



Environment,
Climate Change
& Water

Vapour Intrusion: Technical Practice Note

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Note: This technical note is advisory only. It has been prepared to assist practitioners on contaminated land in NSW. It should be read in conjunction with national guidance documents, recognised industry best practice, standards and other technical publications.

This note will be revised from time to time following feedback from stakeholders, ensuring its ongoing relevance and reflecting advances in best practice as the result of regulator and industry experience. Comments are welcome and should be sent to contlandmgnt@environment.nsw.gov.au.

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1 Introduction

The Department of Environment, Climate Change and Water (DECCW) has prepared this document to provide guidance to consultants in New South Wales undertaking assessment of contaminated sites where there may be exposure to vapours at sufficient concentrations to pose a chronic health risk. It also provides auditors accredited under the *Contaminated Land Management Act 1997* (CLM Act) with guidance for audits of vapour intrusion investigations.

This guidance note provides a policy and regulatory supplement to existing technical guidelines. The reader is referred to these guidelines where relevant, but is cautioned that vapour assessment is a rapidly changing field. Users of this guidance note should satisfy themselves that they are keeping up with latest developments in this field.

Only chronic exposure and risk is considered by this guidance note. If an acute or explosive risk is suspected then immediate action, including contacting relevant emergency services, should be taken to address the risk.

1.1 Background

Low-density residential buildings in NSW are most frequently of brick-pier or concrete-slab construction. Medium-density and high-density residential or commercial developments are often of concrete slab construction, commonly with basement (subsurface) car parking. The trend of improving the energy efficiency of buildings by reducing air exchanges and the removal of a subfloor space in new developments means that proper assessment of vapour intrusion is becoming more important.

Volatile chemicals present as contaminants in soils or groundwater have the potential to partition into the air in the soil pore spaces and can move into buildings, ambient air, confined spaces or excavations on a site. The potential risk to human health from this exposure pathway should be evaluated as part of any site assessment where exposure to vapours is considered to be a risk factor.

1.2 General principles of vapour assessment

Chronic risk

Investigators may need to assess the risk posed by long term exposure to low concentrations of some chemicals. The choice of sample type, methods of sampling and analysis, and sampling locations becomes important to confidently determine whether vapour intrusion is occurring and needs to be mitigated.

Nature of contamination

If a source¹ of volatile² and toxic³ chemicals has been identified on, or adjacent to, the subject site and exposure pathways are likely to be present then consideration should be given to the sampling of volatile substances in their vapour phase. This consideration, including the outcome of any assessment, should be reported in documents submitted to DECCW.

¹ The source may be primary (such as a tank) or secondary (such as contaminated soil, groundwater or NAPL).

² A chemical is considered sufficiently volatile if it has a Henry's law constant greater than 1×10^{-5} atm m³/mol and the vapour pressure is greater than 1 mm Hg at room temperature (NJDEP 2005).

³ A chemical is considered sufficiently toxic if the maximum vapour concentration of the pure component would pose an incremental lifetime cancer risk greater than 10^{-6} or results in a non-cancer hazard index greater than one (USEPA 2002).

A discussion of vapour behaviour, properties, measurement and modelling is given in Davis, GB, Trefry, MG, and Patterson, BM 2004, *Petroleum and solvent vapours: Quantifying their behaviour, assessment and exposure*, CSIRO Land and Water Conservation report to the Western Australian Department of Environment, www.clw.csiro.au/publications/consultancy/#2004

Data quality

Vapour intrusion should be assessed through application of the Data Quality Objectives Process as per soil and groundwater sampling. This involves a stepwise approach to identifying objectives, planning and assessing the data quality requirements for an investigation and is outlined further in the US EPA's quality management tools.⁴

Weight of evidence

A weight of evidence approach is best in assessing vapour intrusion. This means obtaining a good understanding of what might be happening at the site by developing a conceptual site model (CSM) based on previous investigations and then taking samples to validate and refine the CSM. The strength of evidence provided by any one type of sampling may be influenced by limitations of the technique. As a result, more than one method of sampling may be required to adequately demonstrate whether vapour intrusion is occurring, or is likely to occur.

Appropriate methods

The field of vapour assessment is evolving with new methods of vapour sampling emerging regularly. DECCW may not accept data that has been collected through unpublished or unproven techniques, or where DECCW believes the methodology was not sufficiently robust. Therefore it is recommended that vapour intrusion assessments be carried out using methods published in regulatory guidelines, in peer-reviewed journals or that have been the subject of a rigorous and independent review. Practitioners should ensure that they are up to date with the most recent developments in this field.

Evolving guidance

DECCW recommends the use of the guidance documents referenced in this document in designing a site-specific monitoring program. In particular ITRC (2007) includes a set of six useful case studies showing how to design a sampling plan, and the CRC CARE Technical Report 13 (Davis et al. 2009c) provides detailed guidance on field assessment. The VOCs Handbook (Baker et al. 2009) is a comprehensive textbook on vapour intrusion published in the UK. It is consistent with UK Environment Agency guidance on volatiles and is suggested as a useful reference source.

Other guidance is scheduled to be released in 2010–12, including an updated *National environmental protection measure (Assessment of site contamination)* (the NEPM). Practitioners should refer to the latest relevant guidance.

⁴ www.epa.gov/quality/dqos.html

ITRC 2007, *Vapour intrusion pathway: A practical guideline*, Technical and Regulatory Guidance, Interstate Technology and Regulatory Council, Vapour Intrusion Team, Washington DC, www.itrcweb.org/guidancedocument.asp?TID=49

Davis, GB, Wright, J and Patterson, BM 2009c, *Field assessment of vapours*, CRC CARE Technical Report no. 13, CRC for Contamination Assessment and Remediation of the Environment, Adelaide, www.crccare.com/publications/downloads/CRC-CARE-Tech-Report-13.pdf

Baker, K, Hayward, H, Potter, L, Bradley, D and MacLeod, C 2009, *The VOCs handbook: Investigating, assessing and managing risks from inhalation of VOCs at land affected by contamination (C682)*, CIRIA

2 Planning for a vapour assessment

A key to the design of investigations into vapour risk and subsequent interpretation of the results is that a realistic representation of the site and its use should be developed. A robust conceptual site model (CSM) generates an understanding of the variables at play on a site and characterises the fate and transport behaviour of the contaminants. Areas of uncertainty should be considered and the CSM used to shape investigations. Consideration of both current and likely future uses should be made when planning an investigation program.

Contaminated site assessment should be based on sound science which is described by the Society of Environmental Toxicology and Chemistry as 'organized investigations and observations conducted by qualified personnel using documented methods and leading to verifiable results and conclusions'.⁵

2.1 Application of vapour sampling

Vapour sampling is most reliable where the conditions under which the samples are collected are the same as the conditions under which exposure may occur. Remediation and development may change the conditions at a site and may therefore change the factors controlling vapour migration, intrusion and exposure. For example, results from sampling a vacant site may not be applicable to a future development.

To address uncertainty in redevelopment, a weight of evidence approach can be applied to collected data to be compared against health screening levels or used in a vapour intrusion model. These issues are covered in more detail below.

2.2 Conceptual site model

A conceptual site model should be developed prior to undertaking a vapour investigation in order to ensure the sampling plan considers the factors influencing the vapour intrusion pathway and potential exposures. The CSM should include a site-specific explanation of the potential vapour migration and intrusion pathways and processes. The model should be provided in the text and supported by figures.

Each CSM should be based on site-specific information that is available or can easily be obtained at the time of reporting of the model, and should include consideration of the following matters. Note that all of this information will not be available on many sites. In this case an assessment should be made of the significance of any data gaps. The information to be collected includes:

⁵ www.setac.org/node/101

- source, type, depth and location of contaminants
- age of contamination or elapsed time since a spill
- physical and chemical properties of each of the volatile contaminants
- current or proposed buildings on the site and their use (residential or commercial)
- size and type of construction of the buildings (slab-on-grade, crawl space, basement)
- receptor proximity and use of surrounding land
- geology, soil stratigraphy and hydrogeology, particularly noting the presence of layers in the stratigraphy with high and low permeability, the depth to groundwater and height of the groundwater capillary fringe
- physical condition of the subsurface (soil moisture content, soil bulk density, soil grain size, total porosity and fraction organic carbon)
- distance to the source of contamination
- depth to the source of contamination
- environmental conditions (including rainfall, barometric pressure, wind speed and direction, and temperature)
- condition of buildings and pavements – any available details on the integrity of the slab or other flooring (such as age of slab and level of cracking)
- presence of ventilation or heating/cooling systems and other relevant information which may affect air exchange rate
- rate of exchange between indoor and outdoor air (the tightness of the construction) including room connectivity and any through-slab piping
- location and structure of utilities and other potential preferential migration pathways for soil vapours (such as lift wells, sewer and stormwater lines)
- characteristics of any confined space
- likely transport mechanisms operating between the source and receptors (whether diffusive or advective or both).

A site inspection is generally required to develop and refine the CSM, and the factors which influence vapour intrusion should be assessed during the site inspection.

The CSM should be updated as new and more detailed information becomes available. Checklists are provided in the guidance documents to assist in collating all relevant information into a detailed site model (for example Appendix B in ITRC 2007).

Triad Central contains extensive guidance on and examples of conceptual site models.⁶ A useful discussion of CSM is contained in Chapter 3 of Clements et al. (2009). An LNAPL CSM Certainty Screening Tool is available from CRC CARE.⁷

2.3 Assumptions and uncertainty

In every part of a contaminated site assessment such as a vapour investigation, assumptions about the nature of the site environment are made in order to progress the work and form a conclusion about the contamination and its impact. Some assumptions have a relatively minor effect while others can be significant. Assumptions with a significant effect or sensitivity should be reduced or eliminated where possible through direct measurement rather than estimation or modelling.

Each step further away from the receptor that the contamination is measured introduces more uncertainty. Therefore to increase the reliability of the results

⁶ www.triadcentral.org

⁷ www.crccare.com/publications/technical_reports/index.html

measurements should be taken as close as practical to the receptor. The following hierarchy, with reliability decreasing down the list, can be used as a guide (this hierarchy assumes that practical and QA/QC issues can be managed: indoor-air sampling can often result in inconclusive results due to confounding factors and should be used as part of a weight of evidence approach):

- 1 indoor air concentration data (provided that indoor sources can be identified and accounted for)
- 2 subslab or crawl space vapour concentration data
- 3 soil gas concentration data
- 4 groundwater concentration data
- 5 soil concentration data.

For vapour intrusion assessment in NSW it is recommended that, where possible, soil gas data is collected and a weight of evidence approach used. Soil data alone is not considered to be sufficiently reliable to make decisions about whether or not a vapour intrusion risk is present.

3 Site investigations

3.1 Sampling methods

Several methods are available to measure the concentrations of volatile substances, including:

- subsurface soil gas methods (including subsurface soil gas and sub-slab methods)
- surface flux methods
- indoor air methods.

The most appropriate methods will depend on the objectives of the project and the CSM presented for the site. As a weight of evidence approach should be used for vapour assessment, more than one method of assessment for a site is usually appropriate. For all types of samples, quality control is critical to obtaining reliable results. A more detailed description of sampling methods can be found in Davis et al. (2009c).

3.1.1 Active or passive sampling

There is often an option of sampling using either active or passive methods. Active sampling involves pumping a known volume of air from the sample location and collecting either a sample of gas or adsorbent media. Active sampling methods usually provide results in the form of mass of contaminant per volume of air. Passive sampling is based primarily on the principle of diffusion and measures the mass of contaminant that adsorbs to adsorbent media in the sample location over a period of time.

When applied to soil gas, passive sampling is a semi-quantitative tool as it cannot provide concentration data. In some soil types passive sampling can be effective in the preliminary stage of an investigation. The application of passive subsurface sampling in a grid deployment to identify hot spots for detailed assessment can be particularly useful.

When applied to indoor air measurement passive sampling requires some assumptions to be made to determine concentrations. It is not always straightforward to assess whether the conditions during sampling comply with these assumptions. Assumptions as listed by the manufacturer should be documented and QA/QC should

be designed to give as much confidence as possible that these assumptions have been met.

3.1.2 Subsurface soil gas methods

Soil gas samples can be obtained from semi-permanent installations or from temporary push-tube methods. Samples should be obtained from depths that correlate with the CSM to obtain representative samples of concentrations through the profile, taking into consideration surface influences, permeability of soils, preferential pathways, disturbed soils and depth to the source of contamination. Where possible and relevant to the CSM, samples from multiple depths can be collected to provide detail on the vapour profile in the subsurface.

Subslab soil gas measurements can be obtained directly beneath a slab and may provide valuable information on whether chemicals have migrated through the vadose zone and may reach buildings.

3.1.3 Surface flux methods

Flux measurements are intended to quantify the flux of a chemical that is migrating from the subsurface into the atmosphere under current conditions. However, the small surface area of flux chambers and the tendency for vapour concentrations to be influenced by near-surface processes and preferential pathways mean these types of samples may provide unrepresentative results. Data quality can be improved by collecting multiple lines of evidence and combining this method with data collected from other methods.

Flux samples are best suited to scenarios where surface emissions are known and need to be quantified, rather than attempting to demonstrate that surface emissions are low. Flux methods often fail to find petroleum hydrocarbons due to biodegradation in surface soils. The use of data collected with this method should be considered in light of the CSM and any proposed development of the site.

3.1.4 Indoor air methods

Indoor air sampling can provide a relatively direct assessment of the potential health risks to occupants or receptors. The sampling of volatile substances in air in buildings should be considered in the following situations where occupied buildings or sensitive receptors are located in proximity to a source of vapour contamination:

- where elevated concentrations of contaminants are identified from soil gas sampling or in the subslab zone
- where data suggests a complete migration pathway
- where there are odour complaints from building occupants.

Indoor air sampling is usually undertaken subsequent to soil gas sampling, due to difficulties in gaining access to a property and potential indoor sources of vapours. However, it may be appropriate to assess indoor vapour concentrations earlier where there has been a spill or where a building is prone to intrusion by shallow contaminated groundwater.

A limitation of all indoor air methods is the potential for other sources of the chemicals of potential concern to be located inside a building or to occur as background sources. Environmental sampling, including ambient air sampling, requires the detection of trace quantities of contaminants above background levels; hence the results of sampling can be difficult to interpret. Sampling of background (such as outside) ambient air or from a comparable, non-affected location can be useful to provide context to the results and allow better application of guidelines for carcinogenic

chemicals. Prior to any indoor air sampling an inspection of the premises is recommended to identify indoor sources of vapours, and these sources should be removed where possible.

Inspection checklists for indoor air sampling and a list of common sources of background contamination can be found in NJDEP (2005), Baker et al. (2009) and Oregon DEQ (2010)

Indoor air sampling should be undertaken using methods that allow comparison of the results with appropriate health-based guidelines. This normally requires a 24-hour sampling period and low detection limits in the vicinity of 1 µg/m³.

3.1.5 Advanced methods

This document does not contain an exhaustive list of sampling methods. Relevant advanced methods may be justified where appropriate.

3.2 Sample management

3.2.1 Quality assurance

A quality assurance plan should be prepared to ensure that the data obtained meets the data quality objectives of the investigation. Part of that plan is a quality control plan including a sampling plan describing sample numbers, sample collection and maintenance of samples. The quality assurance plan should include consideration of the need for:

- a qualitative or quantitative method of leak detection such as the use of a tracer liquid or gas selected with an appropriate sensitivity, or use of an in-line vacuum gauge for active sampling methods
- duplicate samples (including representative laboratory duplicates for oxygen, carbon dioxide and methane where primary data are obtained from field instrumentation)
- blank samples for every sampling event and laboratory submission
- batch certification of summa canisters for all soil gas investigations and individual certification of summa canisters for indoor air sampling due to the trace level concentrations of contaminants being assessed.
- appropriate certification and use of flow controllers on summa canisters
- equipment blank samples to obtain a background reading for chamber, sweep air and equipment for dynamic flux chamber methods
- maintenance of samples prior to analysis, with chain of custody documentation
- sampling and analysis procedures which minimise the potential for cross contamination.

Further details and references relating to quality assurance and quality control are provided in Appendix B.

3.2.2 Meteorological conditions

Site-specific meteorological monitoring data (including monitoring of temperature, barometric pressure, precipitation and wind speed and direction) should be obtained when sampling unless site-representative data can be obtained from a nearby meteorological monitoring site. Portable weather stations with data loggers are now readily available.

Soil gas concentrations for sources at depth are less likely to be influenced by meteorological variations. Where the source is below 1–2 m depth depending on soil type, an active sample of vapour obtained from near the source is of benefit in a

sampling program to assist in understanding migration and attenuation. Source zone soil gas results can also be modelled to assess how the potential for vapour intrusion may be altered by a change in land use.

3.2.3 Demonstration of natural attenuation

Natural attenuation due to chemicals biodegrading over time may occur in some circumstances with some contaminants and this may reduce the risk posed by vapour intrusion. Some contaminants may generate daughter compounds that are more toxic than the parent compound. Biodegradation as a mechanism of risk reduction should not be assumed to be occurring and must be demonstrated at sites where it is claimed to be occurring. Evidence for biodegradation may include soil gas concentrations at various depths through the soil profile between the source of contamination and the receptor. Oxygen and carbon dioxide concentrations should be measured at more than one location, preferably all locations. The CSM should identify any biodegradation processes likely to be operating at a site.

The biodegradation of petroleum hydrocarbons is covered in detail in Davis, GB, Patterson, BM and Trefry, MG 2009a, *Biodegradation of petroleum hydrocarbon vapours*, CRC CARE Technical Report no. 12, CRC for Contamination Assessment and Remediation of the Environment, Adelaide, www.crccare.com/publications/downloads/CRC-CARE-Tech-Report-12.pdf

3.2.4 Methods for sampling and analysis

Samples should be collected, preserved, transported and analysed in a manner that is consistent with the appropriate standard methods. The methods should be chosen based on the data quality objectives to meet the minimum detection limits for the appropriate guideline levels.

It is recognised that the USEPA TO methods have generally not been updated since 1999 and that newer and better methods may be available. Alternative methods may be appropriate where evidence is provided and reported that validates their use. NATA (or equivalent) accreditation for analysis is preferred.

Thermal desorption of sorbent tubes (the basis of TO-17) is generally preferred over solvent extraction when testing for BTEX compounds because DECCW experience has shown that the carbon disulfide extraction solvent can be contaminated with benzene. This problem can be minimised with appropriate QA/QC.

Methods for vapour sampling and analysis can be found in:

US EPA Air Toxics Monitoring Methods, www.epa.gov/ttn/amtic/airtox.html

NIOSH Manual of Analytical Methods, www.cdc.gov/niosh/docs/2003-154/

If using an occupational health and safety method to assess for non-voluntary chronic exposure, ensure that the detection limits are low enough to compare with the appropriate guideline.

ITRC (2007, Table D-3 Summary of analytical methods for soil gas, indoor and ambient air samples), www.itrcweb.org/Documents/VI-1.pdf

US EPA (2002, Table A-2 VOC Analytical Methods, their Detection Limits and Estimated Costs), www.epa.gov/osw/hazard/correctiveaction/eis/vapor/complete.pdf

3.3 Sampling design

3.3.1 Offset distance

Where the receptor is not close to a source, for example greater than about 30 m laterally, the receptor may be screened out as not requiring a vapour assessment. Refer to Davis et al. (2009c), USEPA (2002) and ASTM (2008a, 2008b) for further information. Where a receptor has been screened out on this basis it should be appropriately documented and justified in the report. Consideration should be given to soil layering and preferential pathways.

Note that in this application, 'source' includes contamination that has migrated offsite, not the original source site.

3.3.2 Number of sample locations

The number of samples recommended spatially for a vapour investigation is dependent upon site-specific conditions and should be carefully justified, taking into account the CSM and the properties of the vapours being assessed. Where subsurface conditions have not been assessed and a vapour investigation is proposed to be undertaken using a systematic pattern, the selection of sampling pattern and density should be designed to be statistically supportable.

Where there is a known point source of vapour contamination, at least one vapour sample should be taken as close as possible to an area of highest concentration. Additional samples should be obtained between the source and the potential receptors.

NJDEP (2005), NYSDOH (2006) and USEPA-OSWER (2002) provide guidance regarding appropriate sample densities for buildings of various sizes and uncharacterised sites.

The number of samples recommended for representative indoor air sampling depends on the size of the indoor area and internal divisions in the building which may limit air movement. Indoor air samples should be obtained from the crawl space and/or basement if present, as well as the living area at the height where occupants sit or sleep.

When flux hood sampling methods are used, a larger number of samples is normally recommended due to the small surface area of the units and significant potential for surface and subsurface heterogeneity.

3.3.3 Sampling depth

The selection of sample depth should reflect the conceptual model for the site, in particular the depth to the source of contamination, overlying soil types and the nature of the contaminant.

Near-surface soil gas sampling (less than 1 m depth) should be avoided or undertaken with caution due to the potential for ambient air dilution of the samples and other near-surface effects. These effects can be caused by changes in barometric pressure, temperature, soil moisture and advection due to natural processes or ventilation and heat regulating systems. Where sampling at shallow depths is required (for example at sites with a high water table or where the potential for natural attenuation is being assessed), careful consideration of a sampling design is needed and quality assurance measures should be specifically targeted to minimise near-surface effects.

Where possible and relevant to the conceptual model, samples from multiple depths can be collected to provide detail on the vapour profile in the subsurface. Relevant

major gases such as oxygen, methane, carbon dioxide and nitrogen can also be measured when taking soil gas measurements at varying depths. Such a profile of vapour concentrations (and oxygen concentrations in the case of sites impacted by petroleum hydrocarbons) can be of great assistance in assessing the likelihood of vapour intrusion and of likely degradation of the volatile substances.

3.3.4 Frequency of sampling

Where possible, focus should be placed on ensuring at least one round of samples is taken in the conditions (such as temperature, pressure, soil moisture) that are likely to result in the highest vapour concentrations.

Repeat sampling should be undertaken where site conditions may change, for example where there is a fluctuating source, varying meteorological conditions, varying building use or conditions, and where remedial work is undertaken, unless vapour concentrations are significantly below screening levels.

ITRC (2007) identifies that there is no need to undertake repeat sampling if soil gas values are a factor of 5–10 times below the risk-based screening levels, unless a major change in conditions occurs at the site (such as an elevated water table) which would significantly change vapour concentrations.

3.3.5 Sampling times and duration

The sample collection time and sample volumes should be consistent with the specific method employed for the vapour sampling and analysis and the guidelines that the data will be compared against. Flux chamber samples should be obtained at regular intervals over a minimum of eight hours, and it may be appropriate to sample over 24 hours where large diurnal variations in meteorological conditions occur. Indoor air samples for domestic dwellings should be collected over 24 hours and for workplaces should correspond with a standard shift (normally eight hours for day shift or 24 hours where night shifts also occur).

Concentrations within a building can vary by up to an order of magnitude due to pressure gradient effects from the diurnal cycle of natural and artificial building heating and cooling. Vapour intrusion can increase when the building is being heated and decrease when the building is cooling. Sampling should aim to average out these variations.

3.3.6 Purge and flow rate

The approach to purge and flow rates should be consistent across a site, recorded at all sampling locations, and selected based on the site condition (formation characteristics such as soil air permeability and sample depth, location in relation to the source).

USEPA (2002) recommends that the purge volume should be the minimum volume deemed adequate to flush the system. Recent papers on the USEPA website have studied differences obtained in adjusting purge volumes, tube diameter, flow rate and sample volume. New methods are emerging that advocate very large sampling volumes in order to average out spatial variability. Whatever approach is used should be appropriately justified.

4 Reporting

4.1 Reporting and data assessment

When evaluating data, the validity of the original assumptions used to design the sampling plan should be reassessed to ensure they remain valid, and adjustments should be made accordingly. Data may need to be clustered if total data variance is high, i.e. the sampling event may be recording large variations in concentrations of vapour in areas previously assumed to be homogeneous.

The following minimum information should be provided in reports:

- conceptual site model
- sample locations, provided in relation to building floor plans for all types of samples
- the relevance or applicability to actual or likely human exposure
- the sampling, preservation, transport and analytical methods used
- description of the measuring equipment used
- the experience and training of the sampler/s
- the dimensions and method of construction of boreholes (for subsurface methods)
- the physical and chemical properties of the soil
- the position of the groundwater table relative the sampling point
- the rate and duration of monitoring (start and end dates and times)
- purge and sample volumes for active sampling methods
- discussion of any factors which may have affected sample results
- details of the most recent calibration of the instrument used to take measurements (including records of calibration)
- results linked to the method detection limit (i.e. not zero)
- conversion of concentration results to $\mu\text{g}/\text{m}^3$
- explicit statement of all assumptions used to calculate results, including equations
- recording of meteorological conditions for all sampling events
- QA/QC protocol
- method performance data (such as details of method detection limit determination, replicate precision and audit accuracy for TO-15 or similar)
- any pertinent observations including odours and field instrument readings
- the limitations of the methods used.

4.2 Units

All vapour concentration results should be uniformly reported to DECCW in micrograms per cubic metre ($\mu\text{g}/\text{m}^3$). Where lab results are reported in parts per billion by volume (ppbV) they should be converted using the ideal gas law ($PV = nRT$). Results and conversions should be provided in tabular form so that the report can be read and understood as a stand-alone document. When converting, care should be taken with significant figures to avoid erroneously increasing the level of precision.

For example, in the case of using an adsorbent tube for active sampling, report the mass per tube, the volume of air passed through the tube and the result in $\mu\text{g}/\text{m}^3$. The level of reporting (practical quantitation limit) should be reported at the same time. For passive vapour sampling that reports results as a concentration, conversion equations and assumptions should be clearly stated. Sampling temperature and pressure and each diffusion coefficient should also be reported.

5 Interpretation

5.1 Acute effects

Prior to the evaluation of chronic health risks from long-term exposure to low-level contamination, it should be determined whether or not immediate actions are required. Exposure to vapours can cause acute health effects such as nausea, headaches and respiratory irritation. The accumulation of contaminant vapours may pose a fire and explosion hazard. Such acute effects can usually be identified because they occur at concentrations that are orders of magnitude higher than corresponding odour thresholds. Should the potential for acute effects be established, buildings may need to be evacuated and emergency services contacted.

5.2 Background concentrations

When assessing the acceptability of the levels of chemicals identified, exposure to chemicals causing threshold effects (this includes the measured concentration plus background concentration) should be less than the threshold dose (risk quotient less than 1) and the lifetime incremental cancer risk should be less than 1×10^{-5} for the total of all genotoxic carcinogens.

For some non-threshold substances the background exposure can be high compared to the guideline value. For example, the reference concentration guideline of $1.7 \mu\text{g}/\text{m}^3$ for benzene found in section 6 will be exceeded in many parts of NSW due to variations in background levels from sources such as vehicle emissions. This guideline value relates to the *increased* cancer risk from the vapour intrusion. Therefore it may be applied to modelled vapour concentration at the receptor, or to a measurement of indoor ambient air minus the background concentration if a background can be reliably obtained.

In order to determine the relevant background values consideration may be given to external air quality, subfloor/crawl space air quality and potential indoor sources. For a screening assessment, generic published background data may be used if justified.

The EPA's Ambient Air Quality Research Project (1996–2001) provides a detailed discussion of background air quality in urban and suburban areas. The project took over 1000 samples at five sites using Summa canisters with a 24-hour regulator. The samples were analysed with USEPA method TO-14.⁸

When assessing volatile compounds that do not readily degrade with oxygen, such as chlorinated solvents, it may be assumed that the ratio of one substance to another will not vary significantly over short distances. Comparing the ratio of compounds in indoor air samples with that in sub-slab or soil gas samples can help to identify indoor sources of target compounds.

5.3 Health risk assessment

Once indoor air concentrations have been assessed through measurement or modelling, the results are compared to health guidance values in order to estimate risk. Recommended guidance values are provided in section 6.

Section 6 has been prepared to assist the novice practitioner in selecting appropriate guidelines for commonly occurring chemicals found in vapour intrusion assessments. The data sources used are generally consistent with the NEPM hierarchy and include information from the current draft NEPM that is under consultation. The experienced practitioner may use other guideline values if they can be appropriately justified.

⁸ www.environment.nsw.gov.au/resources/air/organics04120.pdf

The NEPM health investigation levels have been revised and are due for public consultation in 2010. They include soil gas guidelines for chlorinated compounds and soil, groundwater and soil gas guidelines for TPH/BTEX. These figures will supersede some of those in section 6 for some exposure settings.

5.3.1 Data sources

Several types of guidance values are available that might be considered relevant for contaminated sites potentially affected by vapour intrusion. These include occupational time-weighted averages, public health values such as unit risks, reference inhalation concentrations and tolerable daily intakes.

Public health guidance values are the only appropriate option in situations where exposure is involuntary or where a house, school, childcare centre, health care facility or an aged care facility is involved.

Occupational values can only be used in situations where the site being investigated is a workplace and the chemicals of potential concern from the contaminated soil or groundwater are also used in the workplace. Such occupational exposures to the substances should be measured, monitored and controlled by the employer in accordance with OHS regulations and guidelines. In all other situations the exposure is involuntary and public health guidance values should be used. Some adjustment of the public health values on the basis of time present in the affected building could be considered for an involuntary occupational exposure. Refer to section 5.3.2.

The NEPM for contaminated site assessment schedule B(4) provides a hierarchy for sources of such guidance values and this hierarchy should be used, noting the context in which the guidance values were published. For air, Australian guidelines are limited and include chemicals listed in the air toxics NEPM and the ambient air NEPM. Both of these guidelines are generally prepared with regard to ambient air quality in relation to large-scale development assessment and land-use planning. Due to their consideration of ambient air, they are not well suited to the assessment of vapour intrusion.

The World Health Organisation (WHO) publishes air quality guidelines, drinking water guidelines, environmental health criteria monographs and concise international chemical assessment documents (CICADs) which are all potentially relevant sources for vapour guideline data. WHO is the best source of guideline data for most vapour intrusion assessments.

For chemicals without Australian or WHO guidelines a variety of international sources can be used, such as the US EPA IRIS database, provided they are appropriately justified. In some cases a vapour guideline will need to be derived on a site-specific basis using toxicity data in accordance with EnHealth guidance on health risk assessment.

5.3.2 Exposure assumptions

When using guideline values that are presented as short- and long-term averages, the average should be selected that best represents the exposure scenario. For most cases of vapour intrusion this would be the chronic guideline value.

In some cases the receptor will only be exposed for part of the day. As it is chronic rather than acute risk that is being assessed, where partial exposure can be demonstrated the nominated health guideline value may be divided by the fraction of the day that the exposure occurs. This assumes that the receptor is not exposed at other locations. For example, where exposure can only occur for four hours per day, the guideline can be divided by 4/24 (multiply by 6).

Standard exposure settings are found in enHealth 2001, *Exposure scenarios and exposure settings*, www.health.gov.au/internet/main/publishing.nsf/Content/ohp-enhealth-exp-ctn.htm. This document was revised in 2009 and is due to be issued as a draft for consultation in 2010. Updated exposure settings have been used in derivation of draft NEPM investigation and screening levels for volatile compounds.

5.4 Modelling

5.4.1 Model selection

The Johnson and Ettinger (J&E) model (and related models) is commonly used to calculate indoor air concentrations from measured or estimated concentrations in groundwater, soil or soil gas. Caution should be used when interpreting the results of any vapour modelling as the quality of the results depends on the quality of the input data and the validity of the wide range of assumptions. A greater number of assumptions are required to calculate indoor air concentrations from groundwater or soil data than from soil gas data. Situations have arisen where the risk posed by vapour intrusion has been significantly over- or underestimated when modelling has used soil or groundwater data as inputs.

The J&E model has undergone several modifications since its initial publication in 1991.⁹

Davis et al. (2004) discuss the assumptions which underlie different modelling approaches and compare the capabilities of four risk-based corrective action (RBCA) tools for assessing the risk of soil vapour entry into buildings.

When using models, the practitioner should understand the science and mathematics behind the model and be particularly aware of the assumptions that are made. Some assumptions may preclude the model from being used at a particular site, such as where the water table is shallow enough that the water touches the foundations of the construction. Additionally, the degree of uncertainty in the assumption values may result in an unacceptably wide confidence interval in the estimated result. Reference should be made to further papers published on the J&E model, including:

- Johnson, PC 2002, *Identification of critical parameters for the Johnson and Ettinger (1991) vapour intrusion model*, [http://api-ep.api.org/ehs/groundwater/upload/Bulletin17.pdf](http://api.ep.api.org/ehs/groundwater/upload/Bulletin17.pdf)
- Weaver, JW and Tillman, FD 2005, *Uncertainty and the J&E model for vapour intrusion calculations*, www.epa.gov/athens/publications/reports/Weaver600R05110UncertaintyJohnsonEttinger.pdf

More sophisticated models are available for detailed site-specific vapour intrusion assessments. A discussion of models is contained in CRC CARE Technical Report No. 9, www.crccare.com/publications/downloads/CRC-CARE-Tech-Report-9.pdf, and Chapter 6 of CRC CARE Technical Report No. 4, www.crccare.com/publications/downloads/CRC-CARE-Tech-Report-4.pdf.

Other models include Abreu et al. (2005), Bozkurt et al. (2009) and Turczynowicz and Robinson (2001, 2007).

5.4.2 Modelled vapour concentrations

Vapour concentrations in indoor air can be calculated from contaminant levels measured in soil gas, soil or groundwater. Such calculations normally assume that a

⁹ <http://pubs.acs.org/doi/abs/10.1021/es00020a013>

steady state has been reached in the area where the contamination exists. When carrying out modelling of vapour intrusion it is important to be aware that sampling and analytical methods for soil are often not sensitive enough to reliably detect contaminants at a sufficiently low level. Empirical data from Baker et al. (2009) and referenced in Section 10 of UKEA (2009) suggests that the soil-water-vapour phase partitioning model for soil contamination can be unreliable. Overseas jurisdictions, particularly the USA, have moved away from using soil data for vapour intrusion assessments and instead require direct measurement of soil gas.

In NSW it is recommended that where sensitive receptors are being assessed and/or where screening modelling suggests risks that approach target levels, modelling should be based on groundwater or soil gas data, rather than soil data. Where practical, modelling should be field-validated.

5.4.3 Attenuation factors

Experience using these models in combination with actual field data has resulted in the development of attenuation factors. These can be applied to screen data to determine if a problem is likely to exist at a particular site in the early stages of an investigation. In this case the attenuation factor is defined as the ratio of the concentration determined or estimated inside a building to that in the soil vapour.

The most recent information available in this area is the Indoor Air Vapour Intrusion database.¹⁰

At some sites radon can be used to develop a site-specific attenuation factor to assess the potential for vapours to migrate and enter a building, where the source of contamination is a hydrocarbon. Radon is relevant specifically for hydrocarbon sites, as the rate of (radioactive) decay of radon is at a time scale not significantly different to hydrocarbon biodegradation rates and radon is not chemically reactive; however, unlike with hydrocarbon contaminants, the rate of decay of radioactive substances is not influenced by oxygen concentrations in the vadose zone (Davis et al. 2004). It should be confirmed that the concentrations of naturally occurring radon are sufficiently high in natural soil and there are no significant sources of radon inside a building prior to assessment of the attenuation factor using radon concentrations.

5.4.4 Exposure assessment

If screening of the sample results using the attenuation factor indicates the site might pose a risk, then a more detailed investigation is warranted. A more detailed investigation is likely to include additional sampling and analysis under various weather conditions to generate good quality data that covers the site sufficiently. These data can be used in an appropriate model to better evaluate the potential movement of vapours at the site and to estimate the likely indoor air concentrations that people may be exposed to.

Refer to ITRC (2007) for examples of exposure scenarios of sites where initial screening investigations indicate a likely vapour intrusion issue and the staged approach to quantifying risks.

¹⁰ <http://iavi.rti.org/>

6 Reference concentrations for commonly occurring chemicals (2010)

Chemical	IARC group	Current RfC *	Source	Note
Benzene	1	1.7 µg/m ³	WHO 2000	RfC is for a 1x10 ⁻⁵ risk using a unit risk of 6x10 ⁻⁶ per µg/m ³ .
Toluene	3	260 µg/m ³	WHO 2000	This may change to 5000 µg/m ³ based on USEPA IRIS 2010.
Ethyl benzene	2B	1300 µg/m ³	ATSDR 2007	
Xylenes	3	870 µg/m ³	WHO 1997	
Naphthalene	2B	3 µg/m ³	USEPA IRIS	
Chloromethane	3	18 µg/m ³	WHO 2000b	CICAD 28
Dichloromethane	2B	450 µg/m ³	WHO 2000	
Chloroform (trichloromethane)	2B	140 µg/m ³	WHO 2004	CICAD 58
Vinyl chloride (chloroethene)	1	1.1 µg/m ³	USEPA IRIS	RfC is for a 1x10 ⁻⁵ risk using a unit risk of 8.8x10 ⁻⁶ per µg/m ³
1,1-dichloroethene (1,1-DCE)	Not classified	200 µg/m ³	WHO 2003	CICAD 51
Cis-1,2-dichloroethene (DCE)	Not classified	30 µg/m ³	RIVM 2001	
1,2-dichloroethane (EDC)	2B	700 µg/m ³	WHO 2000	Based on non-cancer endpoints
1,1,1,-Trichloroethane (1,1,1-TCA)	3	5000 µg/m ³	USEPA IRIS	
Trichloroethene (TCE)	2A	23 µg/m ³	WHO 2000	RfC is for a 1x10 ⁻⁵ risk using a unit risk of 4.3x10 ⁻⁷ per µg/m ³
Tetrachloroethene (PCE)	2A	200 µg/m ³	WHO 2006	CICAD 68

* Current recommended reference concentration

Note: Health guidance values are valid at the date of release of this document.

Sources:

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Appendix A: Quality assurance and quality control

Quality assurance (QA) and quality control (QC) are an integral part of the analysis and interpretation of environmental data. Quality assurance involves all of the actions, procedures, checks and decisions undertaken to ensure the data collected are representative and to ensure integrity of samples, and accuracy and reliability of analytical results (NEPC 1999). Quality control is the component of QA which monitors and measures the effectiveness of the procedures by the comparison of these measures to previously decided objectives. Examples of quality assurance components include sample control, data transfer, instrument calibration and staff training. Examples of QC components include the measurement of samples to assess the quality of reagents and standards, cleanliness of apparatus, and accuracy and precision of methods and instruments. Some relevant components relating to vapour intrusion investigations are discussed.

Vapour intrusion sampling should be undertaken by appropriately qualified professionals who have received training in vapour sampling, and the assessment of data should be undertaken by qualified professionals with experience in risk assessment.

The site assessor should consider the potential for cross-contamination between sampling events and ensure any sampling infrastructure is installed and sample equipment used in a manner to prevent sample cross-contamination. The sampling equipment should be decontaminated and the sampling system should be cleaned between measurements. Preference should be given to the use of ultra-high purity gases to minimise the potential for cross-contamination when using flux chamber methods.

It is important that all parts of a sampling system are inert to the soil gas with which they come into contact. Stainless steel is usually a satisfactory material.

Equilibration time should be considered prior to sampling from permanent installations.

Adsorbent materials (tubes or cartridges) can be analysed using either solvents (solvent extraction) or heat (thermal desorption). A common problem for tubes that are extracted by solvent extraction (the Australian Standard method for organic vapours in the workplace) is that the solvent used (carbon disulfide) can be contaminated with benzene, and it is essential to use a correct grade of solvent that has minimal benzene to minimise the likelihood of contamination of the sample and of obtaining false positive results, and to make appropriate use of laboratory blanks to enable any corrections to be made.

Minimum levels of QA/QC are specified in some guidelines, and indicate field duplicate (including blind duplicate and split samples) should be obtained from 10% of samples, field blank should be collected each day of soil gas sampling, and one trip blank should be sent to the laboratory with each shipment of samples. However, the requirements will depend on the sampling methods undertaken and must be justified as the minimum levels may not be sufficient for a particular project.

Sample storage times should be appropriate and specified. Samples containing PAHs or halogenated compounds should be kept in the dark to eliminate photodegradation.

For more information on QA/QC refer to AS4482.1 (1995), AS4482.2 (2005), Hartman (2002) and Davis et al. (2009c).

Appendix B: Conversion of units

Results from vapour sampling must be converted between mass and volume concentrations using the ideal gas law. Unlike soil and water sampling where at parts per million concentrations it is often sufficient to assume that the density of the contaminant is equivalent to the density of the matrix, there is significant variation in gases that is strongly influenced by temperature, pressure and the molecular weight of the gas.

The ideal gas law is:

$$PV = nRT$$

where:

P = pressure (usually assumed to be 101.3 kPa)

V = volume in litres

n = number of moles

R = the universal gas constant, 8.314 L kPa K⁻¹ mol⁻¹

T = temperature (usually assumed to be 298K).

Example 1:

Convert benzene at a concentration of 10 µg/m³ to the equivalent in ppbV.

The molecular weight of benzene is 78.1, therefore 10 µg is 0.128 µmol (= n).

For T = 298K and P = 101.3 kPa, V = nRT/P = 3.1 µL.

Hence 3.1 µL/m³ is 3.1 ppbV.

Example 2:

Convert trichloroethylene at 10 ppbV to the equivalent in µg/m³.

The molecular weight is 131.4; therefore 10 ppbV is 10 µL in 1 m³.

For T = 298K and P = 101.3kPa, n = PV/RT = 0.41 µmol.

This is equivalent to 54 µg/m³.

A simplified method is found on the last page of ITRC (2007). Using 24.47 L as the volume of air that 1 mole occupies at standard temperature and pressure, a ratio of this volume to molecular weight (MW) can be used:

- To convert from ppbV to µg/m³ multiply by MW/24.
- For the reverse multiply by 24/MW.

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