Soil vapour protocol for assessing hydrocarbon sites in the United Kingdom

energy institute

SOIL VAPOUR PROTOCOL FOR ASSESSING HYDROCARBON SITES IN THE UNITED KINGDOM

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FOREWORD

Human health risk assessment considers exposures to chemicals via a variety of exposure routes, including ingestion, dermal contact, and inhalation. For volatile organic chemicals (VOCs), inhalation is often of greatest concern, and vapour intrusion to indoor air is one of the possible inhalation routes. Assessing potential risks associated with this pathway is becoming increasingly common for land redevelopment and transfer, and contaminated land management. Experience has shown that these assessments can be challenging, in part due to an evolving knowledge base and tool set, and lack of practical guidance.

Petroleum hydrocarbons are distinct in their behaviour from chlorinated solvents and some other VOCs because many are degraded significantly over distances of a few metres by naturally-occurring soil microbes in the presence of oxygen. The reduction in concentrations can be sufficient to render health risks associated with subsurface contamination to occupants of overlying buildings insignificant.

This publication provides guidance to practitioners, regulators and other interested parties relating to the use of subsurface vapour monitoring as a component of a site characterisation and risk assessment, specifically for the purpose of evaluating subsurface vapour intrusion to indoor air.

The appropriate strategy, design, tools and methods for a soil vapour survey depend on site-specific conditions (geologic material permeability and moisture content, depth, compounds of interest). Consequently, this protocol provides information needed by practitioners to make informed decisions on a case-by-case basis. Emphasis is placed on identifying potential causes of bias and variability in sample collection, as these are increasingly challenging, as analytical reporting limits get lower. This protocol also provides information about a wide range of options for data needs and quality objectives.

This document is limited to currently available information, even as knowledge in this field continues to evolve with the conduct of new studies and development of new tools. However, efforts have been made to include up-to-date information from the peer-reviewed scientific literature, conferences and symposia. Much of the information has been drawn from North America, but the science and tools discussed are for the most part equally relevant and applicable in the UK.

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EXECUTIVE SUMMARY

In the past few decades, soil vapour monitoring has been used to identify areas of releases of VOCs such as fuels and solvents with concentrations of interest generally greater than about 10 parts per million by volume (ppmv). In recent years, soil vapour sampling has increasingly been used to assess whether subsurface vapour intrusion to indoor air poses unacceptable health risks to occupants. Soil vapour sampling is now commonly conducted with reporting limits of less than 1 part per billion by volume (ppbv). As the concentrations of interest get progressively lower, the care and attention to detail needed for a robust and unbiased monitoring programme increases significantly.

Key to effective and confident pathway assessment at sites involving petroleum hydrocarbon residuals is to anticipate and conceptualise the distribution of hydrocarbon, oxygen, and carbon dioxide vapours in soil vapour. Therefore, the theory of vapour fate and transport, knowledge of the site history (especially hydrocarbon use, storage and handling), and site-specific conditions need to be considered. A vapour monitoring programme can then be designed to test and refine the expected soil vapour distribution.

For petroleum hydrocarbons in particular, the source strength (concentrations and mass transfer rates) and depth are two very important factors. Residual non-aqueous phase liquid (NAPL) petroleum hydrocarbons in soils above the water table and within a few metres of a building generally pose the greatest potential for unacceptable exposure via vapour intrusion. When petroleum hydrocarbon residuals are separated from a building by greater depths or distances and the oxygen supply to the subsurface is sufficient, aerobic biodegradation usually results in substantial concentration reductions over distances of a few metres. Thus, understanding the oxygen supply and distribution becomes an important component of the assessment plan at petroleum hydrocarbon sites. Hydrocarbons are sparingly soluble in groundwater, and off-gassing from groundwater to soil vapour is often limited by mass transfer across the capillary fringe. Therefore, hydrocarbons in groundwater by themselves seldom generate unacceptable indoor air concentrations, except in cases where the water table is very shallow.

The vapour monitoring programme should focus on data needed to develop and defend a site-specific soil vapour distribution conceptual model which supports interpretations of the potential for vapour intrusion into buildings at present and in the future. These data should include the nature and extent of a hydrocarbon source, the distribution of hydrocarbon vapours and oxygen, and the controls on vapour migration (barriers or preferential pathways). The vapour monitoring programme should also involve collecting multiple lines of evidence, as this makes data interpretation and pathway assessment conclusions more robust. Experience and professional judgement are important here, and for that reason, this protocol reflects the aggregate experience and professional judgement of its authors.

Data quality bounds, in general, reflect both the methods used and typical expertise levels of practitioners. Hydrocarbon vapour characterisation is no exception. This protocol includes appendices that provide detailed information for tools and methods relevant to soil vapour sampling programmes, including geologic characterisation, instrumentation, field screening, pneumatic testing, sampling and analysis. These appendices are intended to provide useful information on a variety of alternatives so that practitioners can make informed decisions, rather than to specify a preferred alternative that may not be optimal in all circumstances.

Proper interpretation of the data collected during a vapour assessment requires an objective and realistic appraisal of data quality and data adequacy, as well as the internal consistency of the data set (for example, consistency of oxygen and VOC vapour distributions and geology). A systematic approach is usually warranted to avoid overlooking important information that may not be immediately obvious from initial inspection of the data. Ultimately, the data analysis and interpretation is complete when there are sufficient data of appropriate quality to defend the conceptualisation of the nature, extent, fate and transport of vapours to the degree needed to support assessment, management and communication of potential human health risks at the present time and in the future. This protocol aims to provide a comprehensive compilation of the current best tools and practices to support the practitioner to this end.

LIST OF ACRONYMS

$\mu g\ m^{-3}$	Micrograms per cubic metre
API	American Petroleum Institute
ASTM	American Society for Testing of Materials
ATD	Automatic Thermal Desorption
BS	British Standard
BTEX	Benzene, Toluene, Ethylbenzene, and Xylene
Cl-VOCs	Chlorinated solvents
CIRIA	Construction Industry Research and Information Association
CLEA	Contaminated land exposure assessment
CLR	Contaminated land report
COCs	Compounds of concern
CSM	Conceptual site model
DEFRA	Department for Environment, Food and Rural Affairs
DNAPL	Dense non-aqueous phase liquid
DQO	Data quality objective
EA	Environment Agency of England and Wales
EPA	Environmental Protection Agency
FID	Flame Ionisation Detection
GC	Gas Chromatograph
GC/MS	Gas Chromatography/Mass Spectrometry
LNAPL	Light non-aqueous phase liquid
MDL	Method detection limit
MTBE	Methyl tert-butyl ether
NAPL	Non-aqueous phase liquid
Pa	Pascal
PAH(s)	Polycyclic aromatic hydrocarbons
ppbv	parts per billion by volume
ppmv	Parts per million by volume
PID	Photoionisation Detector
PUF	polyurethane foam
QA/QC	Quality Assurance/Quality Control
RBCA	Risk Based Corrective Action
RPD	Relative percent Difference
SF_6	Sulphur Hexafluoride
SIM	Selected Ion Monitoring
SVOC(s)	semi-volatile organic compound(s)
USEPA	United States Environmental Protection Agency
VI	Vapour Intrusion
VOC(s)	Volatile Organic Compound(s)
VOST	Volatile Organic Sampling Train
WHO	World Health Organisation

1 SCOPE AND OBJECTIVES

When assessing potential human health risks associated with known or potentially contaminated land, one consideration is the potential migration of hazardous ground gases (particularly volatile organic compound (VOC) vapours) into buildings - a process known as vapour intrusion. Over the past two decades there has been development and evolution of both regulatory guidance and technical knowledge that provides a framework for assessing and managing the risks associated with vapour-intrusion related exposures (for example, CLEA 2009, CIRIA 2009, and many others internationally). The purpose of this document is to supplement the existing guidance documents with a protocol for hydrocarbon soil vapour characterisation and interpretation. An overview of the rationale for this protocol is provided in a preceding introductory guidance (EI 2011).

As knowledge of the processes that control the migration and distribution of VOCs along the vapour intrusion pathway has grown, it has been generally recognised that there is a fundamental difference in the behaviour of chlorinated VOC vapours and petroleum hydrocarbon vapours, as they migrate through the vadose zone. The distribution of most chlorinated VOC vapours in the vadose zone is not usually affected by biodegradation processes. However, in the presence of oxygen, petroleum vapour concentrations rapidly decrease over short distances. Soil vapour monitoring (also referred to as soil gas monitoring) can provide data to characterise the influence of degradation more clearly than other lines of evidence commonly used during vapour intrusion assessments. This generally improves the characterisation of potential indoor air quality concerns, compared with assessments based on groundwater quality data alone.

In North America, most of the available regulatory guidance documents include groundwater and soil vapour screening criteria for identifying areas with a potential vapour intrusion risk. These screening criteria are often derived from an indoor air risk-based target concentration and an 'attenuation factor' (or alpha factor, or simply α). These account for the reduction (attenuation) in concentration that occurs as subsurface vapours migrate from a soil or groundwater contaminant source and enter indoor air, as a result of dilution from the building ventilation and other processes.

If the attenuation factor does not consider the role of biodegradation on the distribution of petroleum hydrocarbon vapours, the screening criteria will be overly protective. At some types of sites this may potentially be by several orders of magnitude. This has several adverse consequences: it increases the cost of site characterisation and risk assessment; it poses a barrier to brownfield redevelopment, and it can lead to exaggerated anxiety for occupants of buildings in areas of assessment.

In the UK, CIRIA has published guidance to address the risks associated with the vapour intrusion pathway: CIRIA C665 *Assessing risks posed by hazardous ground gases to buildings* (Wilson et al. 2007); and, CIRIA C682 *The VOCs Handbook* (Baker et al. 2009). These guidance documents provide: a strategy for developing a ground gas conceptual site model, important considerations and key tools for designing and implementing a ground investigation, and a description of different modelling tools to inform site assessment process. However, neither document provides good practice protocol on carrying out a ground gas investigation. Some information is provided in existing documents for landfill-type gases, for example, *The Ground Gas Handbook* (Wilson et al. 2009, British Standard 8567, in press). A comparable good practice protocol for VOCs, including petroleum hydrocarbons, in ground gas has not however, been published.

Chlorinated solvents (Cl-VOCs) tend to pose a human health risk via vapour intrusion more often than petroleum vapours. Most regulatory guidance documents already in use in other countries therefore tend to focus on assessment methods and approaches that will be protective for Cl-VOCs. In situations where degradation is limited, the same approaches may also be appropriate for petroleum hydrocarbons.

To date, there has been insufficient attention paid to the differences in assessment methods and approaches that would generally be more applicable for degradable hydrocarbons. Some 'rules of thumb' have been proposed in the US (Davis 2009) and Australia (Wright 2010) as a basis for identifying circumstances where biodegradation of petroleum hydrocarbon vapours is likely to preclude vapour intrusion. The American Petroleum Institute (API) has published a series of articles related to petroleum vapour intrusion (for example, API 2001, 2005, 2009) and the US Office of Underground Storage Tanks (OUST) has recently compiled relevant information for petroleum vapour intrusion (USEPA 2011). This EI protocol document attempts to provide a compilation and update of world's best practice in this topic area.

To assess the importance of biodegradation it is important to understand the distribution of both hydrocarbons and oxygen in the subsurface. Soil vapour sampling and analysis provide the data needed to understand these vapour distributions, critical for proper characterisation of vapour intrusion risks associated with petroleum hydrocarbon vapours. For chlorinated solvents, biodegradation is often insignificant in attenuating vapour migration. This is one of the key ways in which these two classes of compounds differ.

1.1 THE ROLE OF SOIL VAPOUR IN UK CONTAMINATED LAND MANAGEMENT

Since the mid-1990s 'Brownfields' programmes have been implemented in the US, EU, and UK to revitalise previously developed (potentially contaminated) land. In February 1998 the British Government established a policy stating that 60 % of new housing should be built on brownfield sites. A National Land Use Database (www.uklanddirectory.org.uk/brownfield.asp) was established to identify brownfield sites and encourage redevelopment. The overall approach to land reutilisation is based on a 'suitability for use approach' which relies on the risk assessment process to ensure that after redevelopment, receptors are adequately protected from contaminants at the site.

The CIRIA C682 *VOCs Handbook* presents a detailed description of the regulatory and policy framework which influences the vapour intrusion assessment process. It also presents a framework for conducting a vapour intrusion assessment. The level of detail specific to degradable compounds is, however, limited with the report recommending:

- 'There is a need for further research in the UK into the conditions required for degradation of certain VOCs to occur'.
- 'Further work should be undertaken to develop a UK standard for undertaking soil gas investigations, as has already been developed for investigations of other environmental media'.

Assessing the risks associated with the vapour intrusion pathway presents some technical challenges. The risk-based indoor air guideline concentrations for some petroleum compounds may be very low. In some cases (for example, benzene), it may be at or below the concentrations typically found in indoor air from consumer products, building materials, and even outdoor air in urbanised areas (collectively referred to as background sources in the context of a vapour intrusion assessment). Furthermore, if indoor air samples are collected and analysed with sensitive analytical methods, several hydrocarbons (toluene, xylenes, and various aliphatics) are commonly detected, and even if their concentrations do not exceed risk-based guideline values, this can complicate the evaluation of the source or origin of the vapours. Therefore, indoor air sampling and analysis often yield ambiguous results, especially for petroleum hydrocarbons which are components of many consumer products. Indoor air data also show considerable temporal variability from changes in the weather and seasons, occupants' activities and consumer preferences. Soil vapour samples are less likely to be significantly influenced by background sources (especially deeper soil vapour samples), which make them a valuable tool for screening sites for petroleum vapour intrusion risks. At sites where there is no existing building, indoor air sampling is not an option, and soil vapour sampling is typically the primary line of evidence for assessing risks to future buildings.

Historically, soil gas or soil vapour monitoring has been used for many purposes. (Note that 'soil gas' or 'ground gas' are equivalent terms and generally refer to a mixture of nitrogen, oxygen, carbon dioxide and biogenic gases that occupy subsurface voids. 'Soil vapour' generally refers to VOC vapours that are present in the gas phase. These definitions are not always used consistently and the terms are sometimes used interchangeably.) Methane concentrations near landfills and coal seams are a concern when they approach explosive levels (5 - 15 % by volume at atmospheric pressure), and pressure gradients cause flow into enclosed spaces. This is a process that has been studied using ground gas sampling for several decades. Since the late 1980s, ground gas sampling has also been used for rapid screening surveys around suspected VOC release areas, and to identify the real extent of highly contaminated groundwater plumes (Marrin and Kerfoot 1988). The data quality objectives for ground gas monitoring in vapour intrusion assessments, are typically much more stringent (require quantification to much lower concentrations) than for those previous uses. More stringent quality control and quality assurance methods are needed to ensure that the ground gas samples are truly representative, reproducible and unbiased.

1.2 SCOPE

The purpose of this document is to bridge the gap between:

- the historical ground gas sampling approaches that were employed to identify acute hazards and as tracking tools.
- the more recent need for high quality, contaminant-specific approaches required for vapour intrusion assessments.

This document provides information to foster a better understanding of the processes that control the nature and distribution of petroleum hydrocarbons along the vapour intrusion pathway. It describes the role of the conceptual site model in establishing data quality objectives. In identifying where to collect soil vapour samples, it recommends sampling techniques to promote data of high quality and integrity. Collectively, this information can be used with professional judgement to customise a soil vapour assessment to the site-specific conditions.

1.3 APPLICATION

1.3.1 Intended audience

This document is intended to provide comprehensive information for those with limited prior experience in this topic area as well as up-to-date information for the experienced practitioner.

The main body of this report is intended to provide information for project managers and technical directors of investigative programmes, regulatory agency representatives and reviewers.

1.3.2 How to use this publication

The basic theory, in the framework of a conceptual model, is discussed in section 2. Section 3 describes considerations for developing a scope of an investigation of petroleum vapours. Section 4 discusses data analysis and interpretation following a data collection programme.

The Annexes contain practical information intended more for field sampling professionals to assist in the implementation of field sampling programmes. Annex A describes the characterisation of the subsurface (geologic and made ground) materials. Annex B describes soil gas probe construction. Annex C discusses purging and leak checks. Annex D discusses pneumatic testing. Annex E discusses field screening using portable instruments. Annex F discusses sample collection for laboratory analysis. This document does not discuss mitigation for soil vapour intrusion; the reader is referred instead to USEPA 1993, 1994a, 1994b, 1995, ITRC 2007, CIRIA 2009 and CIRIA 2012.