Accelerating the Redevelopment of a Vapor-Impacted Property Based On Data-Informed Verification of Vapor Barrier Technology

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ABSTRACT

A cold-spray applied vapor barrier equipped with an overlying monitoring layer has been installed as part of an integrated commercial redevelopment, demonstrating protection of human health without the need for indoor air sampling. Over 50 years of manufacturing at the site resulted in volatile organic contamination impacts to soil and groundwater. The extent of contamination posed challenges for site redevelopment. Remedial measures included excavating source area soil, air sparging (AS)/soil vapor extraction (SVE) in overburden and weathered bedrock groundwater, and monitored natural attenuation for deeper bedrock groundwater. Initial assessments indicated these measures would require years to reduce concentrations to levels that would allow future site development without engineering controls.

In order to accelerate redevelopment, a vapor barrier system that includes a venting layer beneath and a monitoring layer above the barrier was constructed using various components manufactured by CETCO Liquid Boot®. The passive venting layer was designed to allow active venting, if needed, to reduce vapor concentrations. Sampling is performed periodically from several ports installed as part of the monitoring layer to verify the barrier's effectiveness. Contingency plans were developed to perform active venting and modified remediation operations, including temporarily ceasing AS and conducting enhanced SVE, if sampling indicated that vapors were penetrating the barrier at concentrations above applicable environmental regulatory action levels. Multiple rounds of monitoring have demonstrated the effectiveness of the vapor barrier and contingency plan. The successful demonstration of the design in meeting applicable vapor intrusion screening levels beneath the building slab removed requirements that regulators were insisting as mandatory. This avoided extensive complications due to confounding indoor sources related to new construction and current business activity.

This site provides an example of how the remediation community and developers can work together to accelerate property reuse while extensive ongoing remedial activities are being conducted. Following the demonstration of effectiveness of this mitigation concept, further explorations are underway to link vapor barrier technologies with green building design to

redevelop brownfields in a sustainable manner while minimizing the energy expenditures and emissions associated with remedial action.

INTRODUCTION

Vapor intrusion[1] emerged in the 1990s to become one of the most important problems involved with investigating and cleaning up sites with chemical contamination in soil and groundwater. Thousands of sites across the United States have been affected by volatile organic compounds (VOCs) and there is an increasing concern that these VOCs may be intruding into overlying occupied buildings (for example, residences, schools, daycare centers, commercial/industrial buildings). As a result, hundreds of these vapor intrusion sites have been investigated.

Vapor intrusion potentially is a significant hurdle to redeveloping brownfield properties. Prior to approving redevelopment plans, regulatory agencies place a high burden of proof on the responsible parties that vapor intrusion will not pose significant health risks, a requirement that triggers costly and time-consuming investigations.

Regulatory agencies recognize engineering controls on building systems as a mitigation measure for vapor intrusion pathways; however, these controls are sometimes not viewed as permanent measures for reducing vapor intrusion risks. Given the historical mindset of cleanup programs, remediation of soil and groundwater often is viewed as the final measures for controlling vapor intrusion as opposed to engineering controls. A regulatory bias against vapor-resistant construction as a remedial measure for controlling vapor intrusion potentially delays redevelopment decisions at these sites.

The following is a case study of applying vapor barriers to support redevelopment of a VOC-impacted brownfield site in New Jersey. This case study focuses on the sampling and abatement procedures intended to provide assurance that implementation and monitoring of an engineered vapor barrier system protected human health following new occupancy of the site.

Site Background

The redevelopment site was a chemical manufacturing facility from the mid-1940s through the early 2000s. Following the end of manufacturing operations, an extensive decommissioning and demolition effort was completed by January 2003.

Historical source areas and the extent of VOC contamination related to former production activities were identified from manufacturing operational information, soil and groundwater sampling, and visual observations. The primary constituents of concern (COCs) at the site are benzene, ethylbenzene, toluene, and xylenes (BTEX); chlorinated benzenes; and acetone. The shallow vadose zone to a depth of approximately 10 feet was highly impacted with aromatic VOCs. Deeper soils were impacted with a “smear zone” created by fluctuations in the water table. Contamination levels in shallow overburden groundwater are higher than state groundwater quality criteria throughout the site, with light nonaqueous phase liquid (LNAPL)

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[1] Vapor intrusion is the migration of volatile constituents from the subsurface (soil or groundwater) into overlying buildings. Vapor intrusion of subsurface constituents can produce concentrations of volatile organic compounds (VOCs) in indoor air. Inhalation of VOCs in indoor air might produce increased health risks.

contamination present in portions of shallow groundwater. Contamination was present in deep overburden groundwater and bedrock, but is not discussed further since constituents in deep groundwater generally are not considered a factor in vapor intrusion (NJDEP, 2005; Rivett, 1995).

Investigation and remedial action supported redevelopment, with a focus on commercial, retail, and warehousing use. Redevelopment of the site was part of an overall strategy to achieve economic revitalization, improve traffic circulation, and upgrade infrastructure, such as the local municipal sewer system. The proposed remediation and redevelopment activities for the site were consistent with the community's overall master plan. Soil and groundwater cleanup goals were established as the most stringent guidelines available at the time from the New Jersey Department of Environmental Protection (NJDEP), specifically the impact to groundwater and soil cleanup criteria and groundwater quality criteria standards.

The selected remedial approach for the site included excavating impacted shallow source area soils, implementing institutional/engineering controls to limit exposure, operating an air sparging (AS)/soil vapor extraction (SVE) system for overburden groundwater, and incorporating monitored natural attenuation for bedrock groundwater. Several contingency remedies were assessed and were deemed feasible using the AS/SVE infrastructure, including enhanced bioremediation.

Remedial action decisions were made for the site in 2004, prior to the publication of state guidance and criteria for the vapor intrusion pathway. Vapor mitigation options, however, were incorporated into the remedial approach because of the following:

- Redevelopment plans included constructing a large commercial building over a significant portion of the site.
- The concentrations present in groundwater were at levels that could pose a concern for the vapor intrusion pathway (that is, 110 milligrams per liter [mg/L] xylene in groundwater).
- The selected remedy for the site was AS, which promotes volatilization of COCs and pressurization in the treatment area.
- The state agency would not issue the documentation needed to begin redevelopment (that is, remediation in progress waiver) without completing a vapor intrusion monitoring and mitigation plan.

ENGINEERED VAPOR BARRIER SYSTEM ALTERNATIVES

Although not published at the time, the Interstate Technology Regulatory Council (ITRC) guidance entitled *Vapor Intrusion Pathway: A Practical Guideline* provides a summary of various building control remedies for existing and new construction that were considered at the time the vapor barrier system was being evaluated for this case study (ITRC, 2007). Following are a few highlights of the vapor barrier system approaches considered for this new construction site:

1. An engineered vapor barrier that acts as a physical barrier (for example, synthetic sheeting) between the building floor slab and contaminated soil. This physical barrier prevents (or significantly retards) the migration of vapors from soil into the building through typical migration pathways such as cracks and penetrations through the building floor slab.

2. An engineered vapor barrier coupled with a passive venting system, where pipe vents or high-permeability ventilation layers are present beneath the vapor barrier, extend vertically upward, and vent to the atmosphere above the building roof. The combination of barometric pressure changes in the atmosphere and low-cost devices installed on the pipe vents, such as a wind turbine, increases the likelihood that a vapor gradient between the subslab and the atmosphere/indoor air is maintained. The primary purpose of the pipe vents and/or constructed ventilation layer is to limit the accumulation of gases below the vapor barrier. It also is designed to allow for a minimal negative pressure beneath the vapor barrier system, such that if a failure occurs in the gas barrier, there is no significant increase in risk to occupants in the building.

3. An engineered vapor barrier coupled with an active venting system that restricts the subsurface migration of gases by using mechanical means to alter and maintain pressure gradients and redirect subsurface gas flow. Major system components generally include gas extraction wells and piping, vacuum blowers, and gas/vapor treatment or reuse systems.

The selected approach for this new construction site was to design a vapor barrier with a passive venting system that can be converted to active if monitoring results indicated it was necessary. The decision was based on the magnitude of groundwater concentrations and the desire to implement a sustainable vapor barrier system that would be flexible enough to provide protectiveness during operation of the AS system.

REMEDIATION AND VAPOR MITIGATION ACTIVITIES

In addition to the AS/SVE remediation system installed to remediate contaminated media, a vapor barrier and passive vent system were designed and installed beneath occupied buildings as a precautionary measure to prevent VOCs from migrating through the building floor to indoor air during site remediation. As stated, the passive vent system could be converted to an active vent system, if needed.

Description of Remediation System

The AS/SVE system was installed following completion of excavation activities. The AS/SVE system is designed to reduce COC concentrations through volatilization and enhanced aerobic biodegradation in vadose zone soil, shallow overburden groundwater, and deep overburden groundwater located at the overburden/ bedrock interface. Because the remediation mechanism chosen to be most cost-effective for this site was AS, which can enhance vapor intrusion risks, the AS/SVE system was designed to capture injected air and create a net subsurface vacuum within the treatment area. In areas of active operations, this created a pressure gradient toward the SVE wells and promoted collection of entrained air from the vadose zone soil, thereby minimizing the potential for vapor intrusion caused by the presence of elevated concentrations of VOCs in groundwater beneath the building and operation of the AS component of the system.

Description of the Selected Vapor Barrier System

A review of engineered vapor barrier systems was performed to identify a system effective for mitigating COC vapor intrusion at the site. Several vapor barrier system manufacturers were screened, and CETCO Liquid Boot, was chosen based on their (1) innovative technology; (2) experience with implementing this technology at similar sites; and 3) experience within New Jersey.

The chosen product uses a monolithic membrane material that is cold-spray applied to a specified thickness (for example, 80 mils) before the construction of the building floor slab on top of the membrane barrier. This particular membrane system is seamless, provides excellent sealing around penetrations, and typically can be applied and cured in less than 1 week (CETCO Liquid Boot, 2008).

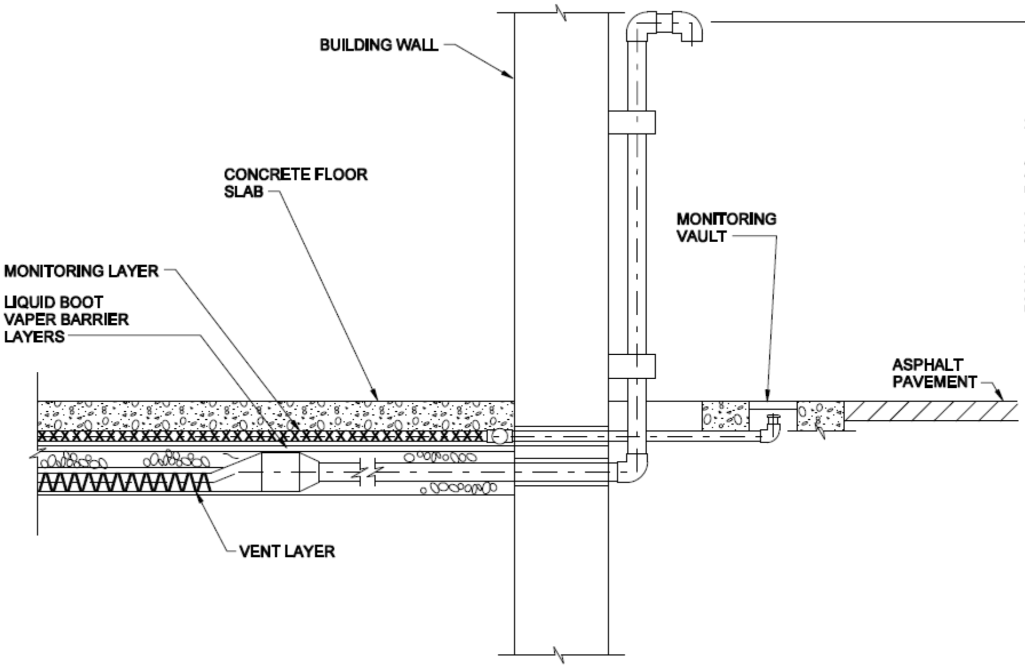
Initial Testing of Vapor Barrier Effectiveness

To prove the effectiveness of its material, an independent testing firm was retained to conduct a series of analytical tests on several 80-mil-thick specimens of these membrane materials. Testing was performed based on standard American Society for Testing and Materials (ASTM) methods and procedures. Tests included determining water and gas permeabilities of specified vapors, elongation, bond seam strength, and weight change of each specimen when exposed to eight different constituents including benzene, xylene, hexane, gasoline, toluene, ethylene, perchloroethylene, and sodium sulfate (LBI, 2000). In addition, the laboratory tested for the permeability and weight change of trichloroethylene (TCE), vinyl chloride, mercury, acetic acid, and sulfuric acid. Overall, the results indicated that the performance of the vapor barrier material was not compromised under the conditions tested. Since the primary site-related COCs evaluated as part of these tests included xylene, benzene, and toluene and site-specific soil gas concentrations were estimated to be much lower than the concentrations tested, it was concluded that the monolithic membrane material would be an effective vapor barrier for use at the site. Since this type of testing does not address any installation issues such as flaws, cracks, holes, gaps or seams, additional smoke testing of the installed barrier was conducted during construction. Any cracks that were observed during the smoke testing activities were sealed and the area was retested.

Vapor Barrier Design

The vapor barrier designed for this site was a layered system that consists of a venting layer, the barrier layer, and a monitoring layer installed beneath the 6-inch-thick concrete floor slab that formed the floor of the proposed building. The venting layer consists of materials and piping for a passive vent system that could be converted to an active system. The vapor barrier was placed on top of the venting layer. The monitoring layer is positioned between the vapor barrier and the building foundation to allow for long-term evaluations of the integrity and effectiveness of the barrier and venting system without having to sample indoor air. A cross-section of the vapor barrier and monitoring system is presented in Figure 1.

Figure 1: Vapor Barrier System Illustration



The vapor barrier consisted of a geotextile, cold-spray applied material, and a protective course consisting of an additional geotextile. The geotextile was placed over the gravel layer, followed by spray-on application of the monolithic membrane layer and application of the protective course geotextile. The cold-spray applied material was smoke tested to ensure the membrane was impermeable prior to installing the protective course.

ABATEMENT AND MONITORING PLAN

At the request of NJDEP, a vapor barrier monitoring and abatement plan was prepared. The state had asked that a formal document be developed that includes procedures for detecting, monitoring, and abating potential vapor intrusion into the proposed buildings.

Soil vapor samples were collected from three passive vents and analyzed using U.S. Environmental Protection Agency (USEPA) Method TO-15, according to guidelines in NJDEP’s (2005; updated in 2007) vapor intrusion guidance document. Initial sampling was conducted to establish baseline conditions during the first week following vapor barrier construction activities and prior to occupancy of the retail building. Following the baseline sampling activities, monthly samples were planned to be collected and analyzed from the worst-case location. Results from baseline and monthly monitoring activities were compared to the NJDEP soil gas screening levels (SGSLs). If detected concentrations remained below the NJDEP SGSLs, sampling frequency was decreased to quarterly, then semiannually and continued by implementing active remediation efforts (for example, operating the AS/SVE system).

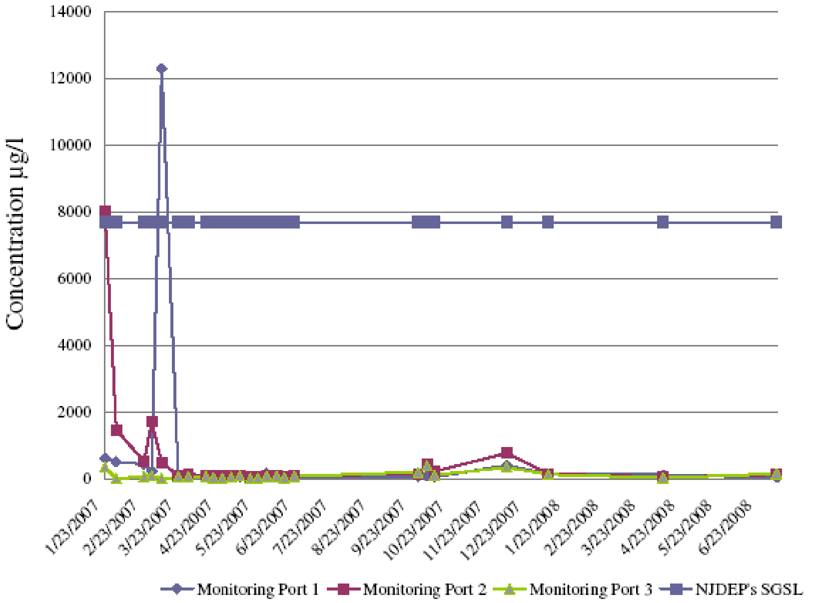
If at any time during monitoring operations, VOCs exceeded NJDEP SGSLs, then one round of confirmatory samples would be collected immediately (for example, within 1 week of receipt of final analytical results from the laboratory) from each of the three passive vent locations, and the AS component of the remediation system would be shut down pending receipt of results. The SVE system would remain operational during this time to reduce the possibility of further migration of VOCs across the vapor barrier. NJDEP would be notified immediately if the confirmation results exceeded SGSLs, and abatement procedures would be implemented.

The abatement procedures used in cases where soil gas concentrations were not reduced to below SGSLs included converting the passive vent system to an active system to further mitigate the elevated vapor concentrations, continued operation of the SVE system to maintain a negative pressure gradient between the indoor air and subslab, and more frequent sampling from the monitoring layer. If after active system adjustments are implemented and the results of weekly measurements are not below SGSLs, a vapor intrusion pathway investigation would be implemented to identify the source of the elevated soil gas concentrations and an alternative means to mitigate the situation before returning the AS/SVE system to normal operations. In addition and as a protective measure, a monitoring and maintenance program would be implemented to identify and seal cracks or openings in the building’s concrete floor.

Soil Vapor Monitoring

In 2007, monitoring from the vapor layer was initially conducted, and initial subslab vapor results were above the NJDEP SGSLs for some compounds. Therefore, purging of the monitoring layer was conducted to remove construction-related residuals, and the vapor barrier venting layer was converted from passive to active using existing AS/SVE treatment system components. Subslab vapor results following implementation of these abatement measures showed a rapidly declining trend in concentrations with time. Subslab soil vapor monitoring results using xylene as the primary site indicator COC are shown on Figure 2.

Figure 2: Vapor Barrier Monitoring Layer Sampling Results: xylene



Indoor Air Monitoring Issues

Indoor air sampling for VOCs likely would not be useful in evaluating the effectiveness of the engineered vapor barrier system because of confounding factors. It is well known that materials used in constructing buildings can emit significant levels of VOCs (USEPA, 2008). Building materials that are known emission sources for xylenes, the primary COC, include carpeting, paint, vinyl flooring, and adhesives (Dols et al., 1995; Hodgson et al., 2002). It would be difficult to distinguish between indoor or subslab sources of COCs detected in indoor samples, and it would not be possible to remove emissions sources to reduce indoor concentrations since building materials represent these sources. The monitoring layer was installed beneath the building to allow for direct and long-term measurements of VOC concentrations to verify performance of the vapor barrier. The design allows this to be done in a manner which does not interfere with the normal operations of the business or its customers. The vapor barrier system ensures receptors within the building are protected from vapor intrusion concerns. In addition, abatement procedures would be implemented if elevated detections were encountered in the monitoring layer beneath the building and is a more conservative plan of action, since elevated detections beneath the building would not necessarily indicate that indoor air is impacted above criteria levels.

A review of some key elements within NJDEP's vapor intrusion and indoor air sampling guidance as it relates to indoor air sampling is summarized below:

- The guidance allows for remedy implementation in preference to further sampling to address the vapor intrusion pathway if SGSLs are exceeded.
- Subslab soil gas results will provide empirical data essential in properly evaluating risk to human receptors within the structures.
- Background contributions create multiple difficulties when conducting indoor air sampling.
- The collection of indoor air samples should be avoided in situations when indoor COC concentrations are expected to be elevated based on the nature of the commercial, industrial, or retail operation. Subslab soil gas samples are recommended where possible in lieu of indoor air samples. If subslab results are in excess of SGSLs, an institutional control may be required.

Although the NJDEP vapor intrusion guidance document was issued after building commissioning for this site, it was determined that the monitoring and abatement program is compliant with the guidance since conservative engineering measures are implemented if SGSLs were to be exceeded. Interpretation of indoor air results is complicated because of potential background indoor air sources and likely would not provide additional information to evaluate the vapor intrusion pathway and the effectiveness of the barrier. In addition, indoor air sampling is not necessary provided engineering measures are implemented that can maintain SGSLs below criteria levels.

DISCUSSION

State and federal regulatory agencies, affected stakeholders, and consultants have made a concerted effort to better understand vapor intrusion pathways, their associated risks, and the steps needed to minimize and control those risks (ITRC, 2007). The control of vapor intrusion falls under the regulatory framework for cleaning up hazardous waste sites, including Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA; that is, “Superfund”), Resource Conservation and Recovery Act (RCRA) corrective action, and corresponding state cleanup programs. The methods for controlling vapor intrusion fall into three categories: (1) remediation of soil and groundwater with the methods used historically in cleanup programs; (2) engineering controls on buildings, including subslab depressurization systems typically used for radon mitigation and vapor barriers; and (3) institutional controls (ITRC, 2007). Regulatory guidance documents routinely state that the final remedy for vapor intrusion involves cleanup of contaminated soil or groundwater since vapor intrusion falls within the cleanup programs and engineering controls (“building-side solutions”) are not typically viewed as permanent solutions.

Regulatory program requirements to clean up affected soil or groundwater have the unintended consequence of creating barriers for many potential solutions to vapor intrusion problems. Final remedies that use technologies designed to reduce contamination volume, toxicity, and mobility often have the unintended consequence of creating a reluctance to apply remedies that rely on institutional or engineering controls to eliminate the exposure pathway.

The objectives of the vapor barrier mitigation system described in this paper, which included a venting layer beneath and a monitoring layer above the barrier, were to:

- Accelerate redevelopment at a site with potential vapor intrusion concerns
- Verify the effectiveness of the barrier without collecting indoor air samples
- Provide a contingency/abatement plan that would address exceedances of action levels potentially detected in the subslab monitoring layer

The extent of VOC impacts at this site posed significant challenges for site redevelopment. An assessment of the remedial measures indicated it would be years before VOCs were reduced to levels that would allow future site development without engineering controls to prevent vapor intrusion. The vapor barrier, coupled with separate venting and monitoring layers greatly accelerated site redevelopment and reuse.

Select VOCs were detected above their action levels during the initial sampling of the subslab monitoring layer (i.e. total xylene at 3500 ppbv; criteria at 1800 ppbv) which could have resulted from operation of equipment (i.e. generators or construction vehicles) during construction or other construction related causes. As a result, the monitoring layer was purged, the venting layer was converted from a passive to an active system and the AS component of the ongoing remedial system was temporarily turned off. Subslab vapor concentrations following these abatement procedures rapidly declined with time, which verified the effectiveness of the vapor mitigation system and the contingency and abatement plan without the need to collect indoor air samples. The sampling frequency has been decreased to semiannually and will continue by implementing the active remediation efforts (that is, operating the AS/SVE system).

SUMMARY

The vapor barrier, venting, monitoring, and contingency plan described in this paper provide an example of how the remediation community, regulators, and developers can work together to accelerate property reuse. From a technology perspective, there is a need to shift the regulatory paradigm away from soil and groundwater remediation being viewed as the only final measure for controlling vapor intrusion to one that also recognizes engineering controls on buildings as a permanent solution.

The architecture, engineering, and construction community has been dealing with similar issues for years when constructing buildings that are subject to moisture vapor intrusion with subsequent mold growth. Integrated (that is, green) building design techniques above and beyond vapor barriers that are used to prevent moisture vapor intrusion also should be considered for mitigating soil gas vapor intrusion over the life of the building. Examples of green building-integrated design solutions to minimize soil gas vapor intrusion include (1) ventilation and climate controls that maintain positive building pressure relative to the subslab; (2) automated building controls that control pressurization; (3) air and vapor barriers, which are the combination of interconnected materials, flexible sealed joints, and other components of the building envelope that help control building pressurization and air infiltration; and (4) building commissioning and re-commissioning to verify building performance at startup and throughout the life of the building.

Integrated building design methods (including subslab barriers) hold the promise to provide an alternative or supplemental mitigation option, accelerating property redevelopment, and offering a sustainable solution for vapor intrusion. Overcoming regulatory hurdles is a key factor in gaining acceptance of building-side techniques as permanent solutions to vapor intrusion concerns.

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