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Notice

The U.S. Environmental Protection Agency (EPA) through its Office of Research and Development funded and managed the research described here through in-house efforts and under Contract No. 68-C-02-092 to the Dynamac Corporation. It has been subjected to the Agency's peer and administrative reviews and has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

All data generated in this report were subjected to an analytical Quality Assurance Plan developed by EPA's New England Regional Laboratory. Also, a Quality Assurance Project Plan was implemented at the Ground Water and Ecosystems Restoration Division. Results of field-based studies and recommendations provided in this document have been subjected to external and internal peer and administrative reviews. This report provides technical recommendations, not policy guidance. It is not issued as an EPA Directive, and the recommendations of this report are not binding on enforcement actions carried out by the EPA or by the individual states of the United States of America. Neither the United States government nor the authors accept any liability or responsibility resulting from the use of this document. Implementation of the recommendations of the document and the interpretation of the results provided through that implementation are the sole responsibility of the user.

Foreword

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet these mandates, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites and ground water; and prevention and control of indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

This report describes the results of an investigation conducted to assist EPA's New England Regional Office in evaluating vapor intrusion in homes and a commercial building near the Raymark Superfund Site in Stratford, Connecticut. Methods were developed to sample sub-slab air and use basement and sub-slab air measurements to evaluate vapor intrusion on a building-by-building basis. Using the methods described in this report, volatile organic compounds detected in basement air due to vapor intrusion could be separated from numerous other halogenated and non-halogenated (e.g., petroleum hydrocarbons) compounds present in basement air.

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Abstract

This report describes the results of an investigation conducted to assist EPA's New England Regional Office in evaluating vapor intrusion at 15 homes and one commercial building near the Raymark Superfund Site in Stratford, Connecticut. Methods were developed to sample sub-slab air and use basement and sub-slab air measurements to evaluate vapor intrusion on a building-by-building basis. A volatile organic compound (VOC) detected in basement air was considered due primarily to vapor intrusion if: (1) the VOC was detected in ground water or soil gas in the vicinity (e.g., 30 meters) of a building, and (2) statistical testing indicated equivalency between basement/sub-slab air concentration ratios of indicator VOCs and VOCs of interest. An indicator VOC was defined as a VOC detected in sub-slab air and known to be only associated with sub-surface contamination. Using this method of evaluation, VOCs detected in basement air due to vapor intrusion could easily be separated from numerous other halogenated and non-halogenated (e.g., petroleum hydrocarbons) VOCs present in basement air. As a matter of necessity, radon was used as an indicator compound at locations where an indicator VOC was not detected in basement air. However, when basement/sub-slab air concentration ratios were compared for radon and indicator VOCs, statistical non-equivalency occurred at three out of the four locations evaluated. Further research is needed to assess the usefulness of radon in assessing vapor intrusion.

Holes for sub-slab probes were drilled in concrete slabs using a rotary hammer drill. Probes were designed to allow for collection of air samples directly beneath a slab and in sub-slab media. Three to five probes were installed in each basement. Placement of a probe in a central location did not ensure detection of the highest VOC concentrations. Schematics illustrating the location of sub-slab probes and other slab penetrations (e.g., suction holes for sub-slab permeability testing) were prepared for each building to document sample locations, interpret sample results, and design corrective measures. Basement and sub-slab air samples were collected and analyzed for VOCs using six-liter SilcoCan canisters and EPA-Method TO-15. Sub-slab air samples were also collected in one-liter Tedlar bags using a peristaltic pump and analyzed on-site for target VOCs. Open-faced charcoal canisters were used to sample radon gas in basement air. Scintillation cells and a peristaltic pump were used to sample radon gas in sub-slab air.

Three methods were used to evaluate infiltration of basement air into sub-slab media during air extraction (purging + sampling). The first method consisted of sequentially collecting five one-liter Tedlar bag samples at a flow rate of 1 standard liter per minute and comparing vapor concentration of four VOCs associated with vapor intrusion as a function of extraction volume. This was performed at three locations with little effect on sample concentration. This testing also indicated the absence of rate-limited mass exchange during air extraction. Replicate canister

samples representing extraction volumes of 5 to 9 and 10 to14 liters were compared at two locations with similar results. A second method was then employed which utilized a mass balance equation and sub-slab and basement air concentrations. When sensitivity of the method permitted, infiltration was shown to be less than 1% at sampled locations. A third method involved simulating streamlines and travel time in sub-slab media during air extraction. Air permeability testing in sub-slab media was conducted to obtain estimates of radial and vertical air permeability to support air flow simulations. Simulations indicated that less than 10% of air extracted during purging and sampling could have originated as basement air when extracting up to 12 liters of air. Overall, extraction volumes used in this investigation (up to 14 liters) had little or no effect on sample results.

To assess the need for an equilibration period after probe installation, advective air flow modeling with particle tracking was employed to establish radial path lengths for diffusion modeling. Simulations indicated that in sub-slab material beneath homes at the Raymark site (sand and gravel), equilibration likely occurred in less than 2 hours. Sub-slab probes in this investigation were allowed to equilibrate for 1 to 3 days prior to sampling. A mass-balance equation was used to estimate the purging requirement prior to sampling. Simulations indicated that collection of 5 purge volumes would ensure that the exiting vapor concentration was 99% of the entering concentration even if vapor concentration inside the sample system had been reduced to zero concentration prior to sampling.

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List of Chemical Abbreviations

1,1,1-TCA	1,1,1-trichloroethane
1,1-DCE	1,1-dichloroethylene
TCE	trichloroethylene
c-1,2-DCE	cis-1,2-dichloroethylene
1,1-DCA	1,1-dichloroethane
1,2-DCA	1,2-dichloroethane
PCE	perchloroethylene
CH_2Cl_2	methylene chloride
$CHCl_3$	chloroform
CCl_4	carbon tetrachloride
CCl_3F	trichlorofluoromethane (F-11)
CCl_2F_2	dichlorodifluoromethane (F-12)
$CHBrCl_2$	bromodichloromethane
CH_3CH_2Cl	chloroethane
CCl_3CF_3	trichlorotrifluoroethane (F-113)
THF	tetrahydrofuran
MEK	methyl ethyl ketone
MIBK	methyl isobutyl ketone
MTBE	methyl tert-butyl ether
1,2,4-TMB	1,2,4-trimethylbenzene
1,3,5-TMB	1,3,5-trimethylbenzene
CS_2	carbon disulfide

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Executive Summary

This report describes the results of an investigation conducted to assist EPA's New England Regional Office in evaluating vapor intrusion at 15 homes and one commercial building near the Raymark Superfund Site in Stratford, Connecticut. Ground water beneath these homes is contaminated with 1,1,1-trichloroethane, 1,1-dichloroethylene, trichloroethylene, cis-1,1-dichloroethylene, and 1,1-dichloroethane. Methods were developed to sample sub-slab air and use basement and sub-slab air measurements to evaluate vapor intrusion on a building-by-building basis. A volatile organic compound (VOC) detected in basement air was considered due primarily to vapor intrusion if: (1) the VOC was detected in ground water or soil gas in the vicinity (e.g., 30 meters) of a building, and (2) the null hypothesis that the basement/sub-slab air concentration ratio of the VOC was equal to the basement/sub-slab air concentration ratio of an indicator VOC could not be rejected using a one-tailed Approximate t-Test at a level of significance less than or equal to 0.05. An indicator VOC was defined as a VOC detected in sub-slab air and known to be associated only with sub-surface contamination (i.e., no outdoor or indoor air sources). The VOCs 1,1-dichloroethylene and 1,1-dichloroethane were considered indicator VOCs in this investigation because they are degradation products of 1,1,1-trichloroethane and not commonly associated with commercial products. The VOC cis-1,2-dichloroethylene was considered an indicator VOC because it is a degradation product of trichloroethylene and also not commonly associated with commercial products. Using this method of evaluation, VOCs detected in basement air due to vapor intrusion could easily be separated from numerous other halogenated and non-halogenated (e.g., petroleum hydrocarbons) VOCs present in basement air. The variance associated with each basement/sub-slab air concentration ratio was calculated using the method of propagation of errors which incorporated the variance associated with both basement and sub-slab air measurement. An average basement/sub-slab air concentration ratio was computed using concentration ratios of all VOCs detected in basement air and associated with vapor intrusion. The method of propagation of errors was then used to calculate the variance associated with the average basement/sub-slab concentration ratio.

As a matter of necessity, radon was used as an indicator compound at locations where an indicator VOC was not detected in basement air. However, when basement/sub-slab air concentration ratios were compared for radon and indicator VOCs, statistical non-equivalency occurred at three out of the four locations evaluated. At these three locations, the null hypothesis that the basement/sub-slab air concentration ratio of radon was equal to the basement/sub-slab air concentration ratio of the indicator VOC, 1,1-DCE, was rejected using a two-tailed Approximate t-Test at a significance level less than or equal to 0.1. There was a visual dissimilarity between the basement/sub-slab air concentration ratio of radon and VOCs associated with vapor intrusion. This was in contrast to visual and statistical (levels of significance always greater than 0.1) similarity of basement/sub-slab air concentration ratios of indicator VOCs and other VOCs associated with vapor intrusion. These two observations indicate, at least in this investigation, use of indicator VOCs was preferable to radon in assessing vapor intrusion. Further research is needed at other sites containing indicator VOCs to determine the usefulness of radon in assessing vapor intrusion.

Holes for sub-slab probes were drilled in concrete slabs using a rotary hammer drill. Probes were designed to allow for collection of air samples directly beneath a slab and in sub-slab media. Three to five probes were installed in each basement. Fifty-five probes were installed in 16 buildings which, on average, resulted in placement of one probe every 220 ft^2. Observation of high coefficients of variation in sub-slab air concentrations (greater than 100% at several locations), and the need for statistical analysis in assessing basement/sub-slab air concentration ratios, indicated that placement of multiple probes in sub-slab media was necessary to evaluate vapor intrusion. Generally, one sub-slab vapor probe was centrally located while two or more probes were placed within one or two meters of basement walls in each building. In this investigation, placement of a probe in a central location did not ensure detection of the highest VOC concentrations in sub-slab media. Schematics illustrating the location of sub-slab probes and other slab penetrations (e.g., suction holes for sub-slab permeability testing) were prepared for each building to document sample locations, interpret sample results, and design corrective measures.

Basement and sub-slab air samples were collected and analyzed for VOCs using six-liter SilcoCan canisters and EPA-Method TO-15. Sub-slab air samples were also collected in one-liter Tedlar bags using a peristaltic pump and analyzed on-site for target VOCs by EPA's New England Regional Laboratory within 24 hours of sample collection. Open-faced charcoal canisters were used to sample radon gas in basement air over a 48-hour period. Scintillation cells and a peristaltic pump were used to sample radon gas in sub-slab air. Scintillation cells were analyzed within four hours using a portable radiation monitor to count and amplify light pulses.

Three methods were used to evaluate infiltration of basement air into sub-slab media during air extraction (purging + sampling). The first method consisted of sequentially collecting five one-liter Tedlar bag samples at a flow rate of 1 standard liter per minute and comparing vapor concentration of four VOCs associated with vapor intrusion as a function of extraction volume. This was performed at three locations with little effect on sample concentration. This testing also indicated the absence of rate-limited mass exchange during air extraction. Replicate canister samples representing extraction volumes of 5 to 9 and 10 to 14 liters were compared at two locations with similar results. A second method was then employed which utilized a mass balance equation and sub-slab and basement air concentrations. When sensitivity of the method permitted, infiltration was shown to be less than 1% at sampled locations. A third method involved simulating streamlines and travel time in sub-slab media during air extraction. Air permeability testing in sub-slab media was conducted to obtain estimates of radial and vertical air permeability to support air flow simulations. Simulations indicated that less than 10% of air extracted during purging and sampling could have originated as basement air when extracting up to 12 liters of air. Overall, extraction volumes used in this investigation (up to 14 liters) had little or no effect on sample results.

To assess the time required after probe installation for sampling (equilibration period), advective air flow modeling with particle tracking was employed to establish radial path lengths for diffusion modeling. Simulations indicated that in sub-slab material beneath homes at the Raymark site (sand and gravel), equilibration likely occurred in less than 2 hours. Sub-slab probes in this investigation were allowed to equilibrate for 1 to 3 days prior to sampling. A mass-balance equation was used to estimate the purging requirement prior to sampling. Simulations indicated that collection of 5 purge volumes would ensure that the exiting vapor concentration was 99% of the entering concentration even if vapor concentration inside the sample system had been reduced to zero concentration prior to sampling. A purge volume for the sample train used in homes near the Raymark site was typically less than 10 cm^3.

In summary, this report constitutes an important first step in the development of a technical resource document on sub-slab air sampling and use of indoor and sub-slab air samples to assess vapor intrusion.