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Environmental Technology Verification Program

Advanced Monitoring Systems Center

Quality Assurance Project Plan for Verification of Building Pressure Control for the Assessment of Vapor Intrusion

ETV ETV ETV

QUALITY ASSURANCE PROJECT PLAN

for

Verification of
Building Pressure Control
for the Assessment of Vapor Intrusion

Version 1.0

October 1, 2010

Prepared by

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SECTION A

PROJECT MANAGEMENT

A1 VENDOR APPROVAL PAGE

ETV Advanced Monitoring Systems Center

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October 1, 2010
APPROVAL:

Name ______________________________

Company ___________________________

Date _______________________________

Disclaimer

The U.S. Environmental Protection Agency, through its Office of Research and Development, partially funded, managed, and collaborated in, the research described herein. It has been subjected to the Agency's peer and administrative review. Any opinions expressed in this report are those of the author(s) and do not necessarily reflect the views of the Agency, therefore, no official endorsement should be inferred. Any mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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A3 LIST OF ACRONYMS AND ABBREVIATIONS

1,1-DCE	1,1-dichloroethylene
ΔP	differential pressure
ΔF_{VI}	error in F_{VI}
AA	ambient air
AER	air exchange rate
ADQ	audit of data quality
AMS	Advanced Monitoring Systems
ASU	Arizona State University
BL	baseline
COA	certificates of analysis
CoC(s)	contaminant(s) of concern
DQIs	data quality indicators
DQOs	data quality objectives
EPA	U.S. Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
ETV	Environmental Technology Verification
F_{VI}	fractional contribution of vapor intrusion to the indoor concentration of a CoC
GC/ECD	gas chromatography with electron capture detection
GC/MS	gas chromatography/mass spectrometry
Hg	mercury
IA	indoor air
IO	indoor/outdoor
LRB	laboratory record book
MDL	method detection limit
NAVFAC	Naval Facilities Engineering Command
NIOSH	National Institute of Occupational Safety and Health
NP	negative pressure
$pCi\ L^{-1}$	picocuries per liter
Pa	pascal
PCE	perchloroethylene (tetrachloroethylene)
PP	positive pressure
PVF	polyvinyl fluoride
QA	quality assurance
QAO	Quality Assurance Officer
QAPP	quality assurance project plan
QC	quality control
QMP	Quality Management Plan
RPD	relative percent difference
SF_6	sulfur hexafluoride
SIM	single ion monitoring
SPAWAR	Space and Naval Warfare Systems Command
SS	subslab
TCE	trichloroethylene
TSA	technical systems audit

$\mu g\ m^{-3}$	microgram per cubic meter
VI	vapor intrusion
VOC	volatile organic compound
VTC	Verification Test Coordinator

A4 DISTRIBUTION LIST

(See Appendix A for technical panelists and QAPP contributors)

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A5 VERIFICATION TEST ORGANIZATION

The verification test described in this document will be conducted under the U.S. Environmental Protection Agency's (EPA's) Environmental Technology Verification (ETV) Program. Testing will be performed by the technology vendor with direction and oversight from Battelle, which is managing the ETV Advanced Monitoring Systems (AMS) Center through a cooperative agreement with the EPA. The scope of the AMS Center covers verification of monitoring technologies for contaminants and natural species in air, water, and soil. In addition to participation by the technology vendor, Battelle and a representative from the U.S. Navy Naval Facilities Engineering Command (NAVFAC) Atlantic will provide independent quality assurance (QA) oversight for this verification test. The EPA AMS Center Quality Manager may also provide independent QA oversight, at her discretion. This testing has been established as an EPA Quality Category III. The subject technology is concurrently being evaluated in a project sponsored by the Environmental Security Technology Verification Program (ESTCP) Project ER-0707. The subject verification effort has received funding from the Navy Environmental Sustainability Development to Integration Program, as part of Project 424 on "Improved Assessment Strategies for Vapor Intrusion (VI)."

This verification test will be coordinated and directed by Battelle in cooperation with the EPA, with the support of the technology vendor staff and the NAVFAC QA Auditor, at two different field sites. Field testing at two different buildings will be conducted over two separate, three-day periods: at the VI research house owned by Arizona State University (ASU) near Hill Air Force Base in Utah; and at Building 107 located at the Navy facilities in Moffett Field, CA. The technology testing will involve the sequential implementation of a set of indoor air (IA), ambient air (AA), and subslab (SS) air monitoring and sampling procedures while the candidate buildings are under three different pressures: baseline (no pressure manipulation), negative pressure, and positive pressure. Building pressures will be manipulated and controlled over the duration of each 24-hour pressure testing period and samples will be collected as designated in this plan. The technology vendor, GSI Environmental Inc., will install/operate the equipment, and conduct the testing at each site as part of the vendor's ESTCP project (ESTCP Project ER-0707); Battelle staff will provide oversight during the verification test.

The organization chart in Figure 1 identifies the responsibilities of the organizations and individuals associated with the verification test. Roles and responsibilities are defined further below.

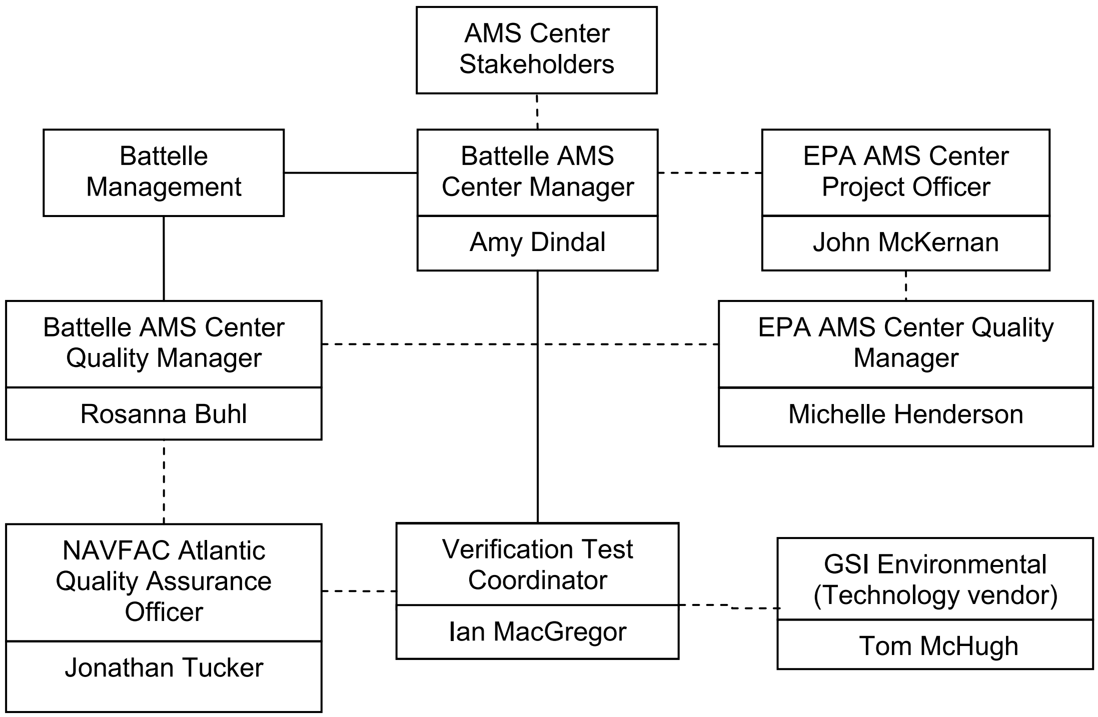

Figure 1. Organizational Chart

A5.1 Battelle

Mr. Ian MacGregor is the AMS Center Verification Test Coordinator (VTC) for this test. In this role, Mr. MacGregor will have overall responsibility for ensuring that the technical, schedule, and cost goals established for the verification test are met. Specifically, he will:

- Coordinate with the technology vendor to ensure that a team of qualified technical staff is in place to conduct the verification test;
- Hold a kick-off meeting approximately one week prior to the start of the verification test to review the critical logistical, technical, and administrative aspects of the

verification test. Responsibility for each aspect of the verification test will be confirmed;

- Oversee the technology vendor staff and the vendor's subcontractors, as appropriate, to perform verification test in accordance with this Quality Assurance Project Plan (QAPP);
- Ensure that all quality procedures specified in the QAPP and in the AMS Center Quality Management Plan[1] (QMP) are followed;
- Maintain real-time communication with the Battelle AMS Center Manager and EPA AMS Center Project Officer and QA Manager on any potential or actual deviations from the QAPP;
- Provide test data, including data from the first day of testing, to the Battelle AMS Center Manager and EPA AMS Center Project Officer and QA Manager;
- Conduct a technical review of all test data. Designate an appropriate Battelle technical staff member to review any data generated by the VTC, if applicable;
- Revise the draft QAPP, verification report, and verification statement in response to stakeholder, collaborator, vendor, and reviewer comments;
- Respond to any issues raised in assessment reports and audits, including instituting corrective action as necessary;
- Serve as the primary point of contact for the vendor representatives;
- Coordinate distribution of the final QAPP, verification report, and statement; and
- Establish a budget for the verification test and manage staff to ensure the budget is not exceeded.

<u>Ms. Amy Dindal</u> is Battelle's manager for the AMS Center. Ms. Dindal will:

- Review the draft and final QAPP;
- Review the draft and final verification report and verification statement;
- Ensure that necessary Battelle resources, including staff and facilities, are committed to the verification test;
- Ensure that confidentiality of sensitive vendor information is maintained;

- Maintain communication with EPA's AMS Center Project Officer and Quality Manager; and
- Facilitate a stop-work order if Battelle, EPA, or NAVFAC Atlantic QA Officer (QAO) discovers adverse findings that will compromise data quality or test results.

Ms. Rosanna Buhl is Battelle's Quality Manager for the AMS Center. Ms. Buhl will:

- Review the draft and final QAPP;
- Coordinate audits with the NAVFAC Atlantic QAO for this verification test, including providing example checklists and audit reports for use as a template;
- Review any audit checklists prepared by the QAO for completeness and detail;
- Review draft and final audit reports prior to release to the VTC and/or EPA for clarity and appropriate assessment of findings;
- Review audit responses for appropriateness;
- Review and approve any deviations, if applicable;
- Review the draft and final verification report and verification statement;
- Maintain real-time communication with the QAO on QA activities, audit results, and concerns;
- Work with the QAO, VTC, and Battelle's AMS Center Manager to resolve data quality concerns and disputes; and
- Recommend a stop-work order if audits indicate that data quality or safety is being compromised.

A5.2 U.S. Navy

Mr. Jonathan Tucker of NAVFAC Atlantic will be the QAO for this test. Mr. Tucker will:

- Participate in the verification test kick-off meeting and co-lead, along with Ms. Buhl, the discussion of the QA elements of the kick-off meeting checklist;
- Verify the presence of applicable training records prior to the start of verification testing;
- Conduct a technical systems audit (TSA) during the first of the two field campaigns;

- Conduct a TSA at the second of the two field campaigns should any quality issues be identified during the first field campaign;
- Conduct audits of data quality (ADQs) for both field campaigns to verify data quality;
- Prepare and distribute an audit report to the Battelle Quality Manager for each audit;
- Verify that audit responses for each audit finding and observation are appropriate and that corrective action has been implemented effectively;
- Communicate to the VTC and/or vendor technical staff the need for immediate corrective action if an audit identifies QAPP deviations or practices that threaten data quality, including recommending the need for a stop-work order if audits indicate that data quality or safety is being compromised;
- Provide a summary of the QA/quality control (QC) activities and results for the verification reports;
- Review the draft and final QAPP, verification report, and verification statement; and
- Maintain real-time communication with the Battelle Quality Manager on QA activities, audit results, and concerns, including potential schedule and budget problems.

A5.3 Vendor

GSI Environmental, Inc. is the VI pressure control technique vendor. Dr. Thomas McHugh will be the lead for GSI. GSI's responsibilities will be as follows:

- Review and provide comments on the draft QAPP;
- Approve the final QAPP prior to test initiation;
- Carry out testing exactly as described in the QAPP, and notify the Battelle VTC of any non-conformance to QAPP procedures;
- Provide all equipment, supplies, sampling vessels, and monitoring instruments needed to carry out the pressure control sampling methodology for the duration of the verification test;
- Prepare all SS sample points, carry out building pressurization/depressurization, collect all air samples, and perform all real-time monitoring for the testing at the two field sites, as described in this QAPP;

- Provide the data from the real-time monitoring instruments to the Battelle VTC within one week of collection;
- Provide the data from all off-site laboratory analyses within one week after the results of the analyses are delivered to the vendor; and
- Review and provide comments on the draft verification report and statement.

A5.4 EPA

EPA's responsibilities are based on the requirements stated in the "Environmental Technology Verification Program Quality Management Plan"[2] (ETV QMP). The roles of specific EPA staff are as follows:

Ms. Michelle Henderson is EPA's AMS Center QA Manager. Ms. Henderson will:

- Review the draft QAPP;
- Review the first day of data from the verification test and provide immediate comments if concerns are identified;
- Perform, at her option, one external TSA and/or ADQ during the verification test;
- Notify the EPA AMS Center Manager of the need for a stop-work order if the external audit indicates that data quality or safety is being compromised;
- Prepare and distribute an assessment report summarizing results of the external audit; and
- Review the draft verification report and statement.

Dr. John McKernan is EPA's Project Officer for the AMS Center. Dr. McKernan will:

- Review the draft QAPP;
- Approve the final QAPP;
- Review and approve deviations to the approved final QAPP;
- Appoint a delegate to review and approve deviations to the approved final QAPP in his absence, so that testing progress will not be delayed. Review the first day of data from the verification test and provide immediate comments if concerns are identified;
- Review and approve the draft verification report and statement;
- Oversee the EPA review process for the verification report and statement; and

- Coordinate the submission of verification report and statement for final EPA approval.

A5.5. Verification Test Stakeholders

A Technical Panel of stakeholders was specifically assembled for the preparation of this QAPP. Appendix A presents a list of participants in the Technical Panel. This QAPP and the verification report and verification statement that will be generated based on the testing described in this document will be reviewed by experts in VI. The following experts provided input to this QAPP:

- Paul Johnson, Arizona State University;
- Todd McAlary, Geosyntec Consultants;
- Ronald Mosley, private citizen;
- Lynn Spence, Spence Environmental Engineering;
- Donna Caldwell, U.S. Navy/NAVFAC Atlantic;
- Doug Grosse, U.S. EPA/ORD/NRMRL;
- Mathew Plate, U.S. EPA/Region 9;
- Brian Schumacher, U.S. EPA/ORD/NERL/ESD-LV.

In addition, the VI technology category was reviewed with the broader AMS Center Stakeholder Committees during regular stakeholder teleconferences, including the November 5 and 12, 2009 meetings, and input from those committees was solicited.

A6 BACKGROUND

A6.1 Technology Need

The ETV Program's AMS Center conducts third-party performance testing of commercially-available technologies that detect or monitor natural species or contaminants in air, water, and soil. Stakeholder committees of buyers and users of such technologies recommend technology categories, and technologies within those categories, as priorities for testing. Among the technology categories recommended for performance testing are methods that can be used to determine whether VI is occurring.

VI is the migration of volatile chemicals from the subsurface (from soils and/or groundwater) into the air of overlying buildings.[3] Known health risks result from inhalation exposure to certain volatile contaminants of concern (CoCs) such as the volatile organic compounds (VOCs) trichloroethylene (TCE), tetrachloroethylene (perchloroethylene, PCE), 1,1-dichloroethylene (1,1-DCE), and benzene. Reducing or controlling the risk to human health related to inhalation exposure of CoCs due to VI is the stated goal of many regulatory and governmental agencies. That said, many building owners and regulated entities (such as the U.S. Navy)[4,5] have developed policies and guidance to state that they are not responsible for the mitigation of CoCs in the indoor air of structures in cases where the CoCs are present due to natural or anthropogenic background sources.[a] Thus, the ability to distinguish concentrations of CoCs in background indoor air – defined for CoCs as everything unrelated to the vapors that migrate into the overlying structure (from sources such as household activities, consumer products, and building materials)[6] – from CoCs present due to vapor intrusion is of key importance so that regulated entities can appropriately manage their limited resources when making remediation and mitigation decisions. However, at present there is a lack of regulatory guidance to determine the impact of VI compared to the impact of natural or anthropogenic background sources on indoor concentrations of CoCs. One technique that has shown promise for distinguishing background indoor sources of CoCs from those present due to VI is the manipulation of building pressure.[7,8,9] Verifying the performance of the building pressure control technique for the assessment of the impact of VI on the concentrations of CoCs in indoor air is the subject of the ETV test described in this QAPP.

A6.2 Technology Description

At buildings with concrete (i.e., impermeable) foundations, intentionally inducing negative or positive building pressure – by use of a fan to drive indoor air out of the building, or ambient air into the building, respectively – should enhance or reduce VI. This is the conceptual basis for the building pressure control technique and is shown in Figure 2. Under conditions of induced negative building pressure (top panel), VI should be enhanced; under induced positive building pressure, VI should be stopped or reduced, as shown in the bottom panel. Arrows in the figures

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[a] Navy guidance states that chemicals from background sources should not be considered CoCs. However, for the purpose of this document, the term CoC may refer to chemicals from either background or VI sources.

indicate the expected direction of air flows. Also during implementation of the building pressure control method, various types of air samples are collected to demonstrate VI manipulation, as shown by the various symbols in the figure.

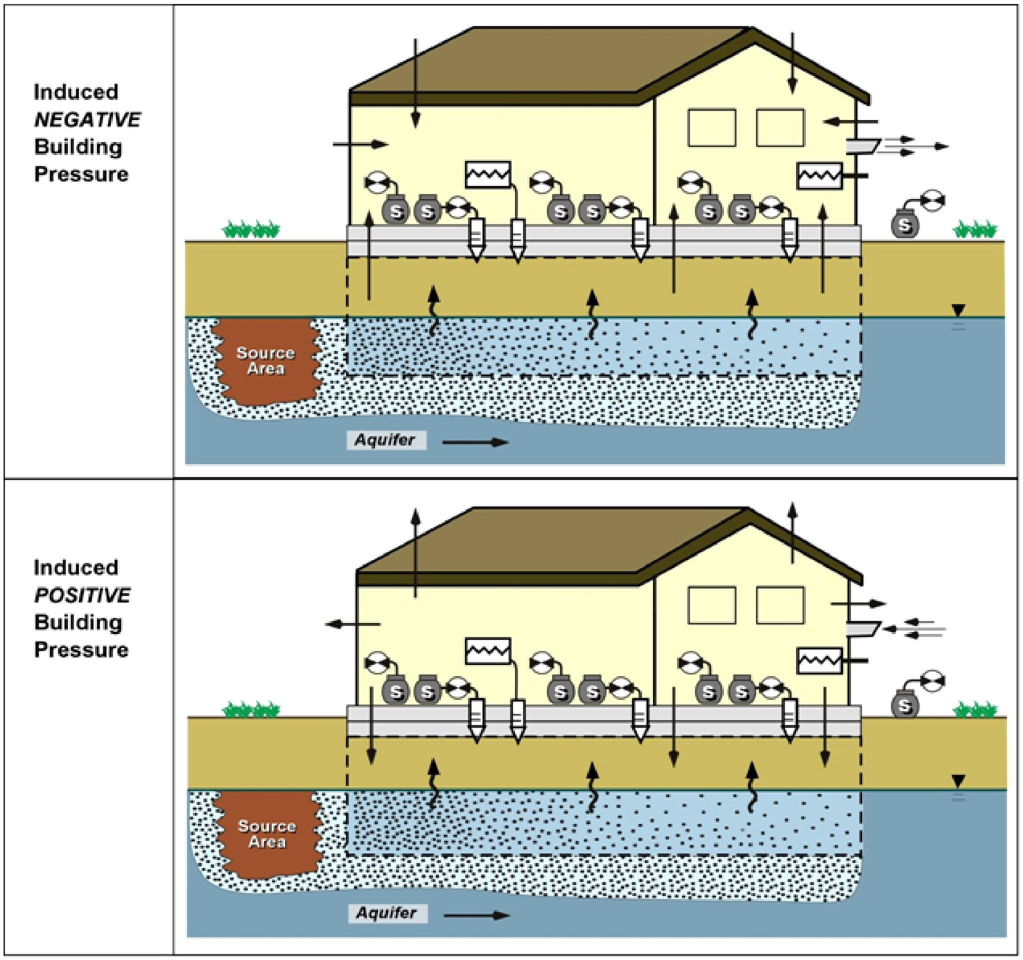

Figure 2. Basis of Building Pressure Control Technique for the Assessment of the Impact of VI on Concentrations of CoCs in Indoor air
(Figure courtesy Dr. Thomas McHugh, GSI.)

To implement the pressure control technique for the assessment of the impact of VI on the indoor air at a given building, testing is planned to take place over approximately 3.5 days. Over the first day and a half, the building is prepared for testing and then operated under baseline (BL) pressure conditions, where building pressure is not manipulated. Over the next 24 hours, a negative pressure (NP) is induced in the building. Over the final 24 hours, a positive pressure (PP) is induced in the building. To accomplish building pressurization and depressurization, building egresses, windows, and other openings are closed[b] and a doorway fan is installed as shown in Figure 3. A window fan may also be used. Fan size and speed will be roughly commensurate with building size.

Figure 3. Fan Installed in Building Doorway to Manipulate Building Pressure
(Photo courtesy Dr. Thomas McHugh, GSI.)

During each day of testing, the inert tracer gas sulfur hexafluoride, SF_6, is released at a known concentration and flow rate from a centralized location in the building. To the extent possible, indoor doors will remain open throughout testing to enhance mixing of the indoor air. The tracer

[b] Doors and windows are closed, but sealing egresses and vents is not attempted.

gas release system used for this purpose is shown in Figure 4.[c] Using the known flow rate of SF_6 and measurements of indoor SF_6 concentrations, building air exchange rate (AER) is determined.

Figure 4. SF_6 Tracer Gas Delivery System for Determination of Building AER
(Photo courtesy Dr. Thomas McHugh, GSI.)

A number of different measurements must also be made to implement the building pressure control technique for assessment of the impact of VI on the concentration of CoCs in indoor air. For instance, real-time measurement of the differential pressure (ΔP) across the building envelope and the building foundation are performed throughout BL, NP, and PP testing. A pressure transducer as shown in Figure 5 records the pressure measurements. To perform the cross-building foundation pressure measurements and other air sampling beneath the building foundation, SS sampling points must be installed prior to implementation of the pressure control technique for assessment of VI.

[c] Tube shown in photo is for subslab sampling and is not part of tracer gas release system.

Figure 5. Real Time Pressure Transducer Installed to Measure Cross-Foundation Pressure Differential
(Photo courtesy Dr. Thomas McHugh, GSI.)

Finally, several different types of air samples from inside, outside, and below the building – IA, AA, and SS gas, respectively – must also be collected to characterize concentrations of various CoCs, SF_6, and radon in these various compartments. The measurement of CoCs is required so that contributions of VI and ambient sources to concentrations in IA may be determined. Determination of SF_6 in IA allows for building AER to be calculated, and measurement of SF_6 in SS gas allows for IA-to-SS infiltration (if any) to be determined. Finally, radon occurs naturally in soil gas due to the radioactive decay of uranium; as a result, radon can be present in ambient air at concentrations of 0.2 to 0.7 picocuries per liter (pCi L^{-1}).[10] Measurement of indoor and ambient radon under the different conditions of building pressure allows for the determination of whether vapor intrusion is enhanced or reduced. For instance, if indoor radon concentrations are greater under negative pressure conditions than under BL conditions, then VI has been enhanced.[d]

[d] Note that this concentration comparison assumes that both building air exchange rates and ambient radon concentrations are similar under both baseline and negative pressure conditions. Thus, such a comparison is oversimplified and a more robust analysis must be conducted to determine if VI has been enhanced under NP conditions.

On the other hand, if indoor radon concentrations under positive pressure conditions are equal to ambient air radon concentrations, then VI has effectively been 'turned off.'

Gas samples for analysis of CoCs and SF_6 are collected into stainless steel sampling canisters, whereas samples for radon analysis are collected into polyvinyl fluoride (PVF) DuPont™ Tedlar® gas sampling bags, or radon is measured in near real-time using an instrument designed for this purpose. While the building is under each of the three pressure conditions (BL, NP, and PP), IA and SS concentrations of CoCs, SF_6, and radon are measured at three different spatially distributed locations throughout the building; in addition, CoCs and radon in AA are also measured in one outdoor sample collected while the building is under each of the three different pressure conditions. Shown schematically in Figure 6 is the SF_6 delivery system, SS sampling for radon into PVF bags, and IA sampling for VOCs and SF_6 into a stainless steel canister. Canisters and PVF bags are delivered to separate off-site contract analytical laboratories for gas analysis.

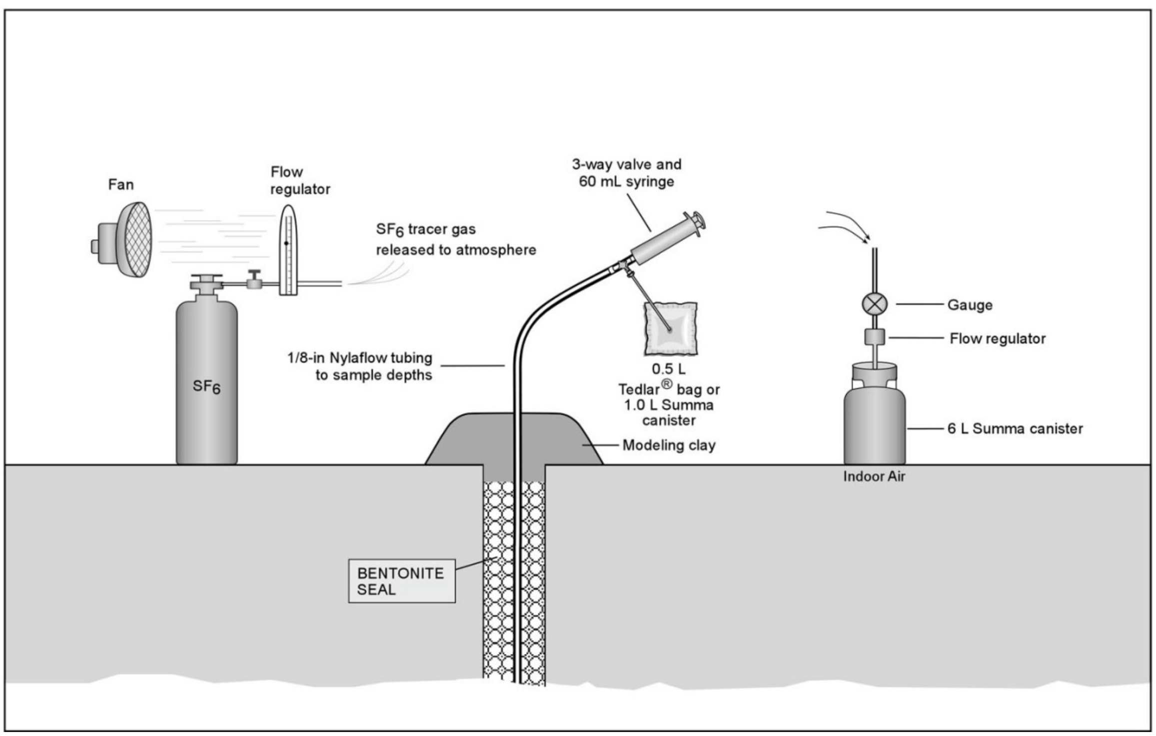

Figure 6. (Left to right) Delivery of SF_6 to the Building Atmosphere; Collection of SS Air Sample with a PVF Bag; and Collection of an IA Sample into a Stainless Steel Canister **(Figure courtesy of Dr. Thomas McHugh, GSI.)**

A7 VERIFICATION TEST DESCRIPTION AND SCHEDULE

A7.1 Verification Test Description

The purpose of this verification test is to generate performance data on the use of the building pressure control technique as a method to assess the impact of VI on the concentrations of CoCs in indoor air. Quantitative performance metrics will be based on assessing how well a building's pressure can be controlled using an installed fan; if vapor intrusion can be enhanced and reduced using building pressure control; and what fraction of a given CoC's indoor air concentration is due to VI. Furthermore, the magnitude of the building pressure that can be induced under negative and positive pressure conditions will be compared at two different buildings. Finally, operational factors will be considered, i.e., what is the cost, time, and level of expertise required to implement the building pressure control technology for the assessment of the impact of VI on concentrations of CoCs in indoor air. The data generated from this verification test are intended to provide organizations and users interested in building pressure control for VI assessment with information on the potential use of this methodology.

The IA model[11] developed by Dr. Ronald Mosley, EPA (retired), will be utilized to calculate one of the quantitative verification parameters for this ETV test, namely F_{VI}, the fraction of CoCs in IA concentration that is due to VI. The Mosley model is presented and described in Appendix B of this QAPP. Furthermore, several other verification parameters will be stated mathematically using the Mosley model notation, as this will facilitate the presentation and calculation of these verification parameters. Performance parameters also include other notation developed based on Mosley's use of superscripts and subscripts to specify building pressure, as shown in Table 1.

Table 1. Mosley Model Notation Used for Description of Several Verification Parameters

Parameter, units	Subscripts	Superscripts
R = radon concentration, pCi m^{-3}	i = indoor air	+ = positive pressure
Q = flow rate, $m^3 h^{-1}$	a = ambient air	- = negative pressure
C = CoC concentration, µg m^{-3}	s = soil gas	(no superscript) = baseline conditions (no pressure perturbation)
T = tracer gas concentration, µg m^{-3}	T = tracer	
G = generation rate of a compound by indoor sources, µg h^{-1} or pCi h^{-1}	C = CoC	
E = entry rate of a compound from a subsurface source, µg h^{-1} or pCi h^{-1}	R = radon	
F = fractional contribution of the concentration of a CoC, unitless	VI = vapor intrusion	
Other symbols and values: V = building volume, m^3 λ = radioactive decay constant for radon, 0.1805 d^{-1} = 0.007251 h^{-1} Q_i/V = air exchange rate (AER), h^{-1}		

Subsequent to the verification test, Battelle will draft a verification report and verification statement for the pressure control technology. The report will be reviewed by the technology vendor and by peer reviewers, revised, and submitted to EPA. In performing the verification test, Battelle will follow the technical and QA procedures specified in this QAPP and will comply with the data quality requirements in the AMS Center QMP.[1]

A7.2 Proposed Testing Schedule

Technology vendor staff, with oversight from Battelle, will implement the building pressure control test at two different buildings. At each building, a single pressure control test will last approximately 3.5 days.

Table 2 shows the planned schedule of testing and data analysis/reporting activities to be conducted in this verification. The verification test is planned to begin in October 2010 and be completed in February 2011.

Table 2. Planned Verification Test Schedule

Test	Approximate Date(s)	Building	Testing Activities	Data Analysis and Reporting
1	October 2010	ASU VI Research House, near Hill Air Force Base, UT	Perform a single building pressure control experiment over three and one half days	Begin preparation of report template Conduct TSA Review and summarize testing staff observations Compile data from real-time analyzers Conduct ADQ
2	October – November 2010	Moffett Field, California Building 107	Perform a single building pressure control experiment over three and one half days	Review and summarize testing staff observations Conduct TSA Compile data from real-time analyzers Conduct ADQ Begin data analysis
	December 2010			Complete draft report(s) Conduct ADQ
	January 2011			Complete peer review of draft report(s)
	February 2011			Revise draft report(s) Submit final report for EPA approval

A7.3 Field Testing Site Selection

Field tests of the building pressure control technique for the assessment of VI will be conducted at two different buildings. To increase the likelihood that the building pressure control methodology can determine the extent to which VI is impacting concentrations of CoCs in indoor air, two buildings at which VI is fairly well characterized have been selected for testing. The selected buildings overlay plumes of CoCs dissolved in underground water, and both buildings are fairly small; thus, building pressure should be fairly easy to control. Access to the buildings and cooperation of the building owners/operators have been arranged in order to install SS gas sampling points, to collect IA and SS samples over several days, and to install a fan in a window or door to manipulate the building pressure. The buildings may remain occupied during testing and the disruption to building occupants will be kept to a minimum.

A7.3.1 ASU Research House, near Hill Air Force Base, Utah

ASU purchased this research house for use on Strategic Environmental Research and Development Program Project ER-1686. It has a partially below-grade finished basement with a single story living space above the basement. This building overlies a dissolved plume of TCE and 1,1-DCE, and as part of the work on ER-1686, ASU has confirmed that VI of these compounds is occurring at this building. Furthermore, ASU has deployed a near real-time gas chromatograph mass spectrometer (GC/MS), the HAPSITE® Smart Chemical Identification System (Inficon, East Syracuse, New York), with which the IA concentrations of CoCs can be monitored every two hours. Tracking IA CoC concentrations with respect to time during building pressurization/depressurization will allow the confirmation that new steady state building conditions have been achieved over the 12-hour equilibration period.

A7.3.2 Moffett Field, California

A number of buildings at Moffett Field are impacted by subsurface sources of TCE and PCE.[12] The proposed site for testing is at Building 107, which is used by the U.S. Navy. It is a single story slab on-grade structure, approximately 500 ft^2 in area.

A8 QUALITY OBJECTIVES AND CRITERIA FOR MEASUREMENT DATA

The primary objective of this verification test is to evaluate the capability of the building pressure control technique to provide decision-makers with the quantitative information required to determine the extent to which CoCs are present in indoor air as a result of VI. Thus, to ensure that this verification test provides suitable data for a robust evaluation of performance, a data quality objective (DQO) has been established. Under building and site conditions where VI contributes substantially to indoor air concentrations, F_{VI}, the factional contribution of VI to a CoC's indoor air concentration, will be greater than the estimated error in F_{VI}, ΔF_{VI}. If such a relationship holds, then decision-makers will have a reasonable degree of confidence that the building pressure control technique provides robust evidence for use in a VI investigation.

To ensure that this verification test meets the above DQO and provides suitable data for a robust evaluation of performance, data quality indicators (DQIs) have been established. DQIs are established for the accuracy of the tracer gas flow rate, as well as for the measurements of the IA concentrations of SF_6 and CoCs. The DQIs are presented in Table 3 along with the test-specific acceptance criteria for each DQI. The acceptance criteria for the various DQIs are based on knowledge of the typical accuracy limits of flow rate measurements and instrumental analysis. Based on these acceptance criteria, a detailed error analysis is presented in Appendix C to determine how large F_{VI} must be in order to reasonably conclude that VI is impacting the IA (i.e., under what conditions is $F_{VI} > \Delta F_{VI}$, based on reasonably attainable acceptance criteria for the DQIs). Other quantitative performance parameters for vendor technology performance are discussed in Section B.

Table 3. DQIs and Acceptance Criteria for Critical Pressure Control Technology Measurements

DQI	Method of Assessment	Frequency	Acceptance Criteria	Corrective Actions
Accuracy of SF_6 tracer gas delivery rate	Comparison to independent flow transfer standard	Before and after each pressure perturbation test at each building	± 10% percent difference	Investigate discrepancy. Inspect rotameter and repair/replace, as needed.
Accuracy of the measurement of the concentration of SF_6 in indoor air	Inspection of recovery of matrix spikes	One matrix spike generated with each sample batch[a]	80 to 120 % recovery	Investigate discrepancy. Request reanalysis of sample batch, if possible. Determine impact that greater analytical variability has on DQO.
Accuracy of the measurement of the concentration of CoCs in indoor and ambient air	Inspection of recovery of matrix spikes	One matrix spike generated with each sample batch	70 to 130 % recovery	Investigate discrepancy. Request reanalysis of sample batch, if possible. Determine impact that greater analytical variability has on DQO.

[a] A batch of samples is defined to comprise no more than 20 individual samples.

The accuracy of the rotameter that delivers the SF_6 tracer gas will be verified using an independent, calibrated flow transfer standard. If greater than 10% difference is found, Battelle will investigate the discrepancy and oversee the appropriate remedial action, such as repairing or replacing the rotameter. Additionally, Battelle will ensure that matrix spikes performed during the off-site analyses of SF_6 and VOCs show recoveries between 80 and 120% and 70 to 130%, respectively.

The NAVFAC Atlantic QAO will perform a TSA of field-based testing activities to augment these QA/QC requirements. A TSA of the testing activities at the first and second test building will be performed. The NAVFAC Atlantic QAO will also perform an ADQ to verify attainment of the acceptance criteria for the accuracy of the SF_6 and VOC matrix spikes. The EPA Quality Manager also may conduct an independent TSA, at her discretion.

A9 SPECIAL TRAINING/CERTIFICATION

Documentation of training related to technology testing, field testing, data analysis, and reporting is maintained in the Battelle VTC's training file. Battelle technical staff supporting this verification test has a minimum of a bachelor's degree in science/engineering. Battelle technical staff involved in this verification test will have experience with the collection of air samples and a background in analytical chemistry. Site owners/operators will provide technology vendor and Battelle staff with any relevant safety information for the two field sites.

A10 DOCUMENTATION AND RECORDS

The documents for this verification test will include this QAPP, certificates of analysis (COA), analytical methods or standard operating procedures, instrument calibration records, vendor instructions, verification reports, verification statements, and audit reports. The project records will include laboratory record books (LRBs), chain-of-custody forms, data collection forms, results of any and all laboratory analyses, supporting laboratory records, training records, electronic files (both raw data and spreadsheets), and QA audit files. Section B10 summarizes data management for the test and the types of data to be recorded. All of these records will be maintained by the VTC during the test and will be transferred to secure storage at Battelle's Records Management Office at the conclusion of the verification test. The VTC will not be present to oversee testing during the second field test at Moffett Field. However, the VTC will conduct a daily debrief with vendor staff (and the NAVFAC Atlantic QAO, if present) during the second field campaign. Daily activities will be summarized and pertinent data will be shared. In addition, if the NAVFAC QAO is not onsite during field testing at the second building, Battelle will arrange to have a staff person at the site for one day to provide independent observations and oversight. Documents and records generated during this second test will be stored by the technology vendor in a secure location until they can be transferred to the VTC within one week after generation of the records in question. Furthermore, the technology vendor will share all results of subcontract analytical work within one week of receipt of such results. Electronic documents and records will also be uploaded to a SharePoint site designated for this test and will be provided to EPA upon request. All Battelle LRBs are stored indefinitely by Battelle's Records Management Office; raw data and supporting records are maintained for 10 years and the final report and verification statements for 20 years. EPA will be notified before any files are disposed.

All data generated during the conduct of this project will be recorded directly, promptly, and legibly in ink. All data entries will be dated on the date of entry and signed or initialed by the person entering the data. Any changes in entries will be made so as not to obscure the original entry, will be dated and signed or initialed at the time of the change and shall indicate the reason for the change. Section B10 further details the data recording practices and responsibilities.

SECTION B

MEASUREMENT AND DATA ACQUISITION

B1 EXPERIMENTAL DESIGN

The building pressure control technique will be evaluated on the following performance parameters:

- Decision-making support;
- Comparability; and
- Operational factors.

Three different sub-parameters comprise the performance parameter decision-making support. The ultimate goal of carrying out a building pressure control test is to determine what fraction, if any, of a given CoC's concentration in IA is due to VI. However, to achieve this goal, it first must be understood whether the pressure control technique has indeed manipulated the building pressure to the extent that VI can be enhanced (under negative pressure) and reduced (under positive pressure). Thus, the first sub-parameter under decision-making support is to understand if the building pressure was in fact changed over the course of the building depressurization and pressurization cycles, and if the average pressure differential within each pressure perturbation cycle is greater than 1 Pa. The next step is to consider, by inspection of the IA and AA radon data and building flow rates, whether VI was in fact enhanced under negative pressure conditions and reduced (or stopped) under positive pressure conditions. The last sub-parameter under decision-making support is to calculate the fractional contribution of VI (F_{VI}) for each of several different concentrations of indoor CoCs. F_{VI} will be calculated for four different CoCs at each of the two test buildings. Of the four CoCs, two will be among those expected to have subsurface sources, such as TCE and 1,1-DCE at the ASU VI research house and TCE and PCE at Moffett Field, and two others will be CoCs not expected to be present in IA as a result of VI, such as benzene and toluene. Further, F_{VI} for each CoC will be calculated at each of the two buildings under both positive and negative pressure conditions according to the Mosley model. These conditions are (1) under negative pressure, equation B-25 (see Appendix B) will be combined with equation B-27 to determine F_{VI}; and (2) under positive pressure, depending on the indoor radon concentration results, either equation B-18 (VI reduced) or equation B-32 (VI 'turned off') will be combined with equation B-27 to determine F_{VI}. The error in each F_{VI} (ΔF_{VI}) calculation will also be estimated based on propagation of errors. The error in VI will determine the degree of confidence with which the pressure control technique can ascribe a CoC's indoor concentration to VI; for instance, if $F_{VI} > \Delta F_{VI}$, then there exists a reasonable degree of confidence that VI is contributing to a CoC's indoor air concentration. Furthermore, a p-value and statistical power will be calculated to provide quantitative measures of the confidence in this determination. Given $F_{VI} \pm \Delta F_{VI}$ (and the quantitative statistics), decision-makers may evaluate the impact of VI on the indoor atmosphere by calculation of the indoor concentration of each CoC attributable to VI and comparison of concentration contribution to risk-based residential screening levels.

Comparability of the pressure control technique as implemented between buildings will be determined by observing the difference between building differential pressures achieved under positive and negative pressure conditions at each building. Other metrics, such as comparison of radon concentrations, CoC concentrations, and building air exchange rates are more site-specific and, therefore, inter-site comparisons of these parameters will not be conducted.

Operational performance parameters such as ease of implementation of the pressure control technology and expertise required to carry out the field work and interpret the results will be determined from observations by the Battelle VTC. Information on costs will be provided by the technology vendor.

Throughout the verification test, the building pressurization/depressurization fans, pressure differential monitoring instruments, and tracer gas release system will be operated by the vendor's staff with oversight provided by Battelle staff. In addition, vendor staff will prepare all SS sample points, collect all air samples, operate all air sampling systems, and procure all analytical services. Battelle will interpret the results of all analyses and calculate the quantitative performance parameters and appropriate statistics.

B1.1 Test Procedures

The proposed testing schedule at each of two buildings is shown in Figure 7. Testing will be conducted in concert with sampling and analysis activities that are occurring on the ESTCP project (ESTCP Project ER-0707).

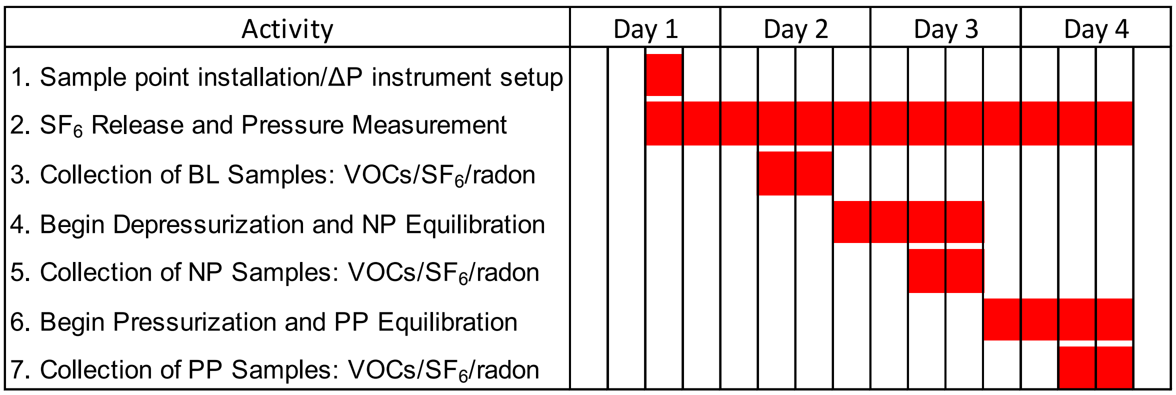

Figure 7. Proposed Test Schedule at Each Building

Over three consecutive days, the building will be maintained for 24 hours at each of the three pressure perturbation conditions. During the first 12 hours at each pressure condition, the building atmosphere will be allowed to come to equilibrium, after which the next 8 to 12 hours will be taken to characterize the concentrations of various species in the building atmosphere.[e]

Work at the field site will begin in the afternoon on the first day of testing, when SS sampling points will be installed. In a given building, three different SS sampling points for air sampling and one SS sampling point for measurement of differential pressure will be installed below the concrete slab. The SS sampling locations will be spatially interspersed throughout the building, and may be located in unobtrusive places such as inside closets. See Figure 8 for installation and construction specifications of the SS sampling points.

[e] Twelve hours is the minimum time for equilibration following a change in building pressure: at a minimum air exchange rate of 0.25 h^{-1}, 3 air changes would occur over 12 hours, after which indoor air concentrations would be $(1 - e^{-3})*100\% = 95\%$ of their expected final equilibrium concentrations. Moreover, given that integrated and other air sampling must occur over the next twelve hours following establishment of the new indoor equilibrium concentrations. 24 hours may be interpreted as the minimum required time for testing at each pressure condition.

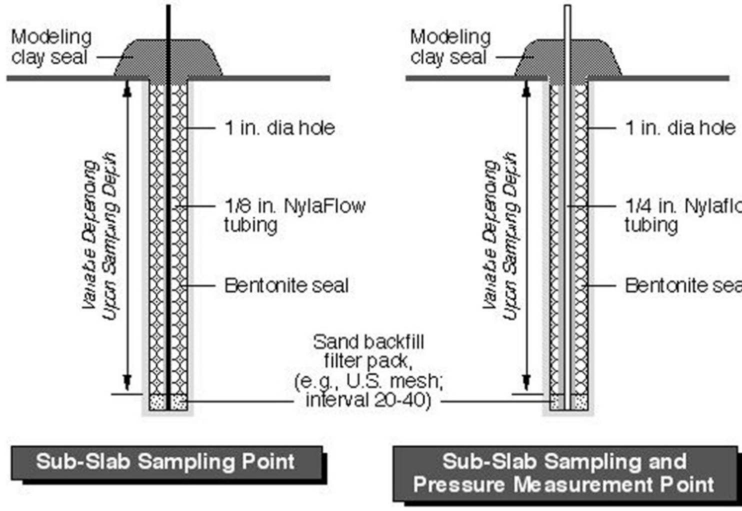

Figure 8. Specifications for Construction of SS Sampling Points for Air Sampling (Left Panel) and Pressure Differential Measurements
(Figure courtesy Dr. Thomas McHugh, GSI.)

Holes extending to a depth of approximately 9 inches below ground surface will be drilled into the concrete using a hammer drill with a 1 inch drill bit. Either 1/8 inch or ¼ inch Nylaflow® (nylon) tubing will be inserted to extend into the length of the borehole. Sand of 20/40 mesh will be packed into the bottom few inches of the borehole and the borehole will be filled with bentonite chips. Water will be added to the bentonite, and the top of the borehole will be sealed with modeling clay to prevent incursion of indoor air into the sub slab, or vice-versa. Completed SS sampling points are shown in Figure 9.

Figure 9. Installed SS Sampling Points
(Photo courtesy Dr. Thomas McHugh, GSI.)

The location of the four different SS sampling points will be documented on the "Site Description and Sampling Locations" data collection form (see Appendix D). The SS point for differential pressure monitoring will be more centrally located within the building. Note that SS sampling points have already been installed at the ASU VI research house, thus this preparation step may be bypassed at this test building.

Following installation of the SS sampling points, indoor/outdoor (IO) building and cross-foundation SS pressure differential measurements will commence using two separate calibrated Omniguard 4® (Engineering Solutions Inc., Tukwila, WA) real-time differential pressure instruments. For the IO measurement, one pressure port on the Omniguard 4® will be open to the indoor atmosphere and the other port will be connected to ¼ inch tubing placed outside of the building envelope, for instance, through a slightly opened window. For the SS measurement, one port on the second Omniguard 4® will be connected to the ¼ inch tubing extending from a SS differential pressure sampling port and the other port will be open to the IA. The same connections to the instruments will be maintained throughout testing so as to maintain consistency with the observed sign of ΔP (negative under NP conditions, and positive under PP conditions). All pertinent data will be recorded on the data collection form entitled "Pressure

Differential Measurements," (see data forms in Appendix D). The minimum and maximum measured pressure differential will be recorded to an internal instrument datalogger every five minutes for the duration of testing (a total of ~84 hours).

The next step in implementing the building pressure control methodology is to begin the release of the tracer gas. The target flow rate of the tracer gas is approximately 50 mL min^{-1} (based on release of 1% SF_6). The flow rate will be independently verified before and after each of the three pressure conditions at each building. Note that the accuracy of the tracer gas flow rate measurement is one of the DQIs discussed in Section A8. The tracer will be released from a central location inside the test building, and will be continued overnight (~12 hours) to allow equilibration of its concentration throughout the building under each of the building pressure conditions.[f] Pertinent details of the operation of the tracer gas release system, including COA information of the certified SF_6 gas standard, and expected and observed flow rates of the tracer gas delivery system will be documented on the "Tracer Gas Release" data collection form (Appendix D). Delivery of the tracer gas will continue for the duration of testing (a total of ~72 hours). Maintaining a steady tracer gas release rate is critical in order to obtain an accurate estimate in the building air exchange rate; thus, the SF_6 release rate will be checked approximately every 16 hours and adjusted if found to have drifted by more than 10%. Drift may occur due to fluctuations in building temperature or gas cylinder pressure. Any such flow rate adjustments will be recorded on the "Tracer Gas Release" data collection form.

In the late afternoon on Days 2 and 3, building pressure will be changed using a fan installed in an outside window or door. NP and PP pressure conditions will be maintained for at least 12 hours before sample collection the next morning to allow the concentrations of the various gas-phase species to come to equilibrium. At the ASU VI research house, the attainment of new equilibrium concentrations for various CoCs will be verified by inspection of IA CoC concentrations as measured by the on-site portable near-real time HAPSITE® GC/MS. Data generated from the HAPSITE® GC/MS will be used as a diagnostic indicator and will not be used to calculate verification parameters.

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[f] Such assumes that after 12 hours the atmosphere of the test buildings is well-mixed.

Beginning on the morning of Days 2, 3, and 4 (for BL, NP, and PP sampling, respectively), after the tracer gas has been well-mixed throughout the test building, and after the indoor chemicals have reached new equilibrium concentrations, gas samples from IA, AA, and the SS will be collected to measure CoCs (VOCs), SF_6, and radon. The numbers of samples and sampling locations are given in Table 4. Specific indoor sampling locations points will be selected as a compromise between attaining spatial representativeness while minimizing disturbance to building occupants and activities. Ambient sampling locations will be selected nominally upwind of the test building, away from obvious VOC sources. Sampling procedures and types of samples collected are described in additional detail below. Pertinent observations and sampling data will be documented as outlined on the "Air Sampling Information" data collection form (Appendix D).

Table 4. Types of Air Samples Collected During Each of the Three Pressure Perturbation Periods

Matrix	Number of Locations	Analyte	Location
Indoor air	3	VOCs, SF_6, radon	Open area on lowest building level plus two additional samples based on building layout.
Ambient air	1	VOCs, radon	Upwind location
Subslab	3	VOCs, SF_6, radon	Three locations distributed across the building foundation.

In order to characterize the concentrations of VOCs, SF_6, and radon in IA, two different types of air samples will be collected at each of three spatially distributed locations throughout the building. At each indoor location, one 8-hour time integrated air sample for analysis of trace level VOCs and SF_6 will be collected into an evacuated 6-L stainless steel canister. Sampling will commence early on Days 2, 3, and 4 and be complete early in the afternoon on each day. Moreover, at each indoor sampling location, a grab sample for radon analysis will be collected into a 500-mL PVF bag using a 60-mL polyethylene syringe and a polymer three-way valve. Each PVF bag will be filled with approximately 250 mL of air in less than five minutes, and the IA grab sampling will be conducted in the afternoon of Days 2, 3, and 4.

Collection of samples for the characterization of the concentrations of VOCs and radon in AA will be performed identically to the sample collection in IA. For VOCs, a single 8-hour composite sample will be collected into an evacuated 6-L stainless steel canister at one outdoor sampling location. For radon, a single PVF bag grab sample will be collected. As with the IA sampling, AA sampling will be performed on Days 2, 3, and 4 of testing.

The measurement of the concentrations of VOCs, SF_6, and radon in SS gas will require collection of several different types of samples. Beginning on the afternoon of Days 2, 3, and 4, one grab sample will be collected at each SS sampling point into an evacuated 1-L stainless steel canister for the measurement of VOC and SF_6 concentrations. Canister grab sampling at each location will be completed in less than one minute. Radon concentrations at each location will be measured using a near real-time instrument, the Durridge (Bedford, MA) RAD7® radon detector. Typically, a total of five readings will be collected, and each reading will be performed over 5 minutes. The average of the final three readings will be used as the radon concentration at that sampling point. Prior to initiating SS sampling at a given sample point, approximately 50 mL of gas will be withdrawn from the sample point using a polyethylene syringe. This SS purge gas will be collected into a PVF bag (for discharge outdoors at a later time) so as to avoid artificially elevating IA concentrations.

At the completion of testing on Day 4, the canister samples will be shipped by common carrier to Columbia Analytical Services (Simi Valley, California) for analysis of VOCs and SF_6, and the PVF bags will be similarly shipped to the University of Southern California (Pasadena), Department of Earth Sciences for radon analysis. Analyses will be performed as specified in Table 5.

Analysis of canister samples for CoCs will be performed using cryogenic preconcentration (GC/MS) according to the procedures outlined in EPA Compendium Method TO-15.[13] The standard full scan TO-15 method will be employed for analysis of CoCs in SS gas. To increase the likelihood that the low levels of CoCs in IA and AA samples will be detected, these samples will be analyzed using TO-15 with single ion monitoring (SIM). The SIM method typically can achieve reporting limits of approximately 0.04 µg m^{-3}. Canister samples for SF_6 will be analyzed using GC/electron capture detection (ECD) according to procedures in National Institute of Occupational Safety and Health (NIOSH) Method 6602.[14] Radon concentrations will be measured by way of alpha scintillation counting following established EPA protocols.[15] Additional details of this method are described by McHugh et al.[16]

Table 5. Methods for the Analysis of Air Samples in Canisters and PVF Bags

Sample type	Target Analyte(s)	Matrix	Analytical Method	Analytical Laboratory
Canister	VOCs	SS	U.S. EPA TO-15	Columbia Analytical Services
Canister	VOCs	IA, AA	U.S. EPA TO-15 SIM	Columbia Analytical Services
Canister	SF_6	IA, SS	NIOSH 6602	Columbia Analytical Services
PVF bag	radon	IA, AA, SS	alpha scintillation	University of Southern California, Department of Earth Sciences

B1.1.1 Decision-Making Support

B1.1.1.1 Building Pressure Differential

One metric for the verification of the performance of the building pressure control methodology is whether the building pressure could be decreased and subsequently elevated at each of the two buildings under NP and PP conditions, respectively. Building pressure control will be verified by inspection of the mean pressure differential across the building envelope that was attained for the 24-hour negative and positive pressure perturbations at each of the two buildings. The Omniguard 4® pressure differential instrument is configured to measure and record the minimum and maximum ΔP every five minutes. The average ΔP for this five minute time interval will be calculated as the arithmetic mean of the minimum and maximum ΔP. Over the approximate 24-hour sampling period for NP and PP, there will be approximately 288 such 5 min arithmetic mean ΔP values. The arithmetic mean of these 288 values will be calculated, and a total of four mean overall pressure differentials will be determined for the two different buildings: (1) ΔP_1^- and ΔP_1^+, the mean differential pressure at building 1 (ASU VI House) under NP and PP conditions, respectively; and (2) ΔP_2^- and ΔP_2^+, the mean differential pressure at building 2 (Moffett Field) under NP and PP conditions, respectively. The standard deviation for each overall mean will also be calculated using the 288 data points. Observed mean pressure differentials less than 1 Pa (under NP conditions) and greater than 1 Pa (under PP conditions) verify that some degree of building pressure control has been attained.

B1.1.1.2 VI Enhancement and Reduction

Under conditions of negative building pressure, the mass transport of chemicals with subsurface sources – including radon and CoCs – into the building atmosphere should be enhanced. Direct measurement of SS to indoor air flow rates is quite difficult; consequently, it is difficult to directly measure SS to IA mass transport. Instead, the radon concentration in indoor air is used as a proxy for subsurface to indoor air transport since the primary source of radon to indoor air is via intrusion from the subsurface (ambient and indoor sources of radon are taken to be negligible compared to subsurface sources). Thus, the performance of the pressure control technique will be investigated at each of the two test buildings as to whether such an enhancement of subsurface to IA chemical transport was observed by comparing the product of the building air flow rate and the IA radon concentration under NP conditions to the product of the building air flow rate and the IA radon concentration under BL conditions. The product of air flow rate ($m^3\ h^{-1}$) and radon concentration ($pCi\ m^{-3}$) is an effective generation rate ($pCi\ h^{-1}$) of radon in IA.

For each building, the mean indoor radon concentration under BL and NP pressure conditions (R_i and R_i^-, respectively, in the notation of the Mosley model) will be determined as the arithmetic mean of the three IA measurements under BL and PP. Q_i, the building air flow rate between indoors and ambient for BL conditions, will be determined from the tracer gas release data:

$$Q_i = \frac{G_T}{T_i} = \frac{C_T Q_T}{T_i}$$

where

G_T = generation rate of SF_6 under BL conditions ($\mu g\ h^{-1}$);
C_T = source concentration of the SF_6 tracer gas ($\mu g\ m^{-3}$);
Q_T = flow rate of the SF_6 tracer gas from the source bottle into the indoor air under BL conditions ($m^3\ h^{-1}$); and
T_i = the mean concentration of the three IA SF_6 measurements under BL conditions ($\mu g\ m^{-3}$).

Q_i^-, the building air flow rate between indoors and ambient for NP conditions will be similarly determined by way of C_T, Q_T^-, and T_i^-.

The degree to which VI has been enhanced under NP conditions will be investigated by comparison of Q_i^- * R_i^- to Q_i * R_i. *If* $Q_i^- * R_i^- > Q_i * R_i$, *then under NP conditions some degree of enhancement of VI has been verified.* A one-sided hypothesis test will provide the statistical support of the comparison of Q_i^- * R_i^- and Q_i * R_i, and a p-value will be calculated and reported in order to provide a quantitative measure of the statistical confidence of the comparison. Failure to find a statistically significant difference between these two quantities could result from either the absence of any underlying difference, or from small sample size and high variability in the data. A retrospective calculation will be employed to estimate the minimum detectable difference with the observed sample size and variability, with 80% power (20% probability of Type II error) and 5% probability of Type I error. To enable the statistical evaluation, propagation of errors will be performed to provide estimates of errors in Q_i^- * R_i^- and Q_i * R_i. The standard deviation of the three individual indoor air measurements under BL and NP conditions will be used for the errors in R_i and R_i^-, respectively; error estimates in Q_i and Q_i^- will be based on percent error estimates of C_T, acceptance limit of the percent error in Q_T, and the standard deviation of the three IA measurements for SF_6 under BL and NP conditions, respectively. (See Appendix B for more information on error estimation techniques.) The comparison described here assumes that $R_a = R_a^-$, i.e., that the ambient radon concentration measured under BL conditions is equal to the ambient radon concentration under NP conditions. R_a and R_a^- are determined by single grab sample measurements of ambient air.

Similarly, under conditions of positive building pressure, the mass transport of chemicals with subsurface sources – including radon and CoCs – into the indoor air of the building should be reduced. Moreover, if transport of chemicals from the subsurface to IA ceases completely under PP conditions, vapor intrusion may be said to be "turned off." Similar to the data treatment for NP conditions, the performance of the pressure control technique will be investigated as to whether such a reduction or elimination of subsurface to IA chemical transport was observed. To do so, the product of the building air flow rate and the IA concentration of radon under PP conditions $Q_i^+ * R_i^+$ will be compared to the product of the building air flow rate and the IA radon concentration under BL conditions, $Q_i * R_i$.

The building air flow rate between indoors and ambient for PP conditions (Q_i^+), will be determined using C_T, Q_T^+, and T_i^+, as described above and in a manner similar to Q_i and Q_i^-. R_i^+ will be calculated as the mean of the three IA concentrations measurements of radon under PP conditions. The degree to which VI has been reduced under PP conditions will be investigated by comparison of $Q_i^+ * R_i^+$ to $Q_i * R_i$. *If $Q_i^+ * R_i^+ < Q_i * R_i$, then under PP conditions some degree of reduction of VI has been verified.* A one-sided hypothesis test will provide the statistical support of the comparison of $Q_i^+ * R_i^+$ and $Q_i * R_i$, and a p-value will be calculated and reported in order to provide a quantitative measure of the statistical confidence of the comparison. Failure to find a statistically significant difference between these two quantities could result from either the absence of any underlying difference, or from small sample size and high variability in the data. A retrospective calculation will be employed to estimate the minimum detectable difference with the observed sample size and variability, with 80% power (20% probability of Type II error) and 5% probability of Type I error. To enable the statistical evaluation, propagation of errors will be performed to provide estimates of errors in $Q_i^+ * R_i^+$ and $Q_i * R_i$. Error estimates for Q_i and R_i will be the same as those described earlier in this section. For the estimated error in R_i^+, the standard deviation of the three individual indoor air measurements under PP conditions will be calculated. The estimated error in Q_i^+ will be based on percent error estimates of C_T, acceptance limit of the % error in Q_T, and the standard deviation of the three IA measurements for SF_6 under PP conditions. The comparison described here assumes that $R_a = R_a^+$, i.e., that the ambient radon concentration measured under BL conditions is equal to the ambient radon concentration under PP conditions. (R_a and R_a^+ are determined by single grab sample measurements of ambient air.) It also assumes that the building foundation's concrete slab is cracked or otherwise permeable enough to allow VI to occur.

If some degree of reduction of VI is observed under PP, then an additional comparison will be performed to ascertain whether VI was 'turned off' under PP conditions. Under the assumption that the only source of radon to the IA is the subsurface, and if under PP conditions the radon concentration in IA (R_i^+) drops to the ambient radon concentration measured under PP conditions (R_a^+), then there is some degree of confidence that VI has been stopped or 'turned off' by the application of additional pressure to the building atmosphere. *That is, if $R_i^+ = R_a^+$, then there is some degree of confidence VI been halted under PP conditions.* A two-sided t-test will provide the statistical support for such a comparison, and a p-value will be calculated and reported in order to provide a quantitative measure of the statistical confidence of the comparison. Failure to find a statistically significant difference between R_i^+ and R_a^+ could result from either the absence of any underlying difference, or from small sample size and high variability in the data. A retrospective calculation will be employed to estimate the minimum detectable difference with the observed sample size and variability, with 80% power (20% probability of Type II error) and 5% probability of Type I error. The error in R_i^+ will be as previously described; the relative error in the single measurement of R_a^+ will be estimated as the relative error observed in the three IA radon measurements.

Note that if the radon and/or SF_6 concentration measurements in IA are highly variable, the outcome of the comparisons described in this section may produce equivocal data of limited utility for quantitative verification of the performance of the pressure control technology.

Also note that for instances where measurement of concentrations yield non-detects, the value of the estimated detection limit will be substituted for the non-detect, as appropriate.

B1.1.1.3 Fractional contribution of VI to indoor CoC concentrations

For each of the two buildings, the fractional contribution of VI (F_{VI}) to the IA concentration of four different CoCs will be calculated under both NP and PP conditions – F_{VI}^- and F_{VI}^+, respectively. Moreover, the error in each F_{VI} (ΔF_{VI}) will be estimated. Thus, a total of 16 different $F_{VI} \pm \Delta F_{VI}$ will be determined (2 buildings* 2 pressure conditions* 4 CoCs).

At each test building, two CoCs will be selected that are expected to have subsurface sources, and two CoCs will be selected that are not expected to be present in the subsurface. At the ASU research house, the four CoCs will be TCE and 1,1-DCE (expected in the subsurface) and benzene and toluene (not expected in the subsurface). At Moffett Field Building 107, the four CoCs will be TCE and PCE (expected in the subsurface) and benzene and toluene (not expected in the subsurface).

At each of the two buildings under NP conditions, F_{VI}^- for each of the four CoCs will be found according to the Mosley model by combining equation B-25 with equation B-27. Q_i, Q_i^-, R_i, R_i^-, R_a, and R_a^- will be calculated as described in Section B1.1.1.2. C_i and C_i^- will be calculated for each of the four CoCs at each building as the arithmetic mean of the three IA concentration measurements under BL and NP conditions, respectively. C_a and C_a^- are the concentrations of each of the CoCs in the single AA sample collected under BL and NP conditions, respectively. The error in F_{VI}, ΔF_{VI}, will be determined for each of the eight F_{VI}^- values by propagation of the estimated errors in all of the applicable variables, according to the general principles of error propagation as described in Appendix C. Estimated errors in Q_i, Q_i^-, R_i, and R_i^- will be determined as given in Section B1.1.1.2. Errors in C_i and C_i^- will be estimated as the standard deviation of the three IA concentration measurements under BL and NP conditions, respectively. Errors in the single measurements of R_a and R_a^- will be assumed to be equal to the relative error in the corresponding triplicate R_i and R_i^- measurements, respectively. The relative error in C_a and C_a^- will be assumed to be equal to the accuracy limit for the TO-15 volatiles analysis, ±30%.

At each of the two buildings under PP conditions, F_{VI}^+ for each of the four CoCs will be found according to the Mosley model by combining either equation B-18 (if VI is only reduced under PP) or equation B-32 (if VI is 'turned off') with equation B-27. If $R_i^+ = R_a^+$, i.e., these quantities cannot be distinguished statistically, then the simplified VI 'turned off' equations will be used to find F_{VI}^+. Q_i, Q_i^+, R_i, R_i^+, R_a, and R_a^+ will be calculated as described in Section B1.1.1.2. C_i and C_a are determined as described above. C_i^+ will be calculated for each of the four CoCs at each building as the arithmetic mean of the three IA concentration measurements under PP conditions, respectively. C_a^+ is the concentration of each of the CoCs in the single AA sample collected under PP conditions. The error in F_{VI}, ΔF_{VI}, will be determined for each of the eight F_{VI}^+ values by propagation of the estimated errors in all of the applicable variables, according to the general principles of error propagation as described in Appendix C. Estimated errors in Q_i, Q_i^+, R_i, and R_i^+ will be determined as given in Section B1.1.1.2. Errors in C_i and C_i^+ will be estimated as the standard deviation of the three IA concentration measurements under BL and PP conditions, respectively. Errors in the single measurements of R_a and R_a^+ will be assumed to be equal to the relative error in the corresponding triplicate R_i and R_i^+ measurements, respectively. The relative error in C_a and C_a^+ will be assumed to be equal to the accuracy limit for the TO-15 volatiles analysis, ±30%.

The 16 $F_{VI} \pm \Delta F_{VI}$ values will be reported. Reported along with these $F_{VI} \pm \Delta F_{VI}$ will be an estimate of the statistical confidence that F_{VI} is larger than ΔF_{VI} (a p-value or confidence interval). Failure to find statistically significant differences could result from either the absence of any underlying differences, or from small sample size and high variability in the data. Retrospective calculations will be employed to estimate the minimum detectable differences with the observed sample sizes and variabilities, with 80% power (20% probability of Type II error) and 5% probability of Type I error. Taken together, these values will determine the degree of confidence with which the pressure control technique can ascribe a CoC's indoor concentration to VI; for instance, if $F_{VI} > \Delta F_{VI}$, then there exists a reasonable degree of confidence that VI is contributing to a CoC's indoor air concentration.

As with the calculations described in Section B1.1.1.2, for instances where measurement of concentrations yield non-detects, the value of the estimated detection limit will be substituted for the non-detect, as appropriate.

B1.1.2 Comparability

The comparability of the building pressure control methodology will be assessed by comparison of the differential pressures across the building envelope under negative and positive pressure.

Specifically, the relative percent difference (RPD) of the mean differential pressure under NP and PP conditions (RPD,ΔP^- and RPD,ΔP^+, respectively) will be calculated and reported as:

$$RPD,\Delta P^- = \frac{\left|\Delta P_1^- - \Delta P_2^-\right|}{0.5\cdot\left(\Delta P_1^- + \Delta P_2^-\right)}\cdot 100$$

$$RPD,\Delta P^+ = \frac{\left|\Delta P_1^+ - \Delta P_2^+\right|}{0.5\cdot\left(\Delta P_1^+ + \Delta P_2^+\right)}\cdot 100$$

B1.1.3 Operational factors

Operational factors for implementation of the entire building pressure control technology will be evaluated based on Battelle's observations with input from the technology vendor. General operational factors include the knowledge, expertise, training, and costs required to carry out all aspects of the field sampling campaign, including installation of the SS sampling points, measurement of pressure differentials, and collection of all of the various air samples. The vendor will provide cost information, including information on rental/purchase prices of the real-time monitoring instrumentation, charges for off-site analysis of VOCs and SF_6 in canisters and radon in PVF bags, and costs for the vendor's time in the field to carry out the sampling campaign. Other factors include the maintenance needs, calibration requirements and frequencies for the real-time pressure differential and radon instruments, data output and analysis, and sustainability factors, such as consumables required and used (if any), ease of use, and repair requirements (if any) of the real-time pressure differential and radon monitoring instruments. Examples of information that would be recorded include the number of canisters received from the analytical laboratory that are deemed unacceptable for field collection, effort or cost associated with maintenance or repair of real-time instruments, vendor effort (e.g., time on site) for repair or maintenance, the duration and causes of any downtime for real-time instruments, Battelle's observations about ease of use, clarity of the vendor's instruction manual, overall convenience of the technologies and accessories/consumables. Battelle will summarize any and all observations to aid in describing the technology performance in the verification report.

B1.2 Validation of Mosley Model Assumptions

A number of different assumptions are stated in the Mosley IA model, several of which may be explicitly tested using the data collected in this verification of the pressure control methodology. Verifying the validity of the assumptions will help to explain the outcomes of the F_{VI} calculations, since these rely directly upon these simplifying assumptions. Assumptions will be tested at each building, and for each of the four CoCs. One- and two-sided t-tests, as appropriate, will be performed for the statistical comparisons. Failure to find statistically significant differences could result from either the absence of any underlying differences, or from small sample size and high variability in the data. Retrospective calculations will be employed to estimate the minimum detectable differences with the observed sample sizes and variabilities, with 80% power (20% probability of Type II error) and 5% probability of Type I error. Estimated errors in each of the parameters will be found as described below. See Table 1 and Appendix B for explanation of the notation.

Assumptions that may be explicitly tested include:

1. $C_s = C_s^- = C_s^+$

C_s, C_s^-, and C_s^+ for each CoC will be calculated as the mean of the three SS concentration measurements under BL, NP, and PP conditions, respectively. Errors in these quantities will be estimated as the standard deviations.

2. $R_s = R_s^- = R_s^+$

R_s, R_s^-, and R_s^+ will be calculated as the mean of the three SS radon concentration measurements for radon under BL, NP, and PP conditions, respectively. Errors in these quantities will be estimated as the standard deviations.

3. $R_a << R_s$
4. $R_a^- << R_s^-$
5. $R_a^+ << R_s^+$

The values of R_a, R_a^-, and R_a^+ are based on a single grab sample of AA; the estimated relative error in their concentrations will be assumed to be equal to the relative error in the corresponding triplicate R_i, R_i^-, and R_i^+ measurements, respectively.

6. $Q_i >> \lambda V$
7. $Q_i^- >> \lambda V$
8. $Q_i^+ >> \lambda V$

Each of the two building's volumes will be estimated based on interior dimensions. The values of Q_i, Q_i^-, and Q_i^+ and estimates of their errors will be calculated as given in section B1.1.1.2.

Note that it is unnecessary to validate assumptions 1 and 2 above under PP conditions when it is determined that VI has been 'turned off', i.e. when $R_i^+ = R_a^+$, since the calculation of F_{VI} (equation B-32 combined with B-27) no longer depends on the simplifying assumption that $C_s = C_s^+$ and $R_s = R_s^+$.

Based on the proposed field measurements described in this QAPP, assumptions that cannot be explicitly verified include:

9. $G_c = G_c^- = G_c^+$
10. $Q_i >> Q_s$

11. $Q_i^- >> Q_s^-$
12. $Q_i^+ >> Q_s^+$

The inability to explicitly verify these four assumptions will add to the overall uncertainty of the test outcomes.

B1.3 Reporting

The data reduction and statistical comparisons will be conducted as described above, and information on the operational performance will be compiled and reported. A verification report will be prepared that presents the test procedures and test data, as well as the results of the statistical evaluation of those data.

Battelle staff will record operational aspects of the building pressure control methodology at the time of observation during the first field test at the ASU research house. These observations will be summarized in the verification report. For example, descriptions of the logistics required to conduct the sampling program, site access requirements, use of the real-time differential pressure and radon concentration monitoring instrumentation, consumables used, repairs and maintenance required for any of the air monitoring equipment and instrumentation, and the nature of any problems will be presented in the report. The verification report will briefly describe the ETV program, the AMS Center, and the procedures used in verification testing. The results of the verification test regarding the performance of the building pressure control technique will be stated quantitatively. Each draft verification report will be subjected to review by the vendor, U.S. Navy, EPA, and other peer reviewers. The resulting review comments will be addressed in a subsequent revision of the report, and the peer review comments and responses will be tabulated to document the peer review process and submitted to EPA. The reporting and review process will be conducted according to the requirements of the ETV/AMS Center QMP.[1]

B2 REFERENCE SAMPLE COLLECTION

Extensive analysis will be conducted at off-site laboratories to confirm the conditions at the sites (concentrations of CoCs, SF_6, and radon) as part of the vendor's technology that is being tested; however, traditional reference samples will not be collected during this test.

B3 SAMPLE HANDLING AND CUSTODY REQUIREMENTS

For all canister and PVF bag samples collected to characterize concentrations of CoCs, SF_6, and radon in IA, AA, and SS gas, sample custody will be documented throughout collection, transport, shipping, and analysis of the samples on standard forms provided by the contract analytical laboratories performing the analyses, or by forms provided by Battelle. The chain-of-custody form will track sample release from the sampling location to the testing laboratory. Technology vendor staff or Battelle staff will complete the appropriate chain-of-custody forms using the sample IDs defined on the field collection data sheets in Appendix D. The custody form will include details about the sample such as the time, date, location, and person collecting the sample. The chain-of-custody form will be signed by the person relinquishing samples once that person has verified that the form is accurate. The original chain-of-custody form will accompany the samples during shipment to the off-site laboratories, one copy will be retained by the technology vendor, and one copy will be retained by Battelle for archival in the project files. Upon arrival at each testing laboratory, custody forms will be signed by the person receiving the sample once that person has verified that all samples identified on the chain-of-custody forms are present. Copies of the completed chain-of-custody forms will be forwarded to the technology vendor and to the Battelle VTC for inclusion in the project files. PVF bags will be placed in a hardsided container for shipment so as to better protect the integrity of the sample containers. Air samples will be shipped by common carrier and temperature control is not required. The common carrier's bill of lading/package routing documentation will also be retained and archived along with the chain-of-custody form.

B4 REFERENCE METHOD REQUIREMENTS

No reference method is being used for this test.

B5 QUALITY CONTROL REQUIREMENTS

A variety of QC measures will be implemented to ensure that data of the highest quality are generated during this verification test. They are described below and in Table 6.

Generic laboratory QC requirements are established for the analysis of VOCs, SF_6, and radon. These include checks on instrument calibration, laboratory blanks, replicate analyses, and spikes. Specific QC measures and acceptance criteria are given in Table 6.

Pressure transducers will be zero checked before beginning differential pressure measurements for BL, NP, and PP conditions.

The pressure of all evacuated canisters will be checked using a calibrated gauge before sampling is initiated to ensure that the canisters did not leak during transport from the analytical laboratory to the field. At the conclusion of sampling, canister pressures will also be recorded so that it can be determined, by way of comparison to canister pressure upon receipt at the analytical laboratory, if the canisters leaked during return shipment. Acceptance criteria for canister pressures are given in Table 6. Pre- and post-sampling canister pressures will be measured using a separate calibrated gauge and will be recorded as absolute pressure measurements. If relative pressure measurements are recorded (as is the case with most analog pressure gauges), they will be corrected for altitude, as appropriate.

Canister cleanliness is of the utmost importance given the very low concentrations of CoCs that are expected in IA and AA samples. For the five CoCs pertinent to this verification test (TCE, PCE, 1,1-DCE, benzene, and toluene), Columbia Analytical Services will certify that all canisters used for such sampling are clean to the level specified in Table 6.

Once canister and PVF bag samples are collected, they will not be held for analysis longer than the times specified in Table 6.

A variety of duplicate samples will be collected during the field campaigns, as given in Table 6. Frequencies for duplicates are specified such that one duplicate is generated at each test building for each type of applicable media/matrix combination.

One PVF bag blank for radon analysis will be generated during air sampling at each test building. An empty PVF bag will be filled with a three-way valve and syringe, similar to how IA and AA samples are collected. The source of the radon-free air will be a PVF bag filled with AA aged at least 21 days. PVF is impermeable to radon, thus by allowing AA (with a radon concentration not exceeding ~0.7 pCi L^{-1}) to age in a bag for 21 days, the radon concentration in the bag will be reduced to 0.7 pCi L^{-1} * [exp (-21 d * 0.18 d^{-1})] = 0.02 pCi L^{-1}, which is an order of magnitude lower than the estimated detection limit of the alpha scintillation measurement method for radon.

Matrix spikes will be generated and analyzed at each of the analytical laboratories. For VOCs and SF_6, a matrix spike is the analysis of a known concentration of a standard gas mixture to an evacuated canister. The gas mixture is independent of the standard gas for instrument calibration. For radon, the matrix spike is generated by the exposure of the alpha scintillation counting cell to a known activity of radon or other radioactive gas.

Table 6. Summary of Quality Control Procedures and Samples

QC Sample Type	Frequency	Spike level	Acceptance Criteria	Corrective Action
Initial calibration (applicable to VOC and SF_6 analyses)	With each sample batch[a]	Varies	$r^2 > 0.99$ or % RSD < 30%	Request reanalysis; flag data
Continuing calibration standard (applicable to VOC and SF_6 analyses)	1 per sample batch, after analysis of all samples	Near midpoint of calibration range	Calculated concentration within ± 20% for SF_6 and ± 30% for VOCs	Request reanalysis; flag data
Laboratory blank (VOC, SF_6, and radon analyses)	1 per sample batch	N/A	concentration < estimated method detection limit	Request reanalysis; flag data
Replicate analysis (VOC, SF_6, and radon analyses)	1 per sample batch	N/A	RPD ≤ 30% VOCs, ≤ 20% SF_6, ≤ 10% radon	Request reanalysis; flag data
Calibration of radon counting cells	Within the last 6 months prior to sample analysis	~1000 pCi L^{-1} (SS) or ~1 pCi L^{-1} (IA and AA)	RPD < 10% compared to previous calibration	Request reanalysis. Flag data.
Zero check of differential pressure instrument	Before beginning ΔP measurements under BL, NP, and PP conditions	N/A	ΔP ≤ 0.001" H_2O = 0.25 Pa	Recheck. Verify the same pressure is applied to both ports. Repair or replace instrument.
Canister pressure	Before beginning sampling, every canister	N/A	P ≤ 27" Hg vacuum	Do not use canister. Request replacement from laboratory.
Canister pressure difference (as received at analytical lab compared to at conclusion of sampling)	Every IA and AA sample	N/A	|ΔP| ≤ 1" Hg	Flag data.

QC Sample Type	Frequency	Spike level	Acceptance Criteria	Corrective Action
Canister cleanliness	Every IA and AA sample	N/A	CoC concentration < 0.025 µg m^{-3}	Reject canister.
Canister hold time	Every canister	N/A	time < 30 days	Flag data.
PVF bag hold time	Every PVF bag	N/A	time < 10 days	Flag data.
Canister duplicate for VOCs/SF_6 in IA & AA	1 in 12 samples (1 per test building)	N/A	RPD ≤ 30% VOCs RPD ≤ 20% SF_6	Request reanalysis. Flag data.
Canister duplicate for VOCs in SS vapor	1 in 9 samples (1 per test building)	N/A	RPD ≤ 30%	Request reanalysis. Flag data.
PVF bag duplicate for radon in IA & AA	1 in 12 samples (1 per test building)	N/A	RPD ≤ 10%	Request reanalysis. Flag data.
PVF bag duplicate for radon in SS vapor	1 in 9 samples (1 per test building)	N/A	RPD ≤ 10%	Request reanalysis. Flag data.
PVF bag blank	1 in 12 samples (1 per test building)	N/A	Radon concentration < 0.2 pCi L^{-1}	Request reanalysis. Flag data.
Canister matrix spike, VOCs at IA/AA levels	1 per sample batch	~1 µg m^{-3}	Recovery between 70 to 130%	Request reanalysis. Flag data.
Canister matrix spike, VOCs at SS levels	1 per sample batch	~500 µg m^{-3}	Recovery between 70 to 130%	Request reanalysis. Flag data.
Canister matrix spike, SF_6 at IA levels	1 per sample batch	~100 µg m^{-3}	Recovery between 80 to 120%	Request reanalysis. Flag data.
Alpha scintillation cell matrix spike, radon at IA/AA levels	1 per sample batch	~0.7 pCi L^{-1}	Recovery between 70 to 130%	Request reanalysis. Flag data.

[a] A batch of samples is defined to comprise no more than 20 individual samples.

B6 INSTRUMENT/ EQUIPMENT TESTING, INSPECTION, AND MAINTENANCE

Operation and maintenance of all air sampling and monitoring equipment and instrumentation will be the responsibility of the technology vendor. Pressure transducers will be calibrated by the instrument manufacturer or appropriately accredited third party and will be zero checked before and after differential pressure measurements for BL, NP, and PP conditions. The near real-time radon instrument will be calibrated by the manufacturer or appropriately accredited third party prior to use in the field. Proof of their calibration will be obtained from the technology vendor and included in the project files. The contract analytical laboratories are responsible for the operation and maintenance of all instrumentation employed for the off-site analysis of air samples collected in canisters (GC/MS and GC/ECD) and PVF bags.

B7 INSTRUMENT CALIBRATION AND FREQUENCY

The calibration of instrumentation used in this verification test, such as Omniguard 4® pressure differential instruments, the RAD7® near real-time radon concentration instrument, and ancillary equipment such as the rotameter for delivery of the SF_6 tracer gas, and the pressure gauge for initial and final canister pressure checks, will be verified immediately prior to use in this verification test.

The GC/MS instrument used for the analysis of canister samples for CoCs will be calibrated according to the procedures generally outlined in EPA Compendium Method TO-15.[13] The standard full scan TO-15 method will be employed for analysis of SS gas, with TO-15 with SIM for IA and AA samples. Reporting limits for the TO-15 SIM method will be approximately 0.04 $\mu g\ m^{-3}$ for each CoC. The GC/ECD instrument used for the analysis of the canister samples for SF_6 will be calibrated according to the procedures as given in NIOSH Method 6602.[14] TO-15 scan, TO-15 SIM, and SF_6 analysis procedures are maintained by the contract analytical laboratory Columbia Analytical Services. Radon concentrations will be measured by way of alpha scintillation counting following established EPA protocols[15]; more detail of the method is described by McHugh et al.[16] The radon analytical instrument will be calibrated according to procedures as outlined by the contract analytical laboratory at the University of Southern California, Department of Earth Sciences. The reporting limit for the radon in air analysis is not greater than approximately 0.4 $pCi\ L^{-1}$. All documentation of instrument calibration and internal QC procedures will be provided to the vendor and to Battelle. Such documentation may include information on method detection limits, method blanks, calibration curves, calibration checks, and secondary source checks.

B8 INSPECTION/ACCEPTANCE OF SUPPLIES AND CONSUMABLES

All materials, supplies, and consumables to support all field testing activities will be supplied by the technology vendor and the technology vendor's contracted analytical laboratories. During testing at the first building, the Battelle VTC will visually inspect and ensure that the materials and consumables used by the vendor are acceptable for their intended use and that there are no visual signs of damage that could compromise the suitability of the air sampling equipment, supplies, and consumables. If damaged or inappropriate goods and supplies are received for use in the field, they will be returned or disposed of and arrangements will be made to receive replacements. The COA or other documentation of analytical purity will be checked for the SF_6 tracer gas.

B9 NON-DIRECT MEASUREMENTS

No indirect measurements will be used during this verification test.

B10 DATA MANAGEMENT

Various types of data will be acquired and recorded electronically or manually by Battelle and vendor staff during this verification test. All manually-recorded data will be recorded in permanent ink. Corrections to records will be made by drawing a single line through the entry to be corrected and providing a simple explanation for the correction, along with a date and the initials of the person making the correction. Table 7 summarizes the types of data to be recorded. All maintenance activities, repairs, calibrations, and operator observations relevant to the operation of the building pressure control methodology, including installation of SS sampling points, operation of fans for building pressure control, and deployment of the air monitoring systems will be documented by Battelle or vendor staff in the Battelle LRB. All calibration documentation for the real time monitoring instruments, flow control devices, and pressure gauges will be stored and maintained in the project files. Any such report formats will include all necessary data to allow traceability from the raw data to final results. Reports from the analytical laboratories will include results of laboratory quality control checks and calibrations, in addition to results of analysis of samples. Raw data will also be included, if available.

Records received by or generated by the vendor or Battelle staff during the verification test will be reviewed by a Battelle staff member within two weeks of receipt or generation, respectively, before the records are used to calculate, evaluate, or report verification results. If a Battelle staff member generated the record, this review will be performed by a Battelle technical staff member involved in the verification test, but not the staff member who originally received or generated the record. The review will be documented by the person performing the review by adding his/her initials and date to the hard copy of the record being reviewed. In addition, any calculations performed by Battelle will be spot-checked by Battelle technical staff to ensure that calculations are performed correctly. Calculations to be checked include any statistical calculations described in this QAPP. Some of the other data management and review tasks that will be performed include:

- Verifying that QC samples and calibration standards were analyzed according to the test/QA plan, compared against acceptance criteria, and results were reported;
- Confirming that corrective action(s) for exceedances was taken;
- Checking for accuracy 100% hand-entered and/or manually calculated data ;
- Verifying calculations performed by software at a frequency sufficient to ensure that the formulas are correct, appropriate, and consistent;
- Checking for accuracy the first and last data value for each cut and paste function; and
- Confirming that data are reported in the units specified in the test/QA plan.

A dedicated shared folder within the ETV AMS Center SharePoint site will be established for all project records. Battelle will provide technology test data (including records; data sheets; notebook records) from the first day of testing within one day of receipt to EPA for simultaneous review. The goal of this data delivery schedule is prompt identification and resolution of any data collection or recording issues. These data will labeled as preliminary and will not have had a QA review before their release.

Table 7. Summary of Data Recording Process

Data to Be Recorded	Where Recorded	How Often Recorded	By Whom	Disposition of Data
Dates, times, and details of test events, including sample collection	Field data collection forms, ETV LRB (if required)	Start/end of test event	Vendor and Battelle staff	Used to organize/check test results; manually incorporated in data spreadsheets as necessary
Maintenance/repair of instruments in the field	Field data collection forms, or ETV LRB	When performed	Vendor and Battelle staff	Incorporated in verification report as necessary
Results of analysis of air collected in canisters for CoCs and SF_6	Data generated at Columbia Analytical Services, the contract analytical laboratory performing the analyses	Recorded samples are analyzed	Subcontractor staff	Hardcopy and electronic files with all results sent to vendor and to Battelle
Results of the analysis of air collected in PVF bags for radon concentrations	Data generated at the University of Southern California Earth Sciences Lab, the contract analytical laboratory performing the analyses	Recorded samples are analyzed	Subcontractor staff	Hardcopy and electronic files with all results sent to vendor and to Battelle
Pressure differential measurements	On instrument datalogger	Minimum and maximum observed ΔP recorded into memory every five minutes	Automatically logged by instrument	Battelle or vendor staff will download datalogger data onto computer hard drive or memory stick at the end of every day of testing
Near-real time subslab radon concentration measurements	On hardcopy printout recorded by instrument; manually transferred to data collection forms	Instrument output generated every 5 to 20 minutes, based on selected integration time	Automatically generated by instrument	Battelle or vendor staff will transfer instrument output to data collection form; hardcopy “receipt” generated by instrument will be archived

SECTION C

ASSESSMENT AND OVERSIGHT

C1 ASSESSMENTS AND RESPONSE ACTIONS

Every effort will be made in this verification test to anticipate and resolve potential problems before the quality of performance is compromised. One of the major objectives of this QAPP is to establish mechanisms necessary to ensure this. Internal QC measures described in this QAPP, which is peer reviewed by a panel of outside experts, implemented by the technical staff and monitored by the VTC, will give information on data quality on a day-to-day basis. The responsibility for interpreting the results of these checks and resolving any potential problems resides with the VTC, who will contact the Battelle AMS Center Manager, Battelle AMS Center Quality Manager, EPA AMS Center Project Officer, and EPA AMS Center Quality Manager if any deviations from the QAPP are observed. In particular, the VTC will be in at least daily contact with site personnel during the second field campaign when he will not be in attendance so that the VTC can be closely monitoring the progress of the verification test and report any deviations to EPA. The VTC will describe the deviation in a teleconference or by e-mail, and once a path forward is determined and agreed upon with EPA, the deviation form will be completed. Technical staff has the responsibility to identify problems that could affect data quality or the ability to use the data. Any problems that are identified will be reported to the VTC, who will work with the Battelle Quality Manager to resolve any issues. Action will be taken by the VTC and Battelle testing staff to identify and appropriately address the issue, and minimize losses and correct data, where possible. Independent of any EPA QA activities, Battelle will be responsible for ensuring that the following audits are conducted as part of this verification test.

C1.1 Performance Evaluation Audit

Since no reference measurements will be conducted, no performance evaluation audits are planned for this verification test. Although several analytical methods will be operated to generate data for this verification test, the quality of the measurements will be the responsibility of the technology vendor since these data are being generated as part of the vendor's pressure control technique.

C1.2 Technical Systems Audits

The NAVFAC Atlantic QAO will perform a TSA during the field activities at the first test building. The NAVFAC Atlantic QAO or a Battelle representative will perform a TSA at the second test building. The purpose of these audits is to ensure that the verification test is being performed in accordance with the AMS Center QMP[1] and this QAPP. During the TSA, the NAVFAC Atlantic QAO will compare actual test procedures to those specified or referenced in this plan, and review data acquisition and handling procedures. The NAVFAC Atlantic QAO will prepare a project-specific checklist based on the QAPP requirements to guide the TSA, which will include a review of the test building and general testing conditions; observation of the testing activities; and review laboratory record books and data collection forms. He will also check the gas standard certification for the SF_6 tracer gas; verify that real-time instruments, pressure gauges, and flow control devices are calibrated; check data acquisition procedures; and may confer with the vendor staff. The NAVFAC Atlantic QAO will prepare an initial TSA report and will submit the report to the Battelle AMS Center Quality Manager. The Battelle AMS Center Quality Manager will review, resolve questions and issues with the NAVFAC Atlantic QAO, then submit the draft report to the EPA Quality Manager (with no corrective actions documented) and VTC within 10 business days after completion of the audit. A copy of each final TSA report (with corrective actions documented) will be provided to the EPA AMS Center Project Officer and Quality Manager within 20 business days after completion of the audit. At EPA's discretion, EPA QA staff may also conduct an independent on-site TSA during the verification test. The TSA findings will be communicated to technical staff at the time of the audit and documented in a TSA report.

C1.3 Audits of Data Quality

The NAVFAC Atlantic QAO will audit at least 10% of the sample results data acquired in the verification test and 100% of the QC and calibration data versus the QAPP requirements. Three ADQs will be conducted for this project: one following the completion of field testing and completion of the analysis of canister and PVF bag samples collected at the first test building; another following completion of all field and subsequent offsite analytical activities related to the testing at the second test building; and the third following completion of the draft verification report. Within 10 business days of receipt of all required field and laboratory data for each test building, data quality will be assessed using a project-specific checklist. During these audits, the NAVFAC Atlantic QAO will trace the data from initial acquisition through reduction and statistical comparisons, to final reporting. All calculations performed on the data undergoing the ADQ will be checked. Data must undergo a 100% validation and verification by technical staff (i.e. VTC or his designee) before it will be assessed as part of the data quality audit. All QC data and all calculations performed on the data undergoing the audit will be checked by the NAVFAC Atlantic QAO. Results of each ADQ will be documented using the checklist and reported by the Battelle Quality Manager to the VTC and EPA within 10 business days after completion of the audit. A final ADQ that assesses overall data quality, including accuracy and completeness of the technical report, will be prepared as a narrative and distributed to the VTC and EPA within 10 business days of completion of the audit.

C1.4 QA/QC Reporting

Each assessment and audit will be documented in accordance with Section 3.3.4 of the AMS Center QMP.[1] The results of all audits will be submitted to EPA within 10 business days as noted above. Audit reports will include the following:

- Name, affiliation, and responsibility of each person interviewed during audit;
- Identification of any adverse findings or potential problems;
- Recommendations for resolving problems. (If the QA audit identifies a technical issue, the VTC or Battelle AMS Center Manager will be consulted to determine the appropriate corrective action;
- Response to adverse findings or potential problems;
- Confirmation that solutions have been implemented and are effective; and
- Citation of any noteworthy practices that may be of use to others.

C2 REPORTS TO MANAGEMENT

During the field and laboratory evaluation, any QAPP deviations will be reported immediately to EPA. The NAVFAC Atlantic QAO and/or VTC, during the course of any assessment or audit, will identify to the technical staff performing experimental activities any immediate corrective action that should be taken. A summary of the required assessments and audits, including a listing of responsibilities and reporting timeframes, is included in Table 8. If serious quality problems exist, the Battelle Quality Manager will notify the Battelle AMS Center Manager, who is authorized to stop work. Once the audit reports have been prepared, the VTC will ensure that a response is provided for each adverse finding or potential problem and will implement any necessary follow-up corrective action. The Battelle Quality Manager will ensure that follow-up corrective action has been taken. The QAPP and final report are reviewed by the EPA AMS Center Quality Manager and the EPA AMS Center Project Officer. Upon final review and approval, both documents will then be posted on the ETV Web site (www.epa.gov/etv).

Table 8. Summary of Audit Reports[1]

Audit	Prepared By	Report Submission Timeframe	Submitted To
Each TSA (Initial)	NAVFAC Atlantic QAO	10 business days after TSA is complete	EPA ETV AMS Center
Each TSA (Final)	Battelle and NAVFAC Atlantic QAO	Battelle's TSA response is due to QAO within 10 business days of receipt from QAO TSA responses will be verified by the NAVFAC Atlantic QAO and provided to EPA ETV AMS Center within 20 business days	EPA ETV AMS Center
ADQs (for testing at field sites)	NAVFAC Atlantic QAO	Within 10 business days after all data for a test area submitted	EPA ETV AMS Center
ADQ (Final)	NAVFAC Atlantic QAO	10 business days after completion of the verification report review	EPA ETV AMS Center

[1] Any QA checklists prepared to guide audits will be provided with the audit report.

SECTION D

DATA VALIDATION AND USABILITY

D1 DATA REVIEW, VERIFICATION, AND VALIDATION REQUIREMENTS

The key data review and data verification requirements for this test are stated in Section B10 of this QAPP. In general, the data review requirements specify that data generated during this test will be reviewed by a Battelle technical staff member within two weeks of generation of the data. The reviewer will be familiar with the technical aspects of the verification test but will not be the person who generated the data. This process will serve both as the data review and the data verification, and will ensure that the data have been recorded, transmitted and processed properly. Furthermore, this process will ensure that the monitoring systems data were collected under appropriate testing.

The data validation requirements for this test involve an audit of the quality of the data relative to the DQI for this test referenced in Table 3. Any deficiencies in these data will be flagged and excluded from any statistical calculations for the building pressure control technology unless these deviations are accompanied by descriptions of their potential impacts on the data quality.

D2 VERIFICATION AND VALIDATION METHODS

Data verification is conducted as part of the data review as described in Section B10 of this QAPP. A visual inspection of handwritten data will be conducted to ensure that all entries were properly recorded or transcribed, and that any erroneous entries were properly noted (i.e., single line through the entry, with an error code, such as “wn” for wrong number, and the initials of the recorder and date of entry). Electronic data from the pressure differential monitors will be inspected to ensure proper transfer from the datalogging system. All calculations used to transform the data will be reviewed to ensure the accuracy and the appropriateness of the calculations. Calculations performed manually will be reviewed and repeated using a handheld calculator or commercial software (e.g., Excel). Calculations performed using standard commercial office software (e.g., Excel) will be reviewed by inspection of the equations used for the calculations and verification of selected calculations by handheld calculator. Calculations performed using specialized commercial software (i.e., for analytical instrumentation) will be reviewed by inspection and, when feasible, verified by handheld calculator, or standard commercial office software.

To ensure that the data generated from this test meet the goals of the test, a number of data validation procedures will be performed. Sections B and C of this QAPP provide a description of the validation safeguards employed for this verification test. Data validation efforts include the completion of QC activities and the performance of a TSA as described in Section C. The data from this test will be evaluated relative to the measurement DQIs described in Section A8 of this QAPP. Data failing to meet these criteria will be flagged in the data set and not used for evaluation of the building pressure control technology, unless these deviations are accompanied by descriptions of their potential impacts on the data quality.

The NAVFAC Atlantic QAO will perform several ADQs to ensure that data review, verification, and validation procedures were completed, and to ensure the overall quality of the data.

D3 RECONCILIATION WITH USER REQUIREMENTS

This purpose of this verification test is to evaluate the performance of the building pressure control technique to assess the impact that vapor intrusion has on the indoor air concentrations of various contaminants of concern. In part, this evaluation will include the investigation of the performance of the building pressure control methodology, at sites expected to be impacted by VI, to determine the fractional contribution of VI to the indoor CoC concentrations at these sites. Verification of the ability to provide such information will be of direct use for decision-makers responsible for the potential remediation of impacted sites. To meet the requirements of the user community, input on the tests described in this QAPP has been provided by users, Agency, and external experts. Additional performance data regarding operational characteristics of the building pressure control technique will be collected by verification test personnel. To meet the requirements of the user community, these data will include thorough documentation of the performance of the monitoring systems during the verification test. The data review, verification, and validation procedures described above will assure that data meeting these requirements are accurately presented in the verification reports generated from this test, and will assure that data not meeting these requirements will be appropriately flagged and discussed in the verification reports.

This QAPP and the resulting ETV verification report(s) will be subjected to review by the vendor, EPA, and expert peer reviewers. The reviews of this QAPP will help to improve the design of the verification test and the resulting report(s) such that they better meet the needs of potential users of this building pressure control technique for the assessment of the impact of VI on CoCs in indoor air.

SECTION E

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APPENDIX B: MOSLEY VAPOR INTRUSION MODEL

A Method for Analyzing Vapor Intrusion Problems Using Indoor Radon and a Second Tracer Gas to Distinguish Soil Sources from Above-Ground Sources of Volatile Organic Compounds (VOCs)

Ronald B. Mosley

INTRODUCTION

By measuring the indoor concentration of the chemical of interest over a relatively long time (two weeks) during each season of the year, a reasonable estimate of the annual average appropriate for estimating long-term risks can be obtained. While this approach may provide a good estimate of the occupant's risk from the chemical, it does not necessarily associate all the risk with chemicals emanating from the soil. Such measurements do not distinguish between chemicals arising from the soil and from indoor sources. Better methods for identifying the sources of these indoor contaminants are needed. This paper will describe a method of using steady-state (time-integrated) measurements of indoor radon and a volatile organic compound (VOC) in a house under three different ventilation scenarios to distinguish between soil and above-ground sources of the chemical of interest. This method does not require measurement of sub-slab concentrations, and consequently will not require drilling holes in the floor.
There has been much discussion of the variability of indoor measurements of volatile organic compounds (VOCs). Short-term sampling with either canisters or PVF bags is the common practice for these measurements.

Using longer-term integrated samples on sorptive media may be a way to reduce the variability by increasing the sensitivity and averaging over short-term variations. We will talk about the use of integrated samples to evaluate the severity of health risks from an indoor VOC contaminant and to determine the fraction of the indoor concentration that is a consequence of vapor intrusion (VI). Samples integrated over one to several weeks offer more reliable measurements through both increased sensitivity and reduced variability.

Once a health risk from indoor VOCs has been established, it may be desirable to determine whether VI is the source of the problem. If indeed the soil gas is the source of the contaminants, mitigation methods are readily available to reduce exposures. However, if the sources of the VOCs are indoors, the soil gas mitigation methods may not be effective.

Since the polluter is liable only for problems that originate from the soil, methods are needed to distinguish between VI sources and indoor sources. One approach for making this distinction without drilling holes in the floor is to compare indoor measurements under normal circumstances with similar measurements when the house is perturbed to have nominally different operating conditions induced by increasing the air exchange rate and soil gas entry rate. This perturbation could result from a fan exhausting air from the ground-floor level. Such an increase in exhalation of air would increase the air exchange rate and should also reduce the indoor pressure relative to the sub-slab region resulting in an increased infiltration of soil gas. Alternatively, the fan could be used to blow ambient air into the house thus increasing the indoor pressure relative to the sub-slab region resulting in a lower entry rate of soil gas. We will look at both types of perturbations. These perturbations must be controlled so that the contaminant concentration in the sub-slab region does not change.

To develop such a method, we need to know the air exchange rate and the soil gas entry rate. To determine these quantities, we will introduce an indoor tracer gas with a constant emission rate and a soil gas tracer to measure the soil gas entry rate. In the present case sulfur hexafluoride (SF_6) has been suggested as the tracer. For a soil gas tracer we choose to use naturally occurring radon.

DEVELOPMENT OF EQUATIONS

As a first approach we will consider buildings that can be represented by a single zone interacting with its environment. The building will exchange air with the surrounding ambient air as well as with the soil gas that is considered to enter from below. To develop the pertinent equations we will refer to the schematic drawing of a house shown in Figure 1. The house consists of a single zone with the ambient air and the soil gas constituting the interacting zones. Houses with multiple Zones will be more complex and may be considered later. For our purposes, we will characterize the house and its surroundings in an idealistic manner. The single zone of the house will be represented by the subscript "i" for indoor. The air in zone "i" is considered to be well mixed. The ambient air constitutes zone "a" which is also well mixed. Zone "S" is the sub-slab region in which the soil gas is not assumed to be well mixed. We only consider interactions between the house and the other two zones individually. We envision the floor of the building to contain a number of distinct openings that constitute entry routes for soil gas. Effective value of concentration means the value of uniform concentration that would produce the actual entry rate when multiplied by the total soil gas entry rate. That is

$$C_{Seff} = \sum_j \frac{q_j}{Q_S} C_{Sj}$$

with

$$Q_S = \sum_j q_j$$

where Q_S is the total flow rate of soil gas into the house, q_j is the flow rate through the jth entry route, and C_{Sj} is the concentration at the jth entry route, C_{Seff} is not a directly measurable quantity, but is a useful concept for mathematical purposes. All sub-slab concentrations discussed in this formulation will be effective values. Consequently, the subscript "eff" will not be necessary to identify these values as mathematical constructs. Note that if the soil gas concentration were uniform, then the effective value and the actual value would be the same.

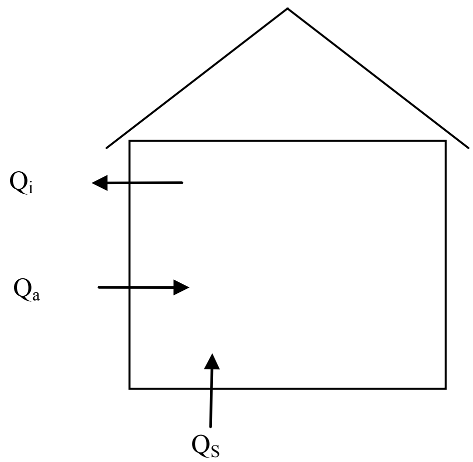

Figure 1. Schematic of a slab-on-grade house with a single zone

Zone i = Indoor air in the building;

Zone s = Soil gas beneath the building; and

Zone a = Ambient air.

Conservation of mass requires the following relationship between the flows.

$Q_i = Q_a + Q_S$ B-1

Where typically

$Q_a >> Q_S$ and $Q_i \approx Q_a$

Q_a = the air flow rate ($m^3\ h^{-1}$) from ambient to the indoors,
Q_i = the air flow rate ($m^3\ h^{-1}$) from indoors to the ambient, and
Q_S = the soil gas flow rate ($m^3\ h^{-1}$) from the sub-slab to the indoors.

The approach to analyzing the movement of gases and contaminants into and out of the building is to apply the principle of mass balance to account for gains and losses of materials. For each gas or contaminant to be studied, one equation of mass balance will result. We will inject a unique tracer gas into the building in order to determine the ventilation rate.

The conditions of mass balance for the three gasses are expressed as:

$$\frac{dT_i}{dt} = \frac{G_T}{V} - \frac{Q_i}{V}T_i \qquad \text{B-2}$$

$$\frac{dR_i}{dt} = \frac{E_R + Q_a R_a}{V} - (\frac{Q_i}{V} + \lambda)R_i \qquad \text{B-3}$$

and

$$\frac{dC_i}{dt} = \frac{E_C + Q_a C_a + G_C}{V} - \frac{Q_i}{V}C_i \qquad \text{B-4}$$

where
T_i is the concentration (μg m^{-3}) of the indoor tracer;
G_T is the generation rate (μg h^{-1}) of the indoor tracer gas;
V is the volume (m^3) of the building;
R_i is the indoor concentration (pCi m^{-3}) of radon;
E_R is the entry rate (pCi h^{-1}) of radon from soil gas;
R_a is the ambient concentration (pCi m^{-3}) of radon;
λ is the decay constant (h^{-1}) of radon;
C_i is the indoor concentration (μg m^{-3}) of the contaminant of concern (CoC);
C_a is the ambient concentration (μg m^{-3}) of the CoC;
E_C is the entry rate (μg h^{-1}) of the CoC from the soil; and
G_C is the generation rate (μg h^{-1}) of the CoC by the indoor sources.

The first term on the right hand side of each equation represents increases due to generation or entry of the contaminant, while the second term on the right represents losses by dilution or decay.

Primary assumptions built into the above mass balance equations include:

1. Soil gas or background indoor source strengths of the tracer gas are negligible compared to the generation rate of the tracer gas.
2. The background indoor source strength of radon is negligible compared to soil gas and outdoor sources.
3. For the tracer gas, radon, and the volatile CoCs, the rate of indoor loss processes such as chemical reaction or sorption to surfaces is negligible compared to air change rates.

Under normal circumstances, the environmental influences such as meteorology acting on the building can be considered to change slowly enough that the building can be considered to be in a steady state. These conditions will be referred to as the baseline case, meaning there has been no intervention in the normal processes of the building-environment interaction. In this event, the steady state representation of equations B-2, B-3, and B-4 can be rewritten as:

$$G_T = Q_i T_i \qquad \text{B-5}$$

$$E_R + Q_a R_a = (Q_i + \lambda V)R_i = Q_S R_S + Q_a R_a \qquad \text{B-6}$$

$$E_C + Q_a C_a + G_C = Q_i C_i \qquad \text{B-7}$$

Where
G_T is the generation rate ($\mu g\ h^{-1}$) of the indoor tracer;
Q_i is the baseline air flow rate ($m^{-3}\ h^{-1}$) from indoors to the ambient;
T_i is the baseline concentration ($\mu g\ m^{-3}$) of the indoor tracer gas;
E_R is the baseline generation rate ($pCi\ h^{-1}$) of radon entering from the sub-slab;
Q_a is the baseline air flow rate ($m^{-3}\ h^{-1}$) from ambient to the indoors;
R_a is the baseline concentration ($pCi\ m^{-3}$) of radon in ambient air;
R_i is the baseline concentration ($pCi\ m^{-3}$) of radon indoors;
Q_s is the baseline flow rate ($m^3\ h^{-1}$) of soil gas into the building;
R_s is the baseline concentration ($pCi\ m^{-3}$) of radon in the sub slab soil gas;
E_C is the baseline entry rate ($\mu g\ h^{-1}$) of the CoC from soil gas;
C_a is the baseline concentration ($\mu g\ m^{-3}$) of the CoC in ambient air;
G_C is the baseline generation rate ($\mu g\ h^{-1}$) of the CoC by the indoor sources; and
C_i is the baseline concentration ($\mu g\ m^{-3}$) of the CoC in indoor air.

We will refer to this steady state condition as the baseline situation in which the normal environmental influences serve as the driving forces that induce soil gas to enter the building. We can write the entry rate of the soil gas contaminant as the product of the soil gas entry rate and the concentration of the contaminant.

$$E_C = Q_S C_S \qquad \text{B-8}$$

The generation rate of the indoor sources is given by substituting equation B-8 into equation B-7.

$$G_C = Q_i C_i - Q_S C_S - Q_a C_a = Q_i C_i - Q_S C_S - (Q_i - Q_S) C_a \qquad \text{B-9}$$

where

C_S is the baseline concentration ($\mu g\ m^{-3}$) of the CoC in the sub slab soil gas (an effective value of concentration.). All other terms are as defined above.

Positive Pressure Perturbation

In order to infer something about the soil gas entry rate without having to sample the sub-slab soil gas, we will perturb the building by blowing air into the building from outdoors using a fan. The perturbing air-flow-rate will be limited to values that do not disturb the sub-slab concentrations of contaminants while changing the air exchange rate significantly. A plus sign will be used as a superscript to denote conditions under applied positive pressure. Under the new flow conditions, we can write a new set of steady state equations as:

$$G_T^+ = Q_i^+ T_i^+ \qquad \text{B-10}$$

$$E_R^+ + Q_a^+ R_a^+ = (Q_i^+ + \lambda V) R_i^+ = Q_S^+ R_S^+ + Q_a^+ R_a^+ \qquad \text{B-11}$$

$$E_C^+ + Q_a^+ C_a^+ + G_C^+ = Q_i^+ C_i^+ \qquad \text{B-12}$$

$$E_C^+ = Q_S^+ C_S^+ \qquad \text{B-13}$$

$$G_C^+ = Q_i^+ C_i^+ - Q_S^+ C_S^+ - Q_a^+ C_a^+ = Q_i^+ C_i^+ - Q_S^+ C_S^+ - (Q_i^+ - Q_S^+) C_a^+ \qquad \text{B-14}$$

where :

G_T^+ is the generation rate (μg h^{-1}) of the indoor tracer during this perturbation period;
Q_i^+ is the perturbed rate of flow (m^3 h^{-1}) of air from indoors to the ambient;
T_i^+ is the concentration (μg m^{-3}) of the indoor tracer gas during the perturbation period;
E_R^+ is the entry rate of radon (pCi h^{-1}) during the perturbation period;
Q_a^+ is the perturbed rate of flow (m^3 h^{-1}) of air from ambient to indoors;
R_a^+ is the ambient concentration (pCi m^{-3}) of radon during the perturbation period;
R_i^+ is the indoor concentration (pCi m^{-3}) of radon during the perturbation period;
Q_S^+ is the rate of soil gas flow (m^3 h^{-1}) from the sub-slab region into the building during the perturbation period;
R_S^+ is the sub-slab concentration (pCi m^{-3}) of radon during the perturbation period;
E_c^+ is the entry rate (μg h^{-1}) of the CoC from soil gas during the perturbation period;
C_a^+ is the indoor concentration (μg m^{-3}) of the CoC during the perturbation period;
G_C^+ is the generation rate (μg h^{-1}) of the CoC by indoor sources during the perturbation period;
Q_i^+ is the rate of soil gas flow (m^3 h^{-1}) from indoors to the ambient during the perturbation period;
C_i^+ is the indoor concentration (μg m^{-3}) of the CoC during the perturbation period; and
C_S^+ is the sub-slab concentration (μg m^{-3}) of the CoC during the perturbation period.

The viability of this approach is based on the assumptions that G_T is known during both steady state periods and that the sub-slab concentrations of radon and the contaminant remain the same during both steady state periods. It is further assumed that the generation rate of the indoor sources do not change during the two periods. If $R_a << R_S$, $R_a^+ << R_S^+$, and $R_S^+ = R_S$, equations B-6 and B-11 can be combined to yield:

$$Q_S^+ = Q_S \frac{(Q_i^+ + \lambda V) R_i^+ - Q_i^+ R_a^+}{(Q_i + \lambda V) R_i - Q_i R_a} \qquad \text{B-15}$$

Combining equations B-9 and B-14 with $G_C^+ = G_C$, $C_S^+ = C_S$, $Q_i >> Q_s$ and $Q_i^+ >> Q_s^+$ yields:

$$(Q_S^+ - Q_S)C_S = [Q_i^+(C_i^+ - C_a^+) - Q_i(C_i - C_a)] \qquad \text{B-16}$$

Substituting eq. B-15 into B-16, and B-16 into B-8 yields:

$$E_C = Q_S C_S = \frac{[Q_i^+(C_i^+ - C_a^+) - Q_i(C_i - C_a)][(Q_i + \lambda V)R_i - Q_i R_a]}{[(Q_i^+ + \lambda V)R_i^+ - Q_i^+ R_a^+] - [(Q_i + \lambda V)R_i - Q_i R_a]} \qquad \text{B-17}$$

Using equations B-5 and B-10 we can eliminate the flow rates Q_i and Q_i^+. Also, since $Q_i^+ > Q_i$, and typically $Q_i > 30 * \lambda V$ (baseline building air change rates are generally no less than 6 d^{-1}, and $\lambda(^{222}Rn) = 0.18\ d^{-1}$), we state $Q_i >> \lambda V$ and $Q_i^+ >> \lambda V$ and obtain:

$$E_C = \frac{[Q_i(C_i - C_a) - Q_i^+(C_i^+ - C_a^+)][Q_i(R_i - R_a)]}{[Q_i(R_i - R_a)] - [Q_i^+(R_i^+ - R_a^+)]} =$$

$$\frac{[\frac{G_T}{T_i}(C_i - C_a) - \frac{G_T^+}{T_i^+}(C_i^+ - C_a^+)][\frac{G_T}{T_i}(R_i - R_a)]}{[\frac{G_T}{T_i}(R_i - R_a)] - [\frac{G_T^+}{T_i^+}(R_i^+ - R_a^+)]} \qquad \text{B-18}$$

This is an expression for the steady-state entry rate of a soil gas contaminant that depends only on measurements performed in indoor and ambient air. The quantities T_i, T_i^+, C_i, C_i^+, R_i, R_i^+, C_a, C_a^+, R_a, and R_a^+ are steady state values under baseline and positive pressure perturbation conditions. G_T and G_T^+ are the generation rates of the inert indoor tracer compound under baseline and positive pressure perturbation conditions calculated from the mass flow rates of the gas and its concentration.

From equation B-7 we can also compute the generation rate of the indoor sources.

$$G_C \approx Q_i C_i - E_C - Q_i C_a = Q_i(C_i - C_a) - E_C \qquad \text{B-19}$$

In this result Q_S has been neglected relative to Q_i ($Q_i >> Q_s$). Since the indoor steady-state concentration is proportional to the sum of the soil gas entry rate, the ambient entry rate, and the indoor generation rate, the fractional contribution from vapor intrusion is given by:

$$F_{VI} = \frac{E_C}{E_C + G_C + \frac{G_T}{T_i}C_a} = \frac{E_C}{\frac{G_T}{T_i}C_i} = \frac{E_C}{Q_i C_i} \qquad \text{B-20}$$

the fractional contribution from indoor sources is given by:

$$F_{in} = \frac{G_C}{\frac{G_T}{T_i} C_i} \qquad \text{B-21}$$

and the fractional contribution from ambient air is given by:

$$F_a = \frac{Q_a C_a}{Q_i C_i} = \frac{(Q_i - Q_S) C_a}{Q_i C_S} \approx \frac{C_a}{C_i} \qquad \text{B-22}$$

where $F_{VI} + F_{in} + F_a = 1$. B-23

To the extent that the steady-state concentration can be replaced by the integrated average, the fraction of the average indoor concentration that originated in the soil gas is given by equation B-20.

Negative Pressure Perturbation

An alternative approach would be to apply a negative pressure to the house to increase the air exchange rate and possibly the entry rate of soil gas. This perturbation will be accomplished by exhausting air from inside the house using a fan. The perturbing air-flow-rate will be limited to values that do not disturb the sub-slab concentrations of contaminants while increasing the air exchange rate significantly. Under the new flow conditions, we can write a new set of steady state equations. Expressions analogous to those in eqs. B-10 – B-23 can be obtained by replacing the plus signs by negative signs. These negative signs indicate quantities corresponding to conditions under negative applied pressure. For brevity, I will not repeat all the intermediate equations, but will simply give the results that may be useful.

$$E_C = Q_S C_S = \frac{[Q_i^-(C_i^- - C_a^-) - Q_i(C_i - C_a)][(Q_i + \lambda V)R_i - Q_i R_a]}{[(Q_i^- + \lambda V)R_i^- - Q_i^- R_a^-] - [(Q_i + \lambda V)R_i - Q_i R_a]} \qquad \text{B-24}$$

$$E_C = \frac{[Q_i^-(C_i^- - C_a^-) - Q_i(C_i - C_a)][Q_i(R_i - R_a)]}{[Q_i^-(R_i^- - R_a^-)] - [Q_i(R_i - R_a)]} =$$

$$\frac{[\frac{G_T^-}{T_i^-}(C_i^- - C_a^-) - \frac{G_T}{T_i}(C_i - C_a)][\frac{G_T}{T_i}(R_i - R_a)]}{[\frac{G_T^-}{T_i^-}(R_i^- - R_a^-)] - [\frac{G_T}{T_i}(R_i - R_a)]} \qquad \text{B-25}$$

$$G_C \approx Q_i C_i - E_C - Q_i C_a \qquad \text{B-26}$$

$$F_{VI} = \frac{E_C}{E_C + G_C + \frac{G_T}{T_i} C_a} = \frac{E_C}{\frac{G_T}{T_i} C_i} = \frac{E_C}{Q_i C_i} \qquad \text{B-27}$$

$$F_{in} = \frac{G_C}{\frac{G_T}{T_i} C_i} \qquad \text{B-28}$$

$$F_a \approx \frac{C_a}{C_i} \qquad \text{B-29}$$

And equation B-23 still applies.

These two sets of results (eqs. B-18 through B-23 and eqs. B-24 through B-29) provide somewhat independent estimates of the same quantities, E_C, G_C, F_{VI}, F_{in}, and F_a. It is also possible to evaluate the effective values of sub-slab concentrations C_S and R_S to determine whether the assumptions that they remain nearly constant are satisfied.

Positive Pressure with Critical Value

There is a third approach to evaluating these quantities that does not require the assumption of constant sub-slab concentrations. This condition is a special case of the positive pressure scenario described above in which a critical value of applied pressure is used. The critical value of positive pressure is the value that yields zero exchange with the sub-slab region. It is the value of pressure that makes Q_S^+ zero. Under these circumstances, $Q_i^+ = Q_a^+$ and $E_C^+ = 0$.

From equation B-11 we obtain

$$R_i^+ = \frac{Q_i^+}{Q_i^+ + \lambda V} R_a^+ \qquad \text{B-30}$$

and from either equation B-12 or B-14

$$G_C^+ = Q_i^+ (C_i^+ - C_a^+) \qquad \text{B-31}$$

This result depends on the assumption that $Q_S^+ = 0$. The baseline entry rate can be computed from equation B-7 and from the assumption that $G_C = G_C^+$:

$$E_C \approx Q_i(C_i - C_a) - G_C = Q_i(C_i - C_a) - Q_i^+(C_i^+ - C_a^+) \qquad \text{B-32}$$

Note that equation B-32 may also be obtained by substitution of the equality $R_i^+ = R_a^+$ into equation B-18; under positive pressure perturbation conditions in which VI is effectively "turned off," this equality holds.

SUMMARY

This presentation proposes a cost-effective screening method to identify houses with concentrations above specified action levels that result from vapor intrusion. The method accounts for confounding issues associated with background concentrations. It has the potential to minimize imposition on the homeowners and to be more acceptable to responsible parties by avoiding drilling holes in the slabs. This method might provide more confidence in the resulting VI evaluation if longer term (integrated) steady state measurements were used. This increased confidence would result from reduced variability in the measured results.

APPENDIX C: ERROR ANALYSIS TO SUPPORT SELECTION OF ACCEPTANCE CRITERIA FOR THE DQI ACCURACY

The purpose of this Appendix is to provide the rationale for the selection of the acceptance criteria for the accuracy DQIs listed in Section A8 of this QAPP. The selection was based on the combination of what is practically attainable given limits of instrumental analysis and also on estimation of concentrations that may be measured during testing at a building where vapor intrusion is obviously a source of CoCs.

For addition and subtraction such as

$$w = x + y + z \qquad \text{C-1}$$

the error in the result, Δw, is given by

$$(\Delta w)^2 = (\Delta x)^2 + (\Delta y)^2 + (\Delta z)^2 \qquad \text{C-2}$$

Note that Δw is the absolute error in w and

$$\Delta w \approx \sigma_w \qquad \text{C-3}$$

where σ_w is the standard deviation in w. Note as well that

$$\Delta w = \%e_w \cdot w \qquad \text{C-4}$$

where $\%e_w$ is the percent relative error in w.

For multiplication and division such as

$$d = \frac{a \cdot b}{c} \qquad \text{C-5}$$

The percent error in the result, $\%e_d$, is calculated by

$$(\%e_d)^2 = (\%e_a)^2 + (\%e_b)^2 + (\%e_c)^2 \qquad \text{C-6}$$

The first step to using the Mosley model (Appendix B) for the determination of the fractional contribution of the concentration of a CoC due to VI, F_{VI}, is to determine the building flow rate (from indoors to ambient) under baseline conditions, Q_i. Q_i may be found by

$$Q_i = \frac{G_T}{T_i} = \frac{C_T Q_T}{T_i} \qquad \text{C-7}$$

Where G_T and T_i are as defined in the Mosley model and

C_T = source concentration of the SF_6 tracer gas (μg m^{-3} or mol fraction); and
Q_T = flow rate of the SF_6 tracer gas from the source bottle into the indoor air (m^3 h^{-1}).

Q_i^- and Q_i^+ are calculated similarly. The error in Q_i is found by way of the knowledge and/or estimation of the relative errors in C_T, Q_T, and T_i:

$$\left(\%e_{Q_i}\right)^2 = \left(\%e_{C_T}\right)^2 + \left(\%e_{Q_T}\right)^2 + \left(\%e_{T_i}\right)^2 \qquad \text{C-8}$$

Assuming that

$\%e_{CT}$ = 5 %, the error in the SF_6 concentration in the source bottle (5 % is typically the stated analytical accuracy of a certified gas standard);

$\%e_{QT}$ = 10 %, the proposed acceptance criterion for the error limit on the flow rate of the SF_6 tracer gas (the SF_6 flow rate will be checked using a calibrated flow meter before and after each building pressure perturbation is started and completed);

$\%e_{Ti}$ = 20 %, the proposed acceptance criterion for the error limit in the measurement of the concentrations of SF_6 at trace (parts per trillion by volume) levels (this acceptance criterion will be verified by the analysis of matrix spikes of SF_6 in stainless steel canisters);

Then $\%e_{Qi}$ = 23 %.

To estimate the error in the fractional contribution of vapor intrusion to the concentration of a CoC measured in indoor air, F_{VI}, assume that under positive pressure conditions, $R_i^+ = R_a^+$, meaning that VI was "turned off." As such, equation B-32 may be substituted into equation B-20 and simplified to calculate F_{VI}:

$$F_{VI} = 1 - \frac{C_a}{C_i} - \frac{Q_i^+ C_i^+}{Q_i C_i} + \frac{Q_i^+ C_a^+}{Q_i C_i} \qquad \text{C-9}$$

Assuming that Q_i^+/Q_i = 5 (compared to baseline conditions, the building AER is five times higher under positive pressure conditions because of the action of the fan blowing air into the building); $C_a = C_a^+$ = 0.04 μg m^{-3} (very low concentrations of the CoC are found in ambient air; 0.04 μg m^{-3} is a typical MDL of the TO-15 SIM analysis for VOCs); C_i = 0.4 μg m^{-3} and C_i^+ = 0.05 μg m^{-3} (there is an obvious source of the CoC to the indoor air, and the CoC concentration dropped substantially with the building under positive pressure, indicating that VI may be a significant source), then F_{VI} = 0.775, or ~ 80% of the indoor concentration of the CoC is due to vapor intrusion.

To estimate the error in FVI under these conditions, the absolute errors in the three right-most terms in equation C-9 must be calculated and added in quadrature. Using equations C-2, C-4, and C-5, the absolute error in F_{VI} is

$$
\begin{aligned}
(\Delta F_{VI})^2 = {} & \left[(\%e_{C_a})^2 + (\%e_{C_i})^2\right]\cdot\left(\frac{C_a}{C_i}\right)^2 + \\
& \left[(\%e_{Q_i^+})^2 + (\%e_{C_i^+})^2 + (\%e_{Q_i})^2 + (\%e_{C_i})^2\right]\cdot\left(\frac{Q_i^+ C_i^+}{Q_i C_i}\right)^2 + \\
& \left[(\%e_{Q_i^+})^2 + (\%e_{C_a^+})^2 + (\%e_{Q_i})^2 + (\%e_{C_i})^2\right]\cdot\left(\frac{Q_i^+ C_a^+}{Q_i C_i}\right)^2
\end{aligned}
\qquad \text{C-10}
$$

Assuming that $\%e_{Q_i} = \%e_{Q_{i+}} = 23$ % and $\%e_{C_a} = \%e_{C_{a+}} = \%e_{C_i} = \%e_{C_{i+}} = 30$ % (the proposed acceptance criterion for the error limit in the measurement of the concentration of a CoC, which is the typical acceptance limit for matrix spikes in the TO-15 SIM method) then $\Delta F_{VI} = 0.6$ and the F_{VI} would be reported as 0.8 ± 0.6.

Note that equation C-8 assumes that all of the quantities (C_T, Q_T, and Q_i) are statistically independent. In fact, Q_T and T_i are likely to have a positive covariance which would result in an additional negative term in the calculation of the error estimate. Omitting this negative term in the estimate of error (i.e., ignoring the covariance) is conservative in that it overstates the expected error in Q_i. With experimental data in hand, it will be possible to estimate the covariance from the data and include it in error calculation.

APPENDIX D: DATA COLLECTION FORMS

Project title: Vapor Intrusion Pressure Control ETV Test
Name and location of building:
Test number:
Person(s) completing this forms:
Date(s) form completed:

SITE DESCRIPTION AND SAMPLING LOCATIONS

- Draw a 2-dimensional building layout (top view) roughly to scale in the box below.
  - Indicate scale and compass direction.
  - Indicate the locations of the following:
    - Three indoor air sampling locations (IA-1, IA-2, IA-3)
    - Three subslab air sampling locations (SS-1, SS-2, and SS-3)
    - One ambient air sampling location (AA-1)
    - One indoor/outdoor pressure sampling location (IO-P)
    - One cross foundation subslab pressure sampling location (SS-P).
  - Note the location and identity of building pressurization and depressurization device(s) (e.g., box fan, blower door, etc.).
- Collect photographs of all measurement locations and pressure control devices.

Abbreviations:
SS = subslab; IA = indoor air; AA = ambient air, IO = indoor/outdoor;
1 = gas sampling point 1; 2 = gas sampling point 2; 3 = gas sampling point 3;
P = sampling point for pressure

Project title: Vapor Intrusion Pressure Control ETV Test
Name and location of building:
Test number:
Building Pressure: ☐ **Baseline** ☐ **Negative** ☐ **Positive**
Person(s) completing this forms:
Date(s) form completed:

PRESSURE DIFFERENTIAL MEASUREMENTS

Date/time (MM/DD/YYYY HH:MM) pressure perturbation begun: ____________________
Date/time (MM/DD/YYYY HH:MM) pressure perturbation complete: ____________________

Indoor/Outdoor Pressure Differential (IO-P)

Pressure transducer information (manufacturer, model #, serial #, calibration information, calibration due date, etc.): ____________________

Pressure transducer zero check. Successful? ☐ **Yes** ☐ **No. If No, describe remedial action(s).** ____________________

Date/time (MM/DD/YYYY HH:MM) IO-P measurements begun: ____________________
Date/time (MM/DD/YYYY HH:MM) IO-P measurements complete: ____________________

Filename[7] (example: 1-BL-IO-P): ____________________

Cross-Foundation Pressure Differential (SS-P)

Pressure transducer information (manufacturer, model #, serial #, calibration information, calibration due date, etc.): ____________________

Pressure transducer zero check. Successful? ☐ **Yes** ☐ **No. If No, describe remedial action(s).** ____________________

Date/time (MM/DD/YYYY HH:MM) SS-P measurements begun: ____________________
Date/time (MM/DD/YYYY HH:MM) SS-P measurements complete: ____________________

Filename[7] (example: 1-BL-SS-P): ____________________

Collect photographs of pressure transducers in installed locations.

[7] File naming convention is "Test # - Pressure Perturbation - Location - P"
(1 or 2) - (BL, NP, or PP) - (IO or SS)

Project title: Vapor Intrusion Pressure Control ETV Test
Name and location of building:
Test number:
☐ **Baseline** ☐ **Negative** ☐ **Positive**
Person(s) completing this forms:
Date(s) form completed:

TRACER GAS RELEASE

Tracer gas compound: ____________________ **Concentration (units):** _______________
Certificate of analysis information:____

Flow rate setpoint (units): ____________________

Flow control device information:
Mass flow controller: ☐ Yes ☐ No
Rotameter: ☐ Yes ☐ No
Description of flow control device (manufacturer, model #, serial #, calibration information, etc.): ______________________________

Initial flow check:
Date/time (MM/DD/YYYY HH:MM): ____________________
Flow (units): ____________________
% difference from set point: ____________________

Final flow check:
Date/time (MM/DD/YYYY HH:MM): ____________________
Flow (units): ____________________
% difference from set point: ____________________

Describe remedial action(s) if % difference of flow rate check compared to setpoint is >10%:______________________________

Description of flow control device (manufacturer, model #, serial #, calibration date, calibration due date, etc.): ______________________________

Date/time (MM/DD/YYYY HH:MM) tracer gas release begun: ____________________
Date/time (MM/DD/YYYY HH:MM) tracer gas release stopped:____________________
NOTE: Photograph SF_6 delivery system

Project title: Vapor Intrusion Pressure Control ETV Test
Name and location of building:
Test number: Test 1
Building Pressure: X Baseline ☐ Negative ☐ Positive
Person(s) completing this forms:
Date(s) form completed:

The following sample naming convention is to be followed when collecting all air samples. Identifiers are shown below the sample naming convention:

Test #	-	Pressure	-	Media Type	-	Target Compound	-	Sampling Location	-	Miscellaneous Information
1	-	BL	-	IA	-	VOC	-	1	-	1
2	-	NP	-	AA	-	Rn	-	2	-	2
	-	PP	-	SS	-		-	3	-	3

Where: BL = baseline IA = indoor air NP = negative pressure
PP = positive pressure SS = subslab Rn = radon
VOC = volatile organic compounds (includes SF_6 for IA, SS samples)
Misc info: 1 = duplicate sample 2 = blank sample 3 = recollected sample

AIR SAMPLING INFORMATION

Indoor Air (IA) Samples

Grab samples in PVF bags for radon (Rn), 8-hr time integrated samples into stainless steel canisters for VOC and SF_6.

Sample ID	Date/Time Collected[8]	Volume Collected (units)	New Syringe Used?
1-BL-IA-Rn-1			☐ Yes ☐ No
1-BL-IA-Rn-2			☐ Yes ☐ No
1-BL-IA-Rn-3			☐ Yes ☐ No
1-BL-IA-Rn- -1			☐ Yes ☐ No
1-BL-IA-Rn- -2			☐ Yes ☐ No
			☐ Yes ☐ No
			☐ Yes ☐ No

Note: for duplicate sample, add sample location where sample was collected

Sample ID	Canister Serial No.	Flow Cont. #	Pres. Gauge #	Initial Vacuum		Final Vacuum	
				Pres. (" Hg)	Date/ Time[8] Stopped	Pres. (" Hg)	Date/ Time[8] Stopped
1-BL-IA-VOC-1							
1-BL-IA-VOC-2							
1-BL-IA-VOC-3							
1-BL-IA-VOC- -1							

Note: for duplicate sample, add sample location where sample was collected

Identity of pressure gauge used for vacuum measurement (manufacturer, model #, serial #, calibration date, calibration due, etc.): ____________________

Notes/comments: ____________________

[8] Date and time to be recorded using a MM/DD/YYYY HH:MM format

Project title: Vapor Intrusion Pressure Control ETV Test
Name and location of building:
Test number: Test 1
Building Pressure: X **Baseline** ☐ **Negative** ☐ **Positive**
Person(s) completing this forms:
Date(s) form completed:

AIR SAMPLING INFORMATION (Continued)

Ambient Air (AA) Samples

Grab samples into a PVF bag for radon (Rn), 8-hr time integrated samples into a stainless steel canister for VOC.

Sample ID	Date/Time Collected[9]	Volume Collected (units)	New Syringe Used?
1-BL-AA-Rn-1			☐ Yes ☐ No
1-BL-AA-Rn-1-1			☐ Yes ☐ No
1-BL-AA-Rn-1-2			☐ Yes ☐ No
			☐ Yes ☐ No
			☐ Yes ☐ No

Sample ID	Canister Serial No.	Flow Cont. #	Pres. Gauge #	Initial Vacuum Pres. (" Hg)	Initial Vacuum Date/ Time[9] Stopped	Final Vacuum Pres. (" Hg)	Final Vacuum Date/ Time[9] Stopped
1-BL-AA-VOC-1							
1-BL-AA-VOC-1-1							

Identity of pressure gauge used for vacuum measurement (manufacturer, model #, serial #, calibration date, calibration due, etc.): ______

Notes/comments: ______

[9] Date and time to be recorded using a MM/DD/YYYY HH:MM format

Project title: Vapor Intrusion Pressure Control ETV Test
Name and location of building:
Test number: Test 1
Building Pressure: X Baseline ☐ Negative ☐ Positive
Person(s) completing this forms:
Date(s) form completed:

AIR SAMPLING INFORMATION (Continued)

Subslab (SS) Samples

Grab samples into stainless steel canisters for VOCs and SF_6; sampling using real-time radon instrument; grab sampling into PVF bags for radon (duplicate).

VOC Grab Samples

Sample ID	Canister Serial No.	Flow Cont. #	Pres. Gauge #	Initial Vacuum		Final Vacuum	
				Pres. (" Hg)	Date/ Time[10] Stopped	Pres. (" Hg)	Date/ Time[10] Stopped
1-BL-SS-VOC-1							
1-BL-SS-VOC-2							
1-BL-SS-VOC-3							
1-BL-SS-VOC- -1							

Note: for duplicate sample, add sample location where sample was collected

Identity of pressure gauge used for vacuum measurement (manufacturer, model #, serial #, calibration date, calibration due, etc.): ______________________________

Real Time Radon Measurement

Sample ID	Date/Time[10] Sampling Started	Date/Time[10] Sampling Stopped	Flow Rate (units)
1-BL-SS-Rn-1			
1-BL-SS-Rn-2			
1-BL-SS-Rn-3			
1-BL-SS-Rn- -1			

Note: for duplicate sample, add sample location where sample was collected

Information on real-time radon instrument:

Manufacturer: ____________________ Model #: ________________
Serial #: ______________ Calibration date: _____________ Caibration Due: ___________

Radon in PVF Bags

Sample ID	Date/Time Collected[10]	Volume Collected (units)	New Syringe Used?
1-BL-AA-Rn-1			☐ Yes ☐ No
1-BL-AA-Rn-1-1			☐ Yes ☐ No
			☐ Yes ☐ No
			☐ Yes ☐ No

Note: sample location for SS PVF bag duplicate must be the same as for the location of duplicate real-time Rn measurement.

Use back of form for any additional notes or comments.

[10] Date and time to be recorded using a MM/DD/YYYY HH:MM format

Project title: Vapor Intrusion Pressure Control ETV Test
Name and location of building:
Test number: Test 1
Building Pressure: ☐ **Baseline** X **Negative** ☐ **Positive**
Person(s) completing this forms:
Date(s) form completed:

The following sample naming convention is to be followed when collecting all air samples. Identifiers are shown below the sample naming convention:

Test #	-	Pressure	-	Media Type	-	Target Compound	-	Sampling Location	-	Miscellaneous Information
1	-	BL	-	IA	-	VOC	-	1	-	1
2	-	NP	-	AA	-	Rn	-	2	-	2
	-	PP	-	SS	-		-	3	-	3

Where: BL = baseline IA = indoor air NP = negative pressure
PP = positive pressure SS = subslab Rn = radon
VOC = volatile organic compounds (includes SF_6 for IA, SS samples)
Misc info: 1 = duplicate sample 2 = blank sample 3 = recollected sample

AIR SAMPLING INFORMATION

Indoor Air (IA) Samples

Grab samples in PVF bags for radon (Rn), 8-hr time integrated samples into stainless steel canisters for VOC and SF_6.

Sample ID	Date/Time Collected[11]	Volume Collected (units)	New Syringe Used?
1-NP-IA-Rn-1			☐ Yes ☐ No
1-NP-IA-Rn-2			☐ Yes ☐ No
1-NP-IA-Rn-3			☐ Yes ☐ No
1-NP-IA-Rn- -1			☐ Yes ☐ No
1-NP-IA-Rn- -2			☐ Yes ☐ No
			☐ Yes ☐ No
			☐ Yes ☐ No

Note: for duplicate sample, add sample location where sample was collected

Sample ID	Canister Serial No.	Flow Cont. #	Pres. Gauge #	Initial Vacuum Pres. (" Hg)	Initial Vacuum Date/ Time[8] Stopped	Final Vacuum Pres. (" Hg)	Final Vacuum Date/ Time[8] Stopped
1-NP-IA-VOC-1							
1-NP-IA-VOC-2							
1-NP-IA-VOC-3							
1-NP-IA-VOC- -1							

Note: for duplicate sample, add sample location where sample was collected

Identity of pressure gauge used for vacuum measurement (manufacturer, model #, serial #, calibration date, calibration due, etc.): ______________________

____

____

Notes/comments: ______________________

____

____

[11] Date and time to be recorded using a MM/DD/YYYY HH:MM format

Project title: Vapor Intrusion Pressure Control ETV Test
Name and location of building:
Test number: Test 1
Building Pressure: ☐ Baseline X Negative ☐ Positive
Person(s) completing this forms:
Date(s) form completed:

AIR SAMPLING INFORMATION (Continued)

Ambient Air (AA) Samples

Grab samples into a PVF bag for radon (Rn), 8-hr time integrated samples into a stainless steel canister for VOC.

Sample ID	Date/Time Collected[12]	Volume Collected (units)	New Syringe Used?
1-NP-AA-Rn-1			☐ Yes ☐ No
1-NP-AA-Rn-1-1			☐ Yes ☐ No
1-NP-AA-Rn-1-2			☐ Yes ☐ No
			☐ Yes ☐ No
			☐ Yes ☐ No

				Initial Vacuum		Final Vacuum	
Sample ID	Canister Serial No.	Flow Cont. #	Pres. Gauge #	Pres. (" Hg)	Date/ Time[9] Stopped	Pres. (" Hg)	Date/ Time[9] Stopped
1-NP-AA-VOC-1							
1-NP-AA-VOC-1-1							

Identity of pressure gauge used for vacuum measurement (manufacturer, model #, serial #, calibration date, calibration due, etc.): ______________________________

____
____
____
____

Notes/comments: ______________________________

____
____
____
____
____
____

[12] Date and time to be recorded using a MM/DD/YYYY HH:MM format

Project title: Vapor Intrusion Pressure Control ETV Test
Name and location of building:
Test number: Test 1
Building Pressure: ☐ Baseline X Negative ☐ Positive
Person(s) completing this forms:
Date(s) form completed:

AIR SAMPLING INFORMATION (Continued)

Subslab (SS) Samples

Grab samples into stainless steel canisters for VOCs and SF_6; sampling using real-time radon instrument; grab sampling into PVF bags for radon (duplicate).

VOC Grab Samples

Sample ID	Canister Serial No.	Flow Cont. #	Pres. Gauge #	Initial Vacuum		Final Vacuum	
				Pres. (" Hg)	Date/ Time[13] Stopped	Pres. (" Hg)	Date/ Time[10] Stopped
1-NP-SS-VOC-1							
1-NP-SS-VOC-2							
1-NP-SS-VOC-3							
1-NP-SS-VOC- -1							

Note: for duplicate sample, add sample location where sample was collected

Identity of pressure gauge used for vacuum measurement (manufacturer, model #, serial #, calibration date, calibration due, etc.): ______________________________

____

____

Real Time Radon Measurement

Sample ID	Date/Time[10] Sampling Started	Date/Time[10] Sampling Stopped	Flow Rate (units)
1-NP-SS-Rn-1			
1-NP-SS-Rn-2			
1-NP-SS-Rn-3			
1-NP-SS-Rn- -1			

Note: for duplicate sample, add sample location where sample was collected

Information on real-time radon instrument:

Manufacturer: ____________________ Model #: ________________
Serial #: _____________ Calibration date: ____________ Caibration Due: ___________

Radon in PVF Bags

Sample ID	Date/Time Collected[10]	Volume Collected (units)	New Syringe Used?
1-NP-AA-Rn-1			☐ Yes ☐ No
1-NP-AA-Rn-1-1			☐ Yes ☐ No
			☐ Yes ☐ No
			☐ Yes ☐ No

Note: sample location for SS PVF bag duplicate must be the same as for the location of duplicate real-time Rn measurement.

Use back of form for any additional notes or comments.

[13] Date and time to be recorded using a MM/DD/YYYY HH:MM format

Project title: Vapor Intrusion Pressure Control ETV Test
Name and location of building:
Test number: Test 1
Building Pressure: ☐ Baseline ☐ Negative X Positive
Person(s) completing this forms:
Date(s) form completed:

The following sample naming convention is to be followed when collecting all air samples. Identifiers are shown below the sample naming convention:

Test #	-	Pressure	-	Media Type	-	Target Compound	-	Sampling Location	-	Miscellaneous Information
1	-	BL	-	IA	-	VOC	-	1	-	1
2	-	NP	-	AA	-	Rn	-	2	-	2
	-	PP	-	SS	-		-	3	-	3

Where: BL = baseline IA = indoor air NP = negative pressure
PP = positive pressure SS = subslab Rn = radon
VOC = volatile organic compounds (includes SF_6 for IA, SS samples)
Misc info: 1 = duplicate sample 2 = blank sample 3 = recollected sample

AIR SAMPLING INFORMATION

Indoor Air (IA) Samples

Grab samples in PVF bags for radon (Rn), 8-hr time integrated samples into stainless steel canisters for VOC and SF_6.

Sample ID	Date/Time Collected[14]	Volume Collected (units)	New Syringe Used?
1-PP-IA-Rn-1			☐ Yes ☐ No
1-PP-IA-Rn-2			☐ Yes ☐ No
1-PP-IA-Rn-3			☐ Yes ☐ No
1-PP-IA-Rn- -1			☐ Yes ☐ No
1-PP-IA-Rn- -2			☐ Yes ☐ No
			☐ Yes ☐ No
			☐ Yes ☐ No

Note: for duplicate sample, add sample location where sample was collected

Sample ID	Canister Serial No.	Flow Cont. #	Pres. Gauge #	Initial Vacuum		Final Vacuum	
				Pres. (" Hg)	Date/ Time[8] Stopped	Pres. (" Hg)	Date/ Time[8] Stopped
1-PP-IA-VOC-1							
1-PP-IA-VOC-2							
1-PP-IA-VOC-3							
1-PP-IA-VOC- -1							

Note: for duplicate sample, add sample location where sample was collected

Identity of pressure gauge used for vacuum measurement (manufacturer, model #, serial #, calibration date, calibration due, etc.): ______________________

Notes/comments: ______________________

[14] Date and time to be recorded using a MM/DD/YYYY HH:MM format

Project title: Vapor Intrusion Pressure Control ETV Test
Name and location of building:
Test number: Test 1
Building Pressure: ☐ **Baseline** ☐ **Negative** **X Positive**
Person(s) completing this forms:
Date(s) form completed:

AIR SAMPLING INFORMATION (Continued)

Ambient Air (AA) Samples

Grab samples into a PVF bag for radon (Rn), 8-hr time integrated samples into a stainless steel canister for VOC.

Sample ID	Date/Time Collected[15]	Volume Collected (units)	New Syringe Used?
1-PP-AA-Rn-1			☐ Yes ☐ No
1-PP-AA-Rn-1-1			☐ Yes ☐ No
1-PP-AA-Rn-1-2			☐ Yes ☐ No
			☐ Yes ☐ No
			☐ Yes ☐ No

Sample ID	Canister Serial No.	Flow Cont. #	Pres. Gauge #	Initial Vacuum		Final Vacuum	
				Pres. (" Hg)	Date/ Time[9] Stopped	Pres. (" Hg)	Date/ Time[9] Stopped
1-PP-AA-VOC-1							
1-PP-AA-VOC-1-1							

Identity of pressure gauge used for vacuum measurement (manufacturer, model #, serial #, calibration date, calibration due, etc.): ____________________

Notes/comments: ____________________

[15] Date and time to be recorded using a MM/DD/YYYY HH:MM format

Project title: Vapor Intrusion Pressure Control ETV Test
Name and location of building:
Test number: Test 1
Building Pressure: ☐ **Baseline** ☐ **Negative** **X Positive**
Person(s) completing this forms:
Date(s) form completed:

AIR SAMPLING INFORMATION (Continued)

Subslab (SS) Samples

Grab samples into stainless steel canisters for VOCs and SF_6; sampling using real-time radon instrument; grab sampling into PVF bags for radon (duplicate).

VOC Grab Samples

Sample ID	Canister Serial No.	Flow Cont. #	Pres. Gauge #	Initial Vacuum		Final Vacuum	
				Pres. (" Hg)	Date/ Time[16] Stopped	Pres. (" Hg)	Date/ Time[10] Stopped
1-PP-SS-VOC-1							
1-PP-SS-VOC-2							
1-PP-SS-VOC-3							
1-PP-SS-VOC- -1							

Note: for duplicate sample, add sample location where sample was collected

Identity of pressure gauge used for vacuum measurement (manufacturer, model #, serial #, calibration date, calibration due, etc.):____

Real Time Radon Measurement

Sample ID	Date/Time[10] Sampling Started	Date/Time[10] Sampling Stopped	Flow Rate (units)
1-PP-SS-Rn-1			
1-PP-SS-Rn-2			
1-PP-SS-Rn-3			
1-PP-SS-Rn- -1			

Note: for duplicate sample, add sample location where sample was collected

Information on real-time radon instrument:

Manufacturer: ____________________ Model #:__________________
Serial #:_______________ Calibration date:______________ Caibration Due:____________

Radon in PVF Bags

Sample ID	Date/Time Collected[10]	Volume Collected (units)	New Syringe Used?
1-PP-AA-Rn-1			☐ Yes ☐ No
1-PP-AA-Rn-1-1			☐ Yes ☐ No
			☐ Yes ☐ No
			☐ Yes ☐ No

Note: sample location for SS PVF bag duplicate must be the same as for the location of duplicate real-time Rn measurement.

Use back of form for any additional notes or comments.

[16] Date and time to be recorded using a MM/DD/YYYY HH:MM format

Project title: Vapor Intrusion Pressure Control ETV Test
Name and location of building:
Test number: Test 2
Building Pressure: X Baseline ☐ Negative ☐ Positive
Person(s) completing this forms:
Date(s) form completed:

The following sample naming convention is to be followed when collecting all air samples. Identifiers are shown below the sample naming convention:

Test #	-	Pressure	-	Media Type	-	Target Compound	-	Sampling Location	-	Miscellaneous Information
1	-	BL	-	IA	-	VOC	-	1	-	1
2	-	NP	-	AA	-	Rn	-	2	-	2
	-	PP	-	SS	-		-	3	-	3
								B		

Where: BL = baseline IA = indoor air NP = negative pressure
PP = positive pressure SS = subslab Rn = radon
VOC = volatile organic compounds (includes SF_6 for IA, SS samples)
Misc info: 1 = duplicate sample 2 = blank sample 3 = recollected sample

AIR SAMPLING INFORMATION

Indoor Air (IA) Samples

Grab samples in PVF bags for radon (Rn), 8-hr time integrated samples into stainless steel canisters for VOC and SF_6.

Sample ID	Date/Time Collected[17]	Volume Collected (units)	New Syringe Used?
2-BL-IA-Rn-1			☐ Yes ☐ No
2-BL-IA-Rn-2			☐ Yes ☐ No
2-BL-IA-Rn-3			☐ Yes ☐ No
2-BL-IA-Rn- -1			☐ Yes ☐ No
2-BL-IA-Rn- -2			☐ Yes ☐ No
			☐ Yes ☐ No
			☐ Yes ☐ No

Note: for duplicate sample, add sample location where sample was collected

Sample ID	Canister Serial No.	Flow Cont. #	Pres. Gauge #	Initial Vacuum		Final Vacuum	
				Pres. (" Hg)	Date/ Time[8] Stopped	Pres. (" Hg)	Date/ Time[8] Stopped
2-BL-IA-VOC-1							
2-BL-IA-VOC-2							
2-BL-IA-VOC-3							
2-BL-IA-VOC- -1							

Note: for duplicate sample, add sample location where sample was collected

Identity of pressure gauge used for vacuum measurement (manufacturer, model #, serial #, calibration date, calibration due, etc.): ____________________

Notes/comments: ____________________

[17] Date and time to be recorded using a MM/DD/YYYY HH:MM format

Project title: Vapor Intrusion Pressure Control ETV Test
Name and location of building:
Test number: Test 2
Building Pressure: X **Baseline** ☐ **Negative** ☐ **Positive**
Person(s) completing this forms:
Date(s) form completed:

AIR SAMPLING INFORMATION (Continued)

Ambient Air (AA) Samples

Grab samples into a PVF bag for radon (Rn), 8-hr time integrated samples into a stainless steel canister for VOC.

Sample ID	Date/Time Collected[18]	Volume Collected (units)	New Syringe Used?
2-BL-AA-Rn-1			☐ Yes ☐ No
2-BL-AA-Rn-1-1			☐ Yes ☐ No
2-BL-AA-Rn-1-2			☐ Yes ☐ No
			☐ Yes ☐ No
			☐ Yes ☐ No

Sample ID	Canister Serial No.	Flow Cont. #	Pres. Gauge #	Initial Vacuum		Final Vacuum	
				Pres. (" Hg)	Date/ Time[9] Stopped	Pres. (" Hg)	Date/ Time[9] Stopped
2-BL-AA-VOC-1							
2-BL-AA-VOC-1-1							

Identity of pressure gauge used for vacuum measurement (manufacturer, model #, serial #, calibration date, calibration due, etc.): ______

Notes/comments: ______

[18] Date and time to be recorded using a MM/DD/YYYY HH:MM format

Project title: Vapor Intrusion Pressure Control ETV Test
Name and location of building:
Test number: Test 2
Building Pressure: X **Baseline** ☐ **Negative** ☐ **Positive**
Person(s) completing this forms:
Date(s) form completed:

AIR SAMPLING INFORMATION (Continued)

Subslab (SS) Samples

Grab samples into stainless steel canisters for VOCs and SF_6; sampling using real-time radon instrument; grab sampling into PVF bags for radon (duplicate).

VOC Grab Samples

Sample ID	Canister Serial No.	Flow Cont. #	Pres. Gauge #	Initial Vacuum		Final Vacuum	
				Pres. (" Hg)	Date/ Time[19] Stopped	Pres. (" Hg)	Date/ Time[10] Stopped
2-BL-SS-VOC-1							
2-BL-SS-VOC-2							
2-BL-SS-VOC-3							
2-BL-SS-VOC- -1							

Note: for duplicate sample, add sample location where sample was collected

Identity of pressure gauge used for vacuum measurement (manufacturer, model #, serial #, calibration date, calibration due, etc.): ________________

Real Time Radon Measurement

Sample ID	Date/Time[10] Sampling Started	Date/Time[10] Sampling Stopped	Flow Rate (units)
2-BL-SS-Rn-1			
2-BL-SS-Rn-2			
2-BL-SS-Rn-3			
2-BL-SS-Rn- -1			

Note: for duplicate sample, add sample location where sample was collected

Information on real-time radon instrument:

Manufacturer: ____________ Model #: ____________
Serial #: ________ Calibration date: ________ Caibration Due: ________

Radon in PVF Bags

Sample ID	Date/Time Collected[10]	Volume Collected (units)	New Syringe Used?
2-BL-AA-Rn-1			☐ Yes ☐ No
2-BL-AA-Rn-1-1			☐ Yes ☐ No
			☐ Yes ☐ No
			☐ Yes ☐ No

Note: sample location for SS PVF bag duplicate must be the same as for the location of duplicate real-time Rn measurement.

Use back of form for any additional notes or comments.

[19] Date and time to be recorded using a MM/DD/YYYY HH:MM format

Project title: Vapor Intrusion Pressure Control ETV Test
Name and location of building:
Test number: Test 2
Building Pressure: ☐ Baseline X Negative ☐ Positive
Person(s) completing this forms:
Date(s) form completed:

The following sample naming convention is to be followed when collecting all air samples. Identifiers are shown below the sample naming convention:

Test #	-	Pressure	-	Media Type	-	Target Compound	-	Sampling Location	-	Miscellaneous Information
1	-	BL	-	IA	-	VOC	-	1	-	1
2	-	NP	-	AA	-	Rn	-	2	-	2
	-	PP	-	SS	-		-	3	-	3
								B		

Where: BL = baseline IA = indoor air NP = negative pressure
PP = positive pressure SS = subslab Rn = radon
VOC = volatile organic compounds (includes SF_6 for IA, SS samples)
Misc info: 1 = duplicate sample 2 = blank sample 3 = recollected sample

AIR SAMPLING INFORMATION

Indoor Air (IA) Samples

Grab samples in PVF bags for radon (Rn), 8-hr time integrated samples into stainless steel canisters for VOC and SF_6.

Sample ID	Date/Time Collected[20]	Volume Collected (units)	New Syringe Used?
2-NP-IA-Rn-1			☐ Yes ☐ No
2-NP-IA-Rn-2			☐ Yes ☐ No
2-NP-IA-Rn-3			☐ Yes ☐ No
2-NP-IA-Rn- -1			☐ Yes ☐ No
2-NP-IA-Rn- -2			☐ Yes ☐ No
			☐ Yes ☐ No
			☐ Yes ☐ No

Note: for duplicate sample, add sample location where sample was collected

Sample ID	Canister Serial No.	Flow Cont. #	Pres. Gauge #	Initial Vacuum		Final Vacuum	
				Pres. (" Hg)	Date/ Time[8] Stopped	Pres. (" Hg)	Date/ Time[8] Stopped
2-NP-IA-VOC-1							
2-NP-IA-VOC-2							
2-NP-IA-VOC-3							
2-NP-IA-VOC- -1							

Note: for duplicate sample, add sample location where sample was collected

Identity of pressure gauge used for vacuum measurement (manufacturer, model #, serial #, calibration date, calibration due, etc.): ____________________

____

____

Notes/comments: ____________________

____

[20] Date and time to be recorded using a MM/DD/YYYY HH:MM format

Project title: Vapor Intrusion Pressure Control ETV Test
Name and location of building:
Test number: Test 2
Building Pressure: ☐ **Baseline** X **Negative** ☐ **Positive**
Person(s) completing this forms:
Date(s) form completed:

AIR SAMPLING INFORMATION (Continued)

Ambient Air (AA) Samples

Grab samples into a PVF bag for radon (Rn), 8-hr time integrated samples into a stainless steel canister for VOC.

Sample ID	Date/Time Collected[21]	Volume Collected (units)	New Syringe Used?
2-NP-AA-Rn-1			☐ Yes ☐ No
2-NP-AA-Rn-1-1			☐ Yes ☐ No
2-NP-AA-Rn-1-2			☐ Yes ☐ No
			☐ Yes ☐ No
			☐ Yes ☐ No

Sample ID	Canister Serial No.	Flow Cont. #	Pres. Gauge #	Initial Vacuum		Final Vacuum	
				Pres. (" Hg)	Date/ Time[9] Stopped	Pres. (" Hg)	Date/ Time[9] Stopped
2-NP-AA-VOC-1							
2-NP-AA-VOC-1-1							

Identity of pressure gauge used for vacuum measurement (manufacturer, model #, serial #, calibration date, calibration due, etc.): ______________________________

Notes/comments: ______________________________

[21] Date and time to be recorded using a MM/DD/YYYY HH:MM format

Project title: Vapor Intrusion Pressure Control ETV Test
Name and location of building:
Test number: Test 2
Building Pressure: ☐ Baseline X Negative ☐ Positive
Person(s) completing this forms:
Date(s) form completed:

AIR SAMPLING INFORMATION (Continued)

Subslab (SS) Samples

Grab samples into stainless steel canisters for VOCs and SF_6; sampling using real-time radon instrument; grab sampling into PVF bags for radon (duplicate).

VOC Grab Samples

Sample ID	Canister Serial No.	Flow Cont. #	Pres. Gauge #	Initial Vacuum		Final Vacuum	
				Pres. (" Hg)	Date/ Time[22] Stopped	Pres. (" Hg)	Date/ Time[10] Stopped
2-NP-SS-VOC-1							
2-NP-SS-VOC-2							
2-NP-SS-VOC-3							
2-NP-SS-VOC- -1							

Note: for duplicate sample, add sample location where sample was collected

Identity of pressure gauge used for vacuum measurement (manufacturer, model #, serial #, calibration date, calibration due, etc.): ______________________

Real Time Radon Measurement

Sample ID	Date/Time[10] Sampling Started	Date/Time[10] Sampling Stopped	Flow Rate (units)
2-NP-SS-Rn-1			
2-NP-SS-Rn-2			
2-NP-SS-Rn-3			
2-NP-SS-Rn- -1			

Note: for duplicate sample, add sample location where sample was collected

Information on real-time radon instrument:

Manufacturer: ____________________ Model #: ________________

Serial #: _____________ Calibration date: ____________ Caibration Due: ___________

Radon in PVF Bags

Sample ID	Date/Time Collected[10]	Volume Collected (units)	New Syringe Used?
2-NP-AA-Rn-1			☐ Yes ☐ No
2-NP-AA-Rn-1-1			☐ Yes ☐ No
			☐ Yes ☐ No
			☐ Yes ☐ No

Note: sample location for SS PVF bag duplicate must be the same as for the location of duplicate real-time Rn measurement.

Use back of form for any additional notes or comments.

[22] Date and time to be recorded using a MM/DD/YYYY HH:MM format

Project title: Vapor Intrusion Pressure Control ETV Test
Name and location of building:
Test number: Test 2
Building Pressure: ☐ **Baseline** ☐ **Negative** **X Positive**
Person(s) completing this forms:
Date(s) form completed:

The following sample naming convention is to be followed when collecting all air samples. Identifiers are shown below the sample naming convention:

Test #	-	Pressure	-	Media Type	-	Target Compound	-	Sampling Location	-	Miscellaneous Information
1	-	BL	-	IA	-	VOC	-	1	-	1
2	-	NP	-	AA	-	Rn	-	2	-	2
	-	PP	-	SS	-		-	3	-	3

Where: BL = baseline IA = indoor air NP = negative pressure
PP = positive pressure SS = subslab Rn = radon
VOC = volatile organic compounds (includes SF_6 for IA, SS samples)
Misc info: 1 = duplicate sample 2 = blank sample 3 = recollected sample

AIR SAMPLING INFORMATION

Indoor Air (IA) Samples

Grab samples in PVF bags for radon (Rn), 8-hr time integrated samples into stainless steel canisters for VOC and SF_6.

Sample ID	Date/Time Collected[23]	Volume Collected (units)	New Syringe Used?
2-PP-IA-Rn-1			☐ Yes ☐ No
2-PP-IA-Rn-2			☐ Yes ☐ No
2-PP-IA-Rn-3			☐ Yes ☐ No
2-PP-IA-Rn- -1			☐ Yes ☐ No
2-PP-IA-Rn- -2			☐ Yes ☐ No
			☐ Yes ☐ No
			☐ Yes ☐ No

Note: for duplicate sample, add sample location where sample was collected

Sample ID	Canister Serial No.	Flow Cont. #	Pres. Gauge #	Initial Vacuum		Final Vacuum	
				Pres. (" Hg)	Date/ Time[8] Stopped	Pres. (" Hg)	Date/ Time[8] Stopped
2-PP-IA-VOC-1							
2-PP-IA-VOC-2							
2-PP-IA-VOC-3							
2-PP-IA-VOC- -1							

Note: for duplicate sample, add sample location where sample was collected

Identity of pressure gauge used for vacuum measurement (manufacturer, model #, serial #, calibration date, calibration due, etc.): ______________________

Notes/comments: ______________________

[23] Date and time to be recorded using a MM/DD/YYYY HH:MM format

Project title: Vapor Intrusion Pressure Control ETV Test
Name and location of building:
Test number: Test 2
Building Pressure: ☐ **Baseline** ☐ **Negative** **X Positive**
Person(s) completing this forms:
Date(s) form completed:

AIR SAMPLING INFORMATION (Continued)

Ambient Air (AA) Samples

Grab samples into a PVF bag for radon (Rn), 8-hr time integrated samples into a stainless steel canister for VOC.

Sample ID	Date/Time Collected[24]	Volume Collected (units)	New Syringe Used?
2-PP-AA-Rn-1			☐ Yes ☐ No
2-PP-AA-Rn-1-1			☐ Yes ☐ No
2-PP-AA-Rn-1-2			☐ Yes ☐ No
			☐ Yes ☐ No
			☐ Yes ☐ No

Sample ID	Canister Serial No.	Flow Cont. #	Pres. Gauge #	Initial Vacuum		Final Vacuum	
				Pres. (" Hg)	Date/ Time[9] Stopped	Pres. (" Hg)	Date/ Time[9] Stopped
2-PP-AA-VOC-1							
2-PP-AA-VOC-1-1							

Identity of pressure gauge used for vacuum measurement (manufacturer, model #, serial #, calibration date, calibration due, etc.): ____________________

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Notes/comments: ____________________

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[24] Date and time to be recorded using a MM/DD/YYYY HH:MM format

Project title: Vapor Intrusion Pressure Control ETV Test
Name and location of building:
Test number: Test 2
Building Pressure: ☐ Baseline ☐ Negative X Positive
Person(s) completing this forms:
Date(s) form completed:

AIR SAMPLING INFORMATION (Continued)

Subslab (SS) Samples

Grab samples into stainless steel canisters for VOCs and SF_6; sampling using real-time radon instrument; grab sampling into PVF bags for radon (duplicate).

VOC Grab Samples

Sample ID	Canister Serial No.	Flow Cont. #	Pres. Gauge #	Initial Vacuum		Final Vacuum	
				Pres. (" Hg)	Date/ Time[25] Stopped	Pres. (" Hg)	Date/ Time[10] Stopped
2-PP-SS-VOC-1							
2-PP-SS-VOC-2							
2-PP-SS-VOC-3							
2-PP-SS-VOC- -1							

Note: for duplicate sample, add sample location where sample was collected

Identity of pressure gauge used for vacuum measurement (manufacturer, model #, serial #, calibration date, calibration due, etc.): ______________________________

Real Time Radon Measurement

Sample ID	Date/Time[10] Sampling Started	Date/Time[10] Sampling Stopped	Flow Rate (units)
2-PP-SS-Rn-1			
2-PP-SS-Rn-2			
2-PP-SS-Rn-3			
2-PP-SS-Rn- -1			

Note: for duplicate sample, add sample location where sample was collected

Information on real-time radon instrument:

Manufacturer: ____________________ Model #: ________________
Serial #: _____________ Calibration date: ____________ Caibration Due: __________

Radon in PVF Bags

Sample ID	Date/Time Collected[10]	Volume Collected (units)	New Syringe Used?
2-PP-AA-Rn-1			☐ Yes ☐ No
2-PP-AA-Rn-1-1			☐ Yes ☐ No
			☐ Yes ☐ No
			☐ Yes ☐ No

Note: sample location for SS PVF bag duplicate must be the same as for the location of duplicate real-time Rn measurement.

Use back of form for any additional notes or comments.

[25] Date and time to be recorded using a MM/DD/YYYY HH:MM format

APPENDIX E: EXAMPLE CHAIN OF CUSTODY FORM

Columbia Analytical Services

2655 Park Center Drive, Suite A
Simi Valley, California 93065
Phone (805) 526-7161
Fax (805) 526-7270

Air - Chain of Custody Record & Analytical Service Request

Page _______ of ________

Requested Turnaround Time in Business Days (Surcharges) please circle 1 Day (100%) 2 Day (75%) 3 Day (50%) 4 Day (35%) 5 Day (25%) 10 Day-Standard	CAS Project No.
	CAS Contact:

Company Name & Address (Reporting Information)	Project Name Project Number
Project Manager	P.O. # / Billing Information
Phone / Fax	
Email Address for Result Reporting	Sampler (Print & Sign)

Client Sample ID	Laboratory ID Number	Date Collected	Time Collected	Canister ID (Bar code # - AC, SC, etc.)	Flow Controller ID (Bar code # - FC #)	Canister Start Pressure "Hg	Canister End Pressure "Hg/psig	Sample Volume	**Analysis Method**		**Comments** e.g. Actual Preservative or specific instructions

Report Tier Levels - please select

Tier I - Results (Default if not specified) _____
Tier II (Results + QC Summaries) _____
Tier III (Results + QC & Calibration Summaries) _____
Tier IV (Data Validation Package) 10% Surcharge _____

EDD required Yes / No
Type: ________________

Project Requirements (MRLs, QAPP)

Reliquished by: (Signature)	Date:	Time:	Received by: (Signature)	Date:	Time:	
Reliquished by: (Signature)	Date:	Time:	Received by: (Signature)	Date:	Time:	Cooler / Blank Temperature ____ºC