

Guidance for the human health risk assessment of volatile chlorinated hydrocarbon vapour intrusion

Environmental Health Standing Committee
(enHealth)

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Executive Summary

Vapour intrusion is the migration of volatile chemical vapours and gases from sub-surface sources through soils and into the indoor air spaces of overlying or nearby buildings. These vapours and gases may pose acute hazards in terms of fire and explosion while also presenting potential health risks to occupants of affected buildings, both on the basis of short-term and long-term exposure.

The Assessment of Site Contamination National Environment Protection Measure 1999 Variation 2013 (NEPM 1999) has limited information with respect to the public health risk assessment and management of vapour intrusion. There are significant gaps in current Australian technical guidance on public health assessment and management of exposures arising from volatile chlorinated hydrocarbon vapour intrusion across residential areas.

From time-to-time environment regulators have engaged with health departments particularly when pronounced vapour intrusion events have been investigated to occur in residential areas. This guidance provides options for the assessment and management of vapour intrusion as it applies to communities impacted by contaminated groundwater, soil and soil vapour. The guidance should be read in conjunction with the “Environmental Health Risk Assessment: Guidelines for assessing risk from environmental hazards” (enHealth, 2012) while noting jurisdiction specific requirements or practices for the assessment of vulnerable populations.

The development of jurisdiction-specific indoor air action frameworks based on the templates present in Attachments 3 and 4 should be made in consultation with an expert toxicologist and jurisdictional decision-makers that have an in-depth knowledge of the risk tolerance of the jurisdiction to involuntary exposures from environmental contaminants.

Audience

This guidance targets three main audiences and it aims to achieve the following objectives for each of these audiences:

- Risk assessment practitioners – Providing clear guidance for risk assessors, environmental health practitioners and toxicologists to assess and manage vapour intrusion as it applies to communities impacted by vapour intrusion.
- The community – Allowing communities impacted by vapour intrusion to understand the decision-making processes and the timeframe to deliver outcomes (for example, aiming to achieve a uniform health objective for all) as it applies to mitigation and or remediation.
- Decision-makers and staff of the jurisdiction – Establishing a clear framework through which the jurisdiction can assess, manage and articulate risk posed by the vapour intrusion pathway to impacted communities.

Acknowledgements

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Suggested Citation

enHealth (2023). *Guidance for the human health risk assessment of volatile chlorinated hydrocarbon vapour intrusion*. Canberra. Australian Government Department of Health and Aged Care.

Introduction

Vapour intrusion is the migration of volatile chemical vapours and gases from sub-surface sources through soils and into the indoor air spaces of overlying or nearby buildings. These vapours and gases may pose acute hazards in terms of fire and explosion while also presenting potential health risks to occupants of affected buildings, both on the basis of short-term and long-term exposure.

The Assessment of Site Contamination National Environment Protection Measure 1999 Variation 2013 (NEPM 1999) has limited information with respect to the public health risk assessment and management of vapour intrusion. More broadly, there are significant gaps in current Australian technical guidance on public health assessment and management of exposures arising from hazardous ground gases (associated with landfills and waste dumps) and volatile chlorinated hydrocarbons (associated with groundwater and soil contamination) across residential areas.

This document “Guidance for the human health risk assessment of volatile chlorinated hydrocarbon vapour intrusion” provides a high-level summary of key considerations in conducting a human health risk assessment of vapour intrusion and co-aligns with the learnings outlined on how Agency for Toxic Substances and Disease Registry (ATSDR) health assessors evaluate public health implications of vapour intrusion described in “*Evaluating Vapor Intrusion Pathways – Guidance for ATSDR’s Division of Community Health Investigations October 31, 2016.*” (ATSDR 2016).

It is important to remember that the assessment of vapour intrusion is a rapidly changing field and users of this Guidance should stay up-to-date with any guidance developments in this area.

Why it is so difficult to assess the vapour intrusion pathway?

In Australia, environment regulators, who have legislated carriage for the management of environmental contamination, have preferred to investigate health-based issues associated with vapour intrusion using environmental characterisation tools, such as the use of predictive models to extrapolate indoor air concentrations from groundwater and soil vapour measurements external to the dwelling. From time-to-time environment regulators have engaged with health departments particularly when pronounced vapour intrusion events have been investigated to occur in residential areas.

Vapour intrusion is a complex problem to assess, with multiple variables for consideration. Human health vapour intrusion investigations and assessments are often constrained by limited access to relevant measurement data. Determining the health hazards from indoor air contamination in homes and commercial buildings is often difficult because of the dynamic nature of the contamination, the environmental influences upon it and how affected buildings are used. This variability requires an estimate of how much of the contaminant people are inhaling over time, rather than a definitive determination of exposure (ATSDR 2016). Communication of risk posed by exposure to a hazard through the vapour intrusion pathway becomes increasing challenging and uncertain with extended duration of exposure (e.g. over years).

Indoor contaminant concentrations from vapour intrusions depend on site-specific and building specific factors such as soil type and moisture beneath and near the building construction, number and spacing of cracks and holes in the foundations, time of year, wind direction, barometric pressure, and the effect of heating and air conditioning systems on increasing or decreasing air flow from the subsurface (ATSDR 2016) (Figure 1 – Simplified schematic of vapour intrusion). The presence of improperly sealed service entry points such as gas, electricity and sewage can act as preferential pathways and potentiate significantly elevated indoor air contaminant concentrations (Delaere et al 2012). Changes to existing heating, ventilation and air conditioning systems and building characteristics can significantly alter indoor contaminant concentrations. For buildings near surface

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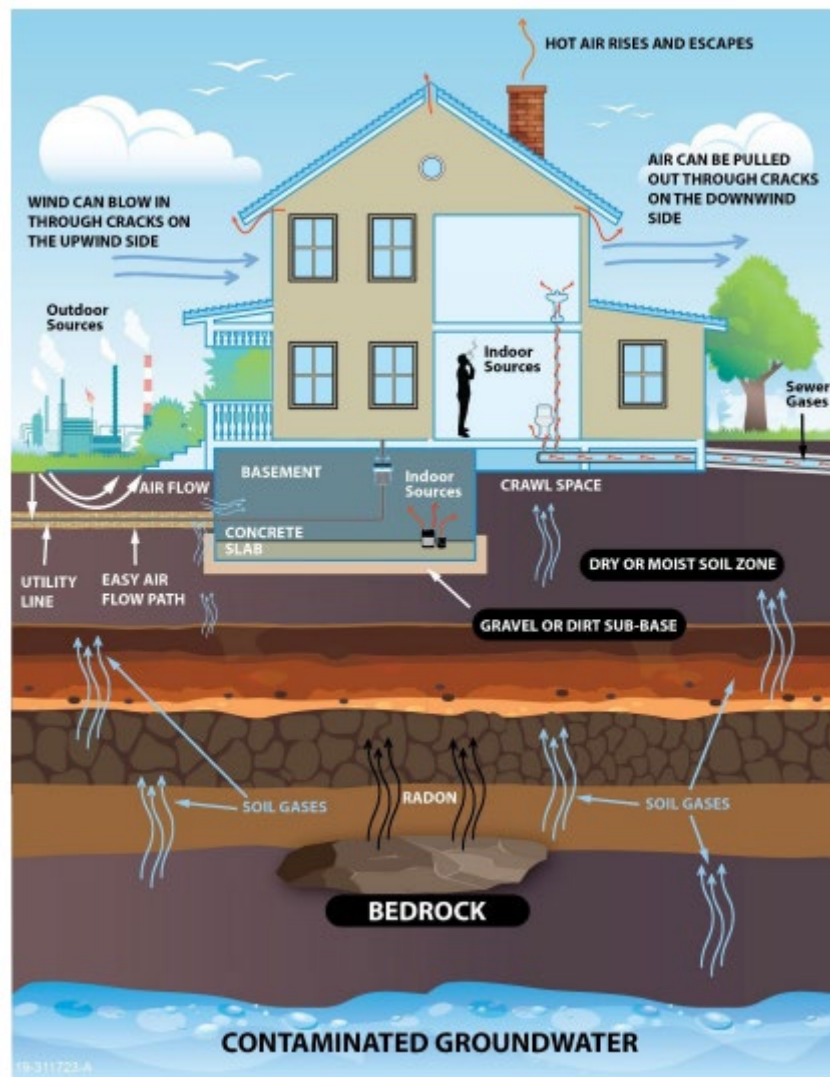
water, rising water levels can affect vapour migration to indoor air. Only indoor air sampling incorporates all the factors influencing vapour intrusion in a given building at any specific time.

However, it should be recognised that indoor air sample collection within buildings can be highly intrusive and property owners can be reluctant to allow it to occur. Health assessors should be sensitive to the disruption and inconvenience vapour intrusion investigations can pose on building occupants and should strive to minimize the stress on occupants and others caused by evaluating and addressing vapour intrusion concerns (ATSDR 2016).

Indoor air sampling is preferable to identify vapour intrusion and possible migration pathways. In the event indoor air sampling cannot be conducted, alternative measures (such as modelling based on environmental sampling) may be required, with all the accompanying assumptions and limitations

In summary, definitive information is rarely available to make a determination of health risk and any necessary action to address that risk means that judgement must be exercised. This judgement is not only based on what vapour intrusion information is available, but broader considerations such as the circumstances of the individuals impacted.

Figure 1. Simplified schematic of vapour intrusion (ATSDR, 2016).



Establishing a Basis for Public Health Action

Due to the difficulty in determining public health risk definitively, it is similarly difficult to determine appropriate actions to take based on this risk and how to communicate risk effectively in these circumstances. This difficulty is further compounded by the lack of relevant exposure standards for chemicals where they are present in residential premises. It is inappropriate to apply occupational exposure standards for chemicals in residential settings particularly as the exposure duration and the populations exposed (e.g. children) are entirely different.

The establishment of risk-based screening and action levels has proven an effective means of addressing these issues. Screening and action levels use ranges of toxicologically based reference values to determine what level of contaminant either modelled or sampled will determine a particular action response.

The starting point for developing risk-based screening and action levels is to link qualitative risk descriptors to quantitative risk measurements and are described in Attachments 1 and 2. For carcinogenic chemicals this may be based on excess lifetime cancer risk from a particular exposure (e.g. low risk for exposure that might result in a one in one hundred thousand increase in cancer risk to very high risk for exposures that might result in a one in ten increase in cancer risk). For non-carcinogenic chemicals, this may be based on a threshold dose below which no adverse effect occurs (e.g. minimal risk for exposures less than or equal to the reference dose to very high risk for exposures one hundred times the reference dose).

The use of an excess life-time increased cancer risk of 1×10^{-5} or higher, and for non-carcinogens, a hazard index of 1.0 can be used as a threshold for determining if a **vapour action level** for indoor air has been reached or exceeded. The use of an excess life-time cancer risk of 1×10^{-4} or higher and for non-carcinogens, a hazard index of 10 can be used as a threshold for **implementing mitigation measures**. While not stated in international guidance documents cancer risks greater than one in ten thousand (10^{-4}), typically **trigger actions** to lower exposures. For non-cancer endpoints where a hazard index is between one and ten, **risk management decisions** should be made on a case-by-case basis as to whether or not, to pursue risk reduction measures. Considerations may include relevance of toxicological endpoint, exposure dynamics and characteristics of particular subpopulations.

Once the qualitative description of risk has been established and agreed, this can be applied to the chemical of concern to establish an “action framework” that describes what ranges of contamination of that chemical in indoor air, measured or modelled, will trigger what action based on the risk it poses. For example, for trichloroethene, a reference value of 2 ug/m^3 was used based on the toxicological literature and a review of regulatory standards in other jurisdictions. Indoor air levels below that level were deemed safe and the action was to validate that the indoor air levels remain below that level. For indoor air levels one hundred times that level (200 ug/m^3) it was deemed that there is a health risk and immediate intervention (e.g. relocation and mitigation) is required. Examples of action frameworks are provided as Attachment 3 and 4.

Experience has shown that the development process for these action frameworks provides a valuable opportunity to discuss a range of issues including the strength of evidence on which the actions are based and the risk tolerance of authorities. Moreover, the use of qualitative risk descriptors linked to quantitative risk measurements in combination with action frameworks provide an excellent basis on which to discuss risk with affected communities and how actions will be taken once the results of the investigation are received.

Evaluation of Vapour Intrusion – Public Health Considerations for Environmental Investigations

A review of national and international vapour intrusion guidance predominantly identifies technical guidance for assessing and mitigating vapour intrusion through a multiple lines of evidence approach to characterise the vapour intrusion.

The ATSDR evaluation of the vapour intrusion pathway is an international best practice health-based approach to address the issue of vapour intrusion in the community. While there are inherent policy, practice and legal limitations to directly translating public health advice developed in the United States into the Australia context, it provides an excellent resource to supplement this guidance.

Some of the key points from the ATSDR guidance that are particularly useful to consider are:

Evaluation of the vapour intrusion pathway

The ATSDR recommends a multiple lines of evidence driven approach for pathway analysis and exposure assessment. Appropriate lines of evidence for evaluating the vapour intrusion pathway include but are not limited to, the following:

- Subsurface sampling
- Vadose zone conditions (above the water table) and preferential pathways
- Building conditions
- Exposure concentrations
- Indoor and outdoor sources of vapour-forming chemicals
- Remediation and mitigation activities
- Maps and figures showing spatial and temporal characteristics

Modelling vapour intrusion

Health conclusions from vapour intrusion exposures cannot be made with high certainty using modelling alone. The Johnson and Ettinger algorithm has been routinely used as the basis for predicting theoretical indoor air concentrations of contaminants from subsurface vapour concentrations (amongst many other model inputs, some of which may not actually be measured during an investigation).

The US EPA does not currently endorse its former workbooks for modelling vapour intrusion using the Johnson and Ettinger algorithm. The Johnson and Ettinger model has been found to under-predict vapour intrusion at some well characterised sites. Therefore, ATSDR only recommends Johnson and Ettinger modelling as a tool to complement robust indoor air and subsurface sampling results (ATSDR 2016).

Concurrence between sampling and modelling results strengthens confidence in an evaluation. A useful approach to modelling is to perform bounding (i.e., estimating a range of predictions based on a range of feasible inputs for sensitive model parameters such as air exchange, soil moisture). The value of the model results should be discussed and the uncertainties clarified when using the data. Modelling that lacks robust indoor air measurements might be used to show that sampling is urgently needed.

Attenuation Factors for Predicting Vapour Intrusion

Vapour attenuation refers to the reduction in concentration of volatile substances that occurs during vapour migration in the subsurface (as a result of diffusion, advection, sorption, transformation reactions and other processes in the soil), coupled with the dilution that can occur when vapour enters a building and mixes with indoor air. The aggregate effect of these physical and chemical attenuation

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mechanisms can be quantified through the use of a vapour intrusion attenuation factor, which is defined as the ratio of the indoor air concentration arising from vapour intrusion to the subsurface vapour concentration at a point or depth of interest in the vapour migration pathway (EPA 2012).

As defined here, the vapour attenuation factor (AF or α) is an inverse measurement of the overall dilution that occurs as vapour migrates from a subsurface vapour source into a building i.e. lower attenuation factors indicate lower vapour intrusion impacts and greater dilution, higher values indicate greater vapour intrusion impacts and less dilution (EPA 2012).

The US EPA has compiled a database of empirical attenuation factors for chlorinated volatile organic compounds and residential buildings with indoor air concentrations paired with sub-slab gas, groundwater, external soil gas, or crawlspace concentrations. Based on these analyses, the US EPA has recommended health protective attenuation factors (typically 95th%) to aid rapid screening-in or screening-out of potential vapour intrusion sites.

Recommended vapour attenuation factors for risk-based screening of the vapour intrusion pathway (EPA 2015).

Sampling medium	Sampling medium-specific Attenuation Factors for Residential Buildings
Groundwater , generic value, does not apply for shallow water tables (less than 5 feet below foundation) or presence of preferential vapour migration routes in the vadose zone soils.	1E-03 (0.001)
Subslab soil gas , generic value	3E-02 (0.03)
“Near source” exterior soil gas , generic value does not apply for sources in the vadose zone (less than 5 feet below foundation) or presence of routes for preferential vapour migration in vadose zone soils	3E-02 (0.03)
Crawl space air , generic value	1E-00 (1.0)

For further information on the use of attenuation factors in risk-based screening see Attachment 5 “*Calculating Indicative Groundwater and Soil Gas Levels using generic attenuation factors for a given toxicity reference value (example)*”

Public health evaluation

Some key areas that are essential in providing a robust public health evaluation that may not be routinely included in an environmental investigation are:

- Indoor contaminant concentrations from vapour intrusion depend on site-specific and building specific factors including building age and quality, building type (e.g. slab on ground or crawl space, cellars) and type of ventilation.
- For temporal variability for chronic health concerns, multiple samples should be collected over multiple seasons. This will not only account for environmental variation but also variations in how buildings are used across seasons (e.g. reduction in external ventilation in winter months due to closing of windows and doors).
- For contaminants with potential health effects from short-term exposures more rapid decisions making is often appropriate.

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- Demographics of building occupants (e.g. women of child bearing age, children).

Inhalational health-based guidance levels and stratification into action levels can inform site prioritisation and regulatory decision making.

Attachments

1. Qualitative Descriptors of Health Risk Used to Establish Action and Screening Levels – Carcinogen (example)
2. Qualitative Descriptors of Health Risk Used to Establish Action and Screening Levels – Non-carcinogen (example)
3. Indoor Air Levels Action Framework – Carcinogen (example)
4. Indoor Air Levels Action Framework – Non-carcinogen (example)
5. Calculating Indicative Groundwater and Soil Gas Levels using generic attenuation factors for a given toxicity reference value (example)

1. Qualitative Descriptors of Health Risk Used to Establish Action and Screening Levels – Carcinogen (example)

Increased cancer risks were estimated by using site-specific information on exposure levels for the contaminant of concern and interpreting them using cancer potency estimates derived for that contaminant. The following qualitative ranking of cancer risk estimates are then used to rank the risk from very low to very high. For example, if the qualitative descriptor was "low," then the excess lifetime cancer risk from that exposure is in the range of greater than one per hundred thousand to less than one per ten thousand. Other qualitative descriptors are listed below:

Qualitative Descriptors for Excess Lifetime Cancer Risk

Risk ratio	Qualitative Descriptor of risk	Action
Equal to or less than 1×10^{-6}	Negligible	No action
Equal to or less than 1×10^{-5}	Very Low	No action
Greater than 1×10^{-5} and less than 1×10^{-4}	Low	Investigate Mitigate on a case-by-case basis
Greater than 1×10^{-4} and less than 1×10^{-3}	Moderate	Immediate intervention Mitigate
Greater than 1×10^{-3} and less than 1×10^{-1}	High	Accelerated intervention Mitigate and consider relocation
Equal to or greater than 1×10^{-1}	Very High	Accelerated intervention Mitigate and consider evacuation

An estimated increased excess lifetime cancer risk is not a specific estimate of expected cancers. Rather, it is a plausible upper-bound estimate of the probability that a person may develop cancer sometime in his or her lifetime following exposure to that contaminant.

There is insufficient knowledge of cancer mechanisms to decide if there exists a level of exposure to a cancer-causing agent below which there is no risk of getting cancer, namely, a threshold level. Therefore, every exposure, no matter how low, to a cancer-causing compound is assumed to be associated with some increased risk. As the dose of a carcinogen decreases, the chance of developing cancer decreases, but each exposure is accompanied by some increased risk.

The Assessment of Site Contamination NEPM Variation 2013 (the NEPM) states that a one in one hundred thousand (10^{-5}) risk level is used as a starting point for analysis of remedial alternatives, all other things being equal, associated with site contamination in Australia.

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While not stated in international guidance documents cancer risks greater than one in ten thousand (10^{-4}), typically trigger actions to lower exposures.

When cancer risk estimates are between one in one hundred thousand (10^{-5}) and one in ten thousand (10^{-4}), a risk management decision should be made on a case-by case basis whether or not to pursue risk reduction measures.

The ultimate risk management decision should consider judgments on not only the strength of the scientific evidence regarding carcinogenicity, but also the actual potential for chronic or lifetime exposure, other sources and levels of everyday exposure, our ability to detect the chemical, the availability and costs of risk reduction options, the societal benefits of the regulated activity, compliance with existing regulations, and, in many cases, the risks, benefits and costs of alternatives.

2. Qualitative Descriptors of Health Risk Used to Establish Action and Screening Levels – Non-carcinogen (example)

For non-carcinogenic health risks, the contaminant intake was estimated using exposure assumptions for the site conditions. This dose was then compared to a risk reference dose (estimated daily intake of a chemical that is likely to be without an appreciable risk of health effects). The resulting ratio was then compared to the following qualitative scale of health risk:

Qualitative Descriptors for Non-carcinogenic Health Risks

Ratio of (Estimated Contaminant Intake: Risk Reference Dose)	Qualitative Descriptor of risk	Action
Equal to or less than risk reference dose	Minimal	No action
One to five times the risk reference dose	Low	Investigate Mitigate on a case-by-case basis
Five to ten times the risk reference dose	Moderate	Immediate intervention Consider relocation
Ten to one hundred times the risk reference dose	High	Accelerated intervention Mitigate consider relocation
Greater than one hundred times the risk reference dose	Very High	Accelerated intervention Mitigate consider evacuation

Non-carcinogenic effects, unlike carcinogenic effects, are believed to have a threshold, that is, a dose below which adverse effects will not occur. As a result, the current practice is to identify, usually from animal toxicology experiments, although at times from human occupational and environmental studies, a no-observed-adverse-effect-level (NOAEL). This is the experimental exposure level in animals at which no adverse toxic effect is observed. The NOAEL is then divided by an uncertainty

factor to yield the risk reference dose. The uncertainty factor is a number that reflects the degree of uncertainty that exists when experimental animal data are extrapolated to the general human population. The magnitude of the uncertainty factor takes into consideration various factors such as sensitive sub-populations (for example, children or the elderly), extrapolation from animals to humans and the incompleteness of available data. Thus, the risk reference dose is not expected to cause health effects because it is selected to be much lower than dosages that do not cause adverse health effects in laboratory animals.

The measure used to describe the potential for non-cancer health effects to occur in an individual is expressed as a ratio of estimated contaminant intake to the risk reference dose. A ratio equal to or less than one is generally not considered a significant public health concern. If exposure to the contaminant exceeds the risk reference dose, there may be concern for potential non-cancer health effects because the margin of protection is less than that afforded by the reference dose. As a rule, the greater the ratio of the estimated contaminant intake to the risk reference dose, the greater the level of concern. This level of concern depends upon an evaluation of a number of factors such as the actual potential for exposure, background exposure and the strength of the toxicological data.

3. Indoor Air Levels Action Framework – Carcinogen (example)

Indoor Air Level µg/m³	Action Level Classification	Consequences for Community	Response Options & Process (Dependent upon individual circumstances & situations)		
Below limit of reporting (LOR) (non detect)	No Action	Safe	No further action		
>LOR - <2	Validate	Safe	Validate results. Consider monitoring and evaluation (if appropriate) based on site specific conditions Time range: months - years		
2 - <20	Investigate	No immediate health concerns Occupants may remain in property Further assessment to validate results and implementation of mitigation measures if necessary Ongoing communication	Case management at individual property level including considerations of: <ul style="list-style-type: none">Assessment of individual circumstancesBuilding construction type and conditionEducation on passive precautionary mitigation strategies (ventilation, sealing cracks and penetrations etc)Agreement to further assessment if required noting the implications of on site testing on private properties Time range: months - years		
			1. Further assessment required including validating results to improve site specific understanding, which could include on site assessment work at individual properties (external soil vapour, sub slab soil vapour) and investigate potential sources	2. Consider and implement further active and/or passive mitigation strategies to reduce indoor air concentrations to acceptable levels (if required) and monitor effectiveness and remediate sources as necessary.	
20 - <200	Immediate Intervention	There may be a health risk Immediate engagement: <ul style="list-style-type: none">Work with individual property owners and occupiers to understand circumstancesCommunicate regarding results and further assessment options to seek agreement on next steps Commence immediate implementation of site specific mitigation and/or further assessment works and/or Agree upon relocation dependent upon circumstances of occupants	Immediate case management at individual level including considerations of: <ul style="list-style-type: none">Assessment of individual circumstancesBuilding construction type and conditionEducation on passive precautionary mitigation strategies (ventilation, sealing cracks and penetrations etc)Agreement to further assessment if required noting the implications of on site testing on private properties Time range: months		
			1. Accelerated on-site assessment programs at individual property level. Could include soil vapour, soil vapour (sub slab & other) and/or indoor air sampling and Investigate potential sources	2. Consider and implement further active and/or passive mitigation strategies to improve indoor air quality, including ongoing monitoring to validate effectiveness and/or consider relocation subject to individual circumstances and Remediate sources as necessary.	
200 & >	Accelerated Intervention	There is a health risk Immediate engagement: <ul style="list-style-type: none">Work with individual property owners and occupiers to understand circumstancesCommunicate regarding results and further assessment options to seek agreement on next steps Immediate action (relocation or mitigation)	Immediate case management at individual level including considerations of: <ul style="list-style-type: none">Assessment of individual circumstancesBuilding construction type and conditionEducation on passive precautionary mitigation strategies (ventilation, sealing cracks and penetrations etc)Agreement to further assessment if required noting the implications of on site testing on private properties Time range: As soon as possible		
			1. Immediate action required – consideration of exposure at indoor air concentration. Recommend relocation subject to individual circumstances linked to indoor air concentrations linked to indoor air concentrations or implement urgent mitigation strategies (passive and/or active)	2. Accelerated assessment program at property level which could include, external soil vapour, sub slab soil vapour, indoor air sampling	3. Remediate sources as necessary and/or further active and/or passive mitigation strategies

4. Indoor Air Levels Action Framework – Non-carcinogen (example)

Indoor Air Level µg/m³	Action Level Classification	Consequences for Community	Response Options & Process (Dependent upon individual circumstances & situations)		
Below limit of reporting (LOR) (non detect)	No Action	Safe	No further action		
>LOR - <40	Validation	Safe	Validate results. Consider monitoring and evaluation (if appropriate) based on site specific conditions Time range: months - years		
40 - <200	Investigate	No immediate health concerns Occupants may remain in property Further assessment to validate results and implementation of mitigation measures if necessary Ongoing communication	Case management at individual property level including considerations of: <ul style="list-style-type: none">Assessment of individual circumstancesBuilding construction type and conditionEducation on passive precautionary mitigation strategies (ventilation, sealing cracks and penetrations etc)Agreement to further assessment if required noting the implications of on site testing on private properties Time range: months - years		
			3. Further assessment required including validating results to improve site specific understanding, which could include on site assessment work at individual properties (external soil vapour, sub slab soil vapour) and investigate potential sources	4. Consider and implement further active and/or passive mitigation strategies to reduce indoor air concentrations to acceptable levels (if required) and monitor effectiveness and remediate sources as necessary.	
200 - <400	Immediate Intervention	There may be a health risk Immediate engagement: <ul style="list-style-type: none">Work with individual property owners and occupiers to understand circumstancesCommunicate regarding results and further assessment options to seek agreement on next steps Commence immediate implementation of site specific mitigation and/or further assessment works and/or Agree upon relocation dependent upon circumstances of occupants	Immediate case management at individual level including considerations of: <ul style="list-style-type: none">Assessment of individual circumstancesBuilding construction type and conditionEducation on passive precautionary mitigation strategies (ventilation, sealing cracks and penetrations etc)Agreement to further assessment if required noting the implications of on site testing on private properties Time range: months		
			3. Accelerated on-site assessment programs at individual property level. Could include soil vapour, soil vapour (sub slab & other) and/or indoor air sampling and Investigate potential sources	4. Consider and implement further active and/or passive mitigation strategies to improve indoor air quality, including ongoing monitoring to validate effectiveness and/or consider relocation subject to individual circumstances and Remediate sources as necessary.	
400 & >	Accelerated Intervention	There is a health risk Immediate engagement: <ul style="list-style-type: none">Work with individual property owners and occupiers to understand circumstancesCommunicate regarding results and further assessment options to seek agreement on next steps Immediate action (relocation or mitigation)	Immediate case management at individual level including considerations of: <ul style="list-style-type: none">Assessment of individual circumstancesBuilding construction type and conditionEducation on passive precautionary mitigation strategies (ventilation, sealing cracks and penetrations etc)Agreement to further assessment if required noting the implications of on site testing on private properties Time range: As soon as possible		
			4. Immediate action required – consideration of exposure at indoor air concentration. Recommend relocation subject to individual circumstances linked to indoor air concentrations linked to indoor air concentrations or implement urgent mitigation strategies (passive and/or active)	5. Accelerated assessment program at property level which could include, external soil vapour, sub slab soil vapour, indoor air sampling	6. Remediate sources as necessary and/or further active and/or passive mitigation strategies

5. Calculating Indicative Groundwater and Soil Gas Levels using generic attenuation factors for a given toxicity reference value (example)

<p>A.</p> <p>Fixed toxicity reference value</p> <p>Health protective attenuation factors</p> <p>TRV – 2 µg/m³ TCE ^e</p> <p>AF's</p> <ul style="list-style-type: none"> ○ 0.1 sub-slab to indoor air ^a ○ 0.01 deep soil vapour to indoor air ^b ○ 0.001 groundwater to indoor air ^c <p>Groundwater and Soil Gas Levels</p> <ul style="list-style-type: none"> ○ 20 µg/m³ sub-slab ○ 200 µg/m³ deep soil vapour ○ 5 µg/L 	<p>B.</p> <p>Fixed toxicity reference value</p> <p><u>Median</u> attenuation factors ^d</p> <p>TRV – 2 µg/m³ TCE ^e</p> <p>AF's</p> <ul style="list-style-type: none"> ○ 0.003 sub-slab to indoor air ○ 0.004 external soil vapour to indoor air ○ groundwater to indoor air 0.0006 (< 1.5m) 0.0001 (1.5 – 3m) 0.00004 (3 – 5m) 0.00005 (> 5m) <p>Groundwater and Soil Gas Levels</p> <ul style="list-style-type: none"> ○ 670 µg/m³ sub-slab ○ 500 µg/m³ deep soil vapour ○ 8 µg/L (<1.5m) 50 µg/L (1.5 – 3m) 125 µg/L (3-5m) 100 µg/L (>5m)
<p>C.</p> <p>Toxicity reference value - range</p> <p>Health protective attenuation factors</p> <p>TRV – 2 to 20 µg/m³ TCE ^f</p> <p>AF's</p> <ul style="list-style-type: none"> ○ 0.1 sub-slab to indoor air ○ 0.01 deep soil vapour to indoor air ○ 0.001 groundwater to indoor air <p>Groundwater and Soil Gas Levels</p> <ul style="list-style-type: none"> ○ 20 to 200 µg/m³ sub-slab ○ 200 to 2000 µg/m³ deep soil vapour ○ 5 to 50 µg/L 	<p>D.</p> <p>Toxicity reference value - range</p> <p><u>Median</u> attenuation factors</p> <p>TRV – 2 to 20 µg/m³ TCE ^f</p> <p>AF's</p> <ul style="list-style-type: none"> ○ 0.003 sub-slab to indoor air ○ 0.004 external soil vapour to indoor air ○ groundwater to indoor air 0.0006 (< 1.5m) 0.0001 (1.5 – 3m) 0.00004 (3 – 5m) 0.00005 (> 5m) <p>Groundwater and Soil Gas Levels</p> <ul style="list-style-type: none"> ○ 670 - 6700 µg/m³ sub-slab ○ 500 - 5000 µg/m³ deep soil vapour ○ 8 – 80 µg/L (< 1.5m) 50–500 µg/L (1.5 – 3m) 125 – 1250 µg/L (3 – 5m) 100 – 1000 µg/L (> 5m)

Calculations

Soil vapour to Indoor air

$$C_{\text{Indoor air}} = AF \times C_{\text{soil vapour}}$$

Indoor air to Soil Vapour

$$C_{\text{soil vapour}} = C_{\text{indoor air}}/AF$$

Indoor air from Groundwater

$$C_{\text{indoor air}} = (C_{\text{gw } \mu\text{g/L}} \times \text{Henry Law constant} \times 1000) \text{ (i.e soil vapour at source)} \times AF$$

Groundwater from indoor air

$$C_{\text{gw } \mu\text{g/L}} = C_{\text{indoor air}}/(AF \times \text{Henry Law constant} \times 1000)$$

Attenuation factor distributions ^d

Relevant attenuation factor distributions from groundwater, exterior soil gas, sub-slab soil gas and crawlspace (abstracted from Table 19 US EPA 2012)

Statistic	Groundwater	Exterior Soil Gas	Sub-slab Soil Gas	Crawlspace
5%	3.6 E-6	7.6 E-5	3.2 E-4	1.0E-1
25%	2.3E-5	6.0 E-4	1.5 E-3	2.2E-1
50%	7.4 E-5	3.8 E-3	2.7 E-3	3.9E-1
75%	2.0 E -4	2.7 E-2	6.8 E-3	6.9E-1
95%	1.2 E-3	2.5 E-1	2.6 E-2	9.0E-1
Range 90% confidence interval	330	3300	80	9

^a 95th% Schedule B7 NEPM ASC Variation 2013 (NEPM 1999)

^b between 75th and 95th% US EPA's Vapor Intrusion Database (US EPA 2012)

^c 95th% US EPA's Vapor Intrusion Database (US EPA 2012)

^d Chapter 6 US EPA's Vapor Intrusion Database (US EPA 2012)

^e Chronic inhalation reference concentration for trichloroethene – US EPA Toxicological Review of Trichloroethylene (US EPA 2011)

^f Indoor air TCE investigation range adopted by SA EPA for the Clovelly Park assessment (SA EPA 2014)

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