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Quality Assurance Project Plan (QAPP)

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QAPP Accessibility: QAPPs will be made internally accessible via the ORD QAPP intranet site and RAPID upon final approval *unless the following statement is selected*.
☐ I do NOT want this QAPP internally shared and accessible on the ORD intranet site.

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Revision History

Date	QAPP ID	Author(s)	Description of Revision & Comments
7/19/2022	J-EPD-0033261-QP-1-0	Kate Bronstein, Chris Lutes	Initial version
7/28/2022	J-EPD-0033261-QP-1-0	Kate Bronstein, Chris Lutes	Revisions to address EPA QA Manager comments

Acronym/Abbreviations/Definitions

Abbreviation	Definition
°C	degrees Celsius
°F	degrees Fahrenheit
BFB	Bromofluorobenzene
bgs	below ground surface
CCV	continuing calibration verification
CEMM	Center for Environmental Measurement and Modeling
CF	chloroform
CO2	carbon dioxide
COC	chain-of-custody
CVOC	chlorinated volatile organic compound
DCE	cis-1,2-Dichloroethene
DNAPL	dense non-aqueous phase liquid
EJ	environmental justice
EPA	Environmental Protection Agency
GC/MS	gas chromatography/mass spectrometry
Hg	mercury
hPa	hectopascal pressure units
HVOC	halogenated VOCs
IA	indoor air
ICAL	initial calibration curve
ICV	initial calibration verification
IS	internal standard
ITS	indicators, tracers, and surrogates
LCS	laboratory control samples
LNAPL	light non-aqueous phase liquid
m^3	cubic meters
mBar/hPa	millibar per hectopascal pressure units
MDL	method detection limit
MOP	Manual of Procedures
NDIR	Non-Dispersive Infra-Red

Abbreviation	Definition
ng	nanogram
NOAA	National Oceanic and Atmospheric Administration
ORD	Office of Research and Development
ORCR	Office of Resource Conservation and Recovery
pCi/L	picocuries per liter
PCE	tetrachloroethene
PID	photoionization detector
$PM_{2.5}$	particulate matter below 2.5 microns
ppb	parts per billion
ppm	parts per million
ppmv	parts per million by volume
Project (aka Research Effort)	The research effort undertaken to fulfil a discrete set of objectives; a project typically results in the generation of one or more RAP Products
QA	Quality Assurance
QAM	Quality Assurance Manager
QAPP	Quality Assurance Project Plan
QC	Quality Control
QA	Quality assurance; management activities involving planning, implementation, assessment, reporting, and quality improvement to ensure that a process, item, or service is of the type and quality needed and expected.
QC	Quality control; technical activities that measure the attributes and performance of a process, item, or service against defined standards to verify that they meet the stated requirements
RH	relative humidity
RL	reporting limit
RME	reasonable maximum exposure
RPD	relative percentage difference
RSD	relative standard deviation
RT	retention time
SGI	soil gas intrusion
SGP	soil gas probe
SOP	Standard Operating Procedure
SV	soil vapor
TCE	trichloroethene
TOL	Task Order Lead
TO	Task Order
TOCOR	Task Order Contracting Office Representative
T	temperature
VI	vapor intrusion
VOC	volatile organic compounds

1 Project Background

Vapor intrusion (VI) assessment is complicated by spatial and temporal variability, largely due to compounded interactions among the many individual factors that influence the vapor migration pathway from subsurface sources to indoor air (Schuver et al., 2018). Past research on highly variable indoor air datasets demonstrates that conventional sampling schemes can result in false negative determinations of potential risk corresponding to reasonable maximum exposures (RME). While high-frequency chemical analysis of individual chlorinated volatile organic compounds (CVOCs) in indoor air is conceptually appealing, it remains largely impractical when numerous buildings are involved and particularly for long-term monitoring. To help reduce the need for intrusive, time consuming, and expensive indoor air analysis, the EPA's Office of Resource Conservation and Recovery (ORCR) has been researching alternative approaches to help guide discrete sampling efforts and reduce sampling requirements while maintaining acceptable confidence in exposure characterization. Indicators, tracers, and surrogates (ITS), which include a collection of quantifiable metrics and tools, have been suggested as a potential solution for making VI pathway assessment and long-term monitoring more informative, efficient, and cost-effective. EPA's Office of Research and Development (ORD) has also conducted studies in support of this effort, examining, for example, how radon and VOCs vary jointly over time and testing the effectiveness of consumer grade radon monitoring equipment.

As the ITS approach for determining when to sample has advanced, the need to expand to the community scale, instead of only select individual homes and buildings, has been identified. Areas encompassing hundreds to thousands of structures are often in need of evaluation at VI sites. Yet government and principle responsible parties (PRPs) resources are frequently insufficient to conduct sampling at all of those structures using current sampling approaches. Moreover, recent studies have highlighted the high risk of false negative results when evaluating a building based on a small number of randomly timed or seasonally scheduled samples. These problems occur in neighborhoods of all income levels but are believed to be especially common in areas with environmental justice concerns (Schuver et. al., 2021).

EPA would like to be able to quickly identify: (a) homes and buildings 'at risk' for VI (i.e., are overlying/proximate to VI 'sources') within a community; (b) contaminants of concern for VI in the subslab soil gas below a structure's foundations, and; (c) 'baseline' measurements showing elevated subslab soil gas intrusion into indoor air. Following the collection of baseline measurements, subsequent samples will be collected at varying intervals, as determined by both a standard calendar-triggered schedule, which VI guidance currently suggests as best practice, and ITS-triggered schedule, which EPA would like to demonstrate as a defensible approach for assessing the VI pathway.

To accomplish these goals, EPA recognizes that community involvement and community scientists/occupants are needed to be an active part of the process. EPA would like each community member 'at risk' for VI in their respective structure(s) to:

- have easy access to participate and collaborate with the remedial program decision makers as an equal participant (along with their expert consultants),
- be given an opportunity to share their **own** building-specific evidence of subslab soil gas intrusion (SGI), and

- be a part of the risk management decision making for their residence or building (for example, continuous soil gas ITS monitoring by the community scientists/occupants).

In cases where the community is economically-challenged or in a vulnerable environmental justice (EJ) community, EPA would: support the ITS monitoring with meters to monitor changing conditions; provide training in chemical sampling for verifying SGI is occurring; and provide training and guidance on means and controls to reduce SGI.

As the program is grown within a community, this new continuous-ITS-monitoring approach could be considered a response that offers potentially-impacted, including communities with EJ concerns, with an opportunity to have more input and decision-making power in their indoor air quality. This is important as society changes over time such as buildings being 'weatherized', and more time being spent indoors. It is anticipated that the societal cost for using this approach is far less than current approaches that emphasize contaminant attribution but provide far fewer benefits to those communities with EJ concerns (Lutes et al., 2021). Ultimately, with the inclusion of numerous community scientists throughout a community providing valuable inputs on changing conditions and collecting SGI samples, an EPA ORCR *Soil Gas Safe Community* designation is planned to help communities acknowledge that progress is being made towards safer indoor air quality as well as to remove some of the negative stigma associated with a community having VI issues.

1.1 Vapor Intrusion Background

VI, the migration of subsurface vapors to indoor air, has emerged as a priority contaminant pathway at hazardous waste sites nationwide, including Superfund, RCRA, and Brownfields sites. VI occurs due to the pressure and concentration differentials between indoor air and soil gas. Indoor environments are often negatively pressurized with respect to outdoor air and soil gas. This pressure difference allows subsurface vapors to migrate into indoor air through advection. In addition, concentration differentials may cause VOCs to migrate from areas of higher to lower concentrations through diffusion.

VI is a complex process influenced by a variety of geological, meteorological, and building operational factors that cause substantial temporal variability in indoor concentrations. Current practice for evaluating the VI pathway consists of a combination of mathematical modeling and direct measurements in groundwater, external soil gas, subslab soil gas, and indoor air. No single line of evidence is considered definitive, and direct measurements can be costly and can have significant spatial and temporal variability requiring repeated measurements at multiple locations to accurately assess the chronic risks of long-term VOC exposure. This project will focus on the collection of external soil gas and indoor air to research how ITS, such as radon, carbon dioxide, temperature, and pressure differentials as driven by barometric pressure change, may provide a better understanding of how sample timing impacts the potential for capturing the reasonable worst case VI exposure so that the need for mitigation/remediation can be assessed more accurately. Most of the in-depth chemical VI research to date has been performed on residential structures, but large non-residential buildings are also affected and may behave differently. The intention for this project is to focus on residential structures (single or multi-family), to the extent possible.

The VI exposure pathway extends from the contaminant source — which can be free product or VOCs sorbed to vadose zone soil, or VOC-contaminated groundwater — to indoor air exposure points.

Contaminated matrices therefore may include groundwater, soil, soil gas, and indoor air. Contaminants of concern typically include halogenated VOCs (HVOCs) such as trichloroethene (TCE), tetrachloroethene (PCE), chloroform (CF), and vinyl chloride (VC), but may also include aromatic VOCs such as benzene, toluene, and xylenes. These contaminants can be present in the dissolved phase, as free phases, or sorbed to the geological matrix. This project will focus on HVOCs, which are resistant to biodegradation in aerobic soils and groundwater. Of the chemicals subject to investigation under this project, HVOCs, like TCE and PCE, are generally considered quite resistant to biodegradation.

An overview of important VI pathways is shown in **Figure 1-1**.

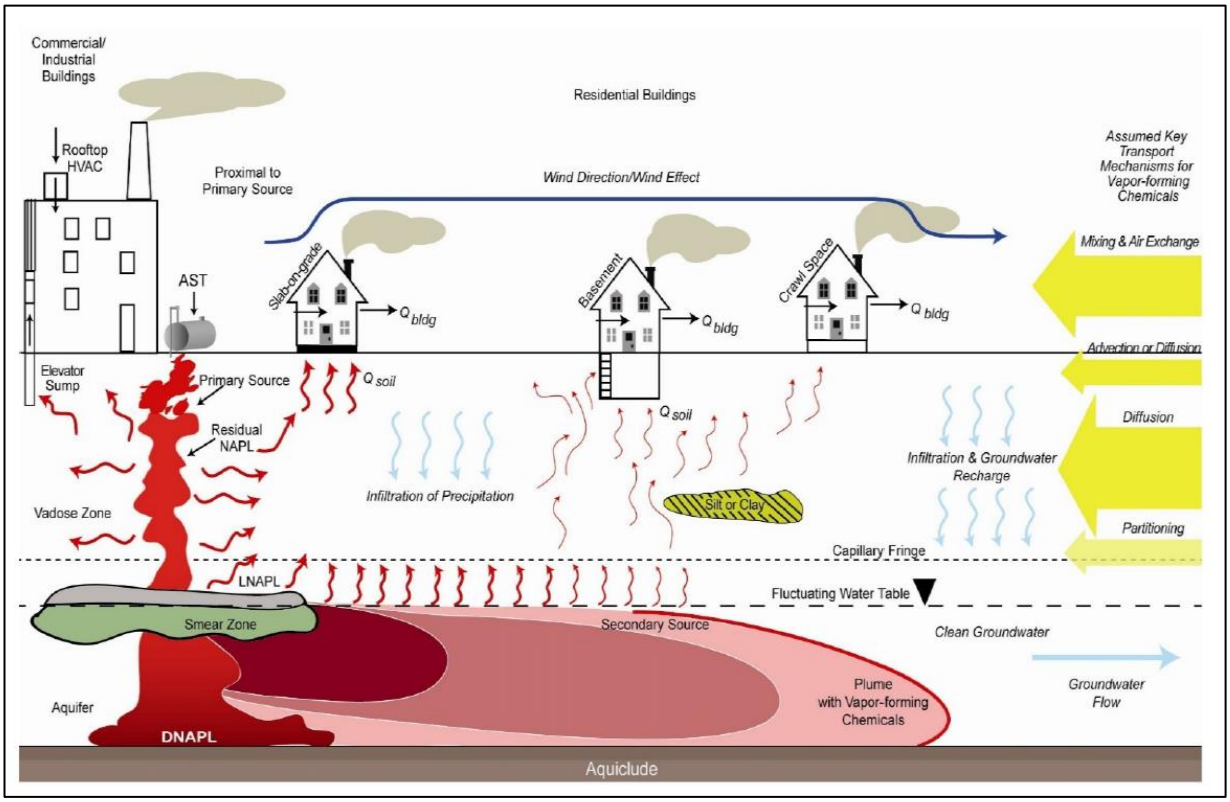


Figure 1-1. An Overview of Important VI Pathways

Source: US EPA 2015

Three main pathways of VOC migration into buildings have been defined for VI:

1. Movement of vapors from shallow soil sources through the unsaturated (vadose) zone
2. Transport of VOCs through groundwater, followed by partitioning of VOCs from the shallowest layer of groundwater into vadose zone soil gas
3. Vapor migration through conduit pathways such as utility corridors either directly into structures or into the subslab layer.

In portions of these three pathways, transport is dominated by advective forces, while in other portions, it is dominated by diffusive forces.

In at least the first two pathways, the final step of VI typically involves soil gas moving from the immediate subslab space into the indoor air. This subslab space is often significantly more permeable than the bulk vadose zone soil, either because a gravel drainage layer was intentionally used, or the soils have shrunk back from the slab in places. In these cases, the subslab space is expected to serve as a common plenum allowing the lateral mixing of VOCs that reach the building through multiple pathways.

Vapor and liquid transport processes and their interactions with various geologic and physical site settings (including building construction and design), under given meteorological conditions, control migration through the VI pathway. Variations in building design, construction, use and maintenance, site-specific stratigraphy, subslab composition, temporal variation in atmospheric pressure, temperature, precipitation, infiltration, soil moisture, water table elevation, and other factors combine to create a complex and dynamic system. Important factors controlling VI at many sites include:

- Biodegradation of VOCs as they migrate in the vadose zone
- Site stratigraphy
- Soil moisture and groundwater recharge
- Fluctuations in water table elevation
- Temporal and interbuilding ventilation system operational variations for commercial/industrial buildings (NJ DEP, 2018; US EPA, 2015a).

Current soil gas sampling U.S. federal and state regulatory guidance (ASTDR, 2016; DoD, 2009; EPA, 2015) indicates that the primary contamination source need not be on the property of interest to pose a potential SGI risk. The primary source may be present on a neighboring property which can contain contamination by vapor-forming chemicals due to migrating plumes of contaminated groundwater or migrating soil gases. At many sites, the subsurface vapor source (e.g., in soil or groundwater) is not in contact with the bottom of the subject building. Under these circumstances, vapors emanating from the source medium enter the pore space around and between the subsurface soil particles in the soil column above the groundwater table, which is called the unsaturated soil zone or vadose zone. If the subsurface vapor source is in the vadose zone, the vapors have the potential to migrate radially in all directions from the source via diffusion or wind induced pressure differentials (EPA, 2015). Due to this potential migration, it is generally considered appropriate to evaluate structures located within 100-feet of a contaminant source by using multiple lines of evidence, such as subslab soil gas, exterior near-source soil gas, indoor air, and outdoor air, as well as ITS parameters. However, one disadvantage of subslab sampling is its intrusiveness to the occupants and the building envelope.

State-specific guidance also generally calls for a minimum of two sampling rounds to collect a sufficient data set for decision making about a site. However recent studies have shown that small numbers of sampling rounds have a high probability of underestimating exposure (Lutes, 2021a; Schuver, 2021). More details will be provided in Subtask 2A on current state and regional requirements.

Based on the various guidance documents, including comparative studies of regulatory guidance (Levy et al., 2019; Eklund et al., 2018; Rolph et al., 2012), this project will focus on collection of exterior soil gas and indoor air samples to assess the potential SGI pathway in each structure. This will reduce the intrusion on building occupants and their respective structures. In addition, the project will consist of multiple sampling events structured around conventional calendar-based sample scheduling (i.e., three events approximately 4 months apart) and a triggered sampling approach using ITS monitoring to dictate when the likelihood of SGI to be occurring may increase.

1.2 Expected Variability in Vapor Intrusion Studies

Through measurements of radon and VOC VI under various conditions, several studies have provided insight of the complexity of temporal variability in indoor air concentrations attributable to VI—the primary focus of this project. Nazaroff et al. (1987) studied how induced-pressure variations can influence radon transport from soil into buildings with roughly hourly resolution. In a more recent study, Mosley (2007) presented the results of experiments, showing that induced building pressure variations influence both the temporal and spatial variability of both radon and HVOCs in subslab samples and in indoor air. Schuver and Mosley (2009) also reviewed numerous studies of radon indoor concentrations, in which multiple repeated indoor air samples were collected with hourly, daily, weekly, monthly, 3-month, and annual sample durations for study periods of up to 3 years; however, detailed soil gas radon data sets are rarer.

Several radon studies have demonstrated that barometric pressure fluctuations can affect the transport of soil gas into buildings (Robinson and Sextro, 1997). The impact of barometric pressure fluctuations on indoor air is influenced by the interaction of the building structures and conditions, as well as other concurrent factors, such as wind (Luo et al., 2009). Changes in atmospheric conditions (e.g., pressure, wind) and building conditions (e.g., open doors and windows) may temporarily over- or under-pressurize a building. Based on long-term pressure differential datasets acquired by EPA's National Exposure Research Laboratory (NERL) at an Indianapolis study site at which both radon and VOCs were measured in both subslab and indoor air, other factors that may cause temporal and spatial variability in soil vapor and indoor air concentrations include:

- Fluctuation in building air exchange rates due to occupant behavior/HVAC operations
- Fluctuations in outdoor/indoor temperature difference
- Rainfall events and resultant infiltration and fluctuations in the water table elevation (US EPA, 2012b, 2015b, and 2015c).

The pressure difference between a house-sized building and the surrounding soil is usually most significant within 1 to 2 meters (m) of the structure, but measurable effects have been reported up to 5 m from the structure (Nazaroff et al., 1987). Temperature differences or unbalanced mechanical ventilation are likely to induce a symmetrical pressure distribution in the subsurface, but the wind load on a building adds an asymmetrical component to the pressure and distribution of contaminants in soil gas.

Folkes et al. (2009) summarize several large groundwater, subslab, and indoor air data sets collected with sampling frequencies ranging from quarterly to annually during investigations of VI from HVOC plumes beneath hundreds of homes in Colorado and New York. They analyzed these datasets to illustrate the temporal and spatial distributions in the concentration of VOCs. In a study of the VI pathway at the Raymark Superfund Site, EPA (2005a) showed that measured subslab concentrations of HVOCs exhibited spatial and temporal variability between neighboring houses and within individual houses. Similar variability in subslab HVOC concentrations within and between houses has been observed during VI evaluations of several sites in New York state (Wertz and Festa, 2007).

In scenarios with coarser soils (e.g., sands, gravels), the soil gas permeability is high, and changes in building pressurization may affect the airflow field and the resultant soil vapor concentration profiles near buildings. In scenarios with fine-grained soils (e.g., silts, clays), the soil gas permeability is low and soil gas flowrates (Qs) may be negligible and not affect the subsurface concentration. Nevertheless, in both soil type scenarios, over-pressurization of the building may still significantly reduce the indoor air concentration due to the reversal of soil gas flow direction from the building into the soil (Abreu and Johnson, 2005 and 2006).

A wind-induced, nonuniform pressure distribution on the ground surface on either side of a house may cause spatial and temporal variability in the subslab or near-foundation soil vapor concentration distribution if the wind is strong and the soil gas permeability is high (Luo et al., 2006). In addition, during or after a rainfall event, the subsurface beneath the building may have a lower moisture content than the adjacent areas due to water infiltration.

1.2.1 Spatial Variability

Spatially, reports of several orders of magnitude variability without apparent patterns between indoor air and subslab concentrations for adjacent structures in a neighborhood are very common (see for example Dawson, 2008). Six orders of magnitude in subslab concentration variability were reported by Eklund and Burrows (2009) for one building of 8,290 sq. ft.

As shown in **Figure 1-2**, Schumacher and colleagues (2010) observed more than three orders of magnitude concentration variability in shallow soil gas below a slab outside a building over 50 lateral feet, suggesting a strong effect of impervious surfaces both in limiting soil gas exchange with the atmosphere and in maintaining relatively high concentrations of VOCs in shallow groundwater. They also observed two orders of magnitude concentration variability with a depth change of 10 ft in the unsaturated zone within one bore hole.

Lee and colleagues (2010) observed two orders of magnitude variability in subslab concentration within a small townhouse. Studies by McHugh and others (2007) have generally found markedly less variability in indoor air concentrations than in subslab concentrations, probably due to the greater degree of mixing in the indoor environment.[1]

[1] See also Lee 2010 op. cit.

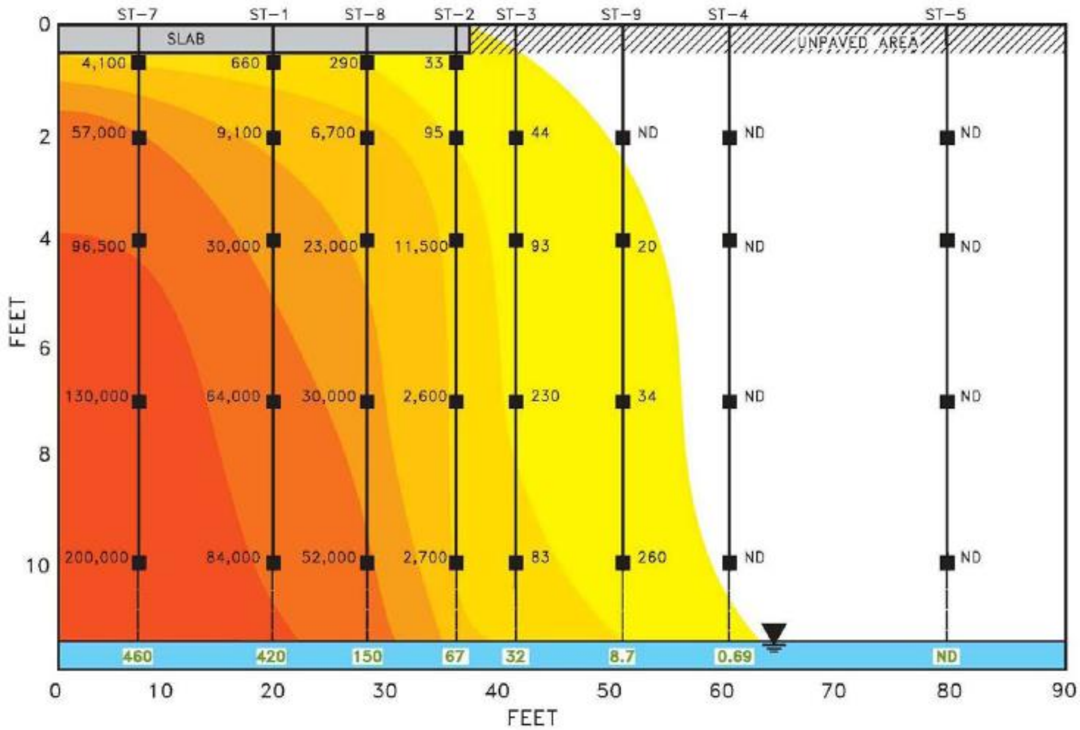


Figure 1-2. Measured Soil Gas and Groundwater Concentrations of TCE Below a Slab.

Figure source: Schumacher et al., 2010

In results from the Indianapolis test house from the 2012 EPA report, VOCs and radon were seen in high concentrations directly beneath the slab (subslab probes) and 6 ft soil gas probes (SGPs), but these were not seen in the shallow external SGPs (3.5 ft SGPs). There was substantial variability among the external SGPs at the 6-ft below ground surface (bgs) level. These values would have underpredicted subslab conditions. When comparing the deeper SGPs, PCE concentrations were lower and more variable outside the building. Average concentrations of chloroform and radon had close agreement both inside and outside the building (USEPA, 2012b).

Studies of VI processes in commercial buildings have generally shown significantly better attenuation factors than have been observed in typical residences (Venable et al., 2015).

1.2.2 Temporal Variability

ITRC (2007) summarizes temporal variability in Section D.4.10:

> *Variations in soil gas concentrations due to temporal effects are principally due to temperature changes, precipitation, and activities within any overlying structure. Variations are greater in samples taken close to the surface and dampen with increasing depth. In 2006 there were a number of studies on temporal variation in soil gas concentrations, and more are under way or planned in 2007 by USEPA and independent groups. To date these studies have shown that short-term variations in soil gas concentrations at depths 4 feet or deeper are less than a factor of 2 and that seasonal*

variations in colder climates are less than a factor of 5 (Hartman 2006). Larger variations may be expected in areas of greater temperature variation and during heavy periods of precipitation, as described below.

- *<u>Temperature</u>. Effects on soil gas concentrations due to actual changes in the vadose zone temperature are minimal. The bigger effect is due to changes in an overlying heating or HVAC system and the ventilation of the structure due to open doors and windows. In colder climates, worse-case scenarios are most likely in the winter season. The radon literature suggests that temporal variations in soil gas are typically less than a factor of 2 and that seasonal effects are less than a factor of 5. If soil gas values are more than a factor of 5 below acceptable levels, repeated sampling is likely not necessary regardless of the season. If the measured values are within a factor of 5 of allowable risk levels, then repeated sampling may be appropriate.*
- *<u>Precipitation</u>. Infiltration from rainfall can potentially impact soil gas concentrations by displacing the soil gas, dissolving VOCs, and by creating a "cap" above the soil gas. In many settings, infiltration from large storms penetrates into only the uppermost vadose zone. In general, soil gas samples collected at depths greater than about 3–5 feet bgs or under foundations or areas with surface cover are unlikely to be significantly affected. Soil gas samples collected closer to the surface (<3 feet) with no surface cover may be affected. If the moisture has penetrated to the sampling zone, it typically can be recognized by difficulty in collecting soil gas samples. If high vacuum readings are encountered when collecting a sample or drops of moisture are evident in the sampling system or sample, measured values should be considered as minimum values.*
- *<u>Barometric Pressure</u>. Barometric pressure variations are unlikely to have a significant effect on soil gas concentrations at depths exceeding 3–5 feet bgs unless a major storm front is passing by. A recent study in Wyoming (Luo et al. 2006) has shown little to no relationship between barometric pressure and soil gas oxygen concentrations for a site with a water table at ~15 feet bgs.*

In summary, temporal variations in soil gas concentrations, even for northern climates, are minor compared with the conservative nature of the risk-based screening levels. If soil gas values are a factor of 5–10 times below the risk-based screening levels, there likely is no need to do repeated sampling unless a major change in conditions occurs at the site (e.g., elevated water table, significant seasonal change in rainfall).

Section D.8 of ITRC (2007) also notes:

Short-term temporal variability in subsurface vapor intrusion occurs in response to changes in weather conditions (temperature, wind, barometric pressure. etc.), and the variability in indoor air samples generally decreases as the duration of the sample increases because the influences tend to average out over longer intervals. Published information on temporal variability in indoor air quality shows concentrations with a range of a factor of 2–5 for 24-hour samples (Kuehster, Folkes, and Wannamaker 2004; McAlary et al. 2002). If grab samples are used to assess indoor air quality, a factor of

> *safety (at least a factor of 5) should be used to adjust for short-term fluctuations before comparing the results to risk-based target concentrations. Long-term integrated average samples (up to several days) are technically feasible, using a slower flow rate this is the USEPA recommended approach for radon monitoring). Indoor air sampling during unusual weather conditions should generally be avoided.*

In Section D.11.8, ITRC (2007) discusses the effect of meteorological changes on VI:

> *A variety of weather conditions can influence soil gas or indoor air concentrations. The radon literature suggests that temporal variations in the soil gas are typically less than a factor of 2 during a season and less than a factor of 5 from season to season). Recent soil gas data from Forensics Used at Colorado's Redfields Site Forensic approaches were used at the Redfield Rifles site in Colorado to determine whether the source of subslab contaminants was in the vadose zone or the overlying structure (McHugh, De Blanc, and Pokluda 2006). D-28 Endicott, New York and Casper, Wyoming are in agreement with the radon results. For soil gas, the importance of these variables will be greater the closer the samples are to the surface and are unlikely to be important at depths greater than 3–5 feet below the surface or structure foundation.*

Recent work in the VI field has highlighted the importance of climate zone and the location of the source relative to the building in controlling the type of temporal variability observed (Barnes and McRae 2017; Brewer et al. 2014, Claussen et al. 2019, Lutes et al. 2019). For example, the temporal variability at commercial buildings in Alaska and New Hampshire has varied from the standard stack effect driven pattern: higher concentrations have been observed in summer, likely due to the source being directly under the slab and the climate.

Barometric pressures generally show a regular diurnal "tidal" pattern of up to 3 millibars variation (300 pascal or 0.089 inches of mercury) in tropical areas and 0.3 millibars (30 pascals, or 0.0089 inches of mercury) in polar areas (Le Blancq, 2011). Larger variations occur during the periodic passage of weather fronts or cyclonic storms and contribute in some cases to peak VI events through barometric pumping of soil gas (Schuver, 2018; Lutes, 2021b; Lutes, 2021c; US EPA, 2015b; US EPA, 2015c).

There have been limited studies of the long-term temporal variability of VI in industrial buildings. The available studies suggest substantial temporal and spatial variability (Barnes and McRae 2017, Brenner 2010, Lund et al. 2019).

Recent studies have highlighted the following indicators and tracers of temporal variability (Lutes, 2021a and 2021b; Lutes, 2022; Schuver, 2015; Schuver, 2018; Schuver, 2021):

- Radon concentration, and change in indoor radon concentration
- Differential temperature (warmer indoor than out), and increases in differential temperature (getting colder)
- Significant changes in barometric pressure beyond the daily diurnal cycle.

1.3 Potential for Use of Radon as a Vapor Intrusion Tracer

Radon, a naturally occurring radioactive gas, is a potentially useful tracer or surrogate for assessing VI of VOCs. This is because the physics of radon intrusion into indoor air is nearly identical to VOC VI. Radon is ubiquitous in the soil and present at measurable quantities throughout the United States. Indeed, much of the research in VOC VI is an expansion of earlier work on radon intrusion.

Radon provides a nearly unique tracer for VI because its presence in the indoor environment is usually a result of radon in the soil gas. In addition, the entry mechanisms are believed to be the same for VOCs and radon in soil gas. Thus, measured radon entry rates should be a good predictor of relative entry rates for VOCs. The advantages of using radon as a tracer for VI characterization include:

- Measurements of radon are easier and much less expensive than canister measurements of VOCs (typically less than 10% of the VOC analysis cost).
- High levels of indoor radon identify buildings as vulnerable to soil gas entry.
- Passive indoor sampling for radon costs approximately $5-20 per sample. Active radon sampling (indoor air and subslab) uses some of the same equipment and setup as for VOCs. This minimizes sampling times and cost.
- Because of the low sampling/analytical costs, it is possible to increase the number of field measurements. This, in turn, increases confidence in the field evaluation.
- Radon measurements before and after installation of VI mitigation systems can be used to assess mitigation system performance.

In summary, the limited data gathered to date suggest that radon may be an inexpensive, reliable tracer or surrogate for characterizing VI, and may significantly enhance VI characterization and decision making, particularly when used in conjunction with subslab or soil gas sampling. However, several key aspects and assumptions of this approach need to be verified before it can be put into widespread use.

For radon to be a valuable tracer:

- Radon detection in building interiors should be quantitatively possible across the wide range of subslab concentrations encountered in the United States. Ideally these measurements can be made with inexpensive passive methods (i.e., charcoal or electrets).
- Radon route and mechanism of entry should be similar to that of VOCs of interest, once both species are present in the subslab soil gas. This would imply that the subslab attenuation factors for radon and VOCs were similar.
- Variance in the natural vadose zone radon concentration across a given building should be low enough to allow radon to be a useful indicator.
- Concentrations of radon and the VOCs of concern should be well correlated in subslab soil gas or near-foundation exterior soil vapor. This would not necessarily be expected as radon and VOCs have different sources. However, they may be approximately correlated if the VOC(s) of interest and radon are both widely dispersed in deep soil gas. In this case, the concentrations of both radon and VOCs at various locations in the subslab may be controlled primarily by the ratio of flow from the deep soil gas to the flow from ambient air (in which both VOC and radon concentrations would be expected to be low).
- Interior sources of radon should be negligible.
- The concentration of radon in soil gas must be sufficient to provide a suitable tracer after the expected attenuation across the building envelope. Note, however, that radon may not always be sufficiently

sensitive to observe relatively small or diluted soil gas entries that could still result in VI concerns related to VOCs if the subslab VOC concentration is unusually high. To evaluate this, compute the ratio of the indoor air screening level to the measured SSSG concentration for the VOC of interest. This ratio would correspond to the minimum attenuation factor for which the indoor air concentration would exceed its screening level. Multiply the ratio by the measured subslab radon; the result (in pCi/L) corresponds to the "threshold" indoor radon concentration above ambient background that would be measured if the VOC indoor air screening level was exceeded. Then for radon to be a suitable tracer, indoor radon concentration must be readily distinguishable from the local ambient air background.

The loss rates to sink effects in the indoor environment should be similar or negligible for radon and VOCs so that the air exchange rate forms the primary control of indoor air concentration once VI has occurred.

This concept was applied in a relatively small study (Cody et. al. 2003) at the Raymark Superfund Site in Connecticut. The study compared the intrusion behavior of radon and individual VOCs by determining attenuation factors between the subslab and indoor (basement) air in 11 houses. The results indicated that the use of radon measurements in the subslab and basement areas was promising as a conservative predictor of indoor VOC concentrations when the subslab VOC concentrations were known. Further work at the Raymark Site (US EPA 2005a) statistically compared basement and subslab concentration ratios for radon and VOCs associated with VI. Of six test locations, three showed that basement/subslab concentration ratios for radon and VOCs associated with subsurface contamination were similar. Three test locations had statistically different ratios, suggesting that further research was needed to evaluate the usefulness of radon in evaluating VI. Conservative VOCs (those believed to be associated only with subsurface contamination) were a better predictor of other individual volatile compounds associated with VI than was radon.

A three-building complex, commercial case study of the radon tracer approach was published by Wisbeck et al. (2006). Radon and indoor air attenuation factors were calculated for five sampling points and were generally well correlated. Subslab radon concentrations varied by approximately a factor of 10 across the five sampling points.

Results of an earlier test program at Orion Park Housing units at Moffett Field have been preliminarily reported (Mosley 2007). Results showed:

- Low levels of radon can be measured with sufficient accuracy to be used in analysis of VI problems.
- Radon is a promising, low-cost surrogate for soil gas contaminants; however, as with VOCs themselves, the complete distribution under the slab must be known to properly interpret its impact on indoor measurements.
- Unexpectedly, the subslab areas under each unit were segmented. The four subslab sampling points installed in one unit were not in good communication with one another. An introduced tracer, SF_6 moved very slowly and not very uniformly under the slab
- Results showed that for soils like these with poor communication, a subslab measurement at a single point is not very reliable for estimating potential VI problems. The average value of subslab measurements at several locations also may not yield a reliable estimate of indoor concentrations. When subslab communication is poor, one must identify a connection between subslab contaminants and a viable entry path.

The potential usefulness of the radon tracer was studied over 2007–2010 by EPA at Moffett Field in California (Lee, 2010; Lutes, 2010b), in the Wheeler Building in Indianapolis (Lutes, 2010b), and in the Indianapolis Duplex Study (Lutes et al., 2015; US EPA, 2012b; US EPA, 2015b). Potential applications of radon in VI studies have been summarized by Schuver and Steck (2015). The use of radon and other ITS to predict peak VOC concentrations has been recently evaluated (Lutes, 2021b). The effectiveness of various radon-based decision rules was evaluated in (Lutes, 2021a; Lutes, 2022).

1.4 Availability of and Quality of Meteorological Forecasts

We expected the indoor air concentration (our dependent variable) to depend on the VI flux from soil gas, which in turn is controlled or influenced by a number of other variables that can affect the VI process. These variables will be collected as follows:

- Weather-related variables, including air temperature, barometric pressure, and wind, were collected from standard National Weather Service (NWS) forecasts (**Table 1-1**).
- Weather forecast accuracy is not perfect even for fewer than 3 days in the United States, as shown for Indianapolis in **Table 1-2**. Weather forecast accuracy statistics for various U.S. locations can be obtained at http://www.forecastadvisor.com/.

Table 1-1. Meteorological Predictor Variables Used to Guide Prediction

Parameter	Proposed Trigger Point	Prediction Source	Monitoring Method
Exterior Temperature	A differential temperature of >20°F between inside and outside. Low temperature decrease of 10°F or more. (The intent is to set a criterion that would be realistic to occur for a given site while representing a significant driving force for that site. For example, we are seeking a criterion that would narrow the sampling days to 35 - 70 days per year).	Local weather station, available 5 to 7 days ahead.	Internet access; 7 day forecasts are commonly available from National Weather Service and many Apps.
Barometric pressure	A sudden change in barometric pressure over less than 6 hours of 1000 Pa or 0.3 in of Hg.	This could be predicted by a meteorologist but is not typically widely reported due to limited general public interest. Individuals may be susceptible to predicting this change based on body/health concerns (e.g., migraines, joint damage).	https://barometricpressure.app/ provides a fairly easy to use 5 day graphical forecast. weatherstreet.com provides pressure forecasts in form of weather map for various future dates.
Indoor radon concentration	>90th percentile of the first month's radon concentration or Day over day radon concentration change of +1.0 pCi/L or more or an increase of 1.5x day over day.	This can only be observed on a radon monitor and cannot be directly predicted except based on structure-specific experience.	Radon map provided by USEPA is accessible at https://www.epa.gov/radon/epa-map-radon-zones-and-supplemental-information and can help individuals identify their typical/expected concentrations within their zone based on geography. On site monitoring will

Parameter	Proposed Trigger Point	Prediction Source	Monitoring Method
			require purchased or rented equipment, operated by the interested or contracted party.
Rainfall	A predicted significant rain event of approximately 1" of rainfall or greater.	Local weather station, available 5 to 7 days ahead.	Internet access – 7 day forecasts are commonly available from National Weather Service and many Apps.

Table 1-2. Ability to Forecast Weather of Major Providers at an Example Location

Weather Forecast Accuracy Data Last Year (2013)					
Provider	**High Temp**	**Low Temp**	**Icon Precip**	**Text Precip**	**Overall**
The Weather Channel	76.12%	75.25%	79.30%	79.30%	77.49%
MeteoGroup	73.03%	75.94%	80.40%	80.40%	77.44%
National Weather Service	70.86%	72.31%	77.15%	75.65%	73.99%
WeatherBug	68.52%	68.58%	79.32%	79.32%	73.94%
AccuWeather	67.16%	66.40%	78.81%	80.30%	73.17%
Weather Underground	68.36%	67.60%	79.54%	76.45%	72.99%
Foreca	72.58%	67.23%	75.77%	75.77%	72.84%
CustomWeather	67.16%	66.30%	77.71%	77.71%	72.22%
Persistence	30.27%	28.11%	57.43%	57.43%	43.31%

Source: ForecastAdvisor, 2014.

Table notes:

Example site is Indianapolis, Indiana.

Forecastadvisor.com describes their statistics as follows: "All the accuracy calculations that appear on ForecastAdvisor are averaged over one to three days out forecasts. The percentages you see for each weather forecaster are calculated by taking the average of four accuracy measurements. These accuracy measurements are the percentage of high temperature forecasts that are within three degrees of what actually happened, the percentage of low temperature forecasts that are within three degrees of actual, the percentage correct of precipitation forecasts (both rain and snow) for the forecast icon, and the percentage correct of precipitation forecasts for the forecast text. The percentages you see are specifically for the listed city. About 90 forecasts from each provider make up the monthly percent (30 days in a month times 3 days of forecasts per day), and over 1000 forecasts from each provider make up the yearly percent."

http://www.forecastadvisor.com/docs/accuracy/ downloaded 6/28/14

2 Research Approach Summary and Project Management

For this study, the ideal test site(s) will have identifiable concentrations of radon in the exterior soil gas, a known VOC plume (contaminants and approximate concentrations and boundary), and mostly residential structures within the study area. Success of this study will depend on involvement of building occupants/owners during the initial screening phase, as well as during the optional community science phases. The objectives and approach, including currently funded and optional tasks, are outlined below.

2.1 Project Objectives

The three large-scale objectives of this project are to:

- conduct a pilot study at a community willing and interested in being designated a Soil Gas Safe Community.
- examine the protectiveness of the ITS methodology and approach as compared to the "traditional" standard chemical sample site selection process, and
- assist EPA in collecting and analyzing the breadth of information needed to establish a Soil Gas Safe (SGS) Community designation.

2.2 Description of Research Activities & Expected Products

2.2.1 Task 1. Assistance in Developing Criteria for the Soil Gas Safe Community Designation

This task seeks to establish criteria for SGS Community designation in collaboration with an Expert Working Group and a study brochure to assist with community outreach.

2.2.2 Task 2. ITS Method Development and Planning

This task seeks to test the protectiveness of ITS in real world situations and settings, as compared to standard or typical chemical sampling techniques at sites throughout the United States.

The RTI Team will work in conjunction with EPA in selecting at least one initial community to test the ITS method's capabilities to predict the best time for sampling of SGI. Additional sites may be selected at EPA's request. Desirable characteristics of the community(ies) selected include being: (a) communities with EJ concerns, (b) a Tribal community, and/or (c) a site undergoing a current VI investigation that need assistance to help making a remedial decision with regard to the potential VI pathway at the site (i.e., traditional convenience sampling practices have not provided a definitive answer). The VI assessment conducted as part of this study may recommend community scale remediation/mitigation through a technology such as soil VI mitigation for individual structures, as appropriate.

Site selection criteria will include EPA's preference for a community with EJ concerns, a tribal community, and/or a site undergoing a current VI investigation needing assistance with a remedial decision. Sites with cooperative regulatory agencies and responsible parties who need assistance to help make a remedial decision on particular buildings or neighborhoods will be sought because this will facilitate a cost-effective and timely study. Selecting a community with freezing winter temperatures during the heating season would be preferable, but not a required sampling frequency under PWS Tasks 3, 4, and 5 and to understand the temporal variability in VI.

Considering the desired timeline to get into the field and obtain community buy-in to complete the initial screening under Task 3 by September 2022, complete all tasks within the period of performance, and be cost-effective, we recommend the following bounds be made around the selected community in addition to EPA's preferences noted above:

- Selected community site(s) are within 30 miles of an RTI Team firm office. Between Jacobs and Geosyntec, there are more than 150 offices nationwide, most in major metro areas, where many communities with EJ concerns and CERCLA and RCRA sites are located.
- The size of the inclusion area will range from 30 to 200 structures.
- To the extent feasible, we recommend selecting a community where radon is most likely to be detectable, but only above EPA's 4 pCi/L action level in a minority of structures. We will confirm whether potential communities are in a county with radon Zone 1 or Zone 2 designation (EPA, 2015c and use finer-scale radon susceptibility data where available [Churchhill 2016]. Note that selecting a community in Zone 1 (higher risk) may result in identifying several homes with a radon issue and may prompt mitigation action.
- Selected community site(s) are those where the primary known soil gas hazards are chlorinated VOCs or radon. Communities where CH_4 is the primary hazard may be of interest in a future project.

The Expert Working Group will review and provide feedback on the list of potential communities (up to five communities) prepared by the RTI Team. The EPA TOCOR and Alt-TOCOR will take the Expert Working Group's feedback into consideration during site selection but will ultimately make the decision themselves.

RTI consultant, Lenny Siegel, will lead community engagement efforts to engage with community leaders (e.g., mayor, neighborhood associations, environmental groups) to confirm whether obtaining enough volunteers to participate in this project is feasible. Once the community is confirmed and on-board, Jacobs field staff will engage with homeowners/occupants and/or business owners within the potential site inclusion area via door-knocking. We anticipate a time-consuming process of community engagement to recruit willing participants, obtain permission to access numerous structures, and gain acceptance of the community to perform the ITS method development under Task 4.

The expected products from this task include the following:

- A list of potential candidate communities to the TOCOR via email.
- A conference call discussion on the potential communities with the TOCOR and Expert Working Group.
- Meeting minutes from any community meetings delivered to the TOCOR via email within 2 business days of the meeting.

2.2.3 Task 3. QAPP Development

Two distinct and sequential activities are included in the PWS – QAPP development and an initial screening of structures in a community in preparation for field testing under Task 4. These activities are presented as separate subtasks for project tracking convenience.

2.2.3.1 Task 3a. QAPP Development

Due to the schedule, the RTI Team will prepare a draft QAPP to complete the initial screening planned under Task 3b with placeholder information to be amended after the communities where field work will occur are selected. This draft QAPP will document the proposed field testing to examine results from ITS guided/triggered SGI sampling versus standard convenience VI sampling protocols (e.g., seasonal sampling twice a year) identified in Task 1.

The QAPP will be amended after the initial community is selected to include site-specific details such as the statistically valid study design to compare a population of buildings, spatially and temporally, of ITS-indicated sampling vs convenience sampling selection.

The amended QAPP will be submitted to the EPA after Task 3b is largely complete and prior to the beginning of Task 4.

The QAPP will be revisited and may be amended prior to beginning Task 5.

2.2.3.2 Task 3b. Initial Screening

This task will include the following initial site/building screening:

- Preparation of a health and safety plan (HASP) to cover both the task 3B and 4A activities.
- Soil gas sampling for VOCs at four locations around each of the potential buildings collected using 7 calendar day passive sorbers (e.g., a total of 120 soil gas locations from 30 buildings). If the buildings are adjacent, then one sample can be used to meet part of the data needs for both buildings, potentially reducing the data need slightly below 120 soil gas locations. A single measurement of soil gas radon will also be conducted with a field portable instrument at each of these locations. A GPS unit will be used to log the coordinates of the soil gas samples.
- Continuous indoor radon monitoring and passive sampling of indoor air for VOC analysis for a period of 7 days in each of the 30 potential buildings.
- A brief initial building survey will be conducted in each building to obtain information about air movement, indoor sources of VOCs, previous mitigation systems, HVAC, and occupancy. Given the substantial efforts associated with the initial screening work, we assume that the initial building surveys may be succinct in content but may be supplemented later under Task 4 (as trust is gained from the homeowners or occupants). It is expected that the structure(s) will be screened using a handheld MultiRae PID and pictures/videos (pending permission of the occupant) will document condition of the building envelope, including floor plan, and potential background VOC sources which may be present.

We assume a 90% completion rate and no resampling of soil gas due to uncontrollable damage from burrowing animals, lawnmowers, or other sources. The external soil gas sampling locations will be installed in unpaved areas to a depth 5 feet using a person portable power auger. During this effort, the open hole at each location will be screened for CH_4 and H_2S with a four-gas meter. Instantaneous measurements of soil gas radon will be made with an EPA-supplied continuous radon monitor (i.e., Rad-7 or AlphaGUARD) at each of the soil gas sampling locations and in three sewer manholes to evaluate the strength of the radon tracer. Outdoor radon will also be measured with this instrument.

In addition to the external soil gas sampling, a radon meter (provided by EPA) and a passive sampler shall be placed in each potential building to determine baseline Rn concentration distributions and completeness of the VI pathway, respectively. Passive samplers shall be left for 7-days. This initial sampling effort of the indoor air will represent a typical convenience sampling.

The passive sorbers will be analyzed by EPA with samples being shipped to: USEPA, attn. John Zimmerman, Chemical Services, Room E-178, Building E Loading Dock, 109 T.W. Alexander Drive, RTP, NC 27709 using SOP: WECD-MMB-SOP-4350-0 "Analysis of Volatile Organic Compounds in Soil Vapor using Thermal Desorption / Gas Chromatography / Mass Spectrometry".

Personally identifiable information (PII) such as building owner/occupant names will be "blinded" by using a unique case identification number per building that Jacobs will manage.

2.2.4 Task 4. Field Testing for Method Development (Optional based on availability of funds)

2.2.4.1 Task 4a. Field Sampling Preparation and Testing

Field testing will occur under this task to determine the effectiveness of ITS methods in predicting when to collect an indoor air sample for decision making purposes of whether to mitigate or not. In task 4 the ITS based sample timing decisions will be made by the RTI team. Information developed in Task 1 when defining the criteria for the SGS community designation will be used in creating a sampling design to determine the success or failure of the ITS methods when compared to the standard or typical convenience VI investigation methodology and compared to long-standing EPA exposure criteria for short- and long-term exposure risks.

Field sampling will follow procedures defined in this EPA-approved QAPP and is expected to include one standard convenience calendar-based sampling and up to three ITS-driven sampling events in each of three seasons (summer, winter, spring/summer) for indoor air collection, for a total of up to 12 sampling events. The primary planned sample type is the 7 day Radiello passive sample, but an optional task 4A for a one day passive sample at the beginning of each of three convenience sampling events and each of three ITS scheduled events is included. It is expected that the predictive ability of the ITS measures may be stronger for daily samples immediately after the ITS decision then for weekly samples. Additionally, the combination of weekly and daily samples provides additional information on short term temporal variability that may be relevant to short term development risks. No external or subslab soil gas sampling will be conducted (since external soil gas was already sampled in task 3).

EPA ORD's laboratory will continue to supply passive samplers and support analyses of the passive indoor samples collected under this task. Samples will be shipped to USEPA, attn. John Zimmerman, Chemical Services, Room E-178, Building E Loading Dock, 109 T.W. Alexander Drive, RTP, NC 27709. Using SOP: WECD-MMB-SOP-4350-0 "Analysis of Volatile Organic Compounds in Soil Vapor using Thermal Desorption / Gas Chromatography / Mass Spectrometry".

2.2.4.2 Task 4b. Database Preparation

RTI will develop and manage a database to store the data from Task 4a after receiving the analytical files from the TOCOR. Data files are expected to undergo QC checks by the TOCOR before delivery to the RTI team. The RTI Team will conduct a data verification level review and engage with the TOCOR regarding corrective actions and data review questions. A minimum of 10% of each dataset provided by the EPA laboratory will be reviewed for outliers and calculation errors. The database will be delivered to the TOCOR upon completion of the project.

The RTI database and tables, figures, summaries, etc. will not include any PII for individual houses. A separate confidential key will be maintained with home contact information and a code designation for each structure. The identity of the community being studied however will be public.

2.2.5 Task 5. Application of ITS Methodology to a New Community – Community Pilot Study (Optional based on availability of funds)

Task 5 will leverage the procedures defined under and findings from Tasks 1, 2, and 4 and test them in a new (pilot) community considered to be an EJ or Brownfields community. The approach will incorporate community science into the ITS assessment for SGS communities by training and assisting the community to be the primary collectors of the radon meter readings and passive samplers.

2.2.5.1 Task 5a. Community Selection

RTI will collaborate with the TOCOR to select a pilot community to test the ITS method's capabilities to predict the best time for sampling of SGI when the citizen scientist makes the sampling decisions. The RTI Team will amend the initial list of communities provided to the TOCOR under Task 1 and assist the EPA in their selection of the pilot community.

As of July 2022, activities are scoped for one pilot community under this task.

After the community has been selected by the TOCOR, Lenny Siegel will initiate community engagements with members of the selected community. Meeting minutes from community meetings will be provided to the TOCOR within two business days.

RTI/Lenny Siegel anticipates working with community outreach groups in the selected communities and may post low-cost advertisements on community social networks such as Nextdoor and Facebook as well as posting advertisements for interested volunteers via local universities, schools, libraries, activist groups, and similar sources. We may develop a simple questionnaire to gauge community interest and willingness to participate. This questionnaire could include questions confirming they live in the selected sampling zone, are willing to participate for the duration of the study and have interest in sample collection and participating in the community science training. We do not anticipate collecting any household demographics other than that already included in the standard ITRC (2007) VI survey form which includes:

- number of household occupants
- Age of occupants[2] (can be reported as broad ranges for example 0-6, 6-12, 12-18; 18-65; >65)
- Whether occupant is owner or renter
- Contact information for occupant and/or owner/landlord
- structure construction style and age
- information about air movement,

[2] Note that EPA 2015a says "As such, EPA recommends the CSM also identify and consider sensitive populations, including but not limited to:
• Elderly,
• Women of child-bearing age,
• Infants and children,
• People suffering from chronic illness, or
• Disadvantaged populations (i.e., an environmental justice situation)." But there may be legal restrictions on collecting some of this information on an individual household basis.

- indoor sources of VOCs,
- previous mitigation systems,
- HVAC system type.

Personally identifiable information will be protected via appropriate privacy security measures such as anonymizing building addresses and using case IDs. Additional demographic information to allow comparison of communities may be available from US census bureau data.

The Jacobs field team will ask each participating building owner or occupant to sign a brief consent form that grants the field team access to the premises to conduct sampling activities. We anticipate building on the standard EPA consent form and standard ITRC VI survey form.

2.2.5.2 Task 5b. Community Science Training

Our technical experts and Community Engagement Specialist will develop a community science training program that is accessible in terms of common language (minimal to no jargon) and disabilities; succinct (to maintain interest and attention); and easy to understand and implement. We plan to engage community members over one training that may last 2 to 3 hours. The training will start with an ice breaker to get to know the Community Engagement Specialist and a key technical field team member who would be interacting with community members to address questions and troubleshoot on the ground, and EPA representatives (if desired). Specific details on the training will be developed after award, but we generally envision the training will:

- Describe the research objectives, general timeline for the study and their roles and responsibilities
- Educate the participants about the basics of VI and exposure risks including some general information about the use of ITS as indicators of VI, probably formatted as “Rules of thumb” such as sample when radon is high or increasing, sample when CO_2 is high, sample when it is cold outside or getting colder in the fall.
- Educate the participants about sample collection, how to operate the equipment, collect samples, and package them for shipping. We will also compile a sampling checklist and guidebook that compiles the training materials and a list of resources for more information (provided in hard copy at the training).

A field team member will conduct a household visit after the training to deliver the sampling kits and follow-up on the training to confirm a designated household member understands what needs to be done. We may also engage a trusted community stakeholder from the selected community to review and comment on the training materials to make them more accessible, assist with getting community members to attend the trainings, and/or facilitate the trainings. One important aspect that will be determined after community selection is whether to offer the trainings more than once to accommodate individual schedules and general availability (e.g., work schedules, child care, elder care). We may also need translation services; however, at this stage, we are anticipating the training materials will be developed in English and anticipate EPA staff could provide significant translation services (if feasible and desired by EPA).

We plan to pull from existing resources to develop the training materials for this task, including the following:

- Basic introductory materials on VI, such as the Minnesota Pollution Control Agency's "What is Vapor Intrusion," and radon risk, such as EPA's "A Citizen's Guide to Radon"
- SOPs from the approved QAPP (simplified if recommended by our Community Engagement Specialist) and ITS measurements developed by the RTI Team for EPA under previous funding (see Appendix B-12 Radon Monitoring and Appendix B-14 Temperature Monitoring).
- Existing publicly available videos on the use of passive samplers such as https://www.youtube.com/watch?v=ZQ5Hp4ZeIB0 and https://www.youtube.com/watch?v=0buReBuI96A.

2.2.5.3 Task 5c. Field Sampling and Database Development

The RTI Team assumes that the additional site in Task 5c will be sampled to the same degree as the site in Task 4a, with the exception that the community members will oversee the timing and collection of samples under Task 5 using Radiello passive samplers to be analyzed by the EPA ORD laboratory. The sampling efforts will span a period of 11 months covering at least three seasons. We anticipate that at least 30 buildings will be supplied with radon monitoring instrumentation transferred from Task 3 or Task 4a and selected for indoor air sampling. The community members will be encouraged to collect 7 day samples at both random times (3 samples or 1 per season) and ITS-driven times (9 samples or 3 per season) for the purpose of evaluation and to designate the reason in the data reporting form. In this case "Data reporting form" will fulfill the function of a chain of custody as well as potentially contain other information such as the reasons for sampling. We assume that each of the 12 samples can be shipped in individual post-paid mailers with data reporting sheets by USPS priority mail to the EPA laboratory without refrigeration but with a thermal protective mailers [22]. In addition to the sampling efforts detailed above, Task 5c also includes an optional cost which includes the use of 1-day samplers for three convenience sampling events and three ITS-scheduled sampling events, for a total of 6 sampling events with 1-day samplers.

Twelve mailers will be provided per structure. The RTI Team will receive from EPA large stocks of ready-to-deploy Radiello cartridges and will distribute them to individual homeowners/occupants as sampling kits in time for each round. As the samples are received, the EPA laboratory will maintain a database (spreadsheet) and be able to communicate back to RTI/Jacobs how many samples had been received from which houses at what time. Community scientists are expected to provide basic information for each sample collected, to identify them from one another upon receipt by the lab. However, the EPA lab will ultimately be responsible for assigning a sample name which removes the attachment of any PII to an individual sample (that is, no street addresses or names). The EPA laboratory will need to store the COCs in a locked filing cabinet or drawer. For the envelopes, once the COC is checked against the samplers received, they should be shredded.

One picked volunteer per neighborhood will be asked to also conduct ambient air sampling. Thus, ambient air samples will not be contemporaneous with all of the individual house indoor samples. Another picked volunteer can be asked to conduct duplicate sampling. Field blanks will be created by Jacobs field staff who will open and the Radiello and immediately mail it to EPA following the instructions given to homeowners. This will reduce the complexity of the tasks that homeowners need to be trained in.

Conducting assessments of homes or businesses with volunteer community scientists will inevitably introduce unique challenges, resulting in attrition during the sampling period and potential data quality issues. We will therefore need to recruit and enroll more than the minimum number of structures to provide valid data in each community. Potential challenges we may encounter, and address include:

- Not all participants will engage at the same level. Some will require reminders or encouragement to complete study activities. Others will not be able to complete study activities due to moving, job or childcare constraints, or changes in family circumstances.
- Engaged participants may be impatient with typical externally driven timelines or the needs of the overall study design protocol for ITS-driven sampling. Some community members may want to move rapidly to a decision on management of their structure to end uncertainty (i.e., mitigation of exposures above screening levels or a no action decision).
- Samples will be collected individually and thus will flow to the EPA laboratory on irregular timings. Residents may expect rapid, predictable analytical results and may want to interpret each set of results after sampling. The RTI Team will develop a letter template that is suitable for transmission to individual owners or occupants with individual building analysis results and/or anonymized neighborhood results if desired. We have assumed that twelve letter reports will be provided per building, with each letter report corresponding to a sampling event.
- Residents/occupants may be focused on their own exposure experience versus regulatory timelines for decision making on the site (community) as a whole, or on EPA ORD timelines for evaluation of the ITS approach.
- There is a moderate chance the COVID-19 pandemic may adversely impact field sampling if community members refuse or are uncomfortable with field staff entering their household, regardless of masking and vaccination status.

To prevent and mitigate these potential challenges, the RTI Team proposes several actions below and will collaborate with EPA social scientists after award. These actions include:

- Completing a data verification review of each EPA laboratory report and provide brief interpretative comments in cover letters for data transmittals.
- Addressing homeowner/building occupant questions that cannot be addressed sufficiently through the FAQ sheet developed under Task 2c. Particular attention will need to be paid to balancing the needs to take rapid action to address problematic exposure while documenting the effects of those actions on the study design.
- Visiting a structure if necessary to collect radon and temperature data at the end of the 6-month period if it cannot be remotely (electronically) downloaded from installed equipment by the field team.
- Record, using structure coded forms, the reasons homeowners/building occupants give for terminating or suspending participation or not being able to sample. Similarly record the general nature of technical questions asked by the homeowners/occupants.
- Suggesting general mitigation measures for a building or group of buildings, as may be warranted by radon or VOC concentrations.
    - Provision of mitigation is not included in the current project budget; however, it is important to consider the potential for mitigation to be funded/performed by others

when selecting study structures during site selection. A general set of mitigation measures (i.e., not specific to each building) can be developed within the current project budget.

- Funding for VOC mitigation is generally provided by potentially responsible parties or by government agencies in the case of "orphan" sites. Funding for mitigation of radon, a natural hazard, is generally the responsibility of individual homeowners; however, there are some governmental and charitable resources that can provide grants or loans for radon mitigation on a limited basis that can be provided to building occupants; see for example:
  - https://sosradon.org/Mitigation-financial-assist
  - https://tooelehealth.org/wp-content/uploads/2018/01/Summary-URC-Low-Income-Radon-Mitigation-Assistance-Program.pdf
  - https://www.ncdhhs.gov/divisions/health-service-regulation/north-carolina-radon-program/partnerships
  - https://www.hokecounty.net/484/NC-Radon-Program.

2.2.5.4 Task 5d. Database and Journal Article Preparation

RTI will follow the same approach proposed for Task 4b to compile the database and prepare a second draft journal article. RTI will also submit the database and draft article within the agreed-upon timeline (within 37 months of the project kick-off date or by March 2025). The RTI database and tables, figures, summaries, etc. will not include any PII.

2.2.6 Task 6. Final Evaluation of ITS Effectiveness (Optional based on availability of funds)

The RTI Team will evaluate the effectiveness of the ITS approach in providing consistent and comparable equivalent spatial and temporal protectiveness for an SGS Community. Factors to be assessed will include, but are not limited to:

- Radon and VOC concentrations
- Environmental parameters (e.g., pressure, temperature), and
- The influence of contractor versus community member sampling (i.e., key differences between Task 4 and 5) on factors such as number of samples collected, quality of results, cost, and other factors to be determined in collaboration with the TOCOR.

The fact sheet and training materials will be amended accordingly to reflect changes and lessons learned from Task 4 and 5 activities.

2.3 Timeline for Expected Products/Sub-Products

The project timeline is generally presented in **Table 2-1**. A detailed schedule is being maintained on Smartsheet; access can be granted by the TOL, Kate Bronstein, as requested. The timeline will be reviewed and revised regularly (weekly or as needed). Copies of the project schedule will be provided to the EPA TOCOR for EPA to maintain in their project study files.

Table 2-1. Project Completion Timeline

Task and Key Activities	Year 1 (4/22 - 3/23)				Year 2 (4/23 - 3/24)				Year 3 (4/24-3/25		
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3
1. Assistance in Developing Criteria for SGS Community Designation											

Task and Key Activities	Year 1 (4/22 - 3/23)												Year 2 (4/23 - 3/24)												Year 3 (4/24-3/25		
	Q1			Q2			Q3			Q4			Q1			Q2			Q3			Q4			Q1	Q2	Q3
List of potential Working Group (WG) participants	■																										
Recruit WG participants / Initiate WG	■																										
WG meetings		■	■	■																							
Fact sheet		■	■	■																							
2. ITS Method Development and Planning																											
2a. Initial Assessment	■	■	■																								
2b. Model Comparison	■	■	■																								
2c. Community Selection																											
Develop initial list of potential communities	■	■																									
Short list of communities			■																								
Community meetings and meeting summaries				■	■	■																					
Final selection of 2 communities					■	■																					
3. QAPP Development																											
3a. Draft QAPP	■	■	■	■	■	■																					
3a. Final QAPP (with final study design)					■	■																					
3b. Installation of radon meters and near building VOC samplers							■	■	■	■	■	■															
3b. VOC sample analysis and interpretation							■	■	■	■	■	■															
3b. QAPP review and amendments prior to Task 5																			■	■	■						
4. Field Testing for Method Development (Optional)																											
4a. Field Sampling Preparation and Testing																											
HASP (draft and final)										■	■	■															
Community meetings (prior to sampling) and meeting summaries				■	■	■	■	■	■	■	■	■															
Field sampling (3 sampling periods of summer, winter, spring)							■	■	■	■	■	■	■	■	■	■	■	■									
Community engagement during and post sampling							■	■	■	■	■	■	■	■	■	■	■	■	■	■	■						
Sample analysis and interpretation							■	■	■	■	■	■	■	■	■	■	■	■	■	■	■						
4b. Journal Article and Database Preparation																											
Draft letter of recommended changes for Task 5																■	■	■	■	■	■						
Update/finalize fact sheet																■	■	■									
Develop and populate database				■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■						

Task and Key Activities	Year 1 (4/22 - 3/23)												Year 2 (4/23 - 3/24)												Year 3 (4/24-3/25		
	Q1			Q2			Q3			Q4			Q1			Q2			Q3			Q4			Q1	Q2	Q3
Draft journal article																			■	■	■	■	■	■			
5. Application of ITS Methodology to a New Community - Community Pilot Study (Optional)																											
5a. Community Selection										■	■	■	■	■	■	■	■	■	■	■	■						
5b. Citizen Science Training (develop materials and deliver trainings)																			■	■	■	■	■	■			
5c. Field Sampling and Database Development																						■	■	■	■	■	■
5d. Database and Journal Article Preparation																						■	■	■	■	■	■
6. Final Evaluation of ITS Effectiveness (Optional)																											
Letter report on effectiveness of ITS approach																										■	■
Modify fact sheet and training materials																										■	■

2.4 Team Roles, Responsibilities and Distribution List

The roles and responsibilities of key individuals involved in performing research activities and developing products within this project are identified below in **Table 2-2**. Additional personnel, based on their expertise (e.g., members of the External Working Group not presented in Table 2-2) and other EPA staff, including social scientists, may be included during the project. This project will also involve community scientists who will remain unnamed in this QAPP for privacy reasons. The TOL will be responsible for the distribution of the most current signed approved version of the QAPP to participants as indicated in Table 2-2.

Table 2-2. Roles and Responsibilities

Name & Organization	**Contact Information (E-mail)**	**Project Role(s)**	**Project Responsibilities**
Kate Bronstein* RTI	kbronstein@rti.org	Task Order Lead (TOL)	Maintain and distribute the official, approved QA project plan (QAPP) to participants. Update project schedule and manage project financials. Prepare monthly reports. Prepare meeting agendas and notes for meetings with EPA. Final review of deliverables. Work with the RTI STREAMS IV QA Manager to resolved data quality issues.
Rohit Warrier RTI	rwarrier@rti.org	Technical support	Provide technical support to the team, including subcontractors with respect to community identification, review of analytical results, preparation of journal article content. Assist with facilitation of the Expert Working Group meetings.
Linda Andrews RTI	trog@rti.org	Database Manager	Set up database to store analytical results from Tasks 3, 4, and 5; run queries to pull data for data tables and figures.

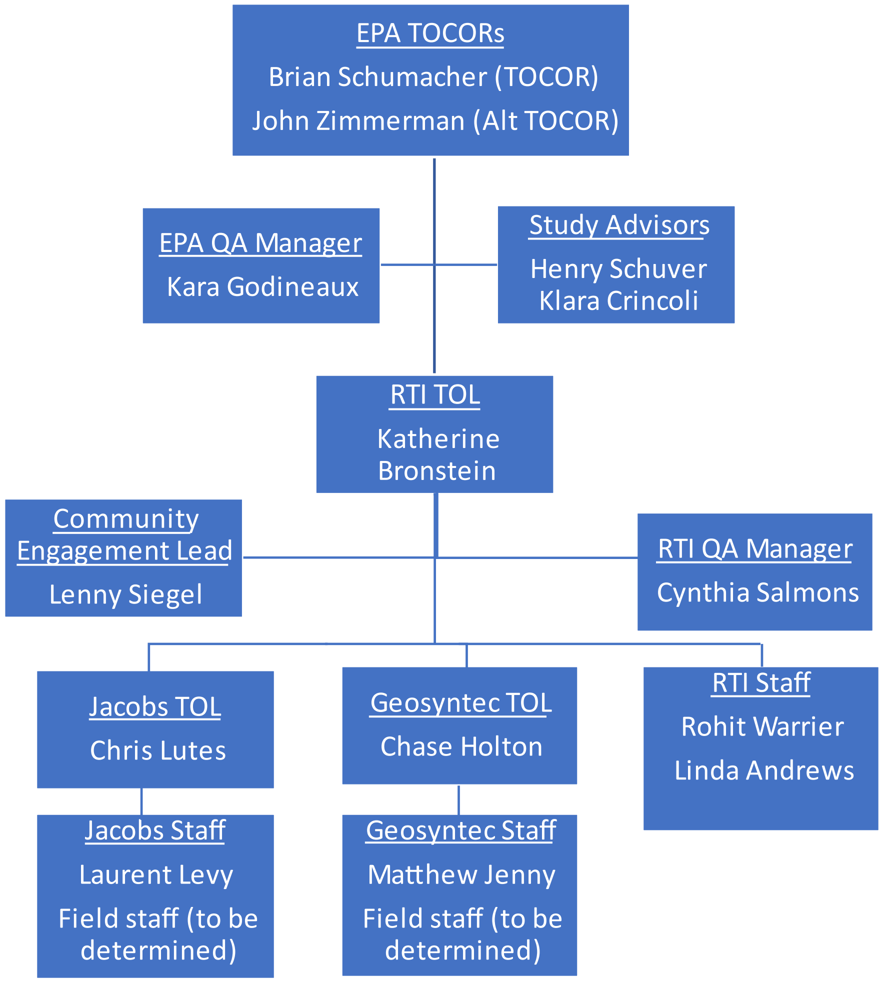
Name & Organization	Contact Information (E-mail)	Project Role(s)	Project Responsibilities
Cindi Salmons* RTI	cas@rti.org	STREAMS IV QA Manager	Complete QA review of the QAPP and work with the RTI TOL to resolve data quality issues throughout the project.
Lenny Siegel	LSiegel@cpeo.org	Community Engagement Specialist	Provide social science and VI perspective for the RTI team; assist with developing SGS community designation criteria; community selection and pros/cons of each site. Assist with developing communications materials; lead engagement with community leaders from selected community for task 3 and 4 activities; and deliver community trainings.
Chris Lutes* Jacobs	Christopher.Lutes@jacobs.com	Jacobs TOL, Subject Matter Expert	Jacobs is leading Tasks 2a, 3a, 3b, 4a, and 5c, which include data collection and analysis, field sampling, analysis of analytical results, and interaction with community members. Participate in the Expert Working Group; provide technical direction to the Jacobs team related to the QAPP study design, field sampling, data analysis, and community trainings; coordinate with RTI's database manager on data entry of analytical results; co-author journal articles and other report deliverables.
Laurent Levy Jacobs	Laurent.Levy@jacobs.com	Subject Matter Expert	Lead the Task 2a initial assessment report; technical review of the overall study design; assist with site identification; QAPP development. Provide input into the data management strategy; serve as a QA manager of field sampling efforts.
To be Named, Jacobs		Field Team Leader/Site coordinator	Lead homeowner/resident interaction on day-to -day basis. Manage field data collection quality and safety. Schedule and oversee field staff.
Chase Holton Geosyntec	CHolton@Geosyntec.com	Geosyntec TOL, Subject Matter Expert	Participate in the Expert Working Group. Provide technical expertise primarily in tasks 1, 2, 4, 5, and 6. Provide technical direction of the model evaluation in task 2a. Serve as co-author of journal articles and other deliverables.
Matthew Jenny Geosyntec	MJenny@Geosyntec.com	Lead on Task 2b Model Evaluation	Provide technical support to Chase Holton on Task 2a initial assessment and lead Task 2b Model Evaluation.

* Copies of the approved QAPP will be sent to the individuals indicated.

2.4.1 Project Organization Chart

Figure 2-1 provides a visual representation of the working relationships and lines of communication among key project participants identified in Table 2-2.

Figure 2-1. Project Organization Chart



3 Documents, Records, and Data Management

This section identifies all research documentation and records that will be needed to support the findings and conclusions of the research products, including those documents that provide objective evidence for the quality of the environmental data collected.

3.1 Documents and Records

The required data package deliverables during each aspect of the project include (1) sample collection and field measurement records, (2) analytical records, and (3) data assessment records. All records will be made available to EPA upon request. All records will be maintained by RTI during the period of performance and then archived for long-term storage.

Sample collection and field measurement records generally include field logbooks, photographic documentation, equipment decontamination records, sampling instrument calibration records, soil boring logs, chain of custody forms (see Appendix H for an example form), and air bills.

The data for the analytical deliverables will be provided electronically as a PDF file if from a commercial laboratory and in excel files from US EPA laboratories. The data provided by the laboratory must be legible and properly labeled.

Data assessment potentially includes verification, review, validation, evaluation, and usability assessment. Only data verification, review, evaluation, and useability assessment are included in this project budget, not functional guidelines data validation. The data review process will be documented with emails between Jacobs, RTI, and the EPA RTP laboratory to facilitate efficient and accurate assessment of data quality and usability. The overall usability of the data is indicated with appropriate qualifiers.

Table 3-1 provides a list of documents and records that will be generated for this project, the parties responsible for generating and maintaining those records, and storage locations, and applicable EPA Records Schedule. The project team will maintain the project files in electronic and/or hard copy formats for the duration of the contract POP. Electronic project files will be maintained on a Jacobs project SharePoint site until transfer of custody to EPA.

Table 3-1. Documents and Records to be Generated During This Project

Document	Generator	Where Maintained
Field notebooks and Daily Reports	Field Team / Field Quality Manager, Jacobs or Geosyntec	Electronic copies in the project file. Hard copy (bound notebook) in the Jacobs project file. Archived at project closeout.
Chain-of-custody records[1]	Field Team / Field Quality Manager, Jacobs or Geosyntec	Electronic and hard copies in the project file (maintained by EPA RTP laboratory). EPA RTP laboratory staff would need to scan and email COCs to Jacobs or RTI if these files are to be maintained by either party. Archived at project closeout.
Corrective action forms	Field Team / Field Quality Manager, Jacobs or Geosyntec	Electronic PDF copies in the project file. Hard copy in the project file. Archived at project closeout.

Document	Generator	Where Maintained
Electronic field data deliverables	Field Team / Field Quality Manager, Jacobs or Geosyntec	Loaded in the field database then transferred to the SQL data warehouse (maintained by RTI) as the final repository.
Various field measurements	Field Team / Field Quality Manager, Jacobs or Geosyntec	Recorded in field notebook and stored in SQL data warehouse (maintained by RTI) as the final repository.
All field equipment calibration information	Field Team / Field Quality Manager, Jacobs or Geosyntec	Recorded in field logbook. Also recorded, as needed, in calibration documentation associated with instrument.
Pertinent telephone conversations	Field Team / Field Quality Manager, Jacobs or Geosyntec	Conversations among project team members recorded in field logbook
Information about occupant/owner participation and questions about project procedures[1]	Field Team / Field Quality Manager, Jacobs or Geosyntec	Conversations with homeowners or occupants would potentially constitute PII and will be recorded in an electronic phone log (by Jacobs) organized by structure code number and a non-name identifier such as “adult female” or an initial “JJ”. The names of the persons conversed with would not be recorded, but initials or a description as in “adult male tenant” or “adult female property owner” can be included.
Field equipment maintenance records	Field Team / Field Quality Manager, Jacobs or Geosyntec	Inspected by FTL. Not maintained in the Jacobs or RTI project file but kept with instrument records.
Sample receipt, custody, and tracking records	Field Team, Jacobs or Geosyntec Project Chemist, EPA ORD (verifier)	Electronic PDF copies in the Jacobs project file. Hard copy in the full data package and stored in project file.
Sample prep logs	Lab/Project Chemist, EPA ORD	Hard copy in the full data package. Archived at project closeout.
Run logs	Lab/Project Chemist, EPA ORD	Hard copy in the full data package. Archived at project closeout. See section 3.2.
Equipment (lab) maintenance, testing, and inspection logs	Lab/Project Chemist, EPA ORD	Maintained in project file to the extent it is project-specific. See section 3.2 for EPA RTP laboratory. Archived at project closeout.
Reported results for field samples, QC checks, and QC samples	Lab/Project Chemist, EPA ORD	Electronic copy in the EPA RTP laboratory provided data package. See section 3.2 for EPA RTP laboratory. Archived at project closeout.
Instrument printouts (raw data) for field samples, QC checks, and QC samples	Lab/Project Chemist, EPA ORD	See section 3.2 for EPA RTP laboratory. Archived at project closeout.
Standards and calibration information for EPA analytical instruments; results of continuing calibrations, internal standards, and laboratory blanks.	Lab/Project Chemist, EPA ORD	See section 3.2. Calibration information normally maintained by the laboratory that are not provided to the RTI team; thus, the RTI team does not verify this information. The EPA laboratory does apply data flags

Document	Generator	Where Maintained
		based on this information as needed and provide flagged data to the RTI team.
Sample disposal records	Lab/Project Chemist, EPA ORD	Maintained by the laboratory. See section 3.2.
Extraction/cleanup records	Lab/Project Chemist, EPA ORD	Maintained by the EPA RTP laboratory. See section 3.2.
Field sampling audit checklists	Field Quality Manager / Project TOL, Jacobs or Geosyntec	If audit completed, hard copy in the RTI project file. Archived at project closeout.
Fixed laboratory audit checklists	Lab/Project Chemist, EPA ORD	If audit completed, hard copy in the RTI project file. Archived at project closeout.
Analytical laboratory data packages	Lab/Project Chemist, EPA ORD	RTI project file. Electronic PDF copies in the project file. Archived at project closeout
Electronic Data Deliverables (EDDs)	Lab/Project Chemist, EPA ORD	RTI project file. Electronic PDF copies in the project file. Archived at project closeout
Minutes from the calls and community meetings[1]	Community Engagement Specialist, TOL, or their designee, RTI	RTI project file. Archived at project closeout.
List of potential participants and proposed dates and times of team meetings	RTI TOL or their designee	RTI project file. Archived at project closeout.
Draft and final fact sheet laying out the key parameters/points that will define a Soil Gas Safe Community	RTI TOL or their designee	RTI project file. Archived at project closeout.
Letter reports and PowerPoint presentation of the salient facts of the current state of practice for SGI and the decision criteria of convenience sampling	RTI TOL or their designee	RTI project file. Archived at project closeout.
Presentation, via PowerPoint, of the resultant evaluation/comparison of Radon:VOC relationships/differences	RTI TOL or their designee	RTI project file. Archived at project closeout.
Initial list of potential candidate communities	RTI TOL or their designee	RTI project file. Archived at project closeout.
Draft, revised, and amended QAPPs	RTI TOL or their designee	RTI project file. Archived at project closeout.
Letter reports, fact sheets, draft journal articles, and training materials	RTI TOL or their designee	RTI project file. Archived at project closeout.

[1] These documents are anticipated to contain personally identifiable information (PII) and will be stored in temporary files during the project and destroyed at project end.

3.2 Data Management

This section describes the data management approach for records generated that will be used to provide traceability from environmental data collection to final use or storage (e.g., the field, laboratory, the office). The types of documents to be generated and how and where they will be stored during the project are summarized in **Table 3-1**. Both primary and secondary data will be used to achieve the objectives of this project.

File names will include a brief descriptive title, the date created or submitted to the EPA TOCOR, and the version number (as applicable).

3.2.1 Primary Data

Data resulting from field sampling, laboratory analyses, and other project activities will be uploaded to a Microsoft Teams site managed by RTI or a password-protected FTP directory where as needed research team members will have access. The website will be set up and maintained by RTI. As the data are assembled for analysis and interpretation, they will be compiled into a single database by RTI, in the format and software specified by EPA and delivered to the TOCORs at the end of the project.

For the EPA analytical laboratory, paper copies of all paper records will be stored in the analysis laboratory, RTP room E-264A or the TOCOR/PI's office, RTP room E-267. Paper records include certification and calibration certificates for reference standards, anything for which no electronic copy is available, and which is not contained in the electronic laboratory notebook which is kept by the analyst on the specific analytical instrumentation that is utilized for sample analyses for this project with a backup copy on their EPA laptop.

Raw chromatographic and spectral data is automatically recorded electronically and will be backed up at least once a month. Processed data will be stored on the TOCOR/PI's EPA laptop and on an external USB storage drive, which will be maintained by the TOCOR/PI. Raw data files downloaded from the GC-MS computer will be maintained in their original state and considered read only.

3.2.2 Secondary Data

Secondary data on potential communities to be involved in the field testing and pilot will be collected under Tasks 4 and 5. Specific elements addressed by this QAPP for secondary data include the following:

- identifying the sources of secondary data (e.g., publisher, authors, year of publication, funding sources, and resident provided building-specific evidence of subslab soil gas intrusion),
- describing the review process and data quality criteria and metrics used for inclusion in assessments,
- discussing QC checks and procedures for transcription from the original source into the data management tool(s),
- explaining how data will be managed (e.g., Excel spreadsheet), analyzed, and interpreted in a QA/QC and Methodology section of the work product.

In compiling input parameters, efforts will be made to identify and select data sources that have undergone peer and/or public review to varying degrees. These parameters are not always readily available from literature and some data elements may be calculated using appropriate estimation procedures. These estimation procedures will be documented in a Methodology section of the work product in a transparent way to facilitate replication and QC review.

For each defined parameter to be included in the work product, RTI, Jacobs, and Geosyntec will:

- Document the data source (author, title, year of publication, hyperlink if available),
- Include relevant notes useful for data analysis and interpretation,
- Identify any significant limitations to the selected data, and
- Ensure that the data are appropriate for their intended use (i.e., relevant to the work product scope, of reliable data quality, within the desired range of timeliness).

Spreadsheets and tabular databases will be used to store and relate data. The design of these tools will be adequate and appropriate for use. The actual data management format and data coding for each work product will be discussed with and approved by the TL to ensure that the format will be effective to meet the purpose(s) of the task.

Cross-cutting data management procedures are defined below:

- *Missing data*: A pre-defined notation key will be used where no data are provided for a category within the data management tool. For example, the cell may be left blank, or clearly marked to indicate a lack of data as opposed to a zero value.
- *Zero values*: If the reported data is zero, the number "0" will be used.
- *Abbreviations*: Abbreviations will be defined and used consistently throughout the data management tool.
- *Availability of Data*: If a qualitative indication of the presence or absence of data is collected, consistent markings for present or absent will be used (e.g., yes/no, 1/0).
- *Analytical Data*: All analytical data will be reported to the detection limit of the analytical technique and the detection limit will be defined within the data management tool. In cases of non-detect or reported below the detection limit, the data will be recorded with a less than sign and the detection limit (e.g., <0.01).
    - Concentration data will be labeled with the constituent's name and concentration units (e.g., Hg (mg/l), or Mercury (mg/l)).
    - Time will be reported in 24:00 increments.
    - Dates will be reported as mm/dd/yyyy.
    - Geographical data will be reported as latitude and longitude in decimal degrees.

The QC procedures to be used when transcribing data from information sources into the data management tool are described below:

- *Data Entry QC*: All manually-entered data will be independently checked against the relevant information source(s) for accurate transcription of values and units. These QC checks specifically confirm the data element name, value, and units were correctly transcribed. We typically perform a random 10% to 20% QC check on individual data elements across the entire data management tool. If transcription errors are identified, a higher percentage of QC checks of the data elements will be performed as deemed necessary by the TOL to ensure overall work product quality.

- *Data Transfer and Analysis QC*: Electronic data transfers of groups of data from internally maintained databases (which have already undergone QC checks of data entry) to a spreadsheet table, chart, figure, etc. will be checked. Specific QC checks will be performed for trends to identify outliers, missing data, systematic errors (e.g., calculation formulas or data interpretation). If any quality concerns are identified, additional QC checks will involve sampling of data elements from the internal database to ascertain whether data transfers occurred without error. The sample size of these QC checks is typically 5%. Other, more complete reviews as indicated by the results of the initial checks will be implemented as necessary.

3.2.3 Data Reduction

The chemical data from discrete samples will be compiled into a simple database that will facilitate data analysis. Data from continuous monitors for chemical and physical parameters will be managed separately as discussed below.

Initial VOC data review will be done by the analyst using the analytical instrument. Spectra, peak shape, baseline integration are among the parameters that will be examined manually. QA sample data will be compared to their respective acceptance criterion and flagged as necessary. The following definitions are intended to assist the data user by providing an explanation of the qualifiers (flags) appended to organic analysis results by the laboratory and/or data reviewer. The purpose of data flagging is to facilitate appropriate data use, consistent with the project objectives. EPA will use its SOP WECD-MMB-SOP-4350-0 titled “Analysis of Volatile Organic Compounds in Soil Vapor using Thermal Desorption / Gas Chromatography / Mass Spectrometry.”

<u>Qualifier Flag Descriptions</u>

J The reported result is an estimate. The value is less than the minimum calibration level but greater than the method detection limit (MDL).

U The analyte was not detected in the sample at the MDL.

E Exceeds calibration range.

B Analyte found in sample and associated blank.

I internal standard associated with target analyte is outside of project QC parameters.

C Calibration verification standard associated with target analyte is outside of project QC parameters.

3.2.4 Data Review and Verification

All sources of secondary data will be cited and identified in individual task work products and in the final report/memorandum. Sources will be identified as to their quality (See Section 3.2.1), which is an indicator of peer-reviewed or non-peer-reviewed status.

Any manually-entered data and information will be independently checked against the data sources for accurate transcription of values and units. Any data that are generated (e.g., summary statistics for the numerical data) will also be checked for accurate transcription of values from the studies and accurate equation setup in Excel. Electronic data transfers of data will be checked for a selected sample (typically 5 to 10 percent) for units and values to ensure completeness and accuracy of data transfers and to identify potential systematic errors. Checks will involve a sampling of data elements from the database and will be used to ascertain whether data transfers occurred without error.

All data handling procedures, including data entry and any unit conversion calculations will be reviewed for completeness and accuracy, for relevance of the technical content, and a check of the data for data entry or transposition errors. A minimum of 5 percent of the data entries will be reviewed for correct entry to the product spreadsheet/database. This includes the verification of spreadsheet/database cell calculations for unit conversions, as applicable.

The following items will be included in the QC review:

- Data selected for use in the reports and analyses under this QAPP meets the QA/QC criteria defined Section 3.2.1.
- Any unit conversion calculations performed will be verified to be correct.
- Data supplied will be checked back to original sources.
- Final data will be reviewed as an entire set to ensure that values for different parameters appear reasonable and consistent.

Documentation of the implementation of the above-mentioned QA/QC process will be maintained for internal purposes. Any noted quality deficiencies will be documented and communicated, in writing, to the Jacobs TOL.

In the case where subcontracted laboratories are used (although not currently anticipated), data packages from the subcontracted laboratories will contain Level II QA/QC data. Subcontracted laboratories will be required to include a case narrative or similar analysis in which a second chemist reviews the dataset and summarizes any deviations from QA/QC criteria. We will evaluate this information during the data analysis process. Data verification (as described in US EPA 2002a) will be conducted by the Jacobs QA Officer or that person's designee to ensure the data's suitability for the intended purpose. A functional guidelines data validation is not planned at this time. However, we will obtain a sufficiently detailed data package to permit a data validation process to be performed should it be directed by the EPA TOCOR.

For internally generated data (from EPA CEMM facilities), the EPA alternate TOCOR will review 100% of the data for reasonableness and completeness. The Jacobs QA officer or that person's designee will conduct a data verification and useability level review of the EPA CEMM produced data for every data set which is normally provided as a simple spreadsheet of results including surrogate recovery and field generated blank results.

3.2.5 Initial Data Screening for Risk Communication and Study Design Alterations

During the data verification process, the Jacobs data reviewer will be alert for two potential situations that may potentially require a risk communication and a study design alteration:

- Observation of concentrations exceeding a rapid action level or removal management level in the applicable jurisdiction. Observations of this type will be rapidly discussed with the EPA TOCOR and local regulatory liaison (within one week).

- Observations of concentrations of target analytes that, while below rapid action levels and removal management levels, are nevertheless implausible for VI and indicative of a dominant indoor source. The primary basis for judging this implausibility will be observation of concentrations above what would be expected from 95th percentile based attenuation factors from EPA (2012c) and available site-specific data. Observations of this type are less urgent and will be discussed with the EPA TOCOR during a scheduled project call and/or by e-mail (typically within two weeks).

In either situation, additional information can be reviewed to evaluate whether the observed indoor air concentrations are truly the result of VI, or are more likely attributable to an indoor source such as the following:

- compound ratios between soil gas and indoor air; among the VOCs and with radon
- whether CVOC constituents are observed that are not observed in soil gas
- whether constituents that are rarely present in indoor sources, such as cis-DCE are observed in indoor air
- whether the observed concentrations exceed those commonly observed in background structures (US EPA, 2011)
- a follow up to the building survey to discuss with the homeowner or occupant whether any new indoor sources could have been introduced, and to review with them potential indoor sources that could be consistent with the data in order to identify potentially hidden chemical storage.

Depending on the results of this review, consideration can be given of requesting the homeowner to properly dispose of unwanted stored chemicals, or to relocate storage to an outbuilding. Additionally depending on the availability of EPA resources additional sampling locations for VOCs, radon etc. within the structure can be established. With additional sampling locations insight into whether the primary source is likely VI or indoor sources could be gathered.

In the final project data analysis, if strong evidence is developed that certain samples may have been dominated by indoor sources, the analysis can be performed both with and without that portion of the data set (see also Section 6.2).

3.2.6 Data Analysis

The project team will analyze collected data to answer the quality objectives and criteria included in Table 4-1. For example, the team will review data to understand if the forecasted weather conditions occurred, whether the anticipated response in indoor air occurred, and whether the indoor air concentrations were controlled by VI versus other indoor air sources.

Data analysis will be accomplished through a series of statistical tests and graphical analysis of data. Statistical analysis usually starts with exploratory analysis, which involves calculation of summary statistics (mean, standard deviation, range, median, and other percentiles) to provide a characterization of the distribution of the data, as well as graphs that display the characteristics of the data. Because the data might not follow a normal distribution function, the Mann–Whitney U-test (also known as the Wilcoxon rank sum test and the Mann–Whitney Wilcoxon test), and the H-test of Kruskal–Wallis can be used to detect significant differences between independent groups of data. For dependent data (e.g., to compare analysis results from replicates), the Wilcoxon signed-rank test and the Wilcoxon matched pairs signed-rank test can be used to assess differences. Box plots, histograms, and cumulative distribution plots can be used to represent summaries of the statistical distributions

3.2.6.1 Field Testing Data Analysis

Preliminary field sample analysis will be performed using ChemStation on the GC-MS instrument computer. EPA SOP: WECD-MMB-SOP-4350-0 "Analysis of Volatile Organic Compounds in Soil Vapor using Thermal Desorption / Gas Chromatography / Mass Spectrometry". Processed data will be copied to the TOCOR/PI's laptop and subsequent analysis will use software programs such as R, SAS, MATLAB, Python, or others.

The primary datasets in Task 3 will be VOC and radon concentrations in external soil gas samples, which will be analyzed by:

- Compound
- Location (structure code number)
- Depth
- GPS coordinates

These will be primarily analyzed as summary statistics site-wide, summary statistics per structure, and based on spatial distribution on a site map.

The primary datasets in Tasks 4 and 5 will consist of distributions of indoor concentrations by:

- Compound
- Location (structure code number, and floor/location)
- Season
- Basis for collection (convenience or ITS driven)
- Specific ITS based rationale
- Sample duration.

This dataset will likely be amenable to analysis using pivot table summary statistics and ANOVA.

An additional dataset in Tasks 4 and 5 will be formed from the radon, indoor temperature, and CO_2 data in each structure and local meteorological information. That information will be aggregated to daily averages, and the hourly as well as daily data used to prepare temporal trend plots for semiquantitative analysis.

3.2.6.2 Spatial Analysis

Spatial trends in indoor VOC and radon concentrations will also be explored graphically across the study site. Spatial variability exists when the distribution or pattern of concentration measurements changes from one location to another (most typically in the form of differing mean levels). Such variation may be natural or synthetic, depending on whether it is caused by natural or anthropogenic factors. The main assumption for considering spatial variability is that sites that are close together in space are often more alike than those that are apart.

Methods for assessing spatial variation include the use of box plots, variograms (plots to determine how similar values are with distance), and linear models that incorporate the latent spatial structure. It is also possible for the mean concentration levels to differ across sample sites but vary in a seemingly random way with no apparent connection to the distance between the sampling points. In that case, the concentrations between pairs of sites are not correlated with distance, yet the measurements within each site are strongly associated with the mean level at that location, whether due to a change in soil composition or another factor.

This program will use the guidance described in the EPA National Geospatial Data Policy (NGDP) (U.S. EPA, 2005b), and the NGDP Procedure for Geospatial Data Metadata Management (U.S. EPA, 2007). Records management will be consistent with the U.S. EPA National Records Management Program Records Program, specifically Schedule 1035 (U.S. EPA, 2022).

The location of the site will be specified at geospatial accuracy tier 4 or better. Accuracy within the site will be at geospatial accuracy tier 2 or better.

3.2.6.3 Temporal Analysis

Time series plots show the data against a time axis (e.g., days, week, year) that display seasonality or trends in the data. Of particular interest, are the plots of radon or VOC concentrations, and meteorological variables versus time. These plots can be examined and show any seasonal or weather front effects observed in the data. These plots are expected to be semi-quantitatively interpreted in the context of the existing knowledge about ITS and VI as described in Section 1 to select potential sampling times.

3.2.7 Data Storage

We expect to collect and primarily use electronic documents and data. All sources used for the deliverables under this QAPP will be saved as a PDF, Microsoft Word, .CSV, .TXT, Microsoft Excel, or Microsoft Access file on an appropriate server space. A Microsoft Teams site will be maintained by RTI for short-term storage (i.e., during the period of performance) of limited documents that are actively being worked on. Other documents will be shared with key team members using email. If data from Web sites are used (e.g., weather-related data), the link to the webpage will be saved with descriptive information (e.g., author, year, brief title, and date the website was accessed).

3.3 Non-detect Values

A common issue in environmental data analysis is the frequent presence of non-detect values, known in statistical terms as left-censored measurements. The magnitude of these sample values is known only to lie somewhere between zero and the detection or reporting limit; hence the true concentration is partially "hidden" or censored on the left and side of the numerical concentration scale. Because most statistical analysis assume that all the sample measurements are known and quantified and not censored, depending on the magnitude of the non-detects issue, we can apply methods for non-detect as discussed by Zhao and Frey (2006) and Helsel (2005) or apply non-parametric test alternatives after accounting for the non-detects.

3.4 Data Reporting

We will prepare a final report in accordance with the *EPA Handbook for Preparing ORD Reports*, which allows for multiple formats including project reports and journal articles. The journal article(s)/final report is anticipated to include the following:

- Introduction including a brief site description, with citations to other sources in which the reader can find more detailed information

- Summary of the sampling and analysis methods used by the project team and the subcontracted laboratories, along with a reference to the approved quality assurance plan in which more detailed information can be found
- Chemical, physical, and quality assurance data in sufficient detail that interested parties can assess the utility of the results
- Data quality problems, necessary corrective actions, and any other limitations of the utility of the data
- Detection/quantitation limit information.

RTI/Jacobs will compile the project chemical data from discrete samples into a simple database that will include data from subcontracted laboratories and any discrete samples analyzed on site or by EPA personnel. Data from continuous monitors for chemical and physical parameters will be managed separately as discussed below but will be included and documented in the final data package delivered to EPA.

To the extent that they are not included in the final report or journal article(s), we will provide EPA with the following information as a supplementary final report in electronic (CD) format:

- Full version of the discrete sample chemical database discussed above
- Data from field instruments in spreadsheet format
    - Radon (continuous and discrete instruments)
    - Temperature, CO_2, and atmospheric pressure data
    - Information regarding accreditation or auditing of subcontractor laboratories.
- Photographs as needed and available to depict field sites, sampling locations and deviations from plans.

3.5 Assessment Oversight

Assessment oversight for field and analytical QA/QC will be handled by the Jacobs QA Officer or their local designee.

3.6 Development of Research Conclusions

Development of conclusions will largely be the responsibility of the EPA TOCORs with contributions from the research team.

4 Quality Objectives and Criteria

Table 4-1 summarizes the quality objectives and criteria for this project. Each objective is expressed first qualitatively in words similar to the EPA PWS. Then each objective is expressed in quantitative/statistical terms where possible. The planned measurements that will be used to achieve each objective are then listed. More details on the measurements to be made are given in the test matrix, which appears below as **Table 4-2**. The test matrix is written using the Corentium Airthings View Plus as the primary indoor monitor for radon, indoor temperature, and CO_2; with the Radon Eye Plus 2 as an optional supplement to provide higher sensitivity/temporal resolution on the radon measurements.

If the number of sites chosen and EPA equipment stocks suggested the use of the Radon Eye Plus 2 as the only indoor radon monitor, it would be necessary to supplement it with additional instruments for the other parameters. Indoor temperature monitoring devices that may be available from previous projects include the following:

- Omega PRTC110 (no longer sold), and the
- Onset Hobo UX100 Temp ($85).

Low cost instruments monitoring of CO_2 in indoor air that may be suitable are also available for purchase include the following:

- Aranet4 Home Indoor air quality monitor (to measure CO_2, temperature, humidity, and barometric pressure with wireless Bluetooth connectivity ($299), and
- Autopilot Desktop CO_2 Monitor with Memory and Data Storage ($103.65; does not have internet connectivity but would store one year of data for download).

Table 4-1. Quality Objectives and Criteria for this Project

Study Question		Measurement	
Qualitatively Stated (from SOW Objectives when applicable)	**Quantitatively/Statistically Stated**	**Used to Support Study Question**	**Performance or Acceptance Criteria for This Question/Description of Data Set Anticipated**
Examine the protectiveness of the ITS methodology and approach as compared to the "traditional" standard chemical site election process and conduct a pilot study at a community willing and interested in being designated as a *Soil Gas Safe Community*.			
Document/quantify the current state of practice for SGI sampling by collecting data on the typical number and timing of samples for VI decisions, whether the data supported the need for mitigation or not, and if possible, what decision criterion were being used to make the decision to mitigate or not	What are the type and number of samples that different states require to support the need to mitigate? What other decision making criteria do states use to make a decision to mitigate or not?	The number and timing of samples for VI decisions across states.	We are seeking to determine if the study design fits within the type and number of samples currently used at the state level to make mitigation decisions. This assessment may also identify states where certain samples are required that are not currently included in the scope of this project (e.g., subslab).
Determine relationship of radon to VOC concentrations at the test site in soil gas.	Is radon in soil gas in a sufficient and uniform concentration to allow it to be used as a useful tracer on a neighborhood scale? Is the VOC distribution in soil gas sufficiently widespread to make the demonstration site suitable? (this does not require uniformity) Is there a statistically significant spatial correlation of radon to VOC concentrations at the test site in soil gas?	Radon and VOC measurements in external soil gas.	We are seeking to establish if a correlation is present here. The absolute values for VOCs are expected to vary several orders of magnitude between structures. The variability for radon is likely to be one order of magnitude. Replicate measurements are expected to be ±30% which should be adequate to establish if a correlation exists between radon and VOCs within a large dataset.
Determine relationship of radon to VOC concentrations at the test site in indoor air.	Is there a statistically significant correlation of radon to VOC concentrations at the test site in indoor air temporally? Is there a statistically significant correlation of radon to VOC concentrations at the test site in indoor air spatially? Does the direction of change in radon concentration predict or track with change in VOC concentrations?	Radon and VOC measurements in indoor and ambient air.	We are seeking to establish if a correlation is present here. This analysis can be done using either the calendar-driven or IT-driven data sets. The absolute values are expected to vary spatially between structures. Replicate measurements are expected to be ±30%, which should be adequate to establish if a correlation exists between radon and VOCs within a large dataset.

Study Question		Measurement	
Qualitatively Stated (from SOW Objectives when applicable)	**Quantitatively/Statistically Stated**	**Used to Support Study Question**	**Performance or Acceptance Criteria for This Question/Description of Data Set Anticipated**
Examine relationship between changes in barometric pressure and indoor air concentrations of VOCs and radon.	Do significant changes in barometric pressure (beyond what is typical in the locality for daily variation) lead to higher indoor air concentrations of radon and VOCs?	Radon and VOC measurements in external soil gas and indoor air.	Barometric pressure measurements by local weather stations are typically reported to 0.01 inches of Hg which is adequate. Measurement of exterior soil vapor and indoor concentrations within ±30% is expected to be adequate. This analysis can be done using either the calendar-driven or IT-driven data sets.
Can VI experts (from the RTI project team) use ITS information to time indoor sampling rounds to have a higher probability of observing reasonable maximum indoor concentration then random or seasonally timed samples?	Are the concentrations observed by the ITS timed samples greater than those observed by the randomly timed samples?	VOC measurements in randomly timed samples and ITS directed samples	Measurement of indoor concentrations within ±30% is expected to be adequate. ANOVA or T-test used to compare randomly timed and ITS directed samples.
If home or business owners are provided with temperature- and radon-measuring devices, can they reliably take samples based on ITS indicators?	Did a high percentage of the home and business owners participate? Are the concentrations observed by the ITS timed samples greater than those observed by the randomly timed samples? Are homeowners/occupants able to state a technically relevant reason for choosing to sample when they did?	We are providing home and business owners with VOC sampling kits, Airthings for temperature monitoring, and Radon detectors in order for them to make their assessments of proper sampling times based on given criteria. We will provide homeowners with information about barometric pressure from local weather stations.	Can we compare results of calendar and IT samples and show that the IT samples are equal to or greater than in quality to the results for the calendar samples? Can we show that just taking IT-driven samples is the better way to go?
Are building owners/occupants willing to participate in an ITS based SGS monitoring program?	What percentage of building owners/occupants approached originally agreed to participate? What percentage of those who originally agreed to participants continued to participate for the duration of the 9 month test period?	Logs of homeowner/occupant outreach and participation.	The project team will strive for 100% completeness of these records but given human nature some information will likely be incomplete. For example, some persons may just stop responding to questions/participating with no explanation.

Table 4-2. Test Matrix: Sample Type and Frequency

Media Sampled	Sample Method	Primary Samples	QA/QC Samples[c]			Total Number of Samples
			Duplicate	Field Blank	Ambient	
Task 3b – Initial Screening Event (30 structures)						
Soil Gas[a]	7-day time-integrated VOC samples using passive sorbent tubes, analyzed by USEPA Method TO-17	120 = 4 single-depth (approx. 5 feet bgs) locations nearby each of the 30 individual structures proposed for optional follow-on sampling. The soil gas probe will be sampled by deploying a passive sorbent tube for approximately 7-calendar day duration.	4 (for 1 sampling event)	4 (for 1 sampling event)	2 (for 1 sampling event)	130
	Field screening for radon	120 = 4 single-depth (approx. 5 feet bgs) locations nearby each of the 30 individual structures proposed for optional follow-on sampling. The soil gas probe will be sampled for radon using a Rad7 or similar equipment (i.e., AlphaGuard) upon retrieval of VOC sampler, with a final measurement recorded once readings at the probe stabilize. Duplicates the same location as for VOCs.	4 (for 1 sampling event)	None	Up to 10 = once per day from the breathing zone on site	134
Indoor Air[b]	7-day time-integrated VOC samples using Radiellos, analyzed by Method TO-17	60 = Up to 2 locations within the breathing zone of each of the 30 individual structures proposed for optional follow-on sampling. Both samples will be collected from the lowest level of the structure if slab on grade, or from one level below ground surface and one level at ground surface if structure has a basement or is split-level. Radiellos will remain in place for approximately 7-calendar days.	6 (for 1 sampling event)	Up to 4 = once per week (for 1 sampling event)	Up to 4 = once per week (for 1 sampling event)	74
	Field monitoring for radon, temperature, humidity, and carbon dioxide	30 (1 location within the breathing zone inside each of the 30 individual structures proposed for optional follow-on sampling). Data will be collected continuously at each location by deploying Corentium Airthings (optionally also Radon Eye Plus 2) connected to the internet for remote accessibility.	None	None	None	30
Sewer Gas	Field screening for radon	3 = Three sewer manhole locations on site, nearby selected structures, within the headspace zone. Radon data will be collected using a Rad7 or similar equipment (i.e., AlphaGuard) upon retrieval of VOC sampler, with a final measurement recorded once readings at the probe stabilize.	NA	NA	NA	3
Task 4a – Optional (25 of the 30 initially screened structures; assumptions included below are per site)						

Media Sampled	Sample Method	Primary Samples	QA/QC Samples[c]			Total Number of Samples
			Duplicate	Field Blank	Ambient	
Outdoor Air	RAD-7 Continuous Radon Monitor	Outdoor air at 1 location	None	None	NA	Outdoor air radon continuous through full project period. Two hour time intervals.
Meteorology	National Weather Service	Meteorological data (such as temperature, wind speed and direction, barometric pressure, and hourly precipitation) will be obtained with data from the closest National Weather Service facility.	NA	NA	NA	One to two closest stations per neighborhood/ site will be used. Hourly data for approximately 9 months will be acquired.
Indoor Air[b]	7-day time-integrated VOC sampling by Radiellos, deployed on a calendar-driven schedule, analyzed by Method TO-17	50 samples per sampling event, with up to 3 calendar-driven sampling events: Summer/Fall, Winter, Spring/Summer = 50 x 3 = 150 total primary samples. Two 7-day Radiellos deployed within the breathing zone of 25 pre-screened structures. Samples collected from the basement (if present) and ground floor, or ground floor only. If a building does not have a basement, consideration will be given to placing the second Radiello as a duplicate, in an easily accessible crawlspace or separate section of the house. In some cases, only 1 sample may be collected per residence. Ambient samples will be collected at 1 location per neighborhood. Two samples per season allows some offset in time to cover multiple exact start dates across houses.	Up to 15 (5 per sampling event)	Up to 3 (1 per sampling event)	6 (2 per sampling event)	174
	7-day time-integrated VOC sampling by Radiellos, deployed on an ITS-driven schedule, analyzed by Method TO-17	50 per sampling event with up to 9 ITS-driven sampling events: Summer/Fall (x3 triggered deployments); Winter (x3 triggered deployments); Spring/Summer (x3 triggered deployments) = 50 x 9 = 450 total primary samples.	Up to 45 (up to 5 per sampling event)	Up to 18 (up to 2 per sampling event)	Up to 18 (up to 2 per sampling event)	531

Media Sampled	Sample Method	Primary Samples	QA/QC Samples[c]			Total Number of Samples
			Duplicate	Field Blank	Ambient	
		Two 7-day Radiellos deployed within the breathing zone of 25 pre-screened structures. Samples collected from the basement (if present) and ground floor, or ground floor only. Multiple field blanks and ambient samples per event allows some offset for sampling different structures at different times and maintaining one field blank per cooler shipment.				
	Field monitoring for radon, temperature, humidity, and carbon dioxide	25 = 1 location within the breathing zone inside each of the 25 individual structures. Data will be collected continuously at each location by deploying Corentium Airthings (optionally also Radon Eye Plus 2) connected to the internet for remote accessibility.	None	None	None	25 datasets each approximately 9 month long with 1 hour time intervals
Optional Addition: Indoor Air[b]	1-day time-integrated VOC sampling by Radiellos, deployed on a calendar-driven schedule, analyzed by Method TO-17	50 per sampling event with up to 3 calendar-driven sampling events: Summer/Fall, Winter, Spring/Summer = 50 x 3 = 150 total primary samples. Two 1-day Radiellos deployed within the breathing zone of 25 pre-screened structures. Samples collected from the basement (if present) and ground floor, or ground floor only.	15 (5 per sampling event)	Up to 3 (1 per sample shipment, may be shared with other durations)	9 (3 per sampling event)	177
	1-day time-integrated VOC sampling by Radiellos, deployed on an ITS-driven schedule, analyzed by Method TO-17	50 per sampling event with up to 3 ITS-driven sampling events: Summer/Fall, Winter, Spring/Summer = 50 x 3 = 150 total primary samples. Two 1-day Radiellos deployed within the breathing zone of 25 pre-screened structures. Samples will be collected from the basement (if present) and ground floor, or ground floor only.	15 (5 per sampling event)	Up to 3 (1 per sampling event may be shared with other durations))	9 (3 per sampling event)	177
Task 5c – Optional (up to 30 structures per each of two sites)						
Outdoor Air	RAD-7 Continuous Radon Monitor	Outdoor air at One location	None	None	NA	Outdoor air radon continuous through full project period. Two hour time intervals.

Media Sampled	Sample Method	Primary Samples	QA/QC Samples[c]			Total Number of Samples
			Duplicate	Field Blank	Ambient	
Meteorology	National Weather Service	Meteorological data (such as temperature, wind speed and direction, barometric pressure, and hourly precipitation) will be obtained with data from the closest National Weather Service facility.	NA	NA	NA	One to two closest stations per neighborhood / site will be used. Hourly data for approximately 9 months will be acquired.
Indoor Air	7-day time-integrated VOC sampling by Radiellos, deployed on a calendar-driven schedule, analyzed by Method TO-17	Up to 3 calendar-driven sampling events, similar to described under Optional Task 4a. 30 x 3 = 90 total primary samples (180 if two sites are selected)	9 (3 per sampling event for 1 site)	9 (3 per sampling event for 1 site)	9 (3 per sampling event for 1 site)	One site – 117 Two sites – 234
	7-day time-integrated VOC sampling by Radiellos, deployed on an ITS-driven schedule, analyzed by Method TO-17	30 per sampling event with up to 9 ITS-driven sampling events, similar to described under Optional Task 4a. 30 x 9 = 270 total primary samples (540 if two sites are selected)	9 (3 per sampling event for 1 site)	9 (3 per sampling event for 1 site)	9 (3 per sampling event for 1 site)	One site – 297 Two sites – 594
	Field monitoring for radon, temperature, humidity, and carbon dioxide	30 per sampling event = 1 location within the breathing zone inside each of the 30 individual structures (60 if two sites are selected). Data will be collected continuously at each location by deploying Corentium Airthings (optionally also Radon Eye Plus 2) connected to the internet for remote accessibility.	None	None	None	30 structure specific data sets for 9 months each with 1 hour time intervals
Optional Addition: Indoor Air	1-day time-integrated VOC sampling by Radiellos, deployed on a calendar-driven schedule, analyzed by Method TO-17	30 per sampling event with up to 3 calendar-driven sampling events, similar to described under Optional Task 4a. 30 x 3 = 90 total primary samples (180 if two sites are selected)	9 (3 per sampling event for 1 site)	9 (3 per sampling event for 1 site)	9 (3 per sampling event for 1 site)	One site – up to 117 Two sites – up to 234

Media Sampled	Sample Method	Primary Samples	QA/QC Samples[c]			Total Number of Samples
			Duplicate	Field Blank	Ambient	
	1-day time-integrated VOC sampling by Radiellos, deployed on an ITS-driven schedule, analyzed by Method TO-17	30 per sampling event with up to 3 ITS-driven sampling events, similar to described under Optional Task 4a. 30 x 3 = 90 total primary samples (180 if two sites are selected)	9 (3 per sampling event for 1 site)	9 (3 per sampling event for 1 site)	9 (3 per sampling event for 1 site)	One site – up to 117 Two sites – up to 234

Notes:

[a] Initial screening results will be reviewed to assess the presence of PFAS in soil gas and refine post-screening sampling design, as necessary.

[b] total VOC field screening performed using handheld PID during building survey to identify potential sources of background VOCs which may be present within selected structures.

[c] Trip blanks will not be collected for field observations. Instead, field blanks in the frequency specified will be collected. A field blank is briefly opened in the field to simulate how samples are collected, while trip blanks are not opened at all and stay in the cooler. Field blanks are considered more rigorous in identifying contamination compared to a trip blank.

4.1 Data Quality Indicators

4.1.1 Bias

Bias is the difference between an observed value and the "true" (or "target") value of the parameter being measured. For chemical analysis, bias is typically expressed as percent bias from a known standard or percent recovery of a spiked quantity in the matrix being analyzed.

To measure bias, begin by calculating the average of all measurements of a parameter. The average $(\bar{x})$ of a set of measurements is given by:

$$(\bar{x}) = \sum_{i=1}^{n} \frac{x_i}{n} \quad (3\text{-}1)$$

where:

x_i = a given measurement

n = the number of measurements.

Percent bias *(%B)* is given by the difference between the average of a measurement and the true value *(T)* of a reference standard.

$$\%B = \frac{100(\bar{x} - T)}{T} \quad (3\text{-}2)$$

Bias can be positive or negative and is estimated by percent recovery (%recovery) of a reference standard.

$$\%recovery = \frac{\bar{x}(100)}{T} \quad (3\text{-}3)$$

Another way to measure bias is to calculate the percent recovery of a standard solution.

$$\%recovery = \frac{100(\bar{A} - \bar{B})}{T} \quad (3\text{-}4)$$

Where:

$\bar{A}$ = Average measurement of the standard samples

$\bar{B}$ = Average measurement of the blank samples

T = Documented value of standard.

4.1.2 Precision

Precision is the level of agreement among multiple measurements, made at the same conditions and with the same method, of the same parameter. The sample standard deviation, s, and the sample coefficient of variation, CV, are used as indices of precision. When precision estimates are obtained from analysis of replicated measures, the range, R (maximum value – minimum value), the relative range, and the relative percent difference (RPD) are frequently used.

Precision is typically expressed as RPD for duplicate measurements or relative standard deviation (RSD) for replicate measurements.

$$RPD = \left(\frac{2 \cdot |x_2 - x_1|}{x_1 + x_2}\right) \cdot 100 \quad (3\text{-}5)$$

Where:

x_1 = initial measurement

x_2 = duplicate measurement

The variance, s^2, of a measurement is given by the sum of the squares of the differences between each measurement and the average, divided by the degrees of freedom of the measurement, $(n - 1)$:

$$s^2 = \frac{\sum_{i=1}^{n} \left(x_i - \bar{x}\right)^2}{n - 1} \quad (3\text{-}6)$$

Standard deviation (s) is the square root of the variance and is a measure of the precision of the measurement.

$$s = \sqrt{s^2} \quad (3\text{-}7)$$

Precision can be expressed as the *CV* or *RSD*. Both are expressed as follows.

$$\%RSD = CV = \frac{s(100)}{\bar{x}} \quad (3\text{-}8)$$

4.1.3 Completeness

Completeness is a measure of the quantity of valid data successfully collected from a measurement system compared to the amount intended in the experimental design and is calculated by Equation 3-10.

$$\%Completeness = 100\left(\frac{valid\ data\ collected}{data\ planned}\right) \quad (3\text{-}9)$$

4.1.4 Comparability

Comparability is a measure of the confidence with which one data set can be compared to another. To show comparability between data sets, the sets are expressed in the same units. The conditions under which the data are taken are well defined.

Data comparability is used to describe analytical data quality for measurements of the same thing made using different sampling/analytical methods. For example, the Radiello and TO-17 samples that are used to measure VOC concentrations for comparable periods can be compared. Ideally, in order to maximize the potential for data comparability, one needs to determine the minimum data elements, including background information, to be included in the data collection effort. An operational framework for comparability ensures that data are well documented, consistent, and of known quality. An operational framework includes the design of data collection methods in the field and laboratory that address study objectives and goals and follow specified data quality objectives. Such a framework is included in later sections of this QAPP.

Several factors can contribute to, or detract from, data comparability. These can be grouped into two general categories: factors related to sample collection and handling and factors related to the analytical methods used. Sample collection issues include sample design, acquisition techniques, environmental conditions at the time of sampling, and sample handling/preservation methods. Analytical issues related to data comparability include sample preparation, cleanup, and determinative methods used.

Standard methods for evaluating data comparability are the use of split samples and regression analysis or correlation coefficients. In the case of regression analysis, the adjusted coefficient of determination is often quoted as a measure of comparability. In the case of correlation coefficients, it is the correlation coefficient itself that measures the linear relationship between two sets of analytical results derived from sample splits.

4.1.5 Representativeness

Representativeness expresses the degree to which data accurately and precisely represent a measured characteristic of a condition of a population or a process.

Representativeness requires that the scale (spatial, temporal, chemical, etc.) of the sampled data be the same (within tolerable uncertainty bounds) as that observed in study region. Representativeness involves two concepts: sample representativeness and analytical representativeness, both of which play a critical role in data uncertainties. Sample representativeness includes procedures related to sampling design, sample selection, collection of data, preservation, and sub-samples. Sample representativeness can be achieved by selecting the sampling design that captures any spatial and temporal dimensions of the study region. Analytical representativeness involves selecting an appropriate analytical method that produces test results that are representative of the decision.

4.1.6 Repeatability and Reproducibility

Repeatability is the variation in data generated on a single sample by a single analyst and/or instrument over a short period. Repeatability can be measured by calculating RPD.

Reproducibility is the variation in data over an extended period and/or by various analysts or laboratories. Reproducibility can be expressed as RSD.

4.1.7 Method Detection Limit and Practical Quantitation Limit

Definitions of these terms are quoted here from an EPA (2003b) document: “EPA uses two measures of analytical capability, the Method Detection Limit (MDL) and the Practical Quantitation Limit (PQL).”

- The MDL is a measure of method sensitivity. As defined in 40 CFR Part 136 Appendix B, the MDL is "the minimum concentration of a substance that can be reported with 99% confidence that the analyte concentration is greater than zero." MDLs can be operator, method, laboratory, and matrix specific. Due to normal day-to-day and run-to-run analytical variability, MDLs may not be reproducible within a laboratory or between laboratories. The regulatory significance of the MDL is that EPA uses the MDL to determine when a contaminant is deemed to be detected and it can be used to calculate a PQL for that contaminant.

- The PQL is defined as "the lowest concentration of an analyte that can be reliably measured within specified limits of precision and accuracy during routine laboratory operating conditions" as defined in the preamble to a November 13, 1985 rulemaking (50 FR 46906). The Agency has used the PQL to estimate or evaluate the minimum concentration at which most laboratories can be expected to reliably measure a specific chemical contaminant during day-to-day analyses of drinking water samples." A PQL is determined either through using interlaboratory study data or, in absence of sufficient information, through the use of a multiplier of 5 to 10 times the MDL.

When the measurement is at or near the limitations of the instrument used to perform the measurement, the detection limit must be known and reported. The MDL for each environmental measurement method is determined by analysis of seven or more replicates of spiked matrix samples. The standard deviation of the responses (s_m) is used to calculate the MDL as follows:

$$MDL = s_m \cdot (t_{0.99}) \tag{3-10}$$

Where:

$t_{0.99}$ = Student's t value for a one-tailed test at the 99 percent confidence level and a standard deviation estimate with $n - 1$ degrees of freedom. For seven replicates, $t_{0.99} = 3.14$ for $n - 1 = 6$ degrees of freedom.

4.2 Assessment and Oversight

Assessment oversight for field and analytical QA/QC will be handled by the Jacobs QA Officer or their local designee.

4.2.1 Field Activities

Assessment and oversight for field and analytical QA/QC will be handled by the Jacobs QA Officer or their local designee.

Audits

At this time, there are no scheduled audits or performance evaluations associated with this TO planned for RTI, Jacobs, or EPA CEMM personnel except as discussed below. We will work with the EPA QAM or designee should any additional audits be required by EPA. This TO will be subjected to random internal system audits performed by the Jacobs QA Officer. The Jacobs QA Officer will also perform a data quality assessment for this project during report preparation.

4.2.2 Corrective Action Procedures

During research and testing, every effort is made to anticipate and resolve potential problems before the quality of the measurement performance is compromised. Personnel responsible for instrumentation and testing activities are cognizant of activities that can affect data quality. Personnel will be familiar with the contents of the QAPP and QA/QC requirements.

Problems that may adversely impact data quality will be corrected by the analyst who is responsible for interpreting the results of the daily calibration check and resolving potential problems based on the procedures referred to in the QAPP and will be reported to the RTI TOL. If the problem is reported by Jacobs staff, the Jacobs TOL will advise the RTI TOL and EPA TOCORs of problems and corrective actions that have been implemented. The field personnel will document corrective actions in bound notebooks. The Jacobs TOL is also responsible for reporting data quality problems and corrective actions to the Jacobs QA Officer, who will review the information. Data quality problems and necessary corrective actions will be reported to the RTI TOL and the EPA TOCOR as soon as they are identified.

5 Project Implementation

5.1 Community Selection

Site selection criteria will include EPA's preference for EJ (economic justice), economically challenged or Tribal communities. Sites with cooperative regulatory agencies and responsible parties who need assistance to help make a remedial decision on particular buildings or neighborhoods will be sought because that will facilitate a cost effective and timely study. In addition, for cost effectiveness, it is assumed that a site within 30 miles of an office of an RTI team firm will be selected (these firms have extensive national office networks in major urban areas). The size of the inclusion area is assumed to be at least 30 structures. To the extent feasible, communities should be selected in an area where radon is most likely to be detectable but only above action levels in a minority of structures. As a costing assumption we are assuming the communities will be ones in which the primary known soil gas hazards are chlorinated VOCs and radon (i.e., not methane or petroleum VOCs). The ideal model would be a site where conduit driven transport is not dominant. Additionally, some seasonal variability is critical. The site does not necessarily need freezing temperatures in winter, but the ideal site should run the heater in the winter and the air conditioning in the summer.

5.2 Sampling and Real Time Monitoring Methods

5.2.1 Measuring/Documenting Building Characteristics

5.2.1.1 Building Surveys

Building features will be noted during initial site visits to obtain access. Walk-through inspections will be conducted, and a survey form will be completed to detail or confirm the layout, construction (e.g., slab-on-grade, crawl spaces), potential VOC sources (e.g., cleaning products, VOC sinks such as carpets, furniture, draperies, etc.), and operating processes (i.e., type of heating, cooling system, etc.) of the units that may influence contaminant entry. During the survey, the dimensions of each room in the units to be tested will be measured, and the volume of the unit will be calculated. The spacing of interior features will be documented. The control settings of the HVAC system will be noted in a project notebook when changed. The survey form to be used (**Appendix A**) will be similar to that recommended in ITRC (2007). If any household products or chemicals are found that could contribute to background levels of VOCs or radon in indoor air, the homeowner will be encouraged to remove those sources from the building (if feasible). However, as this is a long term study of an occupied building, it is likely that many potential indoor sources will remain; although the short target analyte list will somewhat minimize the potential for interferences. In cases with extensive stored chemicals, it may be beneficial as an optional task to do a few additional Radiello indoor air samples for one or two rounds in storage areas such as utility closets.

We do not anticipate collecting any household demographics other than that already included in the standard ITRC (2007) VI survey form which includes:

- number of household occupants

- Age of occupants[3] (can be reported as broad ranges for example 0-6, 6-12, 12-18; 18-65; >65)
- Whether occupant is owner or landlord
- Contact information for occupant and/or owner/landlord
- structure construction style and age
- information about air movement,
- indoor sources of VOCs
- previous mitigation systems
- HVAC system type
- Occupancy by floor (the survey team will attempt to use these questions to also obtain some general information as to whether the occupants are normally home during work/school hours. That information will be useful in interpretating CO_2 sensor data).

For the purposes of project planning, it will be necessary to determine if each homeowner has internet access and whether that can be used in the project (for example for the homeowner obtaining weather forecasts, communication with the homeowner by email or for ITS data logging). For the purpose of this project, it should also be documented when the occupant or owner of a study building changes during the study.

During the initial screening phase of work in Tasks 3 and 4, at a minimum, a succinct building survey will be performed within each structure proposed for sampling. The building survey is expected to be brief, although will aim to detail pertinent information regarding use of the structure, typical potential background sources observed, and general condition of the building envelope. In addition to documenting the broad types of potential background sources of VOCs present within an individual structure, the structure will be screened for total VOCs using a handheld MultiRae PID device. To control cost, consumer products may be documented photographically in groups rather than preparing a detailed item by item inventory. The PID screening will consist initially of PID measurements outside the house and in the rooms where sampling is likely to occur. Screening may also include sites of significant chemical storage such as a basement shop or closet in which many cleaning products are kept. However, the project level of effort does not allow for a detailed drawer by drawer/object by object PID survey. If through the visual inspection or PID screening any significant potential background VOC sources are identified, they will be documented, and occupants will be instructed to restrict usage nearby deployed samples. Identified items will not be removed from structures, nor will occupants be told usage of the items is prohibited. But a reasonable effort will be made to explain the important of collecting an unbiased sample and the benefits of storing VOC containing products in well ventilated places. Data from the consumer product inventory and PID survey will be used to help evaluate the VOC sample results to assess whether an indoor source is likely dominating VOC concentrations in indoor air.

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[3] Note that EPA 2015a says "As such, EPA recommends the CSM also identify and consider sensitive populations, including but not limited to:
• Elderly,
• Women of child-bearing age,
• Infants and children,
• People suffering from chronic illness, or
• Disadvantaged populations (i.e., an environmental justice situation)." But there may be legal restrictions on collecting some of this information on an individual household basis.

If additional optional work is selected where the community science effort will be completed under task 5, occupants within each structure will be taught how to identify and document potential background VOC sources, but no pre-screening is anticipated with a handheld MultiRae device. Under Task 5, the building surveys will be conducted by the residents, but some data management will be performed by the RTI team.

5.2.1.2 Controlling Air Exchange Rate through HVAC Operation, Doors, Windows, and Other Building Openings

The structures will be operated by the owners in as realistic a manner as possible. In general, the operations will be controlled by the regular business/residential occupants. In cases where unoccupied space is sampled, we will simulate actual business/residential occupancy, consistent with the constraints of:

- Personnel and property security
- Work periods and hours of access and operability of the site.

Building operational parameters will be initially assessed in the pre-sampling building survey. Any changes in the routine position or settings of interior and exterior doors, windows, and HVAC systems will be documented in the project notebook or on a data collection form in Task 4 when the project team visits the interior of a building. This information will only be available in Task 5 to the extent that the homeowners self-report it.

5.2.2 External, Passive Soil Vapor Probe Construction for Use During Initial Screening

The initial screening event (Subtask 3b) will require four external, passive soil vapor probes to be installed outside each of the 30 structures to be screened after utility locates are performed at each structure. Soil vapor boreholes will be approximately 2 inches by 5 feet deep. Each of these boreholes will be located at each of the four main sides of each structure. However, if the structures are abutting then one location can be counted against the requirement for two structures. They will be located in unpaved rights-of-way or property yards. Drilling will be performed by 1- or 2-person portable, gas or hydraulic powered augers. A PID and MiniRAE will be used for safety monitoring during the borehole drilling. A GPS unit will be used to locate the points after installation.

The sampling points will be constructed according to the following SOPs:

- Utility Clearance for Intrusive Operations (**Appendix B1**)
- Installation and Abandonment of Permanent and Semi-Permanent Exterior Soil Vapor Probes (**Appendix B7**)
- Soil Vapor Sampling from Exterior Soil Vapor Probes (**Appendix B9**)
- MiniRAE 2000 Operation and Maintenance Manual (**Appendix E**). A low range photo ionization detector (PID), such as the PPB RAE (with a detection limit of approximately 5 ppb/34 µg/m3 for PCE), will be used for three purposes:
    - Health and safety monitoring. Given the VOC concentrations expected at this site, no acute health risks are expected during well and soil gas point installation, but PID screening will be done as a precaution.

- Field screening of soil for VOCs. Given the concentrations expected at this site, this may not detect anything, but if high results are observed it would be of interest.
- Field screening of external soil vapor points. At least some soil vapor points are expected to be in the detectable range with this instrument.

5.2.3 Passive VOC Sample Collection from External Soil Vapor Probes Using Sorbents

VOCs in soil vapor will be determined during the initial screening event by modified EPA Compendium Method TO-17 for passive soil vapor sampling. Passive soil vapor samples can be collected using tube style thermal desorption tubes (Markes ATD or Perkin Elmer equivalent) with diffusive end caps which for PCE with Tenax have an uptake rate of 0.41 ml/min (ISO, 2003). Applications to soil vapor quantitative passive sampling is possible as long as the uptake rate of the sampler is the rate-limiting step (i.e., the rate of diffusive delivery of vapors from the surrounding soil or fill materials is not the rate limiting step) (McAlary et al., 2014a, b, c, d). The rate of diffusive delivery from the soil depends on the porosity and moisture content of the soil as well as the size of the boring in which the samplers are emplaced. It is desired to select a soil vapor sampler with an uptake rate <0.5 mL/min. The storage caps are briefly removed in the field and replaced with diffusion caps immediately before sampling. The passive samplers should be surrounded by a stainless steel or wire mesh cage to protect them from direct contact with soil. The hole into which the passive samplers are inserted is then sealed with a rubber stopper wrapped in aluminum foil hammered into the soil with a mallet. At the conclusion of sampling and before shipment the diffusion caps are replaced with the storage caps.

5.2.3.1 Media Preparation

Stainless steel thermal desorption tubes with dimensions of 3.5” L x 0.25” OD packed with approximately 0.2 g of Tenax TA are used for sample collection in external soil vapor during the initial screening event. A unique identifier is etched on the stainless steel tube by the vendor for tracking purposes which will be recorded on the COC. The Tenax TA sorbent tubes are commercially available from MARKES International Ltd. or equivalent vendors.

Sorbent tubes are cleaned prior to deployment to the field by conditioning at approximately 335°C for a minimum of 30 minutes under nitrogen flow rates of 50-100 mL/min. Tubes are certified as clean by analyzing tubes for the compounds of concern at a frequency of 1 in 20 tubes cleaned. The associated batch of tubes is considered acceptable if there are no detections above the reporting limit for the target compounds.

After cleaning, each tube is sealed with Swagelock caps and inert ferrules and wrapped in aluminum foil to minimize ingress of trace levels of contaminants during storage and shipment. Wrapped tubes are shipped in sealable metal containers with packets of silica gel/charcoal. A clean refrigerator is used for the storage of clean tubes awaiting shipment to the field. Tubes are transported to the field packed in coolers with blue ice.

5.2.3.2 Field QC Samples

Field blanks are collected by removing the caps from a clean sample tube and attaching it to the syringe but not pulling any air through it. The tube is then detached and treated as the soil gas probe samples. Duplicates can be collected by installing two side by side boreholes with one sampler in each. The frequency of field QC samples is specified in **Table 4-2** (no duplicates are included for soil vapor sampling during the initial screening under Task 3B).

5.2.4 Passive Air Sample Collection for VOCs

5.2.4.1 Passive Air Samples for VOCs in Indoor Air

VOCs in indoor air for both the initial screening event and tasks 4 and 5 will be determined using by modified EPA Compendium Method TO-17 for passive indoor air sampling (note that there is an option for 1-day sampling during tasks 4 and 5 using diffusive sorbent samplers [Radiellos]. These would be used concurrently with the 7-day TO-17 passive Radiello indoor air samplers). Samples will normally be collected over a 1-week period. Samplers are normally hung (on a wire ring forming a hook) at a height above the floor approximating the breathing zone (3 to 5 ft). The samplers should be placed away from sources of heat and cold as well as direct air currents. To minimize competition for VOC adsorption, the samplers will be spaced approximately 6 inches (or greater) from each other. Normally existing household racks are used to support the sampler (**Figure 5-1**). In each structure, the arrangement of passive indoor air samples will be either one basement and one first floor sample or one sample on one floor plus a duplicate (taken concurrently on the same rack as the parent but 6 inches or more away).

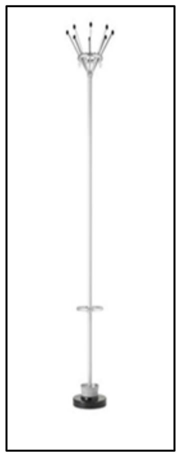

Figure 5-1. Example Sampling Rack

The optimal diffusive sampler configuration for this period has been selected based on sampler sensitivity and sampling rate stability. The sampler sensitivity is a function of analytical sensitivity and sampler sampling rate. The lower the analytical reporting limit and the higher the sampling rate, the lower the sampler reporting limit. Additionally, the sampler reporting limit decreases as the collection time increases. However, the sampling rate can decrease with time as the sorbent reaches saturation or experiences back diffusion of weakly retained VOCs.

Analysis is later accomplished by heating the sorbent and sweeping the desorbed compounds onto a secondary "cold" trap for water management and analyte refocusing. The secondary trap is rapidly heated for efficient transfer of compounds onto the GC/MS.

5.2.4.1.1 Media Preparation

Each Radiello passive sampler has three components—the diffusive body that controls the sampling rate, a sorbent resin bed that adsorbs the VOCs, and a stand and/or clip for ease of deployment. The Radiello diffusive body is described in **Appendix E**.

The Radiello thermally desorbed samplers require the 350 ± 10 mg graphitized charcoal cartridge (RAD145), the general-purpose diffusive body (RAD120), and a triangular base plate. The RAD145 cartridges require no conditioning prior to use when first received from the manufacturer. In principle, the thermal desorption analysis leaves a conditioned cartridge that can be used for another sampling. In practice, the manufacturer recommends re-conditioning the cartridges after analysis, keeping them at 350 °C for 8 hours under nitrogen flow (while not included in the manufacturer's recommendation, a flow rate of 50 to 100 mL/min will be used). Cartridges are certified as clean by analyzing the cartridges for the compounds of concern at a frequency of 1 in 20 tubes cleaned.

The diffusive bodies require no preparation prior to use in the field. Per manufacturer's instructions, the bodies can be reused with no conditioning or cleaning unless sampling in a high particulate environment. New diffusive bodies will be purchased and dedicated to the project. Because sampling will be conducted indoors, minimal issues with particulates clogging the diffusive bodies are anticipated and bodies will be dedicated to a sampling location with just a simple replacement of the cartridge. In addition, the triangular support plates will be dedicated to each sampling location and will not be replaced during the project.

In Task 4, Jacobs staff will collect QA samples in accordance with **Table 4-2**. In Subtask 5c one picked volunteer per neighborhood will be asked to also conduct ambient air sampling. Thus, ambient air samples will not be contemporaneous with all of the individual house indoor samples. Another picked volunteer can be asked to conduct duplicate sampling. Field blanks will be created by Jacobs field staff who will open and close the Radiello and immediately mail it to EPA following the instructions given to homeowners. This will reduce the complexity of the tasks that homeowners need to be trained in.

The graphitized charcoal samplers do not require shipment on ice. Once in the field, the sorbents are stored in a cool, solvent-free area.

5.2.5 Radon Monitoring in Indoor Air

EPA has available for this project:

- 35 new Radon Eye Plus 2 (click here for more information)
- 35 new Airthings View Plus (click here for more information)
- 10 RD 200 Radon Eye instruments previously used in Fairbanks, AK.

Both the Radon Eye Plus 2 and Airthings View Plus have Wi-Fi communication capabilities (with no hub needed for the Airthings – the instrument itself can work as a hub), so remote access should be possible for the Task 4 and Subtask 5c monitoring (1-year duration), and Subtask 3b (1 week-long monitoring).

The Airthings View Plus provides the Task 4 desired measurements (radon, temperature, CO_2) and also has a few other parameters considered ancillary for this project (humidity, PM2.5, total VOCs, and barometric pressure). The Radon Eye Plus 2 measures only radon. These instruments are new, and factory calibrated. They are not capable of field calibration for radon.

The Airthings equipment provides an "App and Dashboard" that reportedly includes short and long term graphs and notifications. The Radon Eye interfaces RMNS (Radon Monitoring Network Service) is an internet web service that allows you to check the data from RadonEye Plus 2 from a distance at any time and provides a 7 day or 30 day graph.

The test matrix is written using the Corentium Airthings View Plus as the primary indoor monitor for radon, indoor temperature, and CO_2; with the Radon Eye Plus 2 as an optional supplement to provide higher sensitivity/temporal resolution on the radon measurements. The non-radon functions of the Airthings View Plus are included in the equipment manual subsection, *Indoor Meteorological Measurements*.

5.2.5.1 Consumer-grade Model Radon Detector: new-generation Corentium Airthings View Plus

For radon data to be obtained and monitored in real time, 25 consumer-grade continuous reading radon monitors will be deployed during the initial survey and tasks 4 and 5 for indoor radon monitoring, with time resolutions of approximately 1 hour. However, although the instrument reports a data point every hour what is reported is actually a 24 hour running average (Tylkowski, 2022). New-generation Corentium Airthings Wave Plus devices have not only radon, temperature, humidity, CO_2, and barometric pressure monitoring capabilities, but also web-based, remote access capabilities. These features are critical for real-time monitoring and thus scheduling the site visits for sampling. Jacobs will provide these devices to the homeowners or building occupants where they are expected to remain in service for approximately 1 year (including periods before and after a decision to go to indoor air sampling). It is assumed that an internet connection with Wi-Fi access will be made available by the homeowners or occupants in most of the buildings studied to allow remote data access by the project team. No Internet subscription cost is included in the project pricing.

The manufacturer states the following specifications for the radon portion of the instrument:

- Radon sampling: Passive diffusion chamber
- Detection method: Alpha spectrometry
- Sensor interval 60 min (fixed)
- Measurement range: 0 – 20,000 Bq/m^3
- 0 – 500 pCi/L
- Typical accuracy after more than 30 days of
- Continuous measuring at 200 Bq/m^3
- 5.4 pCi/L
- 7-day average: ±10 %,
- 2-month average: ±5 %
- Expected precision at 1 pCi/l after 24 hours 1 pCi/L +/- 0.25 pCi/L (standard deviation).

5.2.5.2 Consumer-grade Model Radon Detector: RadonEye RD200

This consumer-grade unit has good sensitivity, agreement with certified devices, and hourly readability (Carmona and Kearfott, 2019). The RadonEye is an ion chamber design, which is a type covered within EPA guidelines for using continuous radon monitors (US EPA, 1992). Please see also the fact sheet "Monitoring Radon as a Vapor Intrusion (VI) Tracer or Surrogate" (**Appendix B12**). The RD200P model is a National Radon Proficiency Program (NRPP)-approved device.[4] However, it sequentially numbers its

[4] https://nrpp.info/devices/approved-devices/

radon readings every hour, rather than creating a time/date stamp. This will require that the field operative note the start and stop times so the running hours can be reconstructed in Excel when the data are downloaded. Additionally, a power sensor can be used in conjunction with the radon detector to detect periods of power outages to help explain data gaps (e.g., Avtech Power Sensor [RMA-PS1-SEN: $65.00]).

Since the RadonEye RD200 does not have remote access capabilities via Wi-Fi, this unit could be used during the initial screening event, but not during Tasks 4 and 5 under the current pricing assumptions. They could perhaps be used for supplemental applications that would allow for periodic access via onsite smartphone. For example, if a homeowner had a smartphone and was willing to install the RadonEye app they could potentially use that instrument.

5.2.5.3 Consumer-grade Model Radon Detector: RadonEye Plus 2

The RadonEye RD200 and RadonEye Plus 2 have very similar technical specifications with the Plus 2 adding WiFi and Bluetooth low energy (BLE) communications. The one other difference in the published specifications is a higher upper limit on the instrument range for the Plus 2 model. Methodology for Ambient Air and Soil Vapor Sample Collection for Radon Both instruments provide a 10-min update (based on a 60 min moving average).

5.2.6 Outdoor Air and Soil Vapor Radon Monitoring

Active, real-time (or near-real-time) samples will be collected from outdoor air and soil vapor using professional-grade instrumentation (either the AlphaGuard or the RAD-7). During the initial screening event, 1 single soil-vapor reading will be taken at each structure at the time of passive-sampler retrieval, using either the AlphaGuard or RAD-7. Ambient radon will be taken at 1 location during each day radon is measured during the screening, using either the AlphaGuard or RAD-7.

5.2.6.1 AlphaGuard Radiation Monitor

Genitron Instruments' AlphaGuard[5] may be used for onsite radon analysis of outdoor air and soil vapor grab samples. The AlphaGuard is a portable, battery-operated radon monitor with high storage capacity. In addition to the radon concentration in air, AlphaGuard measures and records almost simultaneously ambient temperature, relative humidity, and atmospheric pressure with integrated sensors. The instrument can operate in diffusion mode (e.g., long-term monitoring; 10-minute response, 60-minute measuring cycle) or flow mode (1-minute response, 10-minute measuring cycle). In diffusion mode, the instrument operates without a pump. The instrument radon measurement function is insensitive to both high humidity and vibrations. The AlphaGuard can be used for short- or long-term examinations inside or outside and can be set or programmed for continuous data acquisition; data can be downloaded/uploaded to a computer for analysis.

Instrument setup and operation will be performed in accordance with the manufacturer's instructions and EPA guidelines for using continuous radon monitors (US EPA, 1992). A Miscellaneous Operating Procedure (MOP) for the AlphaGuard instrument is provided as **Appendix B13**. We plan to use the AlphaGuard or the RAD 7 owned by EPA/ORD/CEMM/WECD/MMB in the actively pumped mode to collect the primary dataset for radon monitoring. AlphaGuard instruments owned by the EPA

[5] https://www.bertin-instruments.com/product/radon-professional-monitoring/radon-alphaguard/

EPA/ORD/CEMM/WECD/MMB may be used also in an active mode pulling sample through a heated sample line to provide high resolution ambient air monitoring data for radon.

5.2.6.2 RAD-7 Radon Monitor

The Durridge RAD-7 radon monitoring unit may be used for onsite radon analysis of outdoor air and soil vapor grab samples. The RAD-7 is a portable radon monitor (AC or DC capable) with good storage capacity (1,000 cycles under long-term monitoring, lasting ~12 weeks). In addition to the radon concentration in air, the RAD-7 measures and records ambient temperature and relative humidity, but the relative humidity reading is to ensure accuracy of the measurement. The relative humidity must be kept at 10% or less for the most accurate measurements (the unit comes with desiccant, drying tubes, and moisture filters). The RAD-7 unit can run in continuous mode for 24- or 48-hour cycles, or in 2-hour cycles up to 1,000 cycles; sniffing at entry points for at least 15 minutes; grab samples are taken over four, 5-minute cycles, with a 30-minute processing period, and soil gas/subslab testing over 20-minute cycles. Data may be read from the on-board LCD display, paper printout, or downloaded to a PC.

Instrument setup and operation will be performed in accordance with the manufacturer's instructions and with EPA guidelines for using continuous radon monitors (US EPA, 1992). An MOP for the RAD-7 instrument is provided as **Appendix G**. We plan to use the RAD-7 owned by EPA ORD in Durham, NC to collect the primary dataset for outdoor air and soil vapor radon monitoring.

As the project is currently planned, the single ambient RAD-7 will be placed at a location where a homeowner can allow it to operate without causing interference. For example, a garage or basement with power and access to outdoor air may be needed. The RAD-7 is functional between 32 and 113 F so requires shelter. A heated sample inlet line may be needed but was not included in the current project budget. However, a heated sample line from the Fairbanks site may be available for one site. The RAD-7 when set to the "weeks" protocol will collect data for 1000 measurements at 2 hour intervals which provides an 83 day collection duration. Data will be manually downloaded during a "troubleshoot/support" site visit which are budgeted monthly.

5.2.7 Indoor Meteorological Measurements

5.2.7.1 Measurement method

Onsite meteorological measurements at the selected will be made using the new generation Corentium Airthings View-Plus devices, which record (aside from radon) temperature (T), relative humidity (RH), CO_2, PM2.5, total VOCs, and barometric pressure within the manufacturer specifications presented below. The recommended operating conditions are between 4°C and 40°C and 0% to 85% humidity.

- Sensor Resolution:
    - Temperature ± 0.1°C / °F
    - Humidity ± 1%
    - Pressure ± 0.15 hPa
- Temperature, humidity, and pressure:
    - Technology: solid state sensor
    - Sensor interval 5 min (2.5 min with USB cable connected)
    - Temperature Accuracy: ± 0.5 °C / ±1 °F

  - Humidity Accuracy: ± 3% RH
  - Pressure Accuracy: ± 0.6 mBar/hPa.
- Initial calibration time:
  - VOC: ~7 days.
  - CO_2: after an initial calibration time of 7 days, it is self-calibrated using an automatic baseline algorithm that updates once a week.
  - The VOC and CO_2 sensors continuously calibrate by using the cleanest level of air as a baseline to distinguish from polluted air. For this reason, it is important that the sensor is exposed to clean air on a weekly basis.
- CO_2 details:
  - NDIR Sensor (Non-Dispersive Infra-Red)
  - Measurement range 400–5000 ppm
  - Optimum Accuracy ±50 ppm ±3% within 10 – 35°C / 50 - 95°F and 0 – 80% RH after initial calibration time
- VOC
  - Technology: Metal-oxide based gas sensor
  - Measurement interval 5 min (fixed)
  - Settling Time: ~7 days
  - Measurement range: 0 - 10,000 ppb
  - Self-calibrated using an automatic baseline algorithm that updates continuously based on the cleanest air the sensor is exposed to.
- Particulate Matter ($PM_{2.5}$) details:
  - Laser scattering based optical particle counter
  - Particle size detection range: 300 nm to 10 µm
  - Range: 0~200 $\mu g/m^3$
  - Measurement error (PM2.5): 0 ~100 $\mu g/m^3$, ±10µg/m3,100 ~200 $\mu g/m^3$, ±10%.
  - Calibrated with a GRIMM using cigarette smoke source.

5.2.7.2 ITS interpretations of Meteorological Data

The proposed ITS trigger points were introduced in **Section 1.4**.

It is anticipated that the indoor temperature data will be used together with the outdoor temperature measurements discussed in the next section to calculate differential temperature, an important indicator for VI.

It is anticipated that the CO_2 data can be used together with knowledge of the resident's normal occupancy patterns (and pets) as a measure of air exchange rate, which is expected to be inversely proportional to indoor concentrations caused by VI.

The humidity data may be analyzed/reviewed. Previous analyses have suggested a possible association, but not a monotonic one with VI (EPA, 2012b, 2015b, 2015c). In basements, it is known that moisture and radon are related since soil gas intrusion is one source of moisture. Since the causative mechanism if any between humidity and VI has not been elucidated this ancillary parameter may be analyzed but will not be used for timing VOC sampling.

It is anticipated that the total VOC sensor will most likely be more influenced by other sources of VOCs in indoor air then VI. The data will be briefly considered to see if it has any application as an ITS.

It is not anticipated that the $PM_{2.5}$ sensor data will be useful for this project.

The barometric pressure reported indoors will only be used as a backup/check for the outdoor meteorological data. Changes in the outdoor barometric pressure reported by the national weather service will be the primary ITS used for VOC sample timing.

5.2.8 Outdoor Meteorological Methods

Meteorological data (such as temperature, wind speed and direction, barometric pressure, and hourly precipitation) will be obtained with data from the closest National Weather Service facility. Details of measurement procedures and quality assurance are provided in NOAA (1998 and 2005).

5.2.9 Decontamination Procedures

Decontamination procedures are discussed in the following SOPs:

- Appendix B6. Installing Subslab Probes and Collecting Subslab Soil Gas Samples Using Canisters SOP
- Appendix B7. Installation and Abandonment of Permanent and Semi-Permanent Exterior Soil Vapor Probes SOP.

5.2.10 Field Notes

5.2.10.1 Documentation of Sampling Timing Decisions

The following building and sampling specific information will be recorded in an Excel spreadsheet and entered into the database managed by RTI:

- The date and time a decision to initiate sampling is taken, and when it is desired to initiate sampling
- The basis used to make that decision (e.g., radon observed to be rising, cold front forecast)
- The date and time the sample was initiated
- Constraints on sampling
    - In Task 4 these may include EPA contractor staff availability and homeowner/resident availability to provide access
    - In Task 5, these may include homeowner/resident availability.

5.2.10.2 Field Research Logbooks

Field research logbooks will be used to document activities during this study along with the standard Field Test Data Sheets provided in Method TO-17. Logbooks are used to document where, when, how, and from whom any vital project information was obtained. Each activity up through Task 4 will be documented in a logbook in such a manner that the study can be reconstructed in the future by a third party. Individuals may choose to keep their own logbooks or use the main study logbook. However, all pertinent information from these logbooks must be copied and included in the EPA project files.

Logbooks should have consecutively numbered pages. All entries should be legible, written in ink, and signed by the individual making the entries. The types of information to be recorded include:

- Weather conditions
- Concurrent sampling activities
- Individuals present during the day
- Exact sampling locations
- Methods used to collect samples
- Field instrument calibration and quality control checks
- Sample container identification or instrument identification
- Date and time of sample collection
- Types of samples
- Field instrument readings
- Other field observations

In Task 5, notes will only be available for Jacobs field staff activities, and entries provided by homeowners into requested sampling forms. Homeowners can be encouraged to make notes but will not be trained in maintaining a scientific notebook.

5.2.10.3 Photographs

A digital image of each sampling location and description will be acquired at the time of first sampling in Task 4 and included with the field notes if allowed by the homeowner. This information will not be acquired in Task 5 by Jacob's photographers under the current budget, although homeowners could be requested to take photographs and email or upload them.

5.2.11 Sample Nomenclature

Each property will be given a property identification number (a two digit number e.g., 28). Sampling nomenclature will be made from a room identification (i.e., BA = Basement, LR = living room) the property identification number (a two digit number e.g., 28), the type of sample (indoor air [IA] or soil vapor [SV], the sample number within that property (if there are 2 IA samples, then 01 or 02), the date (YYMM), and if a field duplicate is taken, then FD will be added to the end. Grab sample types are for VOCs in indoor air and soil vapor. VOC samples can be by TO-17 or Radiello. Sample names will then be formed by combining the above elements, for example, BA-01-IA-01-2210 (FD, if needed).

In Task 5, it is anticipated that a simpler method of collecting the information will be used that is more homeowner friendly. Homeowners will be asked to fill out a data reporting sheet with separate columns for start and end date/time, location, Radiello number and the reason for sampling (scheduled or ITS-based). Then the EPA laboratory will use that information to generate the standardized sample numbers according to the style above as they log in the samples.

5.2.12 Sample Chain-of-Custody

All samples will be submitted to the laboratories following COC procedures and with a COC form. The COC records will contain the following information:

- Field sample ID
- Date and time collected (start and stop)
- Analysis requested
- Matrix
- Sample type
- Sampler name and signature
- Date and time relinquished
- Remark

- Tube serial numbers if applicable

The COC record will be signed by the sampler and relinquished to the sample custodian. As discussed above a multipurpose data reporting sheet will fulfill the requirements of a chain of custody in task 5.

5.2.13 Packaging and Shipment

Sorbent samples will be packed into appropriate containers supplied by the laboratories with the sampling media. Sample shipping temperature may vary dependent on the type of sorbent used (see Table 5-1). This information will be obtained from the laboratories selected and will be based on their experience with sorbent on other research projects. If chilling is required, samples will be shipped in a study ice chest with ice substitute (i.e., blue ice).

In Task 5, shipping is based on the USPS padded flat rate envelope priority mail shipped at post office or online/from home. Additionally, costs are included to provide an inner “thermal bubble mailer” to enhance protection and temperature control. Task 5 samples will not be shipped on ice and are allowed a 30-day holding time.

5.3 Analytical Methods

5.3.1 Overview of Analytical Measurements

The parameters to be measured will include VOC, radon, temperature, humidity, and atmospheric pressure. Air (ambient, indoor, and external soil gas) is the media to be sampled. The EPA laboratory in Research Triangle Park, NC will conduct laboratory analyses for VOCs in indoor air, ambient air, and exterior soil gas.

All of the VOC and radon data and all of the temperature, and atmospheric pressure are considered critical measurements. Other measurements are considered noncritical **Table 5-1** indicates the measurement methods and the relevant MOP, EPA method, or other method.

Sample holding times and preservation requirements for extractive samples are also summarized in **Table 5-1**.

Table 5-1. Extractive Sample Preservation and Holding

Measurement	Analysis Method	Sample Container/ Quantity of Sample	Preservation/ Storage	Holding Time(s)
VOCs in indoor and ambient air (passive)	Sample analysis performed by the EPA laboratory. EPA Method TO-17 and Methods for the Determination of Hazardous Substances (MDHS) 80: “Volatile Organic Compounds in Air: Laboratory Method Using Diffusive Solid Sorbent Tubes, Thermal Desorption and Gas Chromatography”, August 1995. Published by the Health and Safety Executive of the United Kingdom: https://www.hse.gov.uk/pubns/mdhs/pdfs/mdhs104.pdf	Passive Sampling Tube	Cool (<20C), solvent free, tightly capped. Shipment for short durations with only a thermal bubble wrap protection will be used in Task 5.	30 days
VOCs in Exterior Soil Gas (active)	Sample analysis performed by the EPA laboratory. EPA Method TO-17 modified and Methods for the Determination of Hazardous Substances (MDHS) 80: “Volatile Organic Compounds in Air: Laboratory Method Using Diffusive Solid Sorbent Tubes, Thermal Desorption and Gas Chromatography”, August 1995. Published by the	Tenax TA Tube	4±2°C tightly capped	30 days

Measurement	Analysis Method	Sample Container/ Quantity of Sample	Preservation/ Storage	Holding Time(s)
	Health and Safety Executive of the United Kingdom: https://www.hse.gov.uk/pubns/mdhs/pdfs/mdhs104.pdf			
Radon in indoor air and ambient air	Airthings Corentium Wave-plus or Radon Eye Plus-2 or RD-200	Consumer-grade home unit	Real-time home unit	NA
Radon in ambient air exterior soil gas	EPA 1992; AlphaGuard or RAD7	AlphaGuard radon monitor or RAD7	Real-time hand unit	NA

5.3.2 Real-Time/Field Portable Instruments for Radon

Provision is made in this section for two alternate instruments depending on availability from EPA–the AlphaGuard or RAD-7.

5.3.2.1 AlphaGuard Radiation Monitor

The AlphaGuard monitor incorporates a pulse-counting ionization chamber (alpha spectroscopy with 5 cpm at 3 pCi/L) and is suitable for continuous monitoring of radon concentrations between 0.05 and 50,000 pCi/L. More information on the AlphaGuard can be found at https://www.bertin-instruments.com/product/radon-professional-monitoring/radon-alphaguard/

Analysis will be conducted in accordance with the instrument manufacturer's instructions and with EPA protocols for the use of continuous radon monitors (EPA 1992). An MOP for the AlphaGuard instrument is provided as **Appendix B13**. This device would be classified as a "CR" type device by EPA. Operation of CR devices is covered in Section 2.1 of EPA (1992). Calibration procedures are discussed in Sections 2.1.5 and 2.1.11 of EPA (1992).

5.3.2.2 The RAD-7 Radon Monitor

The RAD-7 monitor incorporates a passivated, implanted planar silicon detector (in sniffer mode, the sensitivity is 0.2 cpm/pCi/L) and is suitable for continuous monitoring of radon concentrations between 0.1 and 10,000 pCi/L. Recovery time is 20 minutes after leaving a hot spot. The pump runs at a rate of 1 L/min, and cycles can be set from 2 minutes to 24 hours. More information on the RAD-7 can be found at https://durridge.com/products/rad7-radon-detector/. The RAD-7 is an NRPP-approved device (https://nrpp.info/devices/approved-devices/),

Analysis will be conducted in accordance with the instrument manufacturer's instructions and with EPA protocols for the use of continuous radon monitors (EPA 1992). An MOP for the RAD-7 instrument is provided as **Appendix G**. Calibration of the RAD-7 instrument is done in house by the manufacturer, and instrument drift is reported by the manufacturer as typically less than 2% per year.

5.3.3 Analytical Methods for VOCs

The target VOC list for this project is given in **Table 5-2**.

Table 5-2. Target VOCs

Compound	Emphasis	Rational for Inclusion
Tetrachloroethene (PCE)	Key project analyte must be on the calibration curve if at all possible.	Detected in all media in screening analyses, results strongly suggest VI. Known dry cleaning compound.
Trichloroethene (TCE)	Key project analyte must be on the calibration curve if at all possible.	Known to be formed as a degradation byproduct of PCE. Known use as dry cleaning agent (Linn et al. n.d.). Seen in indoor air screening sample at this site.
cis-1,2-Dichloroethene (DCE)	Likely to be useful for distinguishing soil gas from indoor sources in some cases.	Known to be formed as a major biological degradation byproduct of PCE and TCE.
trans-1,2-Dichloroethene	Likely to be useful for distinguishing soil gas from indoor sources in some cases.	Associated with the abiotic degradation of TCE (Stroo and Ward 2010).

5.3.3.1 Laboratory Analysis of VOCs in Soil Gas, Method TO-17, US EPA CEMM Laboratory

Upon receipt, sample tubes are stored in a clean refrigerator at <4°C until analysis. Analysis is performed on an Automated Thermal Desorption (ATD) Unit interfaced with a GC/MS. The ATD has autosampler capabilities and utilizes a two-stage thermal desorption process as described in Method TO-17.

Table 5-3 lists the analyte list, reporting limits, and acceptance criteria for EPA Method TO-17, and **Table 5-4** details the calibration and QC procedures.

Table 5-3. TO-17 Soil Gas Compound Reporting Limits and QC Acceptance Criteria

Analyte	Reporting Limit (ng)	Acceptance Criteria		
		ICAL (%RSD)	LCS (%R)	CCV (%D)
Tetrachloroethene	5.0	30	70 – 130	30
Trichloroethene	5.0	30	70 – 130	30
cis-1,2-Dichloroethene	5.0	30	70 – 130	30
trans-1,2-Dichloroethene	5.0	30	70-130	30
Internal Standards				
Analyte	**CCV IS % Recovery**		**Sample IS % Recovery**	
1,4-Difluorobenzene	60 – 140		60 – 140	
Chlorobenzene-d_5	60 – 140		60 – 140	
Analytical Surrogate				
Analyte	**% Recovery**			
Bromofluorobenzene	70 – 130			

CCV IS = continuing calibration verification internal standard

ICAL (% RSD) = initial calibration curve (percent relative standard deviation)

LCS = laboratory control samples

Table 5-4. Summary of Calibration and QC procedures for Method TO-17 Soil Gas

QC Check	Minimum Frequency	Acceptance Criteria	Corrective Action
Bromofluorobenzene (BFB) Tune Check	Before initial and daily calibration. Check is valid for 24 hours.	SW – 846 tune criteria.	Correct problem then repeat tune.
5-Point Calibration	Prior to sample analysis.	See Table 5-3	Correct problem then repeat initial calibration curve.
Laboratory Control Samples (LCS)	After each initial calibration curve and daily with each batch of samples not to exceed 20.	See Table 5-3	Check the system and reanalyze the standard. Re-prepare the standard if necessary. Re-calibrate the instrument if the criteria cannot be met.
Continuing Calibration Verification (CCV)	At the start of each 24-hour clock after the tune check.	See Table 5-3	Maintenance is performed and the CCV test repeated. If the system still fails the CCV, perform a new 5-point calibration curve.
Laboratory Blank	After the CCV and before the samples.	Results less than the laboratory reporting limit (RL).	Inspect the system and reanalyze the blank.
Internal Standard (IS)	As each QC sample and sample are being loaded.	**CCVs**: area counts 60-140%, Retention time (RT) within 20 sec of mid-point in ICAL. **Field blanks and samples**: RT must be within ±0.33 minutes of the RT in the CCV. The IS area must be within ±40% of the CCV's IS area for the blanks and samples.	**CCV**: Inspect and correct system prior to sample analysis. **Field blanks**: Inspect the system and reanalyze the blank. **Samples**: Investigate the problem by verifying the instrument is in control by running a lab blank. Reanalyze recollected samples to verify recovery. Report the run with acceptable IS recovery. If both runs are unacceptable, narrate and flag associated data.
Analytical Surrogates	As each QC sample and sample is being loaded.	70 – 130%	**For field blanks**: Inspect the system and reanalyze the blank. **For samples**: Review data to determine whether matrix interference is present. If so, narrate interference and flag recovery. If no interference is evident, verify the instrument is in control by running a lab blank. Reanalyze recollected sample to verify recovery.
Field Blanks	Collected at a frequency of 5% of samples.	Artifact levels should be less than the reporting limit or less than 5% of the mass measured on the sampled tubes, whichever is less.	Flag associated results and evaluate tube conditioning and storage procedures.
Field Duplicates	Collected at a frequency of 5% of samples.	%RPD (relative percentage difference $\leq$ 50%	Narrate discrepancy.

5.3.3.2 Analysis of Passive Samplers for VOCs in Indoor Air, US EPA CEMM Laboratory

The EPA laboratory will use EPA Method TO-17 and Methods for the Determination of Hazardous Substances (MDHS) 80: “Volatile Organic Compounds in Air: Laboratory Method Using Diffusive Solid Sorbent Tubes, Thermal Desorption and Gas Chromatography” to analyze samples under SOP: WECD-

MMB-SOP-4350-0 “Analysis of Volatile Organic Compounds in Soil Vapor using Thermal Desorption / Gas Chromatography / Mass Spectrometry”

The Radiello sample tube is heated while the carrier gas is flushed in the reverse direction as sample collection, and the analytes are focused on a “cold” trap. Internal standards and the analytical surrogate are automatically added to the trap by flushing a fixed volume loop connected to a 1 ppmv high pressure internal standard cylinder. The ATD unit also has a recollection feature that allows for a portion of the sample mass to split during the initial desorption to the cold trap and after the desorption of the cold trap. The sample splits are recollected onto a clean sample tube. The recollected tube is stored until the data have been reviewed against quality control requirements.

Table 5-5 lists the analyte list, reporting limits, and acceptance criteria for the thermal desorption extraction method, and **Table 5-6** details the thermal extracted diffusive sample reporting limits for short-term intervals. **Table 5-7** summarizes calibration and quality control procedures for thermal desorption GC/MS analytical methods such as TO-17***.***

Table 5-5. Thermal Desorption Radiello Compound Reporting Limits and QC Acceptance Criteria

Analyte	Reporting Limit (ng)	Acceptance Criteria			
		ICAL (%RSD)	ICV (% R)	CCV (%D)	LCS (%R)
Tetrachloroethene	100	20	80 – 120	20	70-130
Trichloroethene	100	30	70 – 130	30	70 – 130
cis-1,2-Dichloroethene	100	30	70 - 130	30	70 – 130
trans-1,2-Dichoroethene	100	30	70-130	30	70-130
Internal **Standards**					
Analyte	**CCV IS % Recovery**		**Sample IS % Recovery**		
1,4-Difluorobenzene	50 – 200		50 – 200		
Chlorobenzene-d_5	50 – 200		50 – 200		
Surrogate					
Analyte	**% Recovery**				
Bromofluorobenzene	70 – 130				

ICAL (% RSD) = initial calibration curve (percent relative standard deviation)
ICV = internal calibration verification
LCS = laboratory control samples
CCV IS = continuing calibration verification internal standard

Table 5-6. Thermal Extracted Diffusive Sample Reporting Limits (µg/m^3) for Various Collection Intervals

Method Detection Limit (MDL)	TCE	PCE
MDL (8 hour, µg/m^3)	0.62	0.83
MDL (24 hour, µg/m^3)	0.21	0.28
MDL (7 day, µg/m^3)	0.03	0.04

Table 5-7. Summary of Calibration and QC Procedures for Thermal Radiello Analysis

QC Check	Minimum Frequency	Acceptance Criteria	Corrective Action
BFB Tune Check	Prior to calibration and at the start of every 12-hour clock.	Method 8260B tuning criteria	Correct problem then repeat tune. Analysis does not proceed until tune criterion is met.
Initial 5-Point Calibration	Prior to sample analysis.	%RSD≤20% for chloroform and PCE	Correct problem then repeat initial calibration.
Initial Calibration Verification (ICV)	Once per initial calibration.	Recovery = 80-120% for chloroform and PCE	Verify concentrations and standard preparation.
Continuing Calibration Verification (CCV)	At the start of analytical batch immediately after the BFB tune check.	%D≤20% for chloroform and PCE	Investigate and correct the problem, up to and including recalibration if necessary.
Internal Standards (IS)	IS added at the time of extraction to all samples and QC samples.	For CCVs: area counts 50 - 200%, retention time (RT) within 30 sec of mid-point in ICAL. For blanks, samples and non-CCV QC Checks: area counts 50 – 200%, RT within 20 sec of RT in CCV.	CCV: inspect and correct system prior to sample analysis. For blanks: inspect the system and reanalyze the blank. For samples: reanalyze; if out again, flag data.
Surrogate	Surrogate is added at the time of extraction to all samples and QC samples.	Recovery = 70-130%	Same as for IS.
Solvent Blanks	Immediately after the calibration standard or after samples with high concentrations.	Results less than laboratory reporting limit.	Re-aliquot and reanalyze solvent blank. If detections remain, flag concentrations in associated samples.
Extracted Laboratory Blank	Each set of up to 20 samples.	Results less than the reporting limit.	Flag sample concentrations in associated extraction batch.
Extracted Laboratory Control Samples (LCS)	Each set of up to 20 samples.	Recovery = 70-130%	Re-aliquot and reanalyze the extract. If within limits, report the reanalysis. Otherwise, narrate.
Field Blank	Collected at a frequency of 5% of samples.	Artifact levels should be less than the reporting limit or less than 5% of the mass measured on the sampled tubes, whichever is less.	Flag associated results and evaluate manufacturing lot cleanliness and storage procedures.
Field Duplicates	Collected at a frequency of 5% of samples.	%RPD ≤ 50%	Narrate discrepancy.

This method is not widely used, and standardized performance evaluation materials are not available, so bias will be assessed using a variety of lines of evidence: (1) the recovery of surrogates for the thermal Radiellos; (2) the results of laboratory control spikes; and (3) the results of the laboratories' independent performance evaluation samples and/or interlaboratory comparison programs for Method TO-15, which shares a similar instrumental approach.

5.3.3.3 Laboratory Analysis of Passive Samplers for VOCs in Soil Gas, US EPA CEMM Laboratory

The EPA laboratory will use EPA Method TO-17 and Methods for the Determination of Hazardous Substances (MDHS) 80: "Volatile Organic Compounds in Air: Laboratory Method Using Diffusive Solid Sorbent Tubes, Thermal Desorption and Gas Chromatography" to analyze samples under SOP: WECD-MMB-SOP-4350-0 "Analysis of Volatile Organic Compounds in Soil Vapor using Thermal Desorption / Gas Chromatography / Mass Spectrometry."

Analysis of these tubes is essentially identical to the analysis of the same tubes when actively sampled as covered under **Section 5.4.3.1** so the reporting limits, acceptance criteria, calibration requirements etc. will be the same. However, the uptake rates will be adjusted for barometric pressure and temperature as called for in EPA Method 325 (2017a).

5.3.3.4 Data Reporting

The data generated from passive samplers is expressed in units of mass (nanograms or micrograms). Concentrations are calculated using the following equation:

Conc (µg/m^3) = {Mass (ng)/[SR (mL/min) x Duration (min)]} x 1000 mL/L x 1000 L/m^3 x µg/1000 ng

Where SR = Sampling Rate provided by the manufacturer.

6 Quality Assurance and Quality Control

Measurement quality objectives and methods of assessment for critical measurements for this project are summarized in **Table 6-1**. Measurement quality objectives and methods of assessment for non-critical measurements for this project are summarized in **Table 6-2**. Bias objectives for the noncritical parameters listed in **Table 6-2** will be evaluated with a periodic comparison to similar/equivalent sources in the selected sites for general reasonableness of the onsite reading. We will assess all completeness objectives based on the planned measurements specified in **Table 4-1**.

Table 6-1. Measurement Quality Objectives and Methods of Assessment for Critical Measurements

Parameters	Method Type	Method Citation	Bias (Accuracy) Objective and method of Verification	Objective		Detection or Reporting Limit Objective and Method of Verification
				Precision	Completeness	
VOC concentration in air	GC/MS (passive soil gas sorbent tube samples)	TO-17 modified	70-130% recovery of analytical surrogate BFB. 70-130% recovery in laboratory control spike except for carbon disulfide and methylene chloride, which will be 50-150%.	30% except for carbon disulfide and methylene chloride, which will be 40%	90%	See Tables 5-3, 5-5, and 5-6 in Section 5.3.3
	GC/MS (passive Radiello samplers of indoor and ambient)	MDHS 88, MDHS 80, TO-17, modified	30%	30%	90%	See Tables 5-3, 5-5, and 5-6 in Section 5.3.3
Radon in Outdoor air, Indoor Air and Soil Gas	RadonEye	EPA 402-R-92-004 (EPA 1992); also see instrument operation manual	15%, not separately evaluated in this project; reference made to NRPP testing and Carmona and Kearfott, 2019; Warkentin et al., 2020	15%	90%	0.1 pCi/L over the long term (sensitivity is 0.5 cpm/pCi/l) so 30 events are observed per hour at 1 pCi/L, 3 at 0.1 pCi/L.
	Airthings View Plus	EPA 402-R-92-004 (EPA 1992); also see instrument operation manual	15%, not separately evaluated in this project; reference made to NRPP testing and Carmona and Kearfott, 2019 and Warkentin et al., 2020	15%	90%	Manufacturer has not yet stated a detection limit. Carmona and Kearfott and Warkentin reported good performance for Airthings radon instruments, but testing was conducted under higher radon conditions >13.5 pCi/l.
	AlphaGuard radon monitor (active)	EPA 402-R-92-004 (EPA 1992); also see instrument	10%, not separately evaluated in this project; reference made to NRPP testing and Carmona and	10%	90%	0.1 pCi/L over the long term when used in indoor air. Sensitivity is approximately 1.85 cpm/pCi/L for the AlphaGuard. When used in

Parameters	Method Type	Method Citation	Bias (Accuracy) Objective and method of Verification	Objective Precision	Objective Completeness	Detection or Reporting Limit Objective and Method of Verification
		operation manual	Kearfott, 2019; Warkentin et al., 2020.			soil gas 3 pCi/L is a reporting limit objective limited by carryover.
	RAD-7 radon monitor	EPA 402-R-92-004 (EPA 1992); also see instrument operation manual	10%, not separately evaluated in this project; reference made to NRPP testing and Carmona and Kearfott, 2019; Warkentin et al., 2020	10%	90%	0.1 pCi/L over the long term when used in indoor air. Sensitivity is approximately 0.5 cpm/pCi/L for the AlphaGuard. When used in soil gas 3 pCi/L is a reporting limit objective limited by carryover.

Table 6-2. Measurement Quality Objectives and Methods of Assessment for Noncritical Measurements

Parameters	Method Type	Method Citation	Bias (Accuracy) Objective and method of Verification	Objective		Detection or Reporting Limit Objective and Method of Verification
				Precision	Completeness	
Total organic vapor	Mini RAE portable continuous VOC monitor	Manufacturer O&M manual in Appendix E; specific applications described in Jacobs SOPs	35%, since this is a screening instrument, bias will not be verified with a second source calibration gas but will be assessed through rechecks of the initial calibration gas throughout the analytical period	30% RPD, which can be assessed with duplicate measurements of the calibration gas.	90%	10 ppbv detection limit for TCE and PCE (manufacturer indicates 5 ppb should be feasible)
Indoor temperature	Airthings View Plus	Manufacturer product sheet; *A Standardized EPA Protocol for Characterizing Indoor Air Quality In Large Office Buildings*, EPA/ORIA/IED and AREAL, February 2003a, Table C2.	+/-1 °F as reported by manufacturer, no assessment planned.	+/-1 °F as reported by manufacturer, no assessment planned.	90%	Solid state sensor, manufacturer does not report range, but expected to be adequate for room temperature measurement. Recommended operating conditions are stated as 4 to 40 °C / 39 to 104 °F
Indoor carbon dioxide	Airthings View Plus	NDIR Sensor, manufacturer product sheet; *A Standardized EPA Protocol for Characterizing Indoor Air Quality In Large Office Buildings*, EPA/ORIA/IED and AREAL, February 2003a, Table C4.	±50 ppm ±3 %RH within 10 – 35 °C / 50 - 95 °F and 0 – 80%RH, after initial calibration time of 7 days Self-calibrated using an automatic baseline algorithm that updates once a week	±50 ppm ±3 %RH within 10 – 35 °C / 50 - 95 °F and 0 – 80%RH, after initial calibration time of 7 days Self-calibrated using an automatic baseline algorithm that updates once a week	90%	400 – 5000 ppm
Indoor air total VOCs	Metal oxide based gas sensor	Manufacturer product sheet and user manual	+/- 50%, not able to be verified, will be used as ancillary and relative measurement	+/- 50%, not able to be verified, will be used as ancillary and relative measurement	70% at sites where Airthings View Plus is used	Not reported, not planned

Parameters	Method Type	Method Citation	Bias (Accuracy) Objective and method of Verification	Objective		Detection or Reporting Limit Objective and Method of Verification
				Precision	Completeness	
Indoor Barometric pressure	Airthings View Plus	Manufacturer product sheet user manual	0.6 mbar = 0.018 in of Hg = 60 pascals	0.6 mbar = 0.018 in of Hg = 60 pascals	90%	manufacturer does not state range but expected to be adequate since normal barometric pressure varies only modestly
Indoor Relative humidity	Airthings View Plus	Manufacturer product sheet; *A Standardized EPA Protocol for Characterizing Indoor Air Quality In Large Office Buildings*, EPA/ORIA/IED and AREAL, February 2003a, Table C3	±3% RH	±3% RH	90%	Recommended operating conditions stated as 0-85% RH

6.1 Detection Limits

Detection limit information is listed for most measurements in **Table 6-1 and 6-2**. Detection limits for sorbent tube and Radiello samplers are covered in **Section 5.3** by total collection duration.

6.2 Consideration of Background Sources of Indoor Air Contamination

A complicating factor of indoor air sampling for VI is the presence of VOCs in indoor air due to ambient (outdoor) atmospheric contamination and the indoor use of common household products and solvents.

During the initial screening phase of work, at a minimum, a succinct building survey will be performed within each structure proposed for sampling. The building survey is expected to be brief, although will aim to detail pertinent information regarding use of the structure, typical potential background sources observed, and general condition of the building envelope. In addition to documenting the broad types of potential background sources of VOCs present within an individual structure, the structure will be screened for total VOCs using a handheld MultiRae PID device. To control cost consumer products may be documented photographically in groups rather than preparing a detailed item by item inventory. The PID screening will consist initially of PID measurements outside the house and in the rooms where sampling is likely to occur. Screening may also include sites of significant chemical storage such as a basement shop or closet in which many cleaning products are kept. However, the project level of effort does not allow for a detailed drawer by drawer/object by object PID survey. If through the visual inspection or PID screening any significant potential background VOC sources are identified, they will be documented, and occupants will be instructed to restrict usage nearby deployed samples. Identified items will not be removed from structures, nor will occupants be told usage of the items is prohibited. But a reasonable effort will be made to explain the important of collecting an unbiased sample and the benefits of storing VOC containing products in well ventilated places.

If additional optional work is selected where the community science effort will be completed, occupants within each structure will be taught how to identify and document potential background VOC sources, but no pre-screening is anticipated with a handheld MultiRae device.

To account for outdoor VOC sources, ambient air sampling is planned at each site in parallel with indoor sampling. Indicator compounds specific to VI (as opposed to indoor sources) such as cis-1,2-DCE may be critical in many cases to discerning indoor sources.

6.3 Consideration of Spatial, Seasonal, and Temporal Variability

As one of the primary objectives of this TO, seasonal and temporal variability are going to be extensively characterized (as outlined in the test matrix **Table 4-2**). Temporal variability will be assessed through various sampling events conducted through approximately 12 months, spaced such that major seasons are targeted for both the calendar-triggered sampling events as well as the ITS-triggered sampling events (that is, winter, summer, and spring or fall). Spatial variability will be assessed by collecting soil gas samples throughout a large area of a single site, which may potentially retain slight elevation changes and slight subsurface condition changes (e.g., depth to water, soil type). Spatial variability will also be evaluated through comparison of indoor air samples collected within separate zones of a single structure (for example, basement and ground floor).

6.4 Consideration of Random or Systematic Error

Evaluation of random and systematic error is an important part of any quality protocol development. Some sources of error are manageable through proper QA planning and methodology as long as they can be foreseen. To achieve the purposes of this TO, all manageable sources of systematic error will be identified and minimized. Examples of manageable potential sources of systematic error include:

- Reduction in vapor concentration due to poorly sealed probes (probe leakage)
- Increase in vapor concentration due to cross-contamination from sampling materials or background sources
- Reduction of vapor concentration due to failure to cap passive samplers tightly (sample container leakage)
- Reduction in VOC concentration due to excessive purging prior to sampling (dilution of subsurface vapors by excessive pumping)
- Incomplete recovery of analytes from sample media, including sorbents (incomplete solvent extraction or thermal desorption).
- Non-recovery of proposed samples (non-responsive building occupants either before or after sample deployment)

Assessment of vapor concentration dilution from poorly sealed vapor probes can be a challenge. There is little published on methods to assess leakage in this type of monitoring system. Also, if leakage is not severe, it may not significantly compromise data (i.e., leakage occurs but is relatively minor compared to gas flow in subsurface material, as with a sand and gravel filled sub-base where gas permeability can be expected to be very high (10^{-7} to 10^{-6} cm^2). However, we will determine the amount and significance of probe leakage by releasing a tracer gas into a shroud over the vapor sampling point and then sampling for that tracer gas through the soil gas probes (SOP for leak check provided as part of Standard Operating Procedure for Installing Subslab Probes and Collecting Subslab Soil Gas Samples Using Canisters).

To avoid systematic error because of increases in vapor concentration due to materials used in vapor probe construction, sample tubing and equipment will follow the recommendations provided in ORD's September 2005 report (US EPA, 2005a). As recommended in the report, subslab vapor samples will be collected from the vapor probes using dedicated high purity FEP-lined polyethylene tubing, which offers very low vapor and gas permeability, is non-photo reactive, and is a low-cost alternative to fluoropolymer tubing.

Reduction of vapor concentration due to failure to cap passive samplers tightly (sample container leakage) is a potential source of error that can be managed primarily through vigilance by the field personnel.

Non-recovery of select proposed samples may occur if occupants/owner of a selected structure are suddenly non-responsive after receiving initial agreement for access. It is unlikely that a building occupant will lose contact with the project team once a sample is deployed but is most likely to occur after access has been granted and before sampling begins (or after several rounds of sampling have been completed and additional samples are needed). Although this error cannot be avoided as property owners and occupants cannot be forced to communicate with the project team, efforts can be made if this situation occurs to meet with occupants face-to-face if interactions over the phone or email are unsuccessful.

It is possible for any given test site to have characteristics that are not nationally valid. Therefore, we will avoid drawing firm conclusions about the entire phenomenon of VI from a single test site. It will be appropriate in the discussion section of the project report to qualitatively compare the results obtained at this site to published results obtained at other sites. Extensive data sets have been published for residences in Utah (Holton, 2015; Holton et al., 2012 and 2013) and Indiana (US EPA, 2012b and 2015b). A significant data set was also acquired on the utility of the radon tracer and passive sorbent methods at the Orion Park/Moffett Field site and Wheeler Building complex under previous EPA APPCD-sponsored studies (Lutes, 2010a and 2010b).

6.5 Analytical QA/QC Checks

Laboratory quality control sample requirements such as calibration checks, method blanks, surrogate recoveries, laboratory control samples, matrix spikes, and others will be performed according to the requirements of the methods, as specified in the following sections.

6.5.1 Summary of Performance Requirements for VOC Analytical Methods

Performance requirements for these methods are listed in section 5.3

6.6 Field Quality Control Samples

Field quality control samples are intended to help evaluate conditions resulting from field activities and are intended to accomplish two primary goals: (1) assessment of field contamination, and (2) assessment of sampling variability. The former looks for substances introduced in the field due to environmental or sampling equipment and is assessed using blanks of different types. The latter includes variability due to sampling technique and instrument performance as well as variability possibly caused by the heterogeneity of the matrix being sampled and is assessed by collecting sample replicates.

Blanks introduced during sample shipment, storage, and collection help evaluate whether samples may be subject to false positives. Different types of air sampling devices have different affinities for blank contamination. Any air sampling device may be subject to contamination in the presence of extremely high levels of the contaminant. Specific types of sampling devices may be subject to specific or systematic practices that may unknowingly introduce contaminates.

6.6.1 Field Blanks

Because there is no good indicator of sample media integrity during sample collection, field blanks will be employed to evaluate potential background contamination during sample collection. Field blanks prepared by the field team will be tracked through the serial number assigned to the device. The blank media will be opened briefly during collection of field samples and then resealed, to be stored at ambient temperature until sample shipment to the laboratory, at which point it may be placed on ice. If contamination above the laboratory reporting limit is found in the blanks, concentrations in associated samples up to five times that found in the blanks will be omitted from data analysis unless otherwise shown to be valid.

The frequency of planned field blanks is defined in the test matrix presented in **Table 4-2**.

6.6.2 Field Duplicates

Duplicate (or replicate) samples are collected simultaneously in separate containers from the same source and under identical conditions. For example, Method TO-17 sorbent tube duplicates will be taken by drawing soil gas through two sorbent tubes (one immediately after the other). Passive sample duplicates will consist of co-located samplers. Each duplicate portion will be assigned its own sample number so that it will be "blind" to the laboratory (i.e., the laboratory cannot tell it is a duplicate). A duplicate sample is treated independently of its counterpart in the same laboratory to assess laboratory performance through comparison of the results. Typically, at least one duplicate will be collected per every 10 primary samples of a selected matrix (i.e., indoor air, soil gas). Agreement between duplicate samples should meet the criteria indicated in **Table 6-1**. Data sets that do not meet these criteria will be flagged as suspect and will be omitted from data analysis unless otherwise shown to be valid.

The frequency of planned field duplicates is defined in the test matrix presented in **Table 4-2**.

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Appendices

Appendix A: Occupied Dwelling Questionnaire

Appendix B: Standard, Miscellaneous, and Field Operating Procedures

- B1: SOP for Utility Clearance Inside Buildings
- B2: SOP for Indoor, Crawl Space, and Ambient Air Sample Collection Using Sorbent Tubes
- B3: Posting for Air Sampling Canisters
- B4: Air Sampling Log
- B5: SOP for Pressure Differential Monitoring to Support Vapor Intrusion Investigations
- B6: SOP for Installing Subslab Probes and Collecting Subslab Soil Gas Samples Using Canisters
- B7: SOP for Installation and Abandonment of Permanent and Semi-Permanent Exterior Soil Vapor Probes
- B8: Soil Vapor Probe Diagram
- B9: SOP for Soil Vapor Sampling from Exterior Soil Vapor Probes
- B10: Exterior Soil Vapor Sampling Form
- B11: Soil Vapor Probe Purge Volume Calculations
- B12: SOP for Radon Monitoring and Sampling to Support Vapor Intrusion Investigations
- B13: 2-56 MOP: AlphaGuard: Operation of the AlphaGuard Portable Radon Monitor
- B14: SOP for Temperature Monitoring in Support of Vapor Intrusion Investigations
- B15: Weather Monitoring to Support Vapor Intrusion Investigations

Appendix C: Corentium Pro Monitor Manual

Appendix D: Radon Eye Plus 2 Manual

Appendix E: MiniRAE 2000 Portable VOC Monitor PGM 7600 Operation and Maintenance Manual

Appendix F: Radiello Manual (selected sections)

Appendix G: Rad7 Manual

Appendix H: Example Chain-of-Custody Form