INVESTIGATING VAPOR INTRUSION AT A SUPERFUND SITE – LESSONS LEARNED

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ABSTRACT
During the remedial investigation phase at an ongoing vapor intrusion investigation at a large Superfund site (Site), the vapor intrusion pathway was assessed in perhaps the most comprehensive evaluation performed in a mixed commercial/residential setting, with more than 3,000 samples collected from approximately 60 large commercial buildings and 40 varying residential structures. Interim mitigation measures, such as sub-slab ventilation, enhanced ventilation, air purification systems, vapor barriers, passive ventilation, and crack and conduit sealing were implemented. This paper demonstrates the effect of mitigation measures on indoor air concentrations and emphasizes one of the lessons learned, that in some cases mitigation measures may need to be applied iteratively.

The Feasibility Study (FS) focused on the potential vapor intrusion pathway following Environmental Protection Agency (EPA) guidance and screened and developed alternatives based on nine evaluation criteria, including effectiveness, implementability, and costs. There were many lessons to be learned from this experience: 1) While a traditional FS that target soil and groundwater can be developed site-wide, when it comes to vapor intrusion, one alternative for one building is not necessarily applicable to an adjacent building. Therefore, on a large site, an FS must recommend more than one alternative depending on the building type and existing features. 2) The alternatives should be flexible enough to address various future building scenarios. 3) Disseminating information to stakeholders is important, as each stakeholder (e.g., EPA, responsible parties [RPs], building owners, tenants, residents, and local agencies) may have a different objective, and the ultimate goal is for the stakeholders to come to agreement. 4) The Site presents an example on how institutional controls (ICs) for the vapor intrusion pathway can be selected for a complex scenario where RPs do not operate, lease, or own properties.

INTRODUCTION

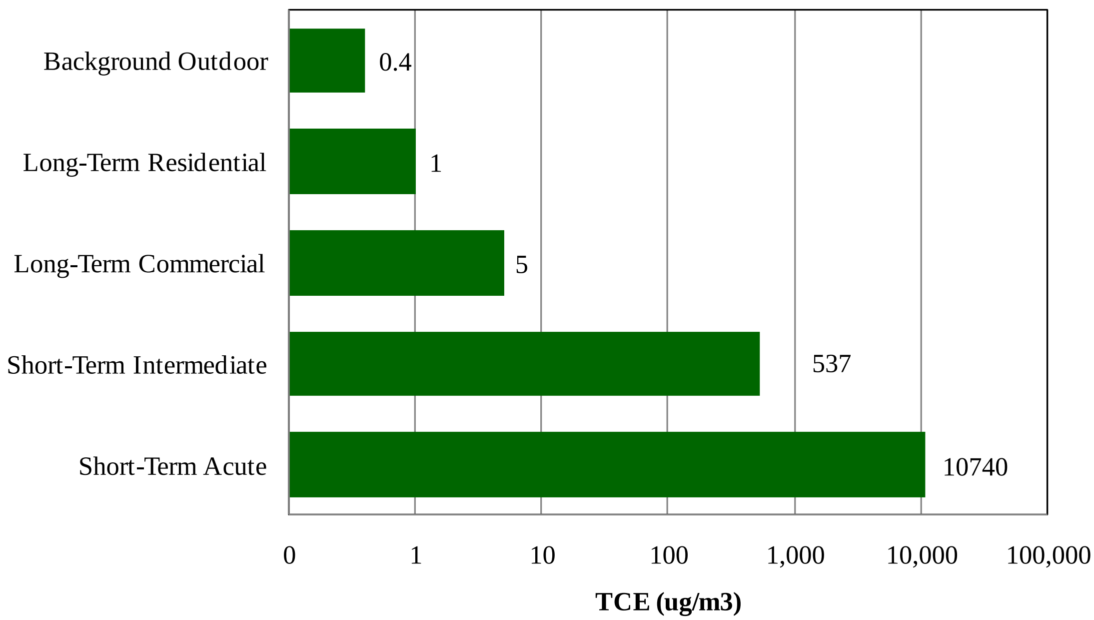
There have been numerous studies of the vapor intrusion pathway in the United States since the early 2000s,, starting with the EPA[1], then with various states[2,3,4], other federal agencies[5], and consortia[6]. EPA has assembled a large dataset on these studies to help in our understanding of this pathway[7].

Most studies and guidance seem to focus on residential scenarios for investigation and mitigation. For commercial scenarios, it is generally assumed that the RPs own or operate the facility, and the guidance does not necessarily address challenges that arise when a third party owns the property and the RP has no legal access to it. This article presents a vapor intrusion study focused on a commercial area of more than 100 buildings, none of them owned or operated by the RPs.

BACKGROUND

Extensive investigations were performed at a large Superfund Site to evaluate the vapor intrusion pathway. Starting in 2002, approximately 3,000 air samples were collected from 60 large commercial buildings and 40 residences, including indoor air, pathway air, outdoor ambient air, background outdoor air, and quality assurance samples. Chemicals of concern at the Site were chlorinated volatile organic compounds (VOCs). Of these VOCs, trichloroethene (TCE) was the main chemical of concern for this pathway. The depth to water at the Site ranges from approximately 20 feet to 10 feet below ground surface. The indoor and pathway air results were evaluated against the following criteria (Figure 1):

Figure 1: TCE Comparison Criteria



1. Background outdoor air and outdoor ambient air concentrations. The background outdoor TCE concentrations calculated for this Site, based on an upper tolerance limit at the 95th percentile with 95% confidence, were 1.8 µg/m^3, using all collected background outdoor data, and 0.57 µg/m^3, eliminating a subset of elevated background outdoor concentrations. However, for decision making purposes, EPA is using 0.4 µg/m^3 as a background level for the Site.

2. Short-term health-based screening levels. For certain chemicals, the Agency for Toxic Substances and Disease Registry developed acute (14 day) and intermediate (15 to 365 day) minimal risk levels (MRLs) applicable to short or moderate exposure periods. For TCE, the acute and intermediate MRLs are 10,740 and 537 µg/m^3, respectively.

3. Long-term indoor air interim action levels are based on EPA's harmonized set of Regional Risk Screening Levels (RSLs) published by three EPA regions. For a

commercial occupation, the exposure period is assumed to be 9.5 hours instead of the 8 hours assumed to calculate the RSLs. The long-term indoor air action levels for TCE are 1 and 5 µg/m^3 for residential and commercial scenarios, respectively, assuming a 25 year exposure period.

FINDINGS

Samples collected at the Site indicate the following conclusions:

- There are no short-term health risks.

- TCE, perchloroethylene, chloroform, 1,1,1-trichloroethane and Freon 113 were frequently detected in background outdoor air samples. TCE concentrations exceeded the interim residential action level of 1 µg/m^3 in 11 of 278 background or outdoor air samples.

- Most sampled buildings at the Site did not exceed long-term indoor air quality goals.

- Vapor intrusion resulted in indoor air concentrations exceeding long-term exposure goals at the Site where 1) commercial building heating, ventilation and air conditioning (HVAC) systems did not provide a sufficient outside air exchange rate [defined as the rate at which the indoor air is exchanged with outdoor air] in all or part of the building, 2) the building had a basement or an earthen cellar, or 3) utilities provided a preferential pathway into the building enclosure.

- Vapor intrusion mitigation measures implemented at the Site were successful in decreasing TCE to below its interim action level in the indoor air breathing zone, with the exception of TCE concentrations in an unoccupied wet basement, where groundwater was seeping onto the basement floor.

- In commercial buildings, TCE concentrations were not detected above the interim action level when the buildings were occupied and standard building occupancy ventilation was operating properly.

- In those buildings where samples were collected twice, first when the HVAC system was off for an extended period of time and then when it was turned back on, samples collected when the HVAC system was off generally had significantly higher TCE concentrations than samples collected when the HVAC system was on. In a majority of cases, there was at least a 10-fold reduction in TCE air concentrations when the HVAC system was on. There is a general decrease of TCE concentrations with increasing air exchange rates.

- There was no significant difference in measured TCE concentrations between building floors with similar ventilation conditions. When TCE exceeded the interim action level, the floor immediately above the subsurface (basement or 1st floor) had higher concentrations than the others.

- Seasonal temperature variation does not appear to significantly affect measured indoor air TCE concentrations.

- Analyses of volatilization from the subsurface to the outdoor air indicate that concentrations in outdoor air from the subsurface are significantly lower than the interim action level, and that the small contribution does not result in outdoor air concentrations above background.

MITIGATION MEASURES

Several interim mitigation measures were implemented at the Site; their results are tabulated instable 1.

Table 1: TCE Concentrations in Indoor Air Pre- and Post-Mitigation

Building	Mitigation Method	Pre-Mitigation			Post-Mitigation			Percent Change	
		No. Samples	Ave. TCE (ug/m3)	Max TCE (ug/m3)	No. Samples	Ave. TCE (ug/m3)	Max TCE (ug/m3)	Ave. TCE	Max TCE
Building A	Basement Exhaust System	7	52	94	6	0.27	0.59	**-99%**	**-99%**
Building B	Enhancing Ventilation	13	2.56	9	5	0.18	0.19	**-93%**	**-98%**
Building C	Enhancing Ventilation	12	0.44	1.4	10	0.18	0.3	**-59%**	**-79%**
Building D	Sealing Conduits	2	160	170	3	10.5	13	**-93%**	**-92%**
	Air Purification	3	10.5	13	10	1.9	8.4	**-82%**	**-35%**
Building E	Air Purification	4	7	18	3	0.31	0.59	**-96%**	**-97%**
Building F	Sealing Conduits	2	255	310	4	5.3	6.5	**-98%**	**-98%**
	Air Purification	4	5.3	6.5	3	0.45	0.79	**-92%**	**-88%**
Building G	Sealing Conduits	2	36	48	4	0.25	0.44	**-99%**	**-99%**

The following presents a summary of the effectiveness of the interim mitigation measures implemented at the Site.

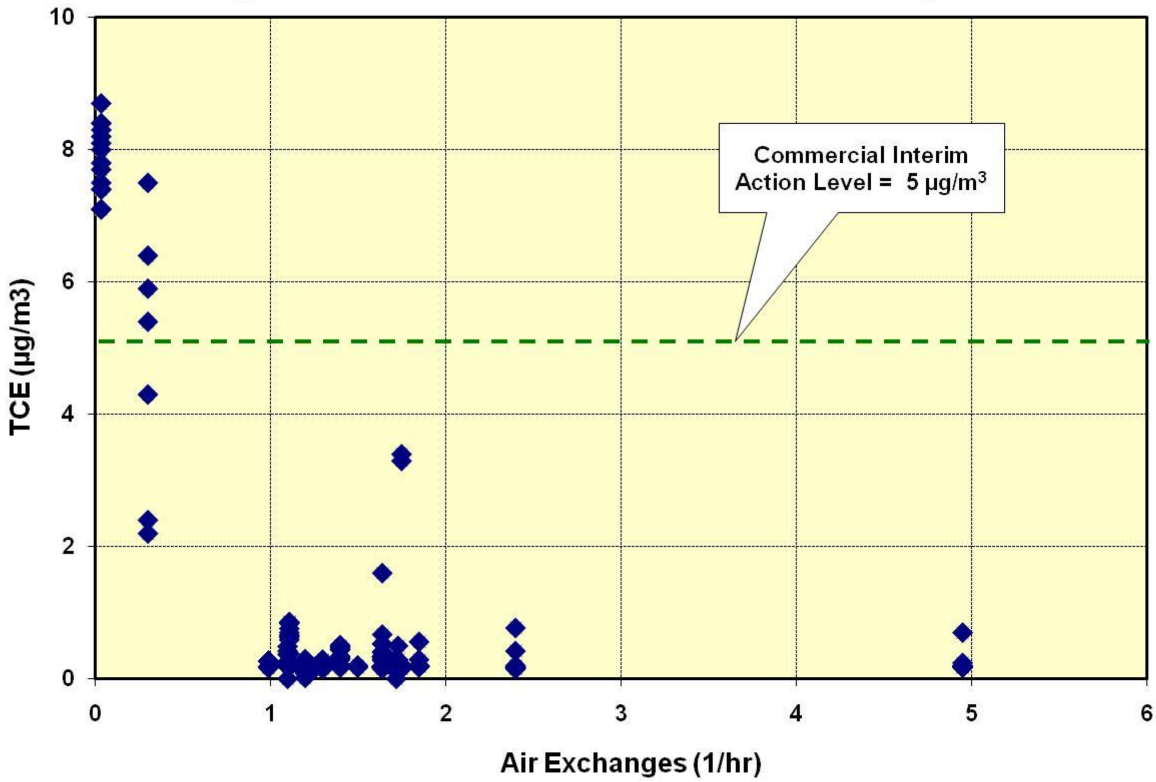
Sealing dry conduits

In general, sealing dry conduits resulted in decreased VOC concentrations transmitted through the conduits. Percentage decreases of up to 99% were observed. In three cases where TCE concentrations were below the interim action level before sealing conduits, TCE concentrations remained virtually the same, or increased slightly after the conduits were sealed, but levels remained below the interim action level.

Refurbishing HVAC systems

In some buildings, existing HVAC systems were refurbished to supply additional outdoor make-up air. HVAC has been shown to be an effective method of reducing indoor air concentrations by providing outdoor make-up air to the indoors. All buildings where adequate outdoor make-up air was provided to the indoors showed TCE concentrations below interim action levels.

Figure 2: TCE Concentrations in Indoor Air vs. Air Exchange Rate



Exhaust/ventilation systems in sub-slab structures

Exhaust/ventilation systems were installed in one basement, one earthen cellar, and one utility room. These systems reduced indoor air concentrations to below long-term exposure goals. An exhaust system installed in the basement of a commercial building showed a 99% reduction in

TCE concentrations on the first and second floors. However, the data indicate that ventilation effectiveness in a basement with an accumulation of VOC-impacted groundwater may be limited; whereas there was a significant decrease in indoor air concentrations in the basement, TCE was measured at levels higher than indoor air long-term interim action levels.

Air purification systems

Air purification systems were installed to reduce indoor air concentrations in enclosed utility rooms. They are simple, low profile, low noise systems that plug in to a standard 110V outlet. These systems were effective in reducing indoor air concentrations to below the TCE interim action level in relatively small enclosed spaces (e.g., utility rooms). Percentage reduction in TCE concentrations varied between 37% (at lower TCE concentrations) and 96% (at higher TCE concentrations).

Figure 3: Air Purification System

Assessment of mitigation measures

Mitigation measures were implemented at the Site soon after results indicated that the vapor intrusion pathway resulted in concentrations above the long-term action levels. The air sampling results and selected mitigation measure were first presented to the property owner. After obtaining access, the mitigation measure was implemented and confirmation samples were collected to confirm the effectiveness of the mitigation. HVAC system modifications, conduits sealing, and air purification systems all resulted in significant decreases in concentrations. In some cases, more than one mitigation measure was implemented. After sealing open conduits in utility rooms in Buildings D and F, a significant decrease was measured in TCE concentration of 92% and 98%, respectively. However, the concentrations in these utility rooms remained higher than the interim action level. Although these rooms are not occupied, air purification systems were installed to further decrease the concentrations by an additional 82% to 92%, to below the interim action level of 5 $\mu g/m^3$. Systematic deployment of simultaneous mitigation measures in these two buildings was necessary to reduce concentrations to below action levels.

FEASIBILITY STUDY

The 1989 Record of Decision (ROD) for the Site selected remedies for soil and groundwater. A recent FS for the Site, finalized in June of 2009, focused on the vapor intrusion pathway, and will be used to amend the existing ROD to address the potential for long-term exposure to VOCs through the vapor intrusion pathway. At the time of this manuscript's preparation, the ROD had not been amended, and therefore the description of the selected mitigation below may change.

A traditional FS that targets soils and groundwater can be developed Site-wide, but for vapor intrusion, this exercise was challenging in that one alternative for one building is not necessarily applicable to an adjacent building. For example, soil vapor extraction can be applicable to remediate soils at a site (design specifics may change based on depth and level of contamination and permeability of soils), while on the other hand, a vapor intrusion mitigation measure, such as sub-slab depressurization or ventilation may not be applicable site-wide since its implementation largely depends on building construction features. Therefore, for a large site with multiple residential and commercial buildings, an FS must 1) recommend more than one vapor intrusion alternative, depending on the building type and existing features; and 2) be flexible in presenting alternatives that can be used for various building scenarios: existing vs. future buildings, residential vs. commercial; basement vs. slab on grade, etc. Otherwise, the effectiveness of the remedy may be jeopardized, and the local economy impacted (e.g., restrictions on types of buildings).

For this Site, depending on the conditions of an existing commercial building, monitoring, sub-slab depressurization, or HVAC was selected. For an existing residential building, however, HVAC was not selected because not all residences are built with an HVAC system, and for those that have it, its operations is typically at the discretion of the owner.

For future buildings, one of these two options would be selected: 1) sub-slab depressurization (passive or active, depending on the underlying concentration) with a vapor barrier, or 2) monitoring.

The mitigation measures listed above are generally expected to be feasible in most types of buildings. When given various types of buildings, however, it is possible that mitigation measures for some buildings will not be feasible for others. For example, the preferred alternative for an existing building without an HVAC system is sub-slab depressurization. However, this alternative is not feasible if the building has a basement floor below the water table. In these cases, one of the other remedial alternatives would be analyzed to determine whether that measure would be protective of human health, if implemented in the building at issue.

INSTITUTIONAL CONTROLS

Institutional controls (ICs) are an essential component of the remedial alternatives. ICs are non-engineered legal and administrative instruments that help to minimize the potential for human exposure to contamination and protect the integrity of a remedy. There are four categories of ICs: government controls; proprietary controls; enforcement tools with institutional control components; and informational devices. Each IC can be used alone or in combination to ensure the protectiveness of an engineered remedy.

The Site presents an example of how ICs can be chosen for a complex scenario for the vapor intrusion pathway because ICs have typically addressed groundwater and soil contamination. ICs are response actions under CERCLA and are subject to the nine evaluation criteria used in developing an FS. The objective, mechanism, timing, and responsibility of an IC are determined before applying the evaluation criteria.

Objective

The objective of any IC is to ensure that the remedial alternatives are implemented and monitored properly to minimize the potential for human exposure to contamination. Here, the IC objectives will be to: (1) ensure that engineering controls used to prevent levels of indoor contaminants associated with the vapor intrusion pathway from reaching EPA's action level are operated and/or monitored as required by the remedy; and (2) ensure that the appropriate engineering controls are installed into any new development at the Site. Some of the ICs proposed for this remedy may differ from traditional ICs. For example, one of the remedial alternatives for existing commercial buildings, HVAC system operation, is typically operated by the property owner, building owner, or building occupant, and not by the RP. Therefore, the proposed remedy is for the RP to verify that the building operator in fact operates the HVAC system adequately to meet long-term indoor air standards. This will require layered ICs to ensure that building owners, building operators, and the RPs are appropriately involved with remedy implementation.

Mechanism

Due to the large number of buildings and properties subject to this vapor intrusion remedy, successful implementation requires significant coordination to ensure that the remedy is operating as designed at each building and property. To coordinate the ICs, an Institutional Control Implementation Plan needs to be developed to detail the management, monitoring, and IC implementation across the Site.

Several stakeholders, including EPA, the city, the RPs, the property and building owners, and the occupants at the Site are working together to develop the necessary "layers" of ICs that will be most effective at the Site. IC layering means using different types of ICs at the same time or at different points in a series to ensure short-term and long-term protectiveness of the remedy.

Timing

Several IC mechanisms for the proposed remedy are already in place, including zoning, local permits, state codes, and certain types of information devices. These pre-existing mechanisms will be monitored and updated as necessary to ensure that they meet the remedy requirements. Other ICs will be implemented after the remedy is selected. This includes any proprietary controls that would need to be implemented. Some ICs will also change as land uses and property owners change over time.

Responsibility

Generally, the RPs have the responsibility to implement ICs. However, ICs rely on enforcement by other entities and the cooperation of other parties. For example, enforcement of zoning and local permits is the responsibility of the local agency (e.g., city or county), while access to and operation of an HVAC systems requires the cooperation of the property and building owners and operators.

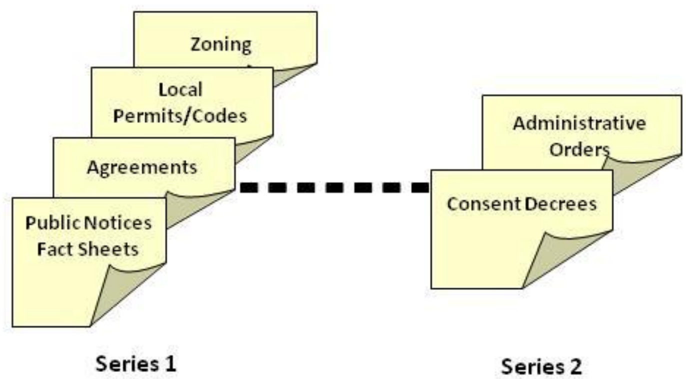
Types of ICs

The following types of ICs were evaluated, and those in *italics* were selected and would be applied in layers and series:

- Government Controls (*zoning* and zoning overlays, municipal ordinances, and *local permits/state codes*)
- Proprietary Controls (covenants and *agreements*)
- Enforcement Tools (administrative orders, and consent decrees)
- Informational Devices (recorded notices, public notices, *fact sheets*, and *public meetings*)

IC selection requires the cooperation of several stakeholders. This Site demonstrates that typical ICs, such as recorded deed restrictions, are very difficult to obtain for properties not owned or occupied by RPs. Local ordinances are also difficult, since they have implications on several stakeholders, including the local agency, owners, and tenants. As such, other IC mechanisms were developed in layers and series to provide remedy protectiveness.

Figure 4: Layering Institutional Controls



STAKEHOLDERS PARTICIPATION

Disseminating information to stakeholders is important, as each stakeholder (e.g., EPA, RPs, building owners, tenants, residents, local agencies) may have varying objectives; the challenge for the stakeholders is to come to an agreement. For this Site, information was provided to stakeholders through public meetings, public notices, fact sheets, direct mailings of technical reports, and meetings with various stakeholders, collectively and individually.

This becomes relevant in the remedy selection, but even more in those ICs where some restrictions could be imposed on a property or a local area. Questions to be resolved include; 1) responsibility of implementation; 2) potential for disruptions of daily building operations; 3) security measures in limited access buildings; 4) potential for restrictions on future redevelopment; and 5) effect on the local real estate market. Resolving these questions early on in the process removes uncertainties in this rather complicated process.

SUMMARY

This paper presents a vapor intrusion approach and lessons learned for a large Superfund Site with a mixed commercial/residential setting where more than 3,000 samples were collected from 60 large commercial buildings and 40 residential structures of varying construction types. Interim mitigation measures (e.g., sub-slab ventilation, enhanced ventilation, air purification systems, vapor barriers & passive ventilation, sealing of cracks and conduits) were implemented. These measures were effective in reducing the concentrations of VOCs in indoor air substantially. In some cases, more than one measure was applied sequentially to achieve the desired action level.

There are many lessons to be learned from this experience, including; 1) Traditional FS that target soils and groundwater may select a remedy that could be applicable site-wide, but for vapor intrusion, an FS must be flexible to allow for more than one remedy because building types vary (e.g., existing vs. future buildings, residential vs. commercial, warehouse vs. office, etc). Without this flexibility, undue restrictions will be placed on the properties that could potentially affect real estate transactions and future development. 2) Disseminating information to stakeholders is important, as each stakeholder (e.g., EPA, RPs, building owners, tenants, residents, and local agencies) may have varying objectives, and the challenge is for the stakeholders to come to agreement. 3) The Site presents an example on how institutional controls (ICs) for the vapor intrusion pathway can be selected for a complex scenario where RPs do not operate, lease, or own properties.Specifically, it is difficult to impose deed restrictions on a third party property not owned or leased by the party responsible for the cleanup. Other ICs would have to be developed (in layers and series if necessary) to ensure the protectiveness of the remedy.

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KEY WORDS

Air purification, feasibility study, institutional controls, mitigation, sub-slab depressurization, vapor intrusion, Superfund, ventilation, VOCs.