Practical Strategies for Addressing the Vapour Intrusion Exposure Pathway

by Dr Kylie Dodd and Dr Sophie Wood

1. INTRODUCTION

The consideration of vapour intrusion risk as part of contaminated land site assessments is receiving increasing attention in Asia. Vapour intrusion assessments are a well established part of site assessments in the US, however, published guidance from the US EPA has not kept pace with actual practice, resulting in uncertainty for international users, who are also heavily reliant on this material.

Vapour intrusion assessments are frequently conducted using the Johnson and Ettinger model, which was recommended in the guidelines produced by the US EPA in the early to mid-2000s. Many sites will, however, fail this kind of vapour intrusion assessment because the vapour fluxes calculated from the soil or groundwater data tend to be overestimated. This is particularly the case for petroleum hydrocarbons because these types of traditional models do not account for the biodegradation of vapours in the presence of oxygen.

Recent developments in the methodology for the assessment of vapour intrusion have seen the adoption of more practical and site specific tiered vapour intrusion risk assessment approaches. This paper reviews some of the most useful guidance and assessment approaches.

2. VAPOUR INTRUSION

Vapour intrusion refers to the movement of volatile contaminants from soil or groundwater, via soil gas, into a building. If sufficient quantities of a contaminant vapour enter a building, and ventilation is insufficient to dilute the vapour, then the air quality inside the building can be affected. This can potentially lead to health and other risks to the building's occupants.

The most common contaminants of concern for vapour intrusion are chlorinated solvents and petroleum hydrocarbons.

3. SCREENING ASSESSMENT PROCESSES

3.1 Conceptual Site Models

The first stage of a vapour intrusion risk assessment is to develop a CSM, which is the qualitative description of the plausible mechanisms ('pathways') by which people or sensitive environments ('receptors') may be exposed to site contamination ('sources').

The CSM should consider the susceptibility of the site to a vapour intrusion risk. Key criteria that influence the likelihood of a vapour intrusion risk include:

- The volatility and toxicity of the contaminant compounds;
- The contaminant depth below ground level;
- The proximity of the contamination to a current or future building; and
- Building construction details, including the presence of basements, surface cover and preferential pathways.

It is possible to produce a 'no risk' conclusion for vapour intrusion at the CSM stage of an investigation, thereby focusing the requirement for more detailed vapour intrusion investigations on the higher risk sites.

3.2 Exclusion Distances

Recent studies have led to a number of bodies such as the Californian State Water Control Board and the American Society for Testing and Materials (ASTM) making recommendations around generic vapour intrusion exclusion distances for contaminated sites. An 'exclusion distance' is the distance (vertical or horizontal) between the soil or groundwater impact and the building structure, beyond which no vapour intrusion risk is likely. Published recommendations on exclusion distances are a useful tool in the first stage of a vapour intrusion risk assessment.

ASTM (2008) [1] recommends a vapour intrusion exclusion distance of 30m for non-biodegradable chemicals, excluding Non-Aqueous Phase Liquids (NAPL). This criterion can be applied across the range of volatile chemicals.

It is well known that there are many petroleum release sites worldwide, but relatively few documented cases of actual vapour intrusion problems associated with petroleum hydrocarbon vapours. A major reason for this is that petroleum vapours biodegrade rapidly in the presence of oxygen (CRC Care, 2009) [2].

The Californian State Water Control Board's (2010) Leaking Underground Fuel Tank (LUFT) Manual provides alternate vapour intrusion exclusion distances specifically for petroleum hydrocarbon contamination, as summarised in Table 1. These exclusion distances account for the potential for petroleum hydrocarbon vapours to biodegrade.

The exclusion distance recommendations outlined in Table 1 were derived on the basis of the following data:

- Paired soil vapour and groundwater field data published by Davis (2006) [3], which reported complete attenuation of hydrocarbon vapours at petroleum release sites; and

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Table 1: Vapour intrusion exclusion distances recommended in the LUFT manual for Petroleum Hydrocarbons

SOURCE CHARACTERISTICS	VAPOUR INTRUSION EXCLUSION DISTANCE (m)
Soil sources	1.5m or more of clean soil be-tween the bottom of the building and the shallowest impacted soil or impacted groundwater.
Low strength groundwater sources (Benzene < 1000µg/L and TPH < 10,000µg/L)	
High strength groundwater sources (Benzene > 1000µg/L and TPH > 10,000µg/L)	3m or more of clean soil between the bottom of the building and the shallowest impacted soil or impacted groundwater.
Measurable LNAPL	10m or more of clean soil be-tween the bottom of the building and the shallowest LNAPL source.

- Biodegradation modelling studies reported by API (2009) [4].

In the unsaturated zone, clean soil is defined as TPH concentrations less than 100mg/kg, PID readings of less than 10ppm, or oxygen present concentrations > 4%.

Under these conditions, it is assumed that natural attenuation is sufficient to mitigate concentrations of volatile petroleum constituents, given the exclusion distances listed in Table 1.

3.3 Chemical Characteristics

The US EPA's current vapour intrusion guidance is a draft document dating from 2002 (US EPA 2002). It provides a framework for assessing whether a risk from vapour intrusion is likely to exist. Although this document is still in the drafting stage, and has become dated in many aspects, it is commonly used as the basis for vapour intrusion risk assessments internationally.

One of the most useful references in the document is a list of common chemicals showing volatility and toxicity, permitting the exclusion of sites where the chemicals of concern are either insufficiently volatile, or insufficiently toxic, to pose a risk from vapour intrusion, thereby negating the requirement for the consideration of vapour intrusion.

This document considers that a chemical is not sufficiently volatile to represent a vapour intrusion risk if its Henry's Law constant is less than 1×10^{-5} atm-m^3/mole.

4. VAPOUR INTRUSION MODELLING

In the event that vapour intrusion cannot be ruled out in the CSM, a more detailed vapour intrusion risk evaluation may be required. One option for a second tier of vapour intrusion risk assessment is traditional vapour intrusion modelling. Recent scientific studies have also provided evidence to support the inclusion of biodegradation into traditional vapour intrusion models for petroleum hydrocarbons, using biodegradation factors or more advanced modelling approaches.

4.1 US EPA Approach

The US EPA's (2004) [6] Users Guide for Evaluating Subsurface Vapour Intrusion into Buildings sets out a quantitative vapour intrusion assessment approach, based on the Johnson and Ettinger model. This approach forms the basis of the US EPA's vapour intrusion spreadsheets and common proprietary risk assessment modelling software, such as BP RISC and the RBCA Toolkit.

It is important to recognise the limitations of the guidance, particularly for assessing vapour intrusion of petroleum hydrocarbons. The age of the guidance means that it was produced when the empirical data available for petroleum hydrocarbons were scarce, and therefore, it is based primarily on the understanding of the behaviour of chlorinated hydrocarbons and, to some extent, radon. The neglect of biodegradation effects in the US EPA's modelling approach will often result in significant overestimation of risks from petroleum compounds.

It is noted that in 2009, the US EPA Office of Inspector General (OIG) carried out a review of the USEPA's vapour intrusion guidance (US EPA, 2009) [7] and concluded that the current guidance was impeding efforts to manage vapour intrusion risk. This review recommended that the US EPA should update and finalise their vapour intrusion guidance, with specific recommendations to include guidance on the use of multiple lines of evidence to evaluate vapour risks and a specific approach for petroleum hydrocarbons.

Indications are that the 2002 guidance will be finalised by November 2012 and a number of improvements and updates implemented.

4.2 The Significance of Biodegradation for Petroleum Hydrocarbons

Petroleum hydrocarbon vapours biodegrade rapidly in the presence of oxygen. This means that a vapour intrusion risk modelled using the US EPA (2004) approach does not necessarily translate into an actual vapour intrusion risk, particularly for petroleum hydrocarbons. Biodegradation typically occurs much more slowly for vapours derived from chlorinated hydrocarbon contaminants and is, therefore, generally much less significant.

Petroleum hydrocarbon biodegradation occurs wherever sufficient oxygen is present, resulting in rapid reductions in hydrocarbon vapour concentrations over very short distances.

The Cooperative Research Centre for Contamination Assessment and Remediation of the Environment (CRC Care, 2009) [2] demonstrated that extensive building foundations can restrict oxygen penetration beneath the ground surface, leading to higher sub-slab vapour concentrations. Buildings with dimensions greater than 15m x 15m are noted in this publication as having the potential to limit subsurface biodegradation of petroleum hydrocarbon vapours. CRC Care (2009) [2] recommends the use of biodegradation adjustment factors of 10 and 100 for sources > 2m deep and > 4m deep respectively, in the absence of a large surface slab and when soil profile oxygen concentrations > 5% can be demonstrated.

The american Petroleum Institute (API) has also recently developed a vapour intrusion model which can accounts for the biodegradation of TPH vapours (API, 2010). This model is available publically and can be applied in site-specific quantitative risk assessments.

5. FIELD VAPOUR ASSESSMENT

A vapour investigation is an additional tier of assessment that can be undertaken to accurately assess the risks of vapour intrusion occurring at a site. The main benefit of site specific vapour investigations is that they have a high level of regulatory acceptance internationally, provide results that represent real time conditions in the soil profile and are easy to interpret by regulators and the community.

5.1 Soil Vapour vs Ambient Air

Soil vapour measurements are generally preferred over ambient air data, as soil vapour is less likely to be influenced by temporal variability and input from other sources. Ambient air frequently contains background concentrations of many common volatile contaminants, derived from soft furnishings, carpets, electrical equipment, consumer products, smoke and road traffic. Therefore, detecting chemicals in ambient air does not provide certainty that vapour intrusion is occurring.

It is also often difficult to obtain access to carry out indoor air sampling where the buildings of concern are off-site.

5.2 Soil Vapour Sampling Challenges and Guidance

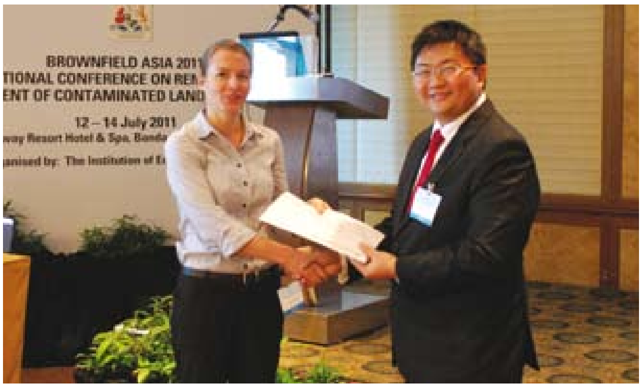
The common difficulties encountered during soil vapour as-sessments include leaky wells, cross contamination between sampling, well saturation, poor choice of location and high levels of temporal variability.

As a result of these inherent uncertainties, much reliance for decision-making is placed on the interpretation of the soil vapour data and associated field observations (e.g. soil type, moisture content, oxygen and carbon dioxide concentrations, atmospheric pressure).

The field methods and the required interpretations are complex, therefore, clear guidance is necessary in order to achieve a reasonable level of consistency across jurisdictions.

The Interstate Technology and Regulatory Council's (ITRC) Vapor Intrusion Pathway: A Practical Guideline (ITRC, 2007) [8] provides a straightforward, complete and up-to-date process for evaluating vapour intrusion risks and is a primary source of guidance for international users.

Other valuable international guidance can be found in the form of Australia's CRC Care (2009) [9] Technical Publication No. 13, which provides a practical guidance on field protocols.



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Key sampling principals highlighted in these documents include:

- Sample Location: The number of locations sampled depends on the CSM. At a minimum, it is recommended that samples be collected at the site of maximum source concentrations and near or under buildings.
- Sample Frequency: There can be a high level of temporal variability in soil vapour samples, particu-larly those installed at < 1m bgl. Multiple sampling rounds are generally recommended, to represent dif-ferent seasonal conditions, particularly if elevated concentrations are detected in the first sampling event.

- Probe seal: Soil gas probes should be installed to ensure that ambient air is not drawn into the sampling bore. A number of tracer methods are available to test the integrity of a probe, including the use of isoproponol and helium gas.
- Sample flow rates: Sample flow rates in the order of 100mL/min are recommended to reduce the potential for suction. This is particularly important for low permeability soils.
- Purging: The sample probe, tubing and equipment must be purged prior to sampling to ensure that the data is representative of soil conditions. It is commonly recommended that one well volume be purged prior to sampling.
- Cross contamination: Vapour can absorb into sample tubing and equipment, resulting in false positives. The sample train should be connected such that the sample is collected prior to the flow meter and sampling pump, and Teflon tubing should be used to minimise the potential for cross contamination. Proper handling and storage of samples is also critical to reduce cross-contamination and false positives.

6. CONCLUSION

Vapour intrusion is an area where following the US EPA's lead has caused confusion; the current US EPA guidance is out of date, and more importantly, is not applicable to petroleum hydrocarbons. Alternate approaches to vapour intrusion risk assessments are provided by a variety of different agencies.

California recently published a draft guide for the assessment of leaking underground storage tanks which specifies the screening criteria based on source concentration and the distance between source and receptor. This system is much less conservative than model-based screening criteria, and is likely to result in a better use of resources.

The ITRC and the Australian CRC CARE body have also produced guidance on site specific vapour intrusion risk assessments that is well ahead of the US EPA guidance and provides practical approaches to vapour sampling and addressing the effect of biodegradation at petroleum hydrocarbon release sites.

US EPA has committed to review and finalise its vapour intrusion guidance by November 2012. In the interim, it is likely that international users will look to a variety of sources to guide their vapour intrusion risk assessment approaches. ■

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[4] API (2009) Simulating the Effect of Aerobic Biodegradation on Soil Vapor Intrusion into Buildings, Evaluation of Low Strength Sources Associated with Dissolved Gasoline Plumes, API Publication 4775.

[5] US EPA (2004) Users Guide for Evaluating Subsurface Vapour Intrusion into Buildings. Office of Environment and Remedial response.

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[9] CRC Care (2009) Field Assessment of Vapours, Technical report No. 13.

CONDOLENCE

With deep regret, we wish to inform that Dato Ir. Lau Foo Sun (F 0004) has passed away on 25 April 2011. On behalf of the IEM Council and management, we wish to convey our condolences to his family.

IEM Editorial Board

COUNCIL ELECTION FOR SESSION 2012/2013

2nd Announcement

Nomination papers for the Election of Council Members for Session 2012/2013 will be posted on the IEM website (http//www.myiem.org.my) and made available at the IEM Secretariat office by 23 November 2011. The closing date for nominations is on 21 December 2011.

Thank you.

Dato' Pang Leong Hoon
Election Officer, IEM