sampling is a simple, powerful, low-cost method which is gaining increasing acceptance as a semi-quantitative screening tool to better characterise sites by improving spatial delineation of plumes when used alongside TO-15 and TO-17 analysis.



Passive samplers allow longer sample duration that provide time weighted average concentrations, which can be more representative of long-term average concentrations than a shorter duration sample. Continuous vapour analysis is at a very early stage of development in the UK but shows promise for determining possible acute risks in real-time.

The assessment of VI is complicated by spatial and temporal variability due to interactions among the many individual factors that influence the migration pathway from subsurface sources to indoor air. Alternative approaches are needed to help guide discrete sampling efforts and reduce sampling requirements while maintaining acceptable confidence in exposure assessment. Indicators, tracers and surrogates (ITS), which include a collection of quantifiable metrics and tools have been used to make the assessment of VI and long-term monitoring more informative, efficient and cost-effective (Schuver, H. et al, 2018). Tracers enhance understanding of the CSM and aid in the identification of preferential pathways and surrogates.

#### **4. SAMPLE ANALYSIS – CONSIDERATION OF METHOD DETECTION LIMITS RELATIVE TO REFERENCE CONCENTRATIONS**

Analytical reporting limits for indoor air samples should be lower than the target indoor air concentrations chosen as part of the assessment, unless this is technically impractical. Analytical reporting limits for soil vapour samples can be higher because soil vapour concentrations are always attenuated to some degree.

As above, canister and sorbent tube methods are commonly used in the UK to determine VOC concentrations in soil vapour, indoor and ambient air.

The US EPA recommend vapour analysis used for direct assessment of VI should meet or exceed requirements for demonstrating method acceptability as specified in TO-15 or TO-17 to achieve a lower method detection limit. The method defined reporting limit for TO-15 is 0.5 ppb. The clean canister certification level for this reporting limit is 0.2 ppb.

Both methods were originally established for measuring low VOC levels in ambient air and not for the high concentrations likely to be seen in soil vapour samples (which can exceed 100,000  $\mu\text{g}/\text{m}^3$ ). High concentrations in soil vapour samples can lead to system carryover, large dilutions and contaminated canisters increasing the potential for false positives, elevated reporting levels and problems associated with managing canisters (Hartman, B. 2006).

For vacuum canisters (TO-15 methodology), the detector can be run in two different modes: full scan and selective ion monitoring (note that some compound selectivity and

ability to identify unknowns may be lost in the use of selective ion monitoring analysis due to the limited masses scanned). Standard TO-15 analysis is normally run in the full scan mode and can give a list of approximately 70 compounds with method detection limits in the range 1 to 15  $\mu\text{g}/\text{m}^3$  (depending on the volume of sample used). It should be noted that UK laboratories typically report a modified list of TO-15 compounds. Selected ion mode (SIM) is used to improve the method detection limit ( $<1 \text{ ug}/\text{m}^3$  or lower) for a selected set of analytes.

In full scan mode, the detector is constantly scanning between a given set of atomic mass units for the duration of the analysis. This means the MS is bouncing back and forth between two limits every second or two, effectively limiting the time the detector can spend "looking" for any specific ion. When using SIM, the analyst programs the MS to look for a specific set of ions in a specific time window. By keeping the number of ions to a minimum, the sensitivity of the detector can be increased up to 100 times. This increase is needed to achieve the parts per trillion (ppt) values specified in US EPA's Regional Screening Levels (US EPA, 2017) – (Reference Concentrations stated in the RfC column).

In general, because soil vapour samples generally have contaminants of concern present at higher concentrations than the SIM mode can calibrate to, and have different attenuation factors<sup>2</sup> applied (generic or site-specific), SIM is rarely needed for these samples. On this basis, most UK laboratories currently only run analysis in full scan mode, although the implementation of SIM for indoor air samples would be preferable.

## **5. DRIVERS FOR ROBUST VAPOUR SAMPLING DATA COLLECTION –QA/QC CONSIDERATIONS**

As vapour sampling becomes more widely used to assess VI pathways, sampling procedures must be carefully evaluated to ensure that data integrity is maintained, and project objectives are met. When sub-ppb reporting limits are required to meet vapour assessment criteria, sample train components and sampling protocols have significant potential to impact soil vapour measurements. The appropriate selection of leak test compound can provide quality control in the field without compromising the analytical data or reporting limit.

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<sup>2</sup> Attenuation factors relate the vapour concentration of a volatile chemical inside a building to its vapour concentration at the subsurface. It is defined as the concentration in indoor air divided by the concentration in soil vapour at the source. The source is defined as the region of highest vapour concentration in the vadose zone.

Several QA/QC measures to be considered are summarised in the following sections, including:

- Integrity testing – shut-in tests and well integrity testing;
- Mechanical leak detection;
- Well purging;
- Duplicate sampling; and
- Equipment blanks.

### **5.1 Shut-in test**

The shut-in test is carried out to create a closed system between the canister, gauge and flow regulator, where any loose connections in the sampling system can be easily identified prior to sample collection in accordance with ASTM D7663-11. The procedure consists of assembling the canisters, regulators and sample train and momentarily opening and shutting the valve in a clean area, preferably outdoors. Vacuum pressures on the regulators gauge are recorded and monitored for one to five minutes, and according to ASTM D7663-11 the vacuum should not drop more than 0.5 inches of mercury equivalent.

After the shut-in test has been validated, the sampling train should not be altered. If the shut-in test failed, then specific measures are needed such as tightening all the fittings and repeating the test until it is validated before proceeding to tracer testing.

### **5.2 Well Integrity testing – using tracer compounds**

A tracer compound is used as a test for an ambient air leakage into the sample system and monitoring well. The selection of leak detection compounds is site and analysis specific. Considerations during selection include whether the leak detection compound is a known contaminant at the site, or if it is included in the laboratory's list of target analytes, and whether it can be monitored with field equipment.

Tracers are substances introduced outside of the sampling equipment. The presence of the tracer in the sample indicates leakage, which could lead to data qualification or rejection. If real-time monitoring with field instruments shows the presence of tracer in sampling tubing, the leak can potentially be eliminated prior to sampling.

There are generally two categories of tracers: volatile liquids (qualitative) and gases (quantitative). Gases can include helium, sulphur hexafluoride and potentially propane and butane. Liquid tracers include alcohols (e.g. ethanol, isopropyl alcohol), solvents (e.g. hexane, pentane) or even consumer products (e.g. butane in shaving foam).

Use of gaseous tracers requires surrounding the sampling equipment, vapour monitoring well or sub-slab location with a shroud and filling the shroud with the tracer gas. This enables an estimate of the leakage rate into the sampling system to be estimated. It is important to ensure that the pressure in the shroud is close to atmospheric pressures, so that normal sampling conditions exist.

The gas concentration in the shroud can be monitored during sample collection, which provides the benefit of being able to assess potential leakage by comparing concentrations in the shroud with concentrations analysed in the field or laboratory. As an example, helium is non-toxic, non-flammable and can be monitored with hand-held instruments that provide reliable readings in the range 0.01% to 100%. Introducing helium from a pressurised cylinder for several seconds will generally be sufficient to create concentrations in the shroud up to 10% by volume or higher. The helium concentration in the shroud should be monitored and maintained at the target concentration during the course of the soil vapour sampling. This can be done with a helium detector connected to a port on the shroud. A small amount of helium does not necessarily indicate an unreliable sample. US guidance, which has been widely adopted in the UK, allows up to 10% of the starting concentration in the shroud before the sample is considered compromised.

Liquid tracers are typically applied to a paper towel. The concentration at the point of application could be estimated if the vapour pressure of the liquid is known for the ambient temperature under which the sample is collected, as long as the volume of liquid used is sufficient that it does not evaporate completely during the sample collection. There are several potential disadvantages to the use of liquid tracers:

- many are flammable and pose a health and safety risk;
- they are applied at very high concentrations, so even a relatively small leak can result in a high concentration in the sample, which will lead to elevated laboratory reporting limits for target analytes; and
- liquid tracers are applied at such high concentrations that some diffusion may occur through sample tubing.

A summary of the advantages and disadvantages associated with several commonly used tracer compounds (liquid and gaseous) is presented in Table 3.

**Table 3. Comparison of tracer compounds**

Compound	Advantages	Disadvantages
<b>Helium</b>	<ul style="list-style-type: none"> <li>• Helium is used as a tracer because it does not interfere with TO-15 or TPH analysis and can be measured in the field using a handheld detector.</li> <li>• Laboratories run a separate analytical method for helium, so this is not an issue even at high concentrations.</li> </ul>	<ul style="list-style-type: none"> <li>• Careful selection of field meter required as some can be subject to false positives caused by methane.</li> </ul>
<b>Isopropyl alcohol</b>	<ul style="list-style-type: none"> <li>• Inexpensive and readily available.</li> </ul>	<ul style="list-style-type: none"> <li>• Isopropyl alcohol will interfere with the quantification of TPH, if present at elevated concentrations (greater than 0.01%) causing: <ul style="list-style-type: none"> <li>• a false positive</li> <li>• elevated reporting limits due to significant dilutions performed by the laboratory.</li> </ul> </li> <li>• Isopropyl alcohol cannot be selectively measured in the field.</li> </ul>
<b>Limonene</b>	<ul style="list-style-type: none"> <li>• Inexpensive and readily available.</li> </ul>	<ul style="list-style-type: none"> <li>• Limonene can cause a high bias in the C9-C12 hydrocarbon range.</li> <li>• Limonene cannot be selectively measured in the field.</li> </ul>
<b>Sulphur hexafluoride</b>	<ul style="list-style-type: none"> <li>• Ability to check for leaks with on-site instruments with very low detection limits.</li> </ul>	<ul style="list-style-type: none"> <li>• Sulphur hexafluoride may not only cause a false positive but may also lead to increased reporting limits if present at elevated concentrations.</li> </ul>

### 5.3 Mechanical leak detection

A leak test can be performed by surrounding, for example a sub-slab location, with de-ionised water and observing if water flows into the slab while purging. The water is kept in place by surrounding the sample point with a plastic pipe coupling and attaching it to the slab with vapour-free modelling clay.

### 5.4 Well purging

Field notes and borehole logs containing information about the above-ground sampling equipment and below-ground installation length and inner diameter should be used to calculate the "dead volume" to be purged. The maximum flow rate for purging should not exceed the flow rate limit used for subsequent sampling (typically <200 ml/min although slower flow rates may be needed for shallower wells in low permeability geology and for sub-slab measurements).

Guidance documents recommend different purge volumes ranging from 1 to 10 purge volumes (API 2005) and the British Standard, BS 8576:2013 (BSI, 2013) recommends the pumping of three times the volume of the headspace in the well. Purging is typically accomplished using a pump or a syringe equipped with a 3-way valve.

Syringes are an inexpensive and simple approach for purging small volumes up to 1 litre. For larger purge volumes, a pump with variable flow rates and a flow meter is more efficient.

Purging may also be conducted using a portable PID where the reporting of stabilised readings can be used to demonstrate that purging is complete and soil vapour can be reliably sampled.

The purge test data (calculated purge volume, purging rate and duration of purging) should be recorded for each sampling location. It is important to ensure that the same purge volumes and rates are used at a given location for each sampling event.

For fine grained soils, large sample volumes are often not possible, or difficult, to collect. Also if large sample volumes are attempted, the chances of leakage in the sampling train increase. A larger volume also increases the uncertainty about the location of soil vapour sampled. Given these uncertainties, it is best to minimise the dead volume that needs to be purged in the sampling train.

### **5.5 Duplicate sampling**

At least one duplicate sample should be obtained during a sampling round or from at least 10% of the samples obtained. A duplicate sample should be collected by using a splitter (such a T-fitting) located between the flow controller and sample canisters with separate sampling tubes connecting the splitter to two canisters. The flow controller must be set such that the flow rate from the sampling probe is <200 ml/min; this will double the required sampling time since two canisters are being filled simultaneously.

### **5.6 Equipment Blanks**

Equipment blanks refer to purified gas (air, nitrogen) samples collected through the sampling system to test for the presence of contaminants introduced by the sampling methods.

### **5.7 QA/QC considerations - Conclusions**

It is acknowledged that greater consideration of QA/QC is required when assessing VI risk in order to produce a robust dataset that can be relied upon for further assessment.

Tracers should be safe (non-toxic, not explosive), conservative (does not react, transform, degrade, sorb, dissolve), naturally buoyant, with limited analytical

interferences, adequate instrument sensitivity, limited background, and no significant concern with greenhouse gas emissions or workplace exposure risks to those conducting the tracer tests.

Not all tracers have these characteristics and different tracer tests have different requirements, so it is useful to have a range of options.

## **6. CONCLUSIONS**

This guidance document has aimed to summarise the various benefits and limitations of vadose zone, sub-slab and internal space vapour sampling for consideration in the context of VI risk assessment as well as providing a synopsis of the various vapour sampling methodologies available, requirements for appropriate laboratory method detection limits and QA/QC considerations for robust vapour sampling data collection.

With regards to designing a soil vapour sampling strategy, consideration of the CSM is fundamental depending on which stage of the potential VI migration pathway from source through to the end receptor is being targeted. As discussed in Section 3, sampling can target the vadose zone in the soils overlying a soil vapour source, or in the case of onsite buildings, sampling can also be designed to target the sub-slab or the building's internal airspace, and there are various benefits and limitations to consider for each.

Whilst designing the soil vapour sampling strategy, consideration of the sampling methodology is also required in the context of the CSM, i.e. whether the soil vapour samples will be obtained via either active (vacuum canisters or sorbent tubes) or passive methods (typically comprising a using a sorbent tube with an open mesh diffusion cap fitted on one end of the tube), or via a combination of methods including onsite analysis. In terms of onsite analysis, although not adequate as a sole method of assessing potential VI risks, the real-time provision of results can have great value in characterising relative concentrations of PHCs and CHCs and in doing so, inform and guide subsequent more targeted sampling and analysis. Critically, no single approach to vapour sampling should be considered as definitive in all situations and the use of complementary techniques is becoming more common in order to determine whether the VI pathway is complete. Assessment of VI is complicated by spatial and temporal variability due to interactions among the many individual factors that influence the migration pathway of soil vapours from subsurface sources to indoor air.

Differing approaches are needed in each situation, guided by the CSM, to help inform sampling efforts and reduce sampling requirements, while maintaining acceptable confidence in exposure assessment.

Finally, in terms of QA/QC consideration for soil vapour sampling, it is acknowledged that greater consideration of QA/QC is required when assessing VI risk in order to produce a robust dataset that can be relied upon for further assessment, and several QA/QC measures are available for consideration, including:

- Integrity testing – shut-in tests and well integrity testing;
- Mechanical leak detection;
- Well purging;
- Duplicate sampling; and
- Equipment blanks.



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## 8. GLOSSARY

Acronyms	Description
ASTM	American Society for Testing and Materials
BS	British Standard
BSI	British Standards Institution
CHCs	Chlorinated hydrocarbons
CIRIA	Construction Industry Research and Information Association
CSM	Conceptual site model
EC	Electrical conductivity
FID	Flame ionisation detectors
GAC	Generic assessment criteria
GC-MS	Gas chromatography-mass spectrometry
HCV	Health criteria value
HVAC	Heating, ventilation and air conditioning
ITRC	Interstate Technology and Regulatory Council
ITS	Indicators, tracers and surrogates
LMDL	Laboratory method detection limit
MIP	Membrane interface probe
PHCs	Petroleum hydrocarbons
PID	Photo-ionisation detector
ppb	Parts per billion
ppm	Parts per million
QA	Quality assurance
QC	Quality control
RfC	Reference concentration
SIM	Selected ion mode
TCE	Trichloroethylene

Acronyms	Description
TD	Thermal desorption
TPH	Total petroleum hydrocarbons
USEPA	United States Environmental Protection Agency
VI	Vapour intrusion
VOCs	Volatile organic compounds

## **LIMITATIONS**

This publication has been developed by members of the SoBRA VI sub-group acting in a voluntary capacity, and details the views of the individual members, not those of their employers. It is provided freely on the SoBRA website to help promote discussion on what should constitute good practice in assessing the potential health risks associated with vapour intrusion into buildings in the UK. Users of the paper must satisfy themselves that the content is appropriate for the intended use and no guarantee of suitability is made.

## **FEEDBACK**

Feedback on this publication is welcomed and should be submitted to SoBRA at [info@sobra.org.uk](mailto:info@sobra.org.uk).