EFFICACY OF SUB-SLAB DEPRESSURIZATION FOR MITIGATION OF VAPOR INTRUSION OF CHLORINATED ORGANIC COMPOUNDS

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ABSTRACT
Active soil depressurization systems have been installed in over 300 residential homes in Denver, Colorado to control indoor air concentrations of 1,1 DCE resulting from migration of vapors from groundwater with elevated DCE concentrations. Over three years of monitoring data have shown that these systems are capable of achieving the very high reductions in concentrations necessary to meet the concentration levels currently mandated by the State regulatory agency. Prior to installation of the system, 1,1 DCE indoor air concentrations ranged from below the reporting limit of 0.040 ug/m^3 to over 100 ug/m^3. Post-mitigation monitoring showed that most 90 watt fan, single suction-point systems were able to reduce 1,1 DCE concentrations by 2 to 3 orders of magnitude to below the State mandated levels. Approximately, 1/4 of the systems required minor adjustment or upgrading after initial installation in order to achieve the levels.

INDEX TERMS
Effectiveness, Groundwater, Mitigation, Residential, VOCs

INTRODUCTION

The groundwater-to-indoor air pathway for migration of and exposure to volatile organic compounds (VOCs) has been recognized for some time (e.g., Johnson & Ettinger 1991, ASTM 1995); however, the potential for chlorinated compounds in groundwater to impact indoor air has been discussed very little in the literature (Richardson 1997, Folkes & Kurz 2000, Kurz 2000). Some states have developed indoor air pathway criteria for groundwater. However, the criteria may underestimate the occurrence of indoor air impacts in certain circumstances (Fitzpatrick and Fitzgerald, 1996) and may be based on models that have not been validated (Altshuler and Burmaster, 1997).

Although 1,1 dichloroethene (DCE) is not used extensively in industry, it is present as an intermediate decay product at many sites having tetrachloroethene (PCE), trichloroethene (TCE), and 1,1,1 trichloroethane (TCA) in groundwater, and may impact indoor air.

Use of soil depressurization systems was described previously for 60 homes (Folkes & Kurz 2000). This paper is intended to provide additional data showing that active soil depressurization systems are capable of achieving very high removal rates necessary to meet the concentration levels currently mandated by the State regulatory agency. More than 600 homes have been tested and mitigation systems have been installed in over 300 residential homes in Denver, Colorado. Home construction styles include full basements and bi-levels both with below grade floor slabs, crawl spaces, combinations of crawl spaces and basements,

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and slabs on grade. This project provides a unique opportunity to evaluate the effectiveness of the soil depressurization systems in many homes at one location.

BACKGROUND

Site Description

The Redfield site is located in Denver, Colorado. Historic use of solvents at a former manufacturing facility and other surrounding facilities resulted in a groundwater 1,1 DCE plume that extends a distance of approximately 2,400 m under residential properties. Other sources also may have contributed to the plume. The compounds of concern include TCA, TCE, PCE, and 1,1 DCE. Concentrations in offsite monitoring wells are highest near the site boundary and decrease with distance from the site (Table 1).

Table 1. Average Observed Concentrations in Off-Site Monitoring Wells.

Compound	Mean Concentration (ug/L)
1,1 DCE	136
PCE	58
1,1,1 TCA	84
TCE	45

As the area of testing increased, the stratigraphy in the residential area varies from uniform sedimentary deposition to localized channel deposits within the test area. Nearest to the site, the lithology is fine-grained silt and clay loess deposits, underlain by weathered sandstone, siltstone and claystone deposits of the Denver Formation at depths of approximately 6 to 12 m. Fine-grained soils typically extend to depths of at least 3 m. The plume has followed a historic sand channel. At homes in this extended area, the lithology is that of alluvial channel deposits including sand and gravel between the loess and bedrock. Groundwater is found at depths of 5 to 6 m near the site boundary, increasing to depths of 10 m in the middle of the plume in the narrow channel deposits, and decreases to approximately 4 m as the channel widens toward the northern end of the plume. Groundwater near the site boundary flows in the upper portion of the weathered bedrock, ultimately discharging to sand and gravel alluvium in the channel deposits.

Indoor Air Testing

The indoor air of 639 homes in the neighborhood was tested over 24-hour periods using inert stainless steel containers (SUMMA canisters) following procedures described previously (Folkes & Kurz 2000). SUMMA canister samples were analyzed at the laboratory in accordance with EPA Test Method TO-15 using a mass spectrometer operated in the Selective Ion Monitoring (SIM) Mode. For tests conducted after October 1998, equipment-tuning procedures met the requirements of CDPHE (1999) guidelines. The SIM Mode monitors a few compounds instead of the entire mass spectra, allowing a 1,1 DCE reporting limit of 0.04 ug/m^3. Measured 1,1 DCE concentrations range from below the reporting limit (0.04 ug/m^3) to 131 ug/m^3.

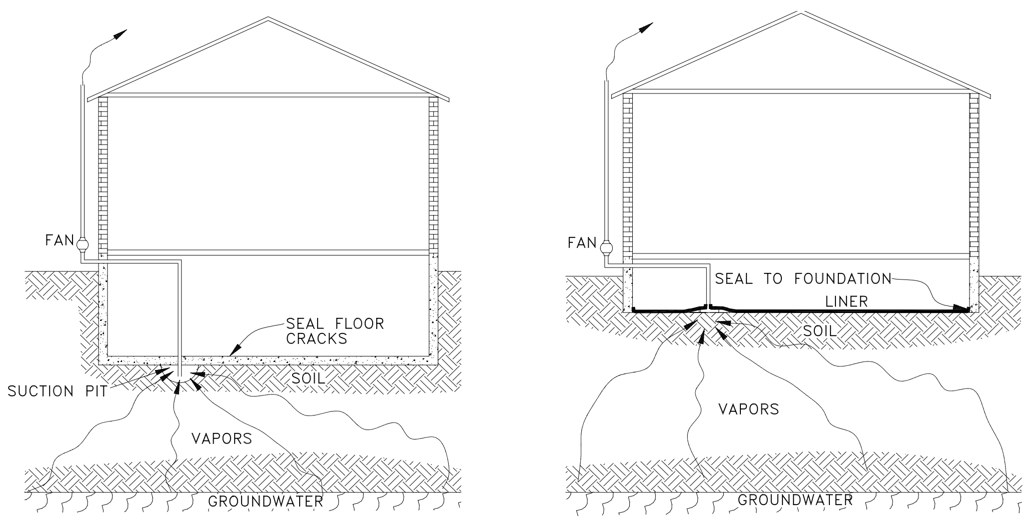
Concentrations in 356 homes exceeded the Colorado Department of Public Health and Environment (CDPHE) interim action level of 0.49 ug/m^3. All but one of these homes were in or immediately adjacent to the area overlying the groundwater plume, defined by 1,1 DCE concentrations exceeding 1 ug/L. Indoor air concentrations of 1,1 DCE are generally higher where groundwater concentrations are higher and where groundwater is shallower, but may vary by up to two orders of magnitude in houses over groundwater of similar concentrations and depth (e.g., adjacent homes) because of individual, site specific conditions. The remaining home (indoor air concentration of 0.88 ug/m^3) was located approximately 300 m cross gradient of the groundwater plume and was impacted by non-groundwater sources. Access was granted for installation and adjustment of venting systems at 337 of the homes having 1,1 DCE results above the action level. Following system installation, periodic performance testing was conducted in homes with systems. For purposes of this evaluation, performance testing had been received for 301 houses.

DESCRIPTION OF MITIGATION SYSTEMS

Vapor mitigation systems were installed generally following USEPA guidelines for radon mitigation. Sub-slab depressurization (SSD) systems were installed in homes with basements, bi-levels, or slab-on-grade construction, while sub-membrane depressurization (SMD) systems were installed in homes with crawl spaces, as described below. A combination system was installed in homes having a basement and crawl space. Due to the large number of homes, systems were installed by several different contractors who used similar, but varying, methods and equipment (e.g., pipe and fans).

Sub-Slab Depressurization Systems

A typical SSD installation is shown on Figure 1. Suction pits were created below the concrete floor slabs by drilling a 9 to 12 cm diameter hole through the slab, ideally but not necessarily located near the middle of slab, then hand-excavating a void approximately 15 cm deep and 40 cm in diameter to increase the effectiveness of the depressurization system (e.g., see Bonnefous et al., 1992). Either 76 mm or 101 mm diameter PVC pipe from the suction side of the fan was inserted in the hole. The annular space between the pipe and slab was sealed with acrylic latex caulk.



SUB-SLAB DEPRESSURIZATION   SUB-MEMBRANE DEPRESSURIZATION

Figure 1. Mitigation Systems (typical)

In each home, one suction point was created in the floor slab, based on information in the literature that indicates that one suction point should be sufficient to depressurize the floor area below most single family homes (e.g., EPA 1993). The fans were installed in the attic or outside the house. Pipe exhausts were located at least 3 m above the ground and 3m from doors or windows, following EPA (1993) guidelines for radon systems. All visible cracks and joints in the floor were sealed with acrylic latex caulk.

Sub-Membrane Depressurization Systems

In homes with a crawl space, SMDs were installed by placing a 0.1 mm thick, cross-laminated polyethylene membrane or liner over the dirt floor and sealing the liner to the concrete foundation walls using acrylic latex adhesive (Figure 1). The end of the pipe (76 mm or 101 mm PVC) from the suction side of the fan was inserted through a hole cut in the liner. The liner was sealed to the pipe at the penetration hole using vinyl tape to prevent loss of vacuum. When concrete footings divided the crawl space, a separate suction point was generally installed in each separate area between the footings. The fan was installed outside the house and the pipe was routed up the outside wall to exhaust above the roofline.

Fans

An inline centrifugal fan by various manufacturers (e.g., Fantech, RAM/GAM, AMG) was used to create the low-pressure zone below the concrete slabs and liners. In most cases a 90-watt fan was installed, with a flow rate of 2.5 m^3/min at 249 Pa. In situations where additional vacuum was desired (see Results and Discussion), a 150-watt fan with a flow rate of 5.7 m^3/min at 249 Pa was installed. The fans operate 24 hours per day and each system has an oil-filled manometer in the pipe providing a visual indicator to the homeowner that the system is operating. All work was conducted by licensed contractors under permits, as required by the City and County of Denver Building Inspection Department.

RESULTS

A total of 301 mitigation systems were evaluated in the study. Of these, 189 were SSDs, 79 were SMDs, and 33 were combined. Approximately 75% of the SSDs, 68% of the SMDs, and 70% of the combination systems met the CDPHE interim action level without requiring modification (i.e., with one suction point, a standard size suction pit, and a 90 watt fan). SSDs, SMDs, and combinations were able to reduce indoor air concentrations of 1,1 DCE by up to two orders of magnitude and, in some cases, almost three orders of magnitude.

The modifications or upgrades to the standard systems (described above) that were required to bring the remaining systems into compliance with the interim action level are also consistent with radon mitigation practices. Enlargement of the suction pit, addition of a second suction pit, and/or replacement of the 90 watt fan with a 150 watt fan were sufficient, singly or in combination, as necessary, to increase the extent of the pressure field induced by SSDs and meet the 1,1 DCE interim action level. In a few homes, a lack of outside combustion air (now required by the Denver building code in new homes) was suspected of contributing to depressurization of the basement air during furnace operation, thus overpowering the suction created by the SSD under the floor slab. The provision of outside combustion air to the furnace in these homes alleviated this condition. In homes with SMDs, typical modifications such as finding and sealing small gaps between the liner and foundation wall, adding more perforated pipe under the liner, and replacing the 90 watt fan with a 150 watt fan were also sufficient, singly or in combination, as needed, to increase subsurface air flow and meet the action level.

As shown in Table 2, most systems were able to achieve the indoor air action level with the standard system or one modification. In a small fraction of homes (i.e., less than 10% of the total homes mitigated), more than one modification was required to meet the action level.

Table 2. Percentages of Systems Requiring Modification to Meet Action Level.

System	SSD	SMD	Combination
No Modifications	75%	68%	70%
One Modification	16%	27%	21%
More than one modification	9%	5%	9%
Totals:	100%	100%	100%

Initial test results were observed to vary between nearby houses above similar groundwater conditions. The periodic performance test results were also observed to vary in individual houses. In some homes, the performance test results for 1,1 DCE were consistently below the action level, even with a high initial test result. In a few homes, the performance test results for 1,1 DCE appeared to consistently vary with seasonal changes, in a few limited cases temporarily exceeding the action level and requiring further system modification. Figure 2 provides example results for three different homes.

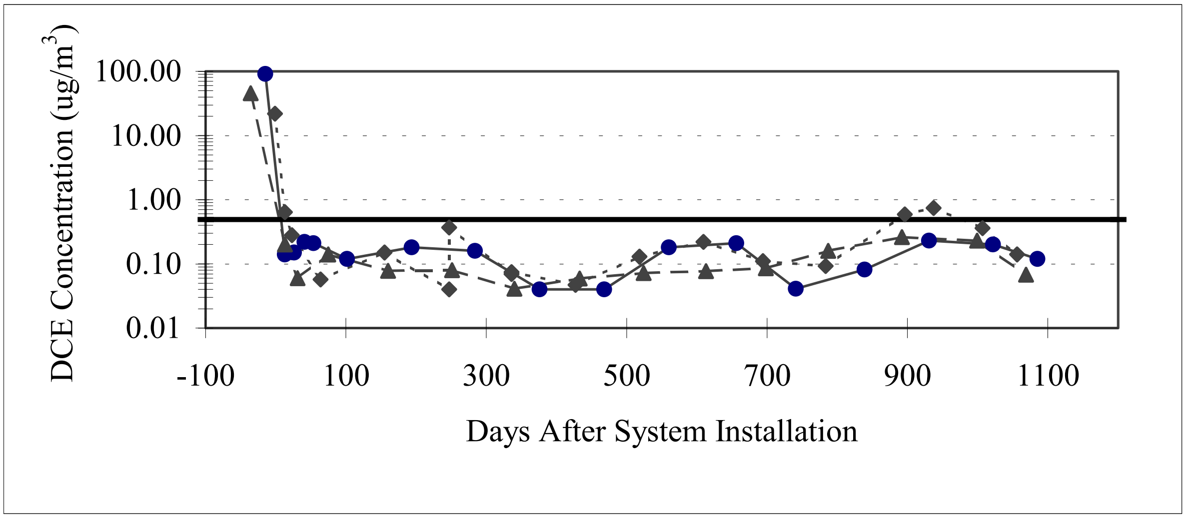


Figure 2. DCE Indoor Air Test Data For Homes with Mitigation Systems

DISCUSSION

Over three years of monitoring data have shown that the standard active soil depressurization methods used for radon mitigation (EPA 1993) are adequate to meet the stringent requirements of 1,1 DCE mitigation in Colorado (i.e., 2 to 3 orders of magnitude reduction). By comparison, radon systems typically are needed to achieve a 1 to 2 order of magnitude reduction. No significant difference in the performance of the SSDs, SMDs, and combination systems was observed. The relatively small percentage of homes that require more than one modification does not appear to be strictly related to high initial test results.

CONCLUSION AND IMPLICATIONS

The results in this project confirm that elevated indoor air concentrations of VOCs can be present in residences overlying groundwater plumes due to vapor intrusion. However, standard vapor mitigation techniques used for radon mitigation are highly effective at remediating the indoor air pathway.

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