Investigation and Validation of Multiple Lines of Evidence to Assess Vapor Intrusion at Kelly Air Force Base, TX for US Air Force School of Aerospace Medicine (USAFSAM/OE)

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

Tetra Tech, Inc. (Tetra Tech) has been contracted by the United States Air Force (USAF), HSW/PKAH to conduct an investigation of multiple lines of evidence (MLE) used in assessing risk associated with the vapor intrusion (VI) pathway. To that end, research is being conducted at up to four Air Force installations where VI is suspected. The purpose of the investigations is to evaluate a variety of parameters related to VI in order to develop a better understanding of the processes that lead to a complete VI pathway, and ultimately, to develop tools for use by the Air Force in assessing VI at other installations.

Tetra Tech conducted a preliminary site visit to former Kelly AFB in August 2008 to identify buildings considered likely to be subject to VI. Data provided by the Air Force Real Property Agency (AFRPA) at former Kelly AFB were reviewed to identify suitable buildings located over shallow groundwater volatile organic compound (VOC) plumes. Criteria used to select candidate buildings were:

- Moderate size (i.e. less than 10,000 square feet)
- Slab-on-grade construction
- Closed interior space
- Limited occupancy (to avoid impacting mission operations)
- Location over a shallow groundwater VOC source
- Availability for conducting experiments

Based on these criteria, four candidate buildings were selected: Building 317, Builing 323, Building 348A and Building 1416. In August 2008, air samples were collected from these four building to verify the presence of VOCs. Similarly low concentrations of trichloroethene were detected in each of the buildings, and based on the preliminary sampling results and other considerations such building size and construction, Building 1416 was selected for the comprehensive investigation discussed in this report.

2 SITE BACKGROUND INFORMATION

2.1 Site background information

Building 1416 is located at the north end of former Kelly AFB, San Antonio, Texas on North Frank Luke Drive, near the intersection with Growdon Road (Figure 2-1). Building 1416 is located immediately southeast of an aircraft hanger in an industrial use area.

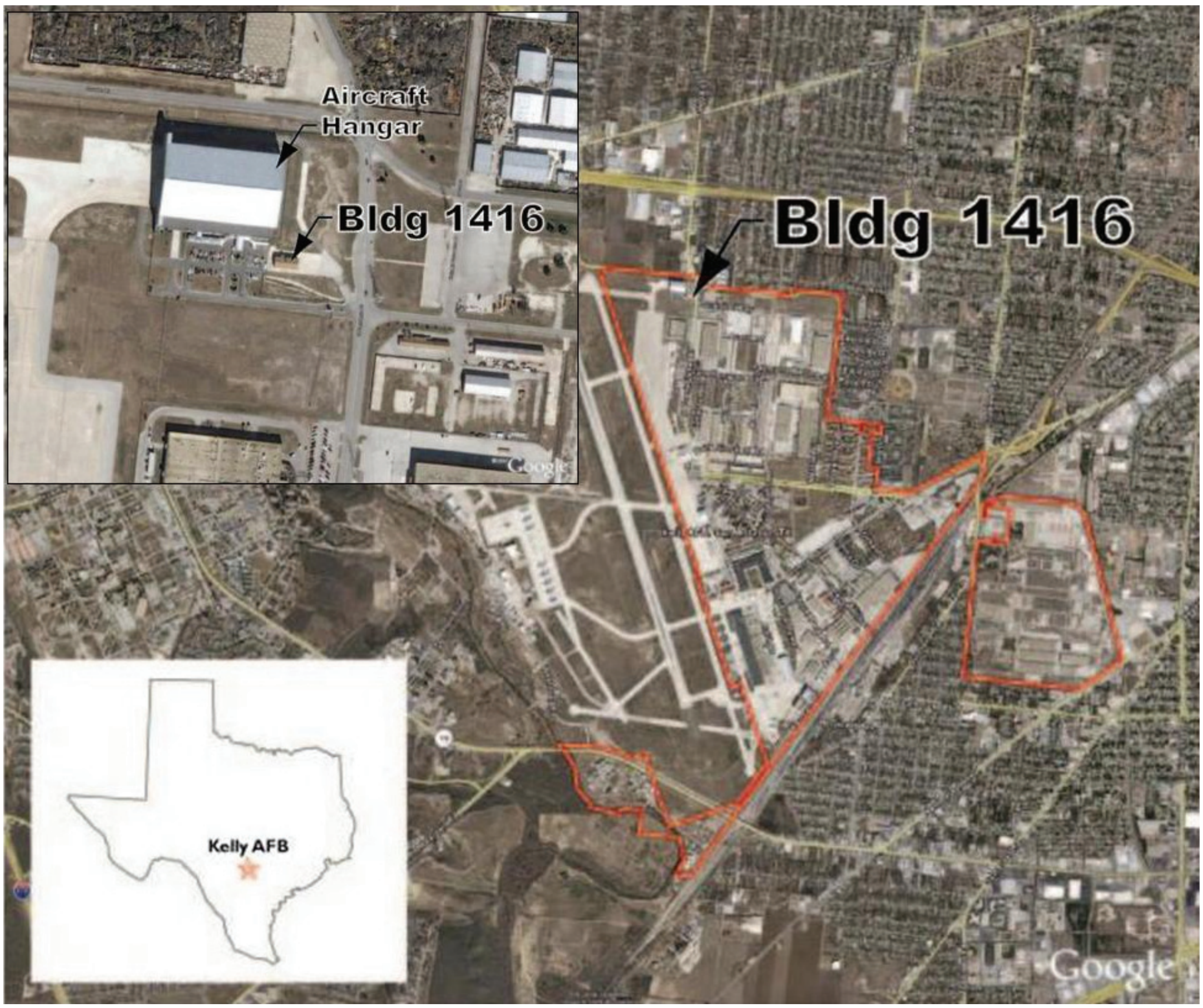


Figure 2-1
Location of Building 1416 at former Kelly Air Force Base. (Source: Google Earth 2008)

Construction of Building 1416 was completed in 1944 and it was used for paint and dope storage by the San Antonio Air Service Command. The building was relocated from its original location to the present site in 1956. It became a reclamation facility shop in 1963 (U.S. Army Corps of Engineers [USACE] 1997). Currently, Building 1416 is a paint shop used for training purposes.

The depth to groundwater in March 2007 was approximately 25 feet below ground surface (bgs) and groundwater appears to flow toward the south and southeast in the vicinity of Building 1416

(Air Force Center for Engineering and the Environment [AFCEE] 2008; Figure 2-2). Groundwater sampling in March 2007 at monitoring wells adjacent to Building 1416 indicates that TCE is present at concentrations up to 690 micrograms per liter (µg/L), tetrachloroethene (PCE) is present at concentrations up to 2.7 µg/L, and total (*cis*- + *trans*-) 1,2-dichloroethene (DCE) is present at concentrations up to 400 µg/L. Figure 2-3 shows well locations and plume contours for TCE and Table 2-1 summarizes the volatile organic compounds (VOCs) detected in groundwater wells adjacent to Building 1416.

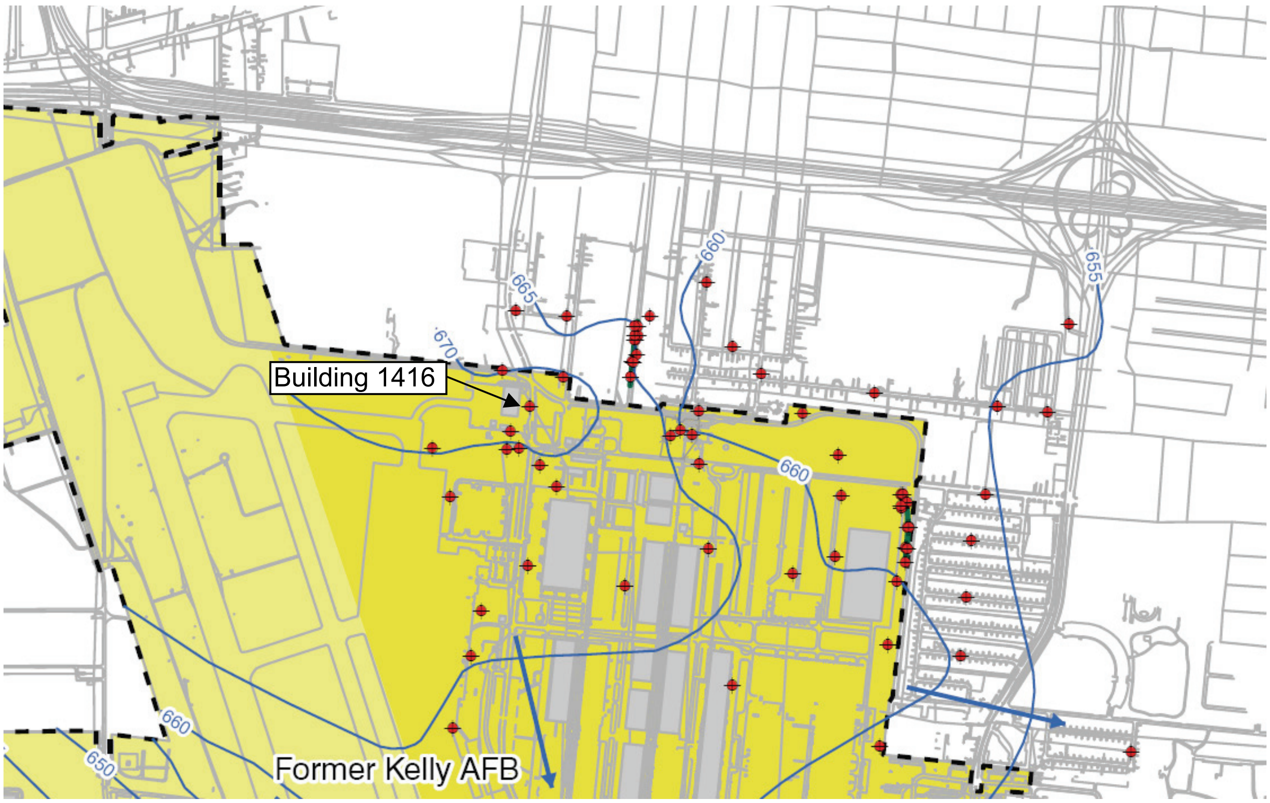


Figure 2-2
Shallow groundwater contours near Building 1416. (Source: AFCEE 2008)

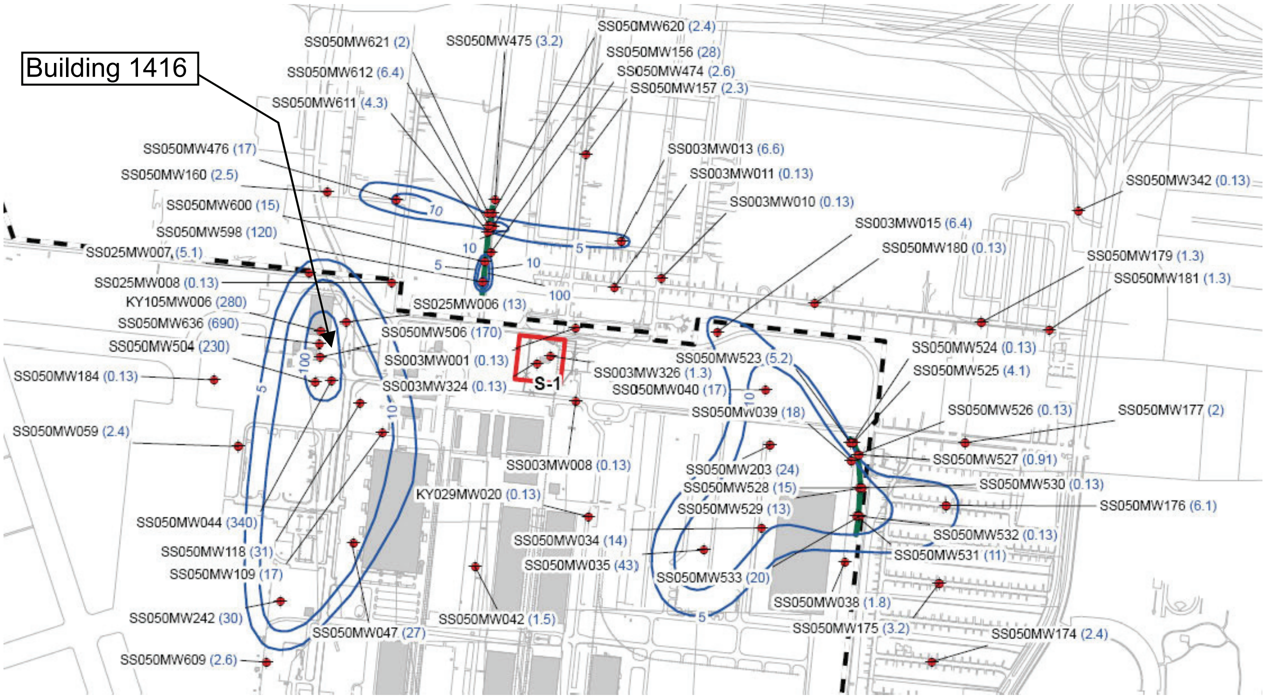


Figure 2-3
Monitoring wells near Building 1416 and TCE contours from March 2007. (Source: AFCEE 2008)

Table 2-1
Summary of Groundwater Sampling Results from March 2007

Analyte	Maximum Concentration (µg/L)	Well I.D.
PCE	2.7	SS050MW636
TCE	690	SS050MW636
Total 1,2-DCE	400	SS050MW636

2.2 Preliminary Field Sampling for MLE Investigation

In August 2008, Tetra Tech conducted a reconnaissance visit to Kelly AFB to identify buildings suitable for this investigation. Candidate buildings were selected based on the criteria listed in Section 1.0. Four buildings were selected for preliminary indoor air sampling to verify the presence of VOCs in indoor air. Indoor air sampling was conducted at each building using Summa Canisters equipped with 24-hour flow controllers. The Summa Canisters were deployed on August 6 and retrieved on August 7, 2008, and submitted to Air Toxics Ltd, located in Folsom, California, for analysis via EPA method TO-15 with selected ion monitoring (SIM). The results of the preliminary indoor air sampling are summarized in Table 2-2.

Table 2-2
Preliminary Indoor Air Sampling Results (μg/m^3)

	TCE	PCE	1,2-DCA	Freon 113
Reporting Limit:	**0.016**	**0.020**	**0.081**	**0.77**
Building				
1416 (Shop)	0.025 J	0.026 J	0.33	0.59 J
1416 (Paint booth Rm)	0.11	0.056	0.056 J	0.33 J
348A	0.021 J	0.10	ND	0.47 J
323 (Main Rm)	0.28	1.5	0.030 J	0.58 J
323 (Utility Rm)	0.15	0.65	0.043 J	0.60 J
317 (Restroom)	0.24	0.46	0.045 J	0.48 J

Notes:
DCA – dichloroethane
μg/m^3 – micrograms per cubic meter
PCE – tetrachloroethene
TCE - trichloroethene

While Building 1416 had some of the lower concentrations of VOCs in indoor air, other characteristics including size and construction method made it preferable to the other sampled buildings. In addition, the presence of concrete slab extending 15 to 20 feet beyond the north and south sides of the building and ending in unpaved area presents an opportunity to study the behavior of sub-slab soil gas both beneath and adjacent to the building, which may provide some insight into the relative importance of the slab versus the overlying building in influencing soil gas behavior.

2.2.1 Chemicals of Potential Concern Identified at the Site

Based on the indoor air sampling results presented above, the primary chemicals of potential concern (COPC) at Building 1416 are TCE, PCE, and 1,2-dichloroethane (DCA) (Table 2-3). Freon 113 was detected in indoor air, but not in groundwater; therefore, it is considered a secondary COPC. The dichloroethenes (*cis*-1,2-, *trans*-1,2-, and 1,1-) are present in groundwater, but were not detected in indoor air; therefore, these compounds are also considered secondary COPCs.

Table 2-3
Chemicals of Potential Concern at Building 1416

COPC	Level
Tetrachloroethene	Primary
Trichloroethene	Primary
1,2-dichloroethane	Primary
Freon 113	Secondary
cis-1,2-dichloroethene	Secondary
trans-1,2-dichloroethene	Secondary
1,1-dichloroethene	Secondary

3 MULTIPLE LINES OF EVIDENCE FIELD INVESTIGATION

The MLE field investigation for former Kelly AFB was conducted during the period of 2 through 4 December 2008. A variety of parameters were measured during the field investigation to develop a comprehensive understanding of the processes occurring at the Site. The following sections detail the field activities.

3.1 Building description and indoor volume estimates

Building 1416 is an approximately 2,400-square-foot, single story slab-on-grade structure. The building consists of five areas: an entry way room, class room, shop, restroom, and paint booth room (Figure 3-1). The paint booth room is not air conditioned, although the rest of the building is. A concrete apron extends out from all sides of the building. On the east (front) side the apron extends over 100 feet to the road. On the west side, the concrete apron extends approximately 25 feet, where it abuts an asphalt parking lot. On the north and south sides, the apron extends approximately 25 and 12 feet, respectively, where it abuts unpaved grassy areas (Figure 3-1).

The paint room has a vaulted ceiling, while the remaining rooms have hanging ceilings. The paint room and the shop have an uncovered concrete floor, while the entry, classroom, and restroom have linoleum floors. The concrete slab in the paint room and shop is cracked and the additional presence of expansion joints in the concrete slab may provide soil vapor intrusion pathways. A substantial part of the paint room is occupied by the paint booth. Figure 3-2 through Figure 3-5 are photographs of the outside and inside of Building 1416.

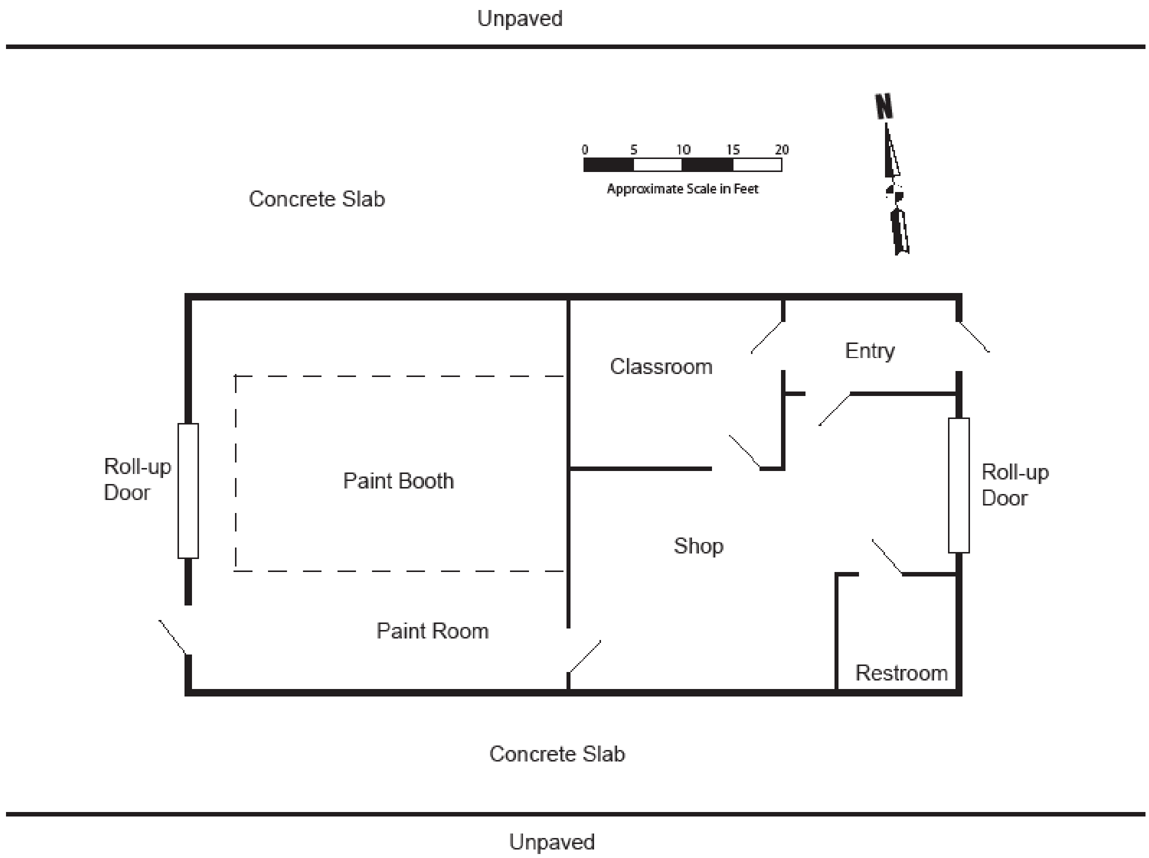


Figure 3-1
Floor plan of Building 1416.

Figure 3-2
View of the southeast corner of Building 1416 with concrete apron.

Figure 3-3
View of the north side of Building 1416 from the northwest with concrete apron.

Figure 3-4
View of the shop from the roll-up door. The classroom is through the door on the right. The room has hanging ceilings under a pitched roof and the floor shows expansion joints and past concrete cutting work.

Figure 3-5
(A) View of the paint booth in the paint room from the southeast corner of Building 1416. This shows the rollup door on the left and the insulated doors of the paint booth on the right. (B) View down the corridor on the south side of the paint booth (visible on the left), with the vaulted ceiling visible above the double doors leading into the shop.

During December 2008, detailed measurements were taken of each room in order to assess the indoor volume of Building 1416. Indoor volume estimates are presented in Table 3-1. Each room contained various amounts of furniture and equipment that filled space. Therefore, the volume estimates presented in Table 3-1 are considered to have a margin of error of ±10 percent.

Table 3-1
Summary Table of Indoor Volumes for Building 1416.

Room	Length (in)	Width (in)	Height (in)	Volume (ft^3)
Paint Room	487	478	172 - 249	28,357
(Paint Booth)	420	244	120	7,117
Classroom	271	179	114	3,200
Entry	198	138	114	1,803
Shop	various	various	various	8,193
Restroom	115	138	114	1,047
Total volume including vaulted ceiling in all rooms				**56,181**
As above without paint booth				**49,064**
Total volume with hanging ceilings				**42,600**
As above without paint booth				**35,484**

3.2 Sampling program design and execution

Field activities in support of the investigation were conducted from 2 through 4 December 2008 with Building 1416 under normal operating conditions, i.e., with the HVAC system turned on and training classes in session. During the sampling event, the paint booth was in use and the roll-up door on the west side of the building was thus open from approximately 8 a.m. to 1 p.m. each day.

Field activities included the installation of five sub-slab soil vapor probes inside the building and four sub-slab soil vapor probes under the concrete apron around the building, installation of sixteen deep (15 to 25 feet bgs) to soil vapor probes around the outside of the building, collection of soil samples from selected outdoor vapor probe borings, collection of soil vapor samples from each probe, and deployment of seven SUMMA canisters and co-located TO17 badges. In addition, a known quantity of helium was released into the building, and periodic indoor air samples were collected for off-site helium analysis in order to develop an estimate of the building air exchange rate. A summary of field activities including dates is provided in Table 3-2.

Table 3-2
Summary of Field Activities

2 December 2008	• Five indoor sub-slab soil vapor probes installed • Borings 1416-SG-1, 1416-SG-4, 1416-SG-5, and 1416-SG-8 driven to total depth; no groundwater encountered, but borings left open overnight to allow formation water to infiltrate.
3 December 2008	• Borings 1416-SG-2, 1416-SG-3, 1416-SG-6, and 1416-SG-7 driven to total depth; no groundwater encountered. Sounder indicated no groundwater present in any of the eight borings; therefore, groundwater samples were not collected. • Three soil samples collected for offsite physical testing. • Two nested soil vapor probes installed in each of the eight borings and four outdoor sub-slab soil vapor probes installed. • Air exchange rate investigation initiated via instantaneous release of approximately 375 ft^3 of helium gas into building and subsequent periodic sampling of indoor air. • Seven SUMMA canisters deployed (Four indoors plus one duplicate and two outdoors). • Six “Radiello” badges for TO-17 analysis co-located with SUMMA canisters.
4 December 2008	• SUMMA canisters and TO-17 badges collected. • Soil vapor samples collected from each soil vapor probe. • Site cleaned up. • All samples sent to offsite laboratories for analysis.

Sampling locations are shown on Figure 3-6. The prefix “1416” has been deleted from all sample location IDs on Figure 3-6 for visual clarity; the prefix has, however, been retained in text and tables for the presentation and discussion of results in following sections. All indoor air sampling locations were co-located with the numerically associated sub-slab soil gas sampling points.

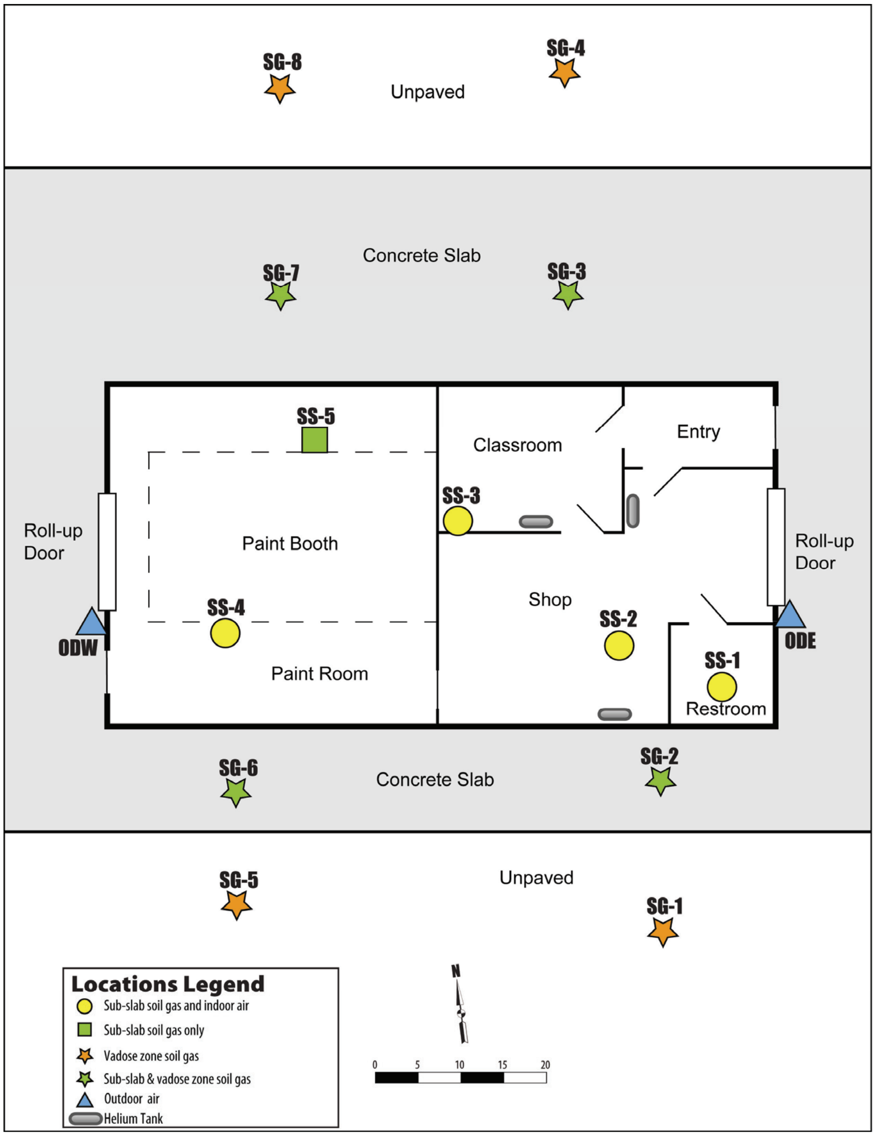


Figure 3-6
Location map showing sample points for near-slab soil gas, sub-slab soil gas, and indoor and outdoor air at Building 1416, as well as helium tank locations.

3.2.1 Soil Vapor Probe Installations

Nine sub-slab soil vapor probes (1416-SS-1 through 1416-SS-5 and 1416-SG2-SS, 1416-SG3-SS, 1416-SG6-SS and 1416-SG7-SS) were installed directly beneath the slab inside and outside of Building 1416 (green and yellow locations on Figure 3-6). Soil vapor probes consisting of 1-inch long gas permeable filters attached to 1/8-inch outer diameter Nylaflow tubing terminated by 3-way stopcock Luer valves were installed in holes drilled through the building slab using a rotohammer drill with a 1.125-inch diameter drill bit and penetrating the sub-slab material just enough to accommodate the filters (approximately 1 to 2 inches). Prior to installation, the holes were cleaned with a damp towel to ensure a good seal. Sand to 1 inch above the filters and hydrated granulated bentonite to grade completed the installations. Cement caps were not installed, because these probes are not permanent. The tubing extends approximately six inches above the surface from each location.

Two nested soil vapor probes were installed outside Building 1416 at each location designated with an "SG" on Figure 3-6. The shallow probes set at 15 feet bgs were designated 1416-SG1-15 through 1416-SG8-15 and the deep probes, which were set at various depths, were designated 1416-SG1-# through 1416-SG8-#, where the # denotes the depth at which the probe was set (see soil vapor probe construction details provided in Appendix A). These probes were constructed in the same manner as the indoor soil vapor probes, but extend to greater depths. A direct-push Geoprobe system was used to hydraulically drive 2.25-inch diameter rods containing 1.25-inch acetate sampling sleeves to total depth. Total depth at each location was determined by when the drill rig encountered refusal in formation gravel, with the exception of location 1416-SG-5, where the casing was driven to a total depth of 30 feet bgs. Groundwater had been determined to be approximately 25 to 28 feet bgs from measurements taken in two nearby groundwater wells; therefore, drilling at location 1416-SG-5 was stopped at 30 feet bgs, before encountering refusal. Temporary PVC wells were installed at locations 1416-SG-4 and 1416-SG-5, because these were the two deepest borings and therefore represented the best chance at collecting groundwater samples. All other borings did not extend beyond 25 feet bgs, which was the upper surface of measured groundwater in the two nearby wells. Therefore, borings that did not extend below 25 feet bgs were not considered likely to fill with groundwater. Soils were logged from continuous cores sampled with acetate sleeves. Boring logs describing soils are provided in Appendix A. The probes were installed after a sounder indicated that no groundwater was present in any of the borings. At each location, the deep probe filter was lowered to 3 inches above the total depth of the boring, except in borings 1416-SG-4 and 1416-SG-5, which were backfilled with bentonite to 25 feet bgs, so as not to set the filters below the estimated groundwater table. Sand was then poured into the boring so as to extend from 3 inches below to 3 inches above the filter. Then, granulated bentonite was poured into the boring and hydrated in several lifts to slightly below 15 feet bgs, where the second probe was set with a sand pack extending from 3 inches below to 3 inches above the filter. The near-slab borings were then filled to grade with granulated bentonite, which was repeatedly hydrated during several lifts to ensure a proper seal. The borings installed through the exterior concrete slab (i.e. the exterior sub-slab borings) were filled with granulated bentonite to the bottom of the concrete slab and capped with concrete to the surface. All soil vapor probes were installed through the open boring. The tubing extended approximately 12 inches above the surface from each location.

3.2.2 Soil and Soil Vapor Probe Sampling

While drilling at the eight outside vapor probe locations, three distinct soil types were identified. The first, occurring directly beneath the surface soil and extending to a depth of 8 feet bgs, consisted of a stiff, black, organic clay. Below this depth, and separated by a sharp contact, a strong brown, organic-poor, softer, and moister clay was logged. Finally, and at varying depths, this clay transitioned into a clayey gravel, consisting of weathered limestone clasts with white, calcareous silt. Three in-tact soil samples were collected (one from each lithologic soil type) from locations 1416-SG-2 and 1416-SG-6 for physical and chemical testing. When possible, two 1-foot sections of the acetate sampling sleeve were carefully cut and capped at either end, minimizing disturbance to the soil sample within. The sample collected from the gravel layer consisted of only one 14-inch long sleeve, due to the refusal generally encountered by the direct push rig in the gravel at the site. Analytical results for soil samples are presented in Section 3.3.2 and Table 3-3 and discussed in Section 4.0.

Table 3-3
Soil Physical Parameters Building 1416 Former Kelly AFB, Texas

Sample ID	Collection Date	USCS Classification	Moisture Content (%)	Dry Density (pcf)	TOC (%)	Total Porosity (%)	Effective Permeability (millidarcy)	Air Conductivity (cm/second)
1416SG2-11	03-Dec-08	CL	33.8	88.6	1.33	0.55	1.41	9.97E-08
1416SG6-15	03-Dec-08	SM-CL	20.7	119.4	0.78	0.33	0.782	5.53E-08
1416SG6-21	03-Dec-08	CL (with gravel)	4	126.8	0.61	0.22	13.74	9.72E-07

Definitions:
cm-centimeter
pcf-pounds per cubic foot
SP-poorly graded sand
SW-well graded sand
TOC-total organic carbon
USCS-Universal Soil Classification System
Note:
1-Samples contain shell fragments.

On 4 December 2008, each soil vapor probe was sampled using a 60 milliliter (mL) syringe. In each case, three system volumes were purged prior to filling a 500-ml Tedlar bag with 480 mL of soil gas. Thus, approximately 4.5 mL from the sub-slab soil vapor probes, 48 mL from the shallow vapor probes, and between 57 and 78 ml for the deep vapor probes were purged prior to sampling each location. In some cases, a vacuum was encountered during sampling, due to the tight formation surrounding the probes, in which case less than 480 mL of soil gas were sampled. Purging and sampling with the same syringe at each location was accomplished via use of a 3-way stopcock Luer valve, minimizing the potential for outside contamination. Analytical results for soil gas samples are presented in Section 3.3.3 and Table 3-4 and discussed in Section 4.0.

3.2.3 Air Exchange Rate and Indoor and Outdoor Air Sampling

In order to estimate the indoor-outdoor air exchange rate, approximately 375 cubic feet (ft^3) of helium gas from three point sources were released into the building on 3 December 2008. The sources were three 125 ft^3 cylinders, which were placed in the shop and classroom of Building 1416 (Figure 3-6). The roll-up door to the paint room was open during much of the day; however, the doorway between the paint room and shop was kept closed. Therefore, helium was not released into the paint room, and the air exchange rate calculations were based on the interior volume of the building with the paint room excluded. The tank valves were fully opened simultaneously by the field crew, allowing the tanks to empty into the building. Each cylinder emptied in approximately 1 minute. Indoor air samples integrated throughout each room of the building (except the paint room) were subsequently collected into Tedlar bags using a 60-ml syringe 15, 30, and 60 minutes after the initial release, and again at 2, 4, 6, 8, and 10, hours after the initial release. Analytical results are presented in Section 3.3.4 and Table 3-5 and discussed in Section 4.0.

On 3 December 2008, five SUMMA canisters were deployed inside the building (including one duplicate) and two were deployed outside (yellow and blue markers on Figure 3-6). Passive dosimeters (Radiello passive diffusive samplers), co-located with each SUMMA canister (except at 1416-ODE), were deployed at the same time as the SUMMA canisters. The indoor canisters were placed near the sub-slab soil gas sampling points and at elevated locations where possible (e.g., on tables), in order to obtain samples more representative of the breathing zone. A duplicate sample was obtained from a canister placed next to location 1416-SS-2. All SUMMA canisters were closed on 4 December 2008, after sampling for a 24-hour period. Analytical results are presented in Section 3.3.4 and Table 3-6 and Table 3-7 and discussed in Section 4.0.

Table 3-4
VOCs in Soil Gas Building 1416 Former Kelly AFB, Texas

Sample Location	**1416-SG-1**	**1416-SG-1**	**1416-SG-2**	**1416-SG-2**	**1416-SG-2**	**1416-SG-3**	**1416-SG-3**
Sample Depth (feet bgs)	**23**	**15**	**18**	**15**	**SS**	**24**	**24**
Sample ID	**1416-SG1-23**	**1416-SG1-15**	**1416-SG2-18**	**1416-SG2-15**	**1416-SG2-SS**	**1416-SG3-24**	**1416-SG-DUP1**
Collection Date	**12/4/2008**	**12/4/2008**	**12/4/2008**	**12/4/2008**	**12/4/2008**	**12/4/2008**	**12/4/2008**
cis-1,2-Dichloroethene	12	1.7	6.3	1.1	<0.50	9.1	10
Chloroform	<0.10	<0.10	<0.10	<0.10	<0.10	0.23	0.26
Benzene	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Trichloroethene	40	3.0	42	2.9	0.35	77	93
Toluene	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
m,p-Xylene	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Tetrachloroethene	0.14	<0.10	0.19	<0.10	<0.10	0.54	0.62
Sample Location	**1416-SG-3**	**1416-SG-3**	**1416-SG-4**	**1416-SG-4**	**1416-SG-5**	**1416-SG-5**	**1416-SG-6**
Sample Depth (feet bgs)	**15**	**SS**	**25**	**15**	**25**	**15**	**22**
Sample ID	**1416-SG3-15**	**1416-SG3-SS**	**1416-SG4-25**	**1416-SG4-15**	**1416-SG5-25**	**1416-SG5-15**	**1416-SG6-22**
Collection Date	**12/4/2008**	**12/4/2008**	**12/4/2008**	**12/4/2008**	**12/4/2008**	**12/4/2008**	**12/4/2008**
cis-1,2-Dichloroethene	1.3	<0.50	12	5.5	2.5	0.74	4.9
Chloroform	<0.10	<0.10	0.16	<0.10	<0.10	<0.10	<0.10
Benzene	0.13	<0.10	<0.10	0.11	0.13	<0.10	<0.10
Trichloroethene	5.2	<0.10	29	8.6	10	1.2	21
Toluene	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
m,p-Xylene	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Tetrachloroethene	<0.10	<0.10	0.12	<0.10	<0.10	<0.10	0.19
Sample Location	**1416-SG-6**	**1416-SG-6**	**1416-SG-6**	**1416-SG-7**	**1416-SG-7**	**1416-SG-7**	**1416-SG-8**
Sample Depth (feet bgs)	**22**	**15**	**SS**	**20**	**15**	**SS**	**23**
Sample ID	**1416-SG-DUP2**	**1416-SG6-15**	**1416-SG6-SS**	**1416-SG7-20**	**1416-SG7-15**	**1416-SG7-SS**	**1416-SG8-23**
Collection Date	**12/4/2008**	**12/4/2008**	**12/4/2008**	**12/4/2008**	**12/4/2008**	**12/4/2008**	**12/4/2008**
cis-1,2-Dichloroethene	4.4	0.85	<0.50	7.1	3.5	<0.50	8.7
Chloroform	<0.10	<0.10	<0.10	0.16	<0.10	<0.10	0.14
Benzene	<0.10	<0.10	<0.10	0.12	<0.10	<0.10	<0.10
Trichloroethene	19	1.8	0.25	24	6.4	0.19	26
Toluene	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
m,p-Xylene	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Tetrachloroethene	0.17	<0.10	<0.10	0.17	<0.10	<0.10	0.18
Sample Location	**1416-SG-8**	**1416-SS-1**	**1416-SS-2**	**1416-SS-3**	**1416-SS-3**	**1416-SS-4**	**1416-SS-5**
Sample Depth (feet bgs)	**15**	**SS**	**SS**	**SS**	**SS**	**SS**	**SS**
Sample ID	**1416-SG8-15**	**1416-SS-1**	**1416-SS-2**	**1416-SS-3***	**1416-SS-DUP3**	**1416-SS-4***	**1416-SS-5***
Collection Date	**12/4/2008**	**12/4/2008**	**12/4/2008**	**12/4/2008**	**12/4/2008**	**12/4/2008**	**12/4/2008**
cis-1,2-Dichloroethene	0.69	<0.50	<0.50	<0.005	<0.50	<0.005	<0.005
Chloroform	<0.10	<0.10	<0.10	<0.005	<0.10	<0.005	<0.005
Benzene	<0.10	<0.10	<0.10	<0.005	<0.10	<0.005	<0.005
Trichloroethene	0.97	0.16	0.10	<0.005	<0.10	0.0051	<0.005
Toluene	<1.0	<1.0	<1.0	0.026	<1.0	0.028	0.033
m,p-Xylene	<0.50	<0.50	<0.50	0.016	<0.50	0.019	0.019
Tetrachloroethene	<0.10	<0.10	<0.10	<0.005	<0.10	<0.005	<0.005

Definitions:
bgs - below ground surface
µg/L - micrograms per liter
ml - milliliter
SS – sub-slab
Notes:
* Sample analyzed using EPA method TO-15, all others by modified EPA method SW8260
All results in µg/L

Table 3-5
Helium Concentrations in Indoor Air (percent) Air Exchange Measurement Building 1416 Former Kelly AFB, Texas

Sample ID	Collection Date	Collection Time	Time After He Release (min)	RL	Result
He 15	03-Dec-08	0805	15	0.050	1.0
He 30	03-Dec-08	0820	30	0.050	0.73
He 60	03-Dec-08	0850	60	0.050	0.42
He 120	03-Dec-08	0950	120	0.050	0.14
He 240	03-Dec-08	1150	240	0.050	<0.050
He 360	03-Dec-08	1350	360	0.050	<0.050
He 480	03-Dec-08	1550	480	0.050	<0.050
He 600	03-Dec-08	1750	600	0.050	<0.050

Definitions:
ASTM-American Society for Testing and Materials
RL-reporting limit
Note:
Samples analyzed using ASTM method D-146
All results in percent

Table 3-6
VOCs in Air Building 1416 Former Kelly AFB, Texas

Sample ID		1416-SM-1		1416-SM-2		1416-SM-3		1416-SM-4		1416-SM-ODW		1416-SM-ODE		1416-SM-DUP	
Collection Data	**RL**	**03-Dec-08**		**03-Dec-08**		**03-Dec-08**		**03-Dec-08**		**03-Dec-08**		**03-Dec-08**		**03-Dec-08**	
PCE	0.020	0.059		0.64		0.054		0.054		0.042		0.051		0.064	
TCE	0.02	0.17		0.28		0.10		0.20		0.030		0.048		0.18	
cis-1,2-DCE	0.08	<0.14		<0.14		<0.14		<0.13		<0.13		<0.14		<0.14	
trans-1,2-DCE	0.40	<0.69		<0.68		<0.68		<0.67		<0.64		<0.71		<0.69	
1,1-DCE	0.040	<0.069		<0.068		<0.068		<0.067		<0.064		<0.071		<0.069	
1,2-DCA	0.081	0.23		0.23		0.43		0.050	J	0.048	J	0.054	J	0.22	
Freon 113	0.77	0.77	J	0.83	J	0.65	J	0.59	J	0.66	J	0.63	J	0.76	J
Vinyl chloride	0.03	0.015	J	<0.044		0.024	J	<0.043		<0.041		<0.046		<0.045	

Data Validity Qualifier(s):
J-The analyte was positively identified and the result is usable; however, the analyte concentration is an estimated value.

Definitions:
DCA-dichloroethane
DCE-dichloroethene
EPA-Environmental Protection Agency
μg/m^3-micrograms per cubic meter
NA-not analyzed
N/A-not applicable
ND-not detected
PCE-tetrachloroethene
RL-reporting limit
TCE-trichloroethene
VOC-volatile organic compound

Notes:
Samples analyzed using EPA method TO-15 SIM
All results in μg/m^3

Table 3-7
Comparison of EPA Methods TO 15 and TO 17 Air Sample Results Building 1416 Former Kelly AFB, Texas

		PCE					TCE				
	Method:	**TO-15**		**TO-17**			**TO-15**		**TO-17**		
	RL:	**0.020**		**0.15**		**RPD**	**0.016**		**0.14**		**RPD**
Sample Location	**Collection Date**										
1416-1	03-Dec-08	0.059		ND		N/A	0.17		0.13		27%
1416-2	03-Dec-08	0.64		ND		N/A	0.28		0.17		49%
1416-3	03-Dec-08	0.054		0.060	J	11%	0.10		0.099	J	1%
1416-4	03-Dec-08	0.054		ND		N/A	0.20		0.20		0%
1416-ODW	03-Dec-08	0.042		ND		N/A	0.030		0.053	J	55%
1416-DUP	03-Dec-08	0.064		0.078	J	20%	0.18		0.18		0%

Data Validity Qualifier:
J-The analyte was positively identified and the result is usable; however, the analyte concentration is an estimated value.
Definitions:
EPA-Environmental Protection Agency
µg/m^3-micrograms per cubic meter
N/A-not applicable
NS-not sampled
ND-not detected
PCE-tetrachloroethene
RL-reporting limit
TCE-trichloroethene
VOC-volatile organic compound
Notes:
All results in µg/m^3
All samples collected over a concurrent 24-hour period

3.2.4 Variances

Groundwater samples were not collected from the site. During drilling, groundwater was not encountered in any of the borings, with the exception of boring 1416-SG-5, where possibly groundwater bearing zones were encountered in sands at 27 ft bgs and clays at 28 ft bgs. This finding was consistent with the measured groundwater tables at 25 and 28 ft bgs in nearby wells, as discussed in Section 3.2.1. A temporary PVC well was installed in boring 1416-SG-5 and left to fill with formation groundwater overnight. However, a down-well sounder indicated that no groundwater was present the following day, and it was decided that any formation groundwater present at the site would likely take more than several days to infiltrate the open borings and temporary wells installed by the field crew. In addition, several borings encountered refusal in gravels at depths shallower than the measured groundwater tables in the nearby wells. Therefore, no groundwater samples were collected as it was not feasible.

Only one SUMMA canister (and one collocated Radiello sampler) was deployed in the paint room. The work plan proposed a second indoor air sample in the paint room at location 1416-SS-5; however, because the paint room roll-up door was open for most of the day, it was determined that collection of two indoor air samples from this room was not warranted.

A Radiello sampler was not deployed at location 1416-ODE because the laboratory only provided six samplers.

3.3 Analytical Data results

3.3.1 Meteorology During Sampling Event

The Helium for the air exchange rate investigation was released at 0750 on 3 December 2008 and sampling for Helium in indoor air was performed from 0805 to 1750 on 3 December 2008. The SUMMA canisters and Radiello badges were deployed at 1345 on 3 December 2008 and sampling was stopped at 1345 on 4 December 2008. Soil gas sampling was conducted between 1135 and 1400 on 4 December 2008. Figure 3-7 and Figure 3-8 illustrate local meteorological data from 3 and 4 December 2008, respectively. The data were gathered from weather station KSKF at Kelly AFB Airport, located approximately one mile south of Building 1416 (Weather Underground 2008).

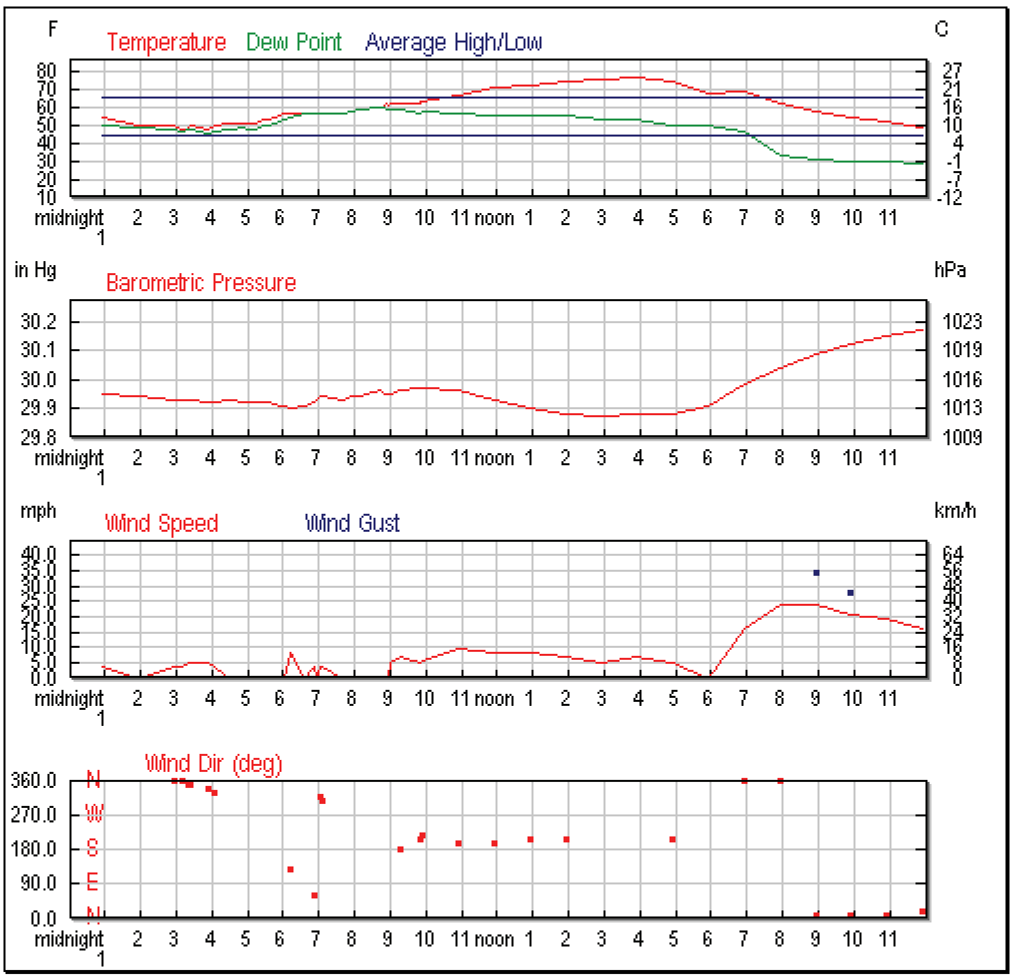


Figure 3-7
Meteorological data for 3 December 2008, collected from weather station KSKF. (Source: Weather Underground 2008).

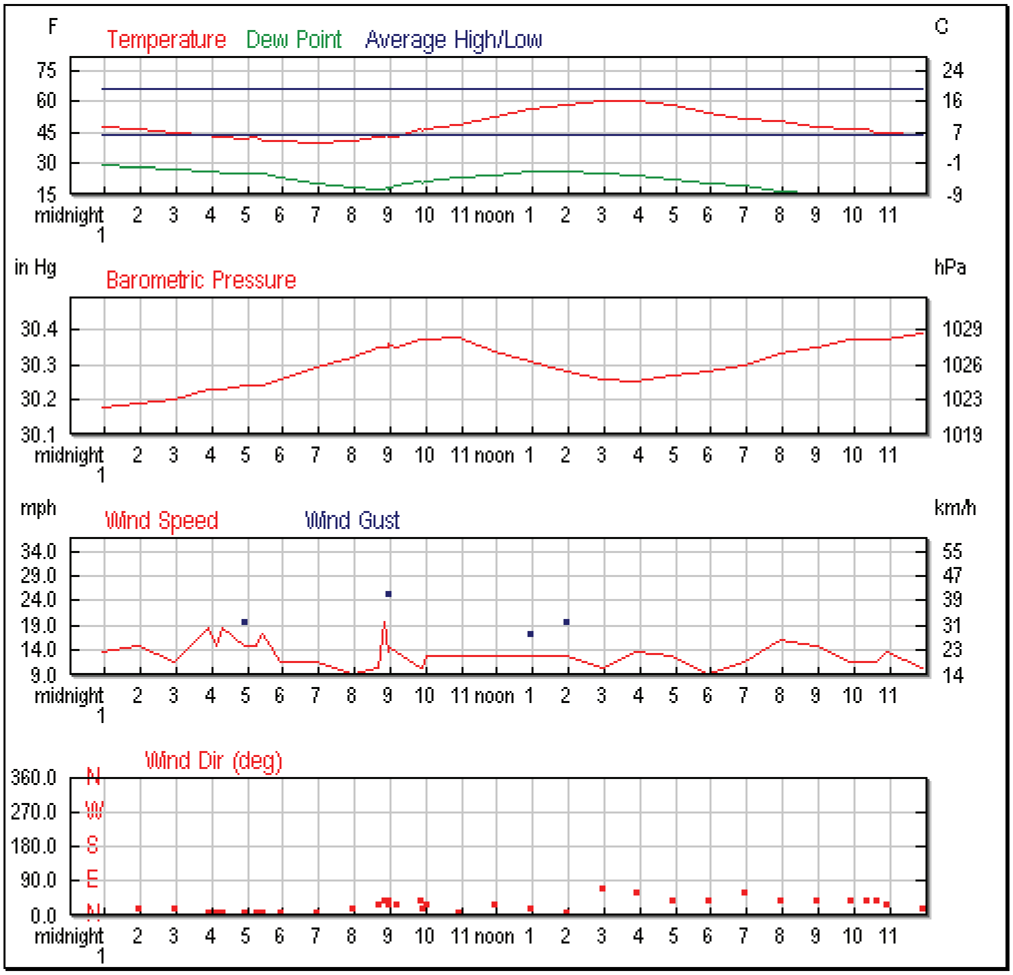


Figure 3-8
Meteorological data for 4 December 2008, collected from weather station KSKF. (Source: Weather Underground 2008).

3.3.2 Soil Physical Properties

Off-site laboratory analysis for soil physical properties was performed by Keantan Laboratories, located in Diamond Bar, California. Soil samples 1416SG2-11, 1416SG6-15, and 1416SG6-21 were analyzed for moisture content, dry density, total organic carbon (TOC), total porosity, effective permeability, and air conductivity. Analytical test results are presented in Table 3-3 and discussed in Section 4.0. Boring logs describing soil lithology at sample depth are provided in Appendix A. The laboratory report for these analyses is provided as Appendix B.

3.3.3 Soil Vapor Sample Results

Off-site laboratory analysis for soil gas samples was performed by H&P Laboratories, located in Carlsbad, California. Indoor sub-slab samples 1416-SS-1 through 1416-SS-5 and 1416-SS-Dup3 (associated with sampling location 1416-SS-3), and outdoor samples 1416-SG1-15, 1416-SG1-23, 1416-SG2-SS, 1416-SG2-15, 1416-SG2-18, 1416-SG3-SS, 1416-SG3-15, 1416-SG3-24, 1416-SG4-15, 1416-SG4-25, 1416-SG5-15, 1416-SG5-25, 1416-SG6-SS, 1416-SG6-15, 1416-SG6-22, 1416-SG7-SS, 1416-SG7-15, 1416-SG7-20, 1416-SG8-15, 1416-SG8-23, 1416-SG-Dup1 and 1416-SG-Dup2 (associated with sampling locations 1416-SG3-24 and 1416-SG6-22, respectively) were analyzed for VOCs using EPA method SW8260 and TO15. All samples were initially analyzed using method SW8260; the samples from locations 1416-SS-3 through 1416-SS-5 were subsequently reanalyzed using method TO15 to attain lower detection levels. Analytical results are presented in Table 3-4 and are discussed in Section 4.0. The laboratory report is provided as Appendix C.

3.3.4 Indoor and Outdoor Air Data

Off-site laboratory analysis for indoor air in support of the air exchange rate investigation was performed by Air Toxics Ltd., located in Folsom, California. All samples were analyzed for Helium in air by modified ASTM Method D-1946. Analytical data results are presented in Table 3-5 and are discussed in Section 4.0. Laboratory reports are provided in Appendix D.

Off-site laboratory analysis for indoor and outdoor air samples was performed by Air Toxics Ltd. Samples 1416-SM-1 through 1416-SM-4, 1416-SM-ODE, 1416-SM-ODW, and 1416-SM-Dup, collected with SUMMA canisters, were analyzed using EPA method TO-15 in selected ion monitoring (SIM) mode. Samples 1416-RD-1 through 1416-RD-4, 1416-RD-ODW, and 1416-RD-Dup, collected with passive diffusion Radiello badges, were analyzed using EPA method TO-17. The badges were co-located with SUMMA canisters to assess the comparability of results obtained via the two methods. Analytical data results for TO-15 are presented in Table 3-6 and results from the two methods are compared in Table 3-7. Laboratory data reports are provided in Appendix D.

3.3.5 QA/QC Considerations

All laboratory analyses and data validation were performed in accordance with Appendix E. One QA/QC issue was identified during the investigation:

- The paint-room roll-up door was open throughout much of the day during the field sampling. In addition, the paint booth was used intermittently, which includes a large capacity blower to draw air into the booth and back out to the atmosphere via a roof-mounted vent. Operation of the paint booth likely induced extremely high air exchange rates in the paint room. Due to these consideration, the air exchange rate assessment was limited to the east half of the building, excluding the paint room. Nevertheless, it is possible that operation of the paint booth affected the air exchange rates in the rest of the building, but the significance of the effect is not known.

4 Analysis of Data

4.1 Air Exchange Rate (AER) Analysis

Air exchange rates were experimentally determined by instantaneously releasing a known mass of helium into Building 1416, and periodically collecting samples of air containing helium in the building at times subsequent to the release. The theoretical basis for each of two methods used is presented in Appendix H. The results are presented graphically in Figure 4-1 for each of the two methods. The predicted air exchange rate ranged from 27.1/day (Method 2) to 37.6/day for Method 1. Method 2, as described in Appendix H, does not rely on knowing the initial mass of helium released, while Method 1 does.

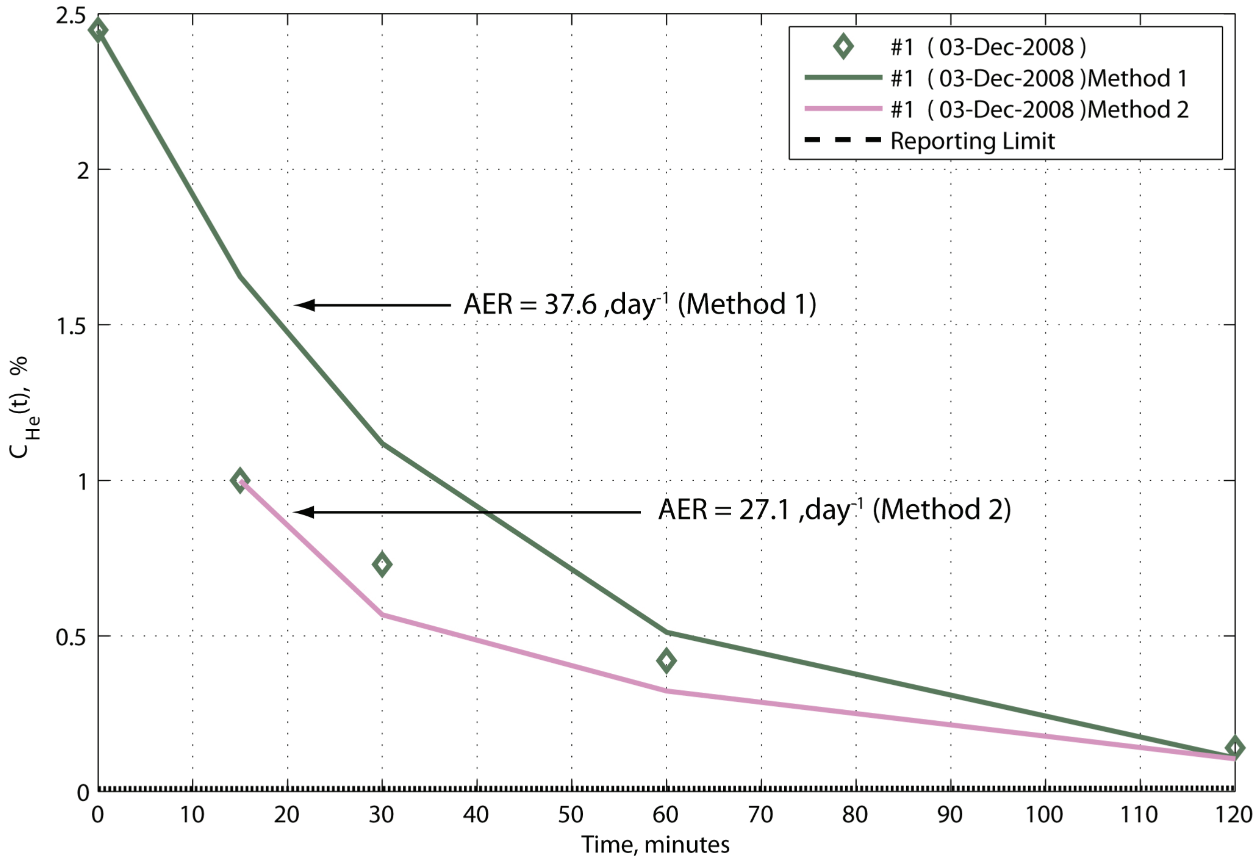


Figure 4-1
Analysis of Air Exchange Rate (AER) Using Instantaneously Released He. (Method 1 and 2)

Due to ongoing Air Force activities in a portion of Building 1416 (paint room), the AER calculated was in the remaining part of the building and the door between that part of the building and the paint room was closed. The volume of the portion of the building for which AERs were calculated was 14,200 ft^3. The volumes of the restroom, shop, classroom, and entry are shown in Figure 4-2, along with the locations of the three helium-containing cylinders. The mass of helium in the three cylinders was determined by directly weighing the three cylinders, and was found to be 1.54 kg.

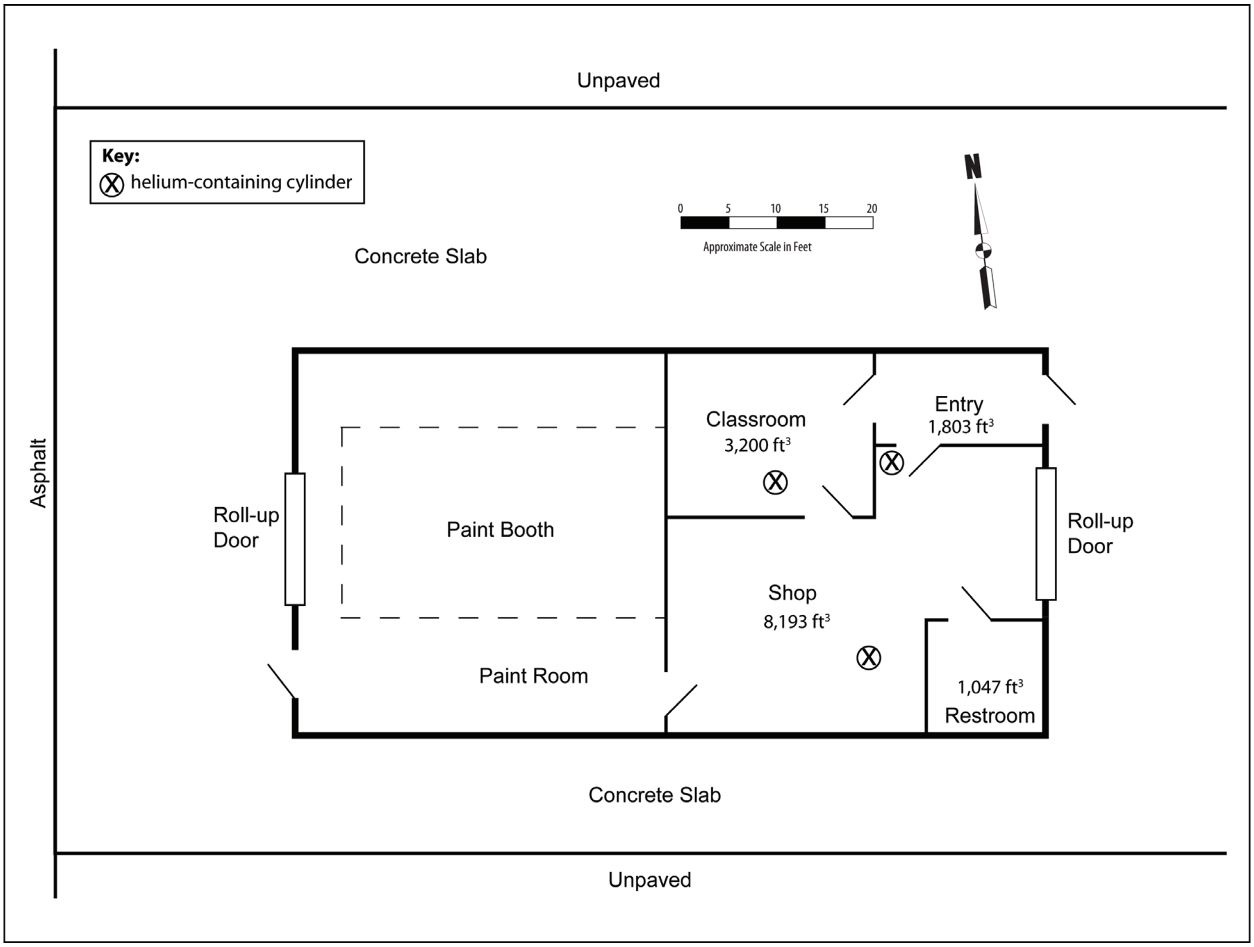


Figure 4-2
Floor plan for Building 1416, with volumes of classroom, shop, entry, and restroom shown. Also shown are the locations of the three helium-containing cylinders.

The AERs for Building 1416 were higher than expected based on previous applications at other sites, and consequently the helium concentration dropped off to near background in a little over two hours. Sample collection continued after 120 minutes because preliminary calculations prior to the fieldwork predicted the air exchange rate would be lower, and helium would be detectable for a longer period of time. The AER information is used subsequently in simulating soil vapor intrusion.

4.2 Discussion of sub-slab data, near-slab data, indoor air data, and outdoor air data collected during the field investigation

The focus of this discussion is on TCE and cis-1,2-DCE and their distribution as characterized by the samples collected. These two chemicals were most often found to be above detection limits. All of the TCE data collected are shown in Table 4-1, and all of the cis-1,2-DCE data are shown in Table 4-2. Section 5.0 presents analyses of these data using the Johnson and Ettinger (J&E) model (Johnson and Ettinger 1991) and the Vapor Intrusion Model (ViM) (Mills, et al. 2007). The source terms used as input for the J&E and ViM models are developed from the data presented in Tables 4-1 and 4-2, and can change depending on how the data are processed; therefore, Tables 4-1 and 4-2 also show the alternative source terms used as model input in Section 5.0.

Table 4-1
TCE data collected at Former Kelly AFB December 4, 2008

Location/Surface Cover	Soil Gas, µg/m³				Indoor Air, µg/m³	Outdoor Air, µg/m³
	Sub-Slab		Shallow (15 ft)	Deep (18-25 ft)		
	Concrete Slab (Outdoor)	Concrete Slab (Indoor)				
SG-1/Unpaved	-	-	3000	40000	-	-
SG-2/Concrete Slab (Outdoor)	350	-	2900	42000	-	-
SG-3/Concrete Slab (Outdoor)	<100 *	-	5200	77000	-	-
SG-4/Unpaved	-	-	8600	29000	-	-
SG-5/Unpaved	-	-	1200	10000	-	-
SG-6/Concrete Slab (Outdoor)	250	-	1800	21000	-	-
SG-7/Concrete Slab (Outdoor)	190	-	6400	24000	-	-
SG-8/Unpaved	-	-	970	26000	-	-
SS-1/Concrete Slab (Indoor)	-	160	-	-	0.17	-
SS-2/Concrete Slab (Indoor)	-	100	-	-	0.28	-
SS-3/Concrete Slab (Indoor)	-	<5 *	-	-	0.1	-
SS-4/Concrete Slab (Indoor)	-	5.1	-	-	0.2	-
SS-5/Concrete Slab (Indoor)	-	<5 *	-	-	-	-
ODWConcrete Slab (Outdoor)	-	-	-	-	-	0.03
ODE/Concrete Slab (Outdoor)	-	-	-	-	-	0.048
Alternative Source Term Representations						
Maximum, µg/m³	350	160	8600	77000	0.28	0.048
Arithmetic mean, µg/m³	210	54	3759	33625	0.19	0.039
Spatially Weighted mean, µg/m³	203	42	3907	35235	-	-
UCL95	-	-	5584	47216	-	-

* 1/2 the detection limit was used in the calculation of means for these samples.
Note: Spatially Weighted mean was calculated using an inverse distance weighting interpolation with a variable search radius and distance power of 2.

Table 4-2
cis-1,2-DCE data collected at Former Kelly AFB December 2008.

Location/Surface Cover	Soil Gas, µg/m³ Sub-Slab Concrete Slab (Outdoor)	Soil Gas, µg/m³ Sub-Slab Concrete Slab (Indoor)	Soil Gas, µg/m³ Shallow (15 ft)	Soil Gas, µg/m³ Deep (18-25 ft)	Indoor Air, µg/m³	Outdoor Air, µg/m³
SG-1/Unpaved	-	-	1700	12000	-	-
SG-2/Concrete Slab (Outdoor)	<500 *	-	1100	6300	-	-
SG-3/Concrete Slab (Outdoor)	<500 *	-	1300	9100	-	-
SG-4/Unpaved	-	-	5500	12000	-	-
SG-5/Unpaved	-	-	740	2500	-	-
SG-6/Concrete Slab (Outdoor)	<500 *	-	850	4900	-	-
SG-7/Concrete Slab (Outdoor)	<500 *	-	3500	7100	-	-
SG-8/Unpaved	-	-	690	7800	-	-
SS-1/Concrete Slab (Indoor)	-	<500 *	-	-	< 0.14 *	-
SS-2/Concrete Slab (Indoor)	-	<500 *	-	-	< 0.14 *	-
SS-3/Concrete Slab (Indoor)	-	<5 *	-	-	< 0.13 *	-
SS-4/Concrete Slab (Indoor)	-	<5 *	-	-	< 0.13 *	-
SS-5/Concrete Slab (Indoor)	-	<5 *	-	-	-	-
ODWConcrete Slab (Outdoor)	-	-	-	-	-	< 0.14 *
ODE/Concrete Slab (Outdoor)	-	-	-	-	-	< 0.14 *
Alternative Source Term Representations						
Maximum, µg/m³	< 500	< 500	5500	12000	< 0.14	< 0.14
Arithmetic mean, µg/m³	250	101.5	1922.5	7712.5	0.068	0.07
Spatially Weighted mean, µg/m³	250	87	1892	7415	-	-
UCL95	-	-	3490	9922	-	-

* 1/2 the detection limit was used in the calculation of means for these samples.
Note: Spatially Weighted mean was calculated using an IDW interpolation with a variable search radius and distance power of 2.

These data have been plotted in Figure 4-3 for TCE and in Figure 4-4 for cis-1,2-DCE. Both figures show plan views of the site and illustrate the extent of the concrete slab, the unpaved area, and the asphalt. The outdoor vadose zone samples and sub-slab samples were taken at either two or three depths, and the depths are shown next to the sample concentrations.

Five indoor sub-slab samples were collected (sub-slab means the samples were collected just beneath the slab) and indoor air concentrations were determined at four of these locations (the yellow coded samples shown in the figures). Outdoor air samples were collected just outside of the building near the east and west facing walls. The indoor air TCE concentrations ranged from 0.1µg/m^3 to 0.28µg/m^3, while the outdoor samples were approximately an order of magnitude less. For cis-1,2-DCE all air samples were below detection limits. The TCE results are suggestive of the occurrence of vapor intrusion, while it is not possible to make such a determination for cis-1,2-DCE because all indoor and outdoor concentrations are below detection limits.

The VOC source beneath Building 1416 is a mature contaminated groundwater plume, yet it can be seen in Table 4-1 and Figure 4-3 that the five measured sub-slab TCE concentrations beneath the building varied from non-detect with a detection level of 5.0 µg/m^3 to 160 µg/m^3, which is a factor of more than 30 times. This is an important observation, as it indicates that sub-slab concentrations are highly variable, and it is necessary to collect numerous samples in order to adequately characterize the sub-slab environment. Conversely, TCE concentrations measured at eight locations at 15 feet bgs and at 18 to 25 feet bgs varied by less than a factor of 10. The reason for the greater variability in sub-slab concentrations is not known; however, two possibilities are (1) heterogeneity in the soil column affects the rate of upward diffusion and/or degradation such that the rate at which TCE reaches the sub-slab environment is variable, or (2) the slab and underlying, relatively high permeability, aggregate base material promote lateral diffusion toward certain areas under the slab. This could be due to varying thickness of the base material, or the presence of utility penetrations through the slab (for example, the highest concentrations measured beneath Building 1416 were in and adjacent to the restroom).

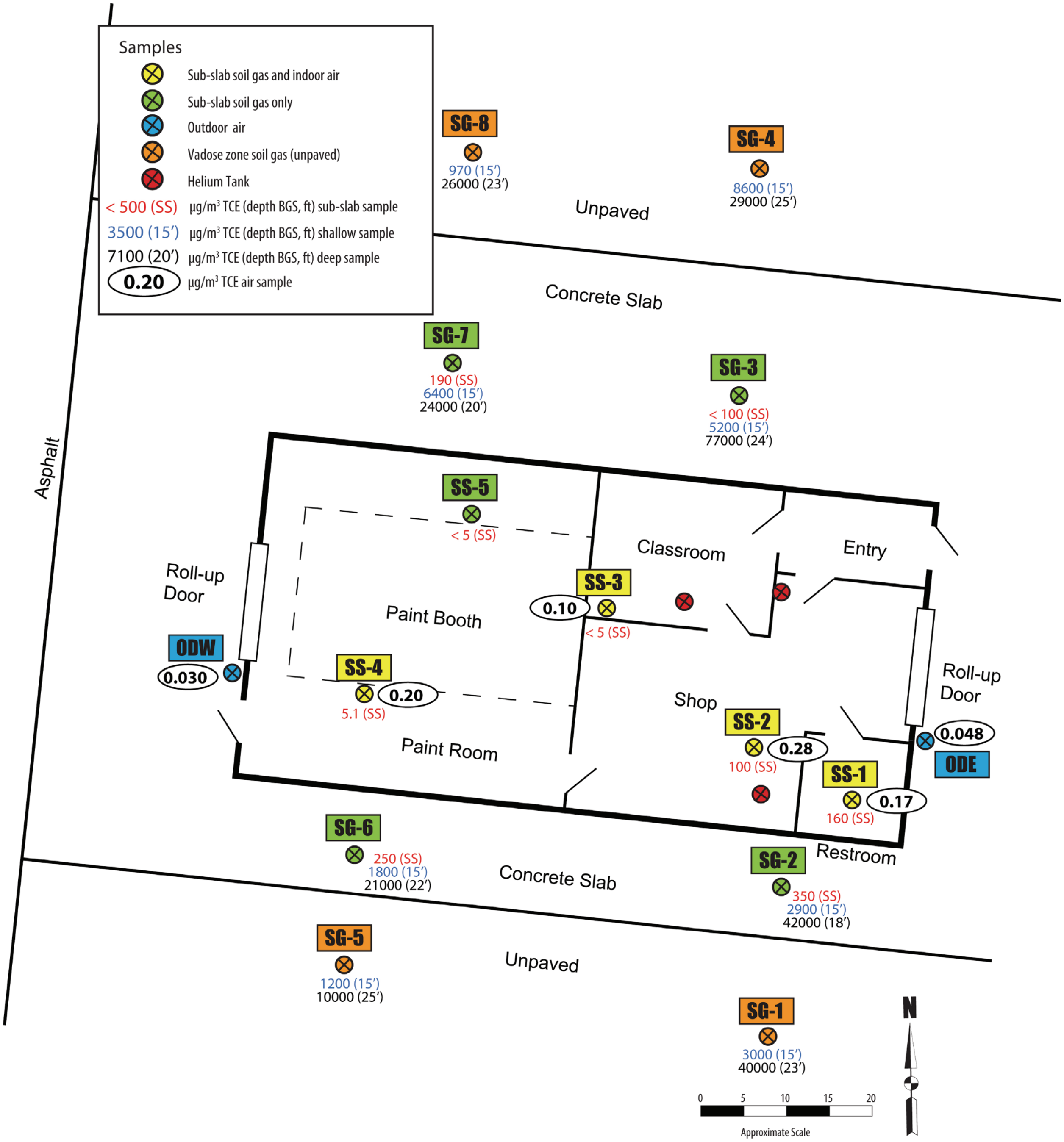


Figure 4-3
Profile view of Building 1416 with TCE data included

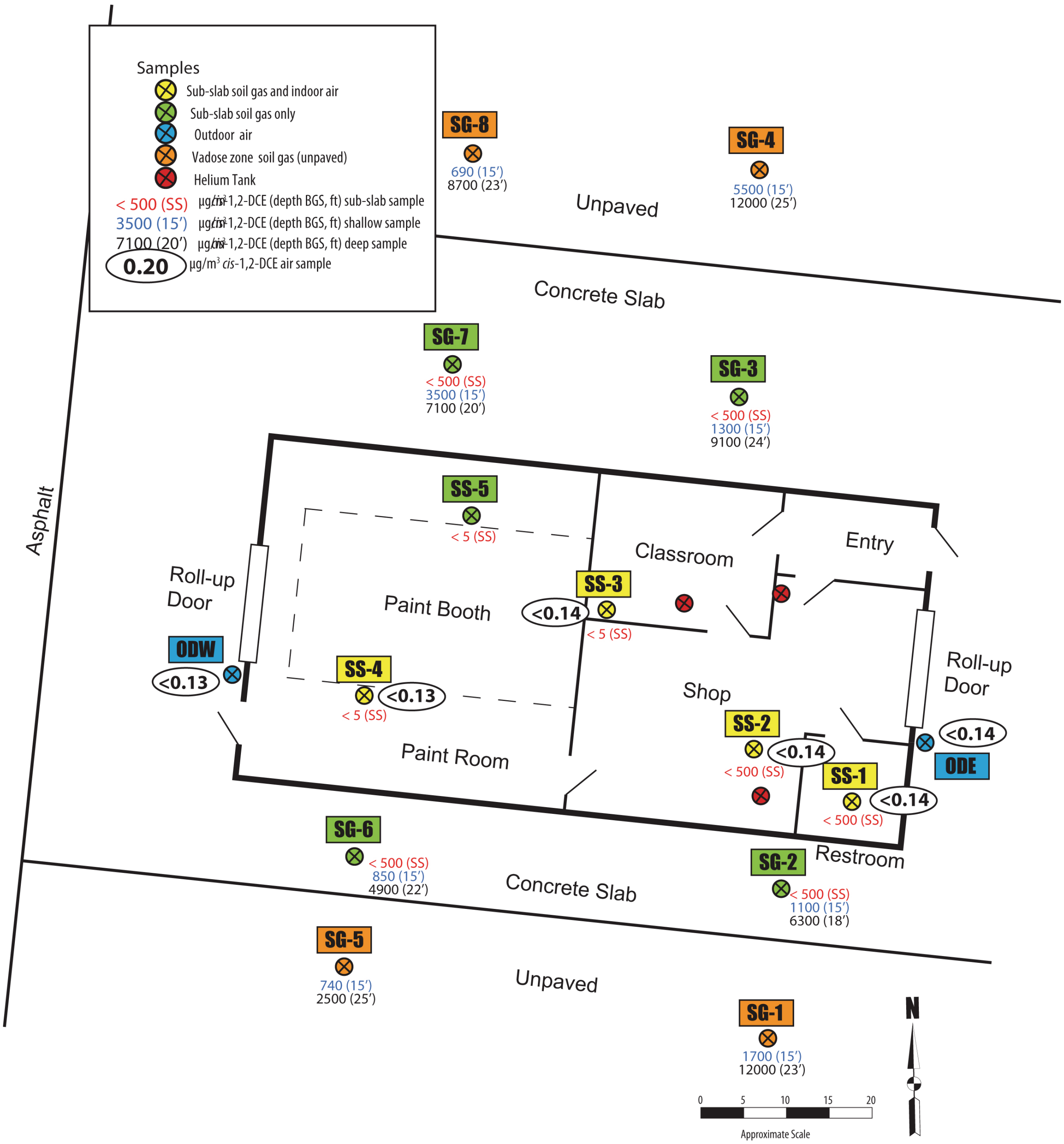


Figure 4-4
Profile view of Building 1416 with cis-1,2-DCE data included

Two transects (transect #1 and transect #2) have been created that show the distribution of cis-1,2-DCE and TCE in the soil over depth, in indoor air, and in outdoor air. See Figure 4-5 for transect 1 and Figure 4-6 for transect 2. Results for cis-1,2-DCE are shown on the top half of each figure, and results for TCE are shown on the bottom half. Looking at TCE results first it is clear that the highest concentrations are those deepest in the soils (and range from about 7,700 µg/m^3 to 42,000 µg/m^3). The depth to groundwater is not known precisely but evidence indicates groundwater is only a few feet beneath the deepest samples. While deep soil gas samples were not collected directly beneath the building, the patterns of deep soil gas concentration on each side of the building suggest concentrations beneath the building are similar to those on either side of the building. At mid depth (e.g., about 15 feet (4.6m) below ground surface) concentrations are dramatically lower, by up to a factor of 10 or more. The rapid concentration decreases continue from mid depth to the sub-slab level. It is interesting to note that sub-slab TCE concentrations beneath Building 1416 are generally less than the sub-slab concentrations outside the footprint of the building. For example sub-slab TCE concentrations beneath the building along transect #1 are about 5 $\mu g/m^3$, while at SG-6 and SG-7 the sub-slab concentrations are 250 $\mu g/m^3$ and 190 $\mu g/m^3$, respectively. To a lesser degree this pattern is present at transect #2 for TCE. In spite of these lower concentrations, sub-slab sub-building concentrations are generally well above indoor air concentrations, suggestive of the possibility of vapor intrusion.

Reasons for the observed pattern of sub-slab concentrations are not known. A possibility includes the following: the slab foundation within the building footprint might offer less resistance to diffusion than does the slab outside the building. This could be caused by additional cracking, preferential pathways, or a thinner slab.

The patterns for cis-1,2-DCE are similar to those for TCE: high concentrations at depth to rapidly decreasing concentrations near the surface. However, sub-slab concentrations are ND at all locations. Due to the higher TCE concentrations (compared to cis-1,2-DCE concentrations) the modeling analysis will focus on TCE, and modeling results are presented in the following section.

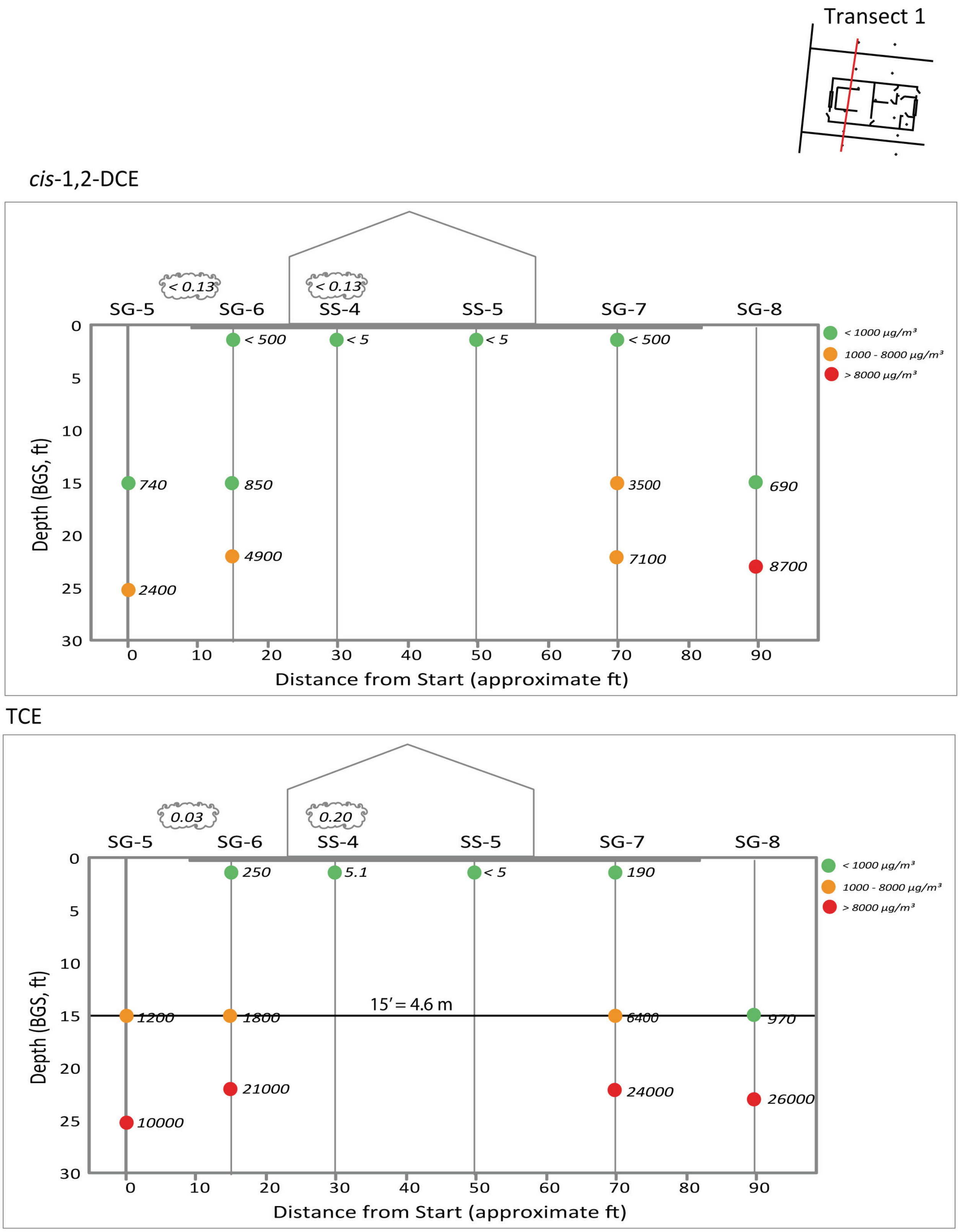
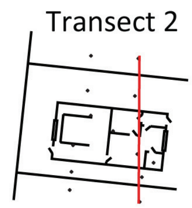
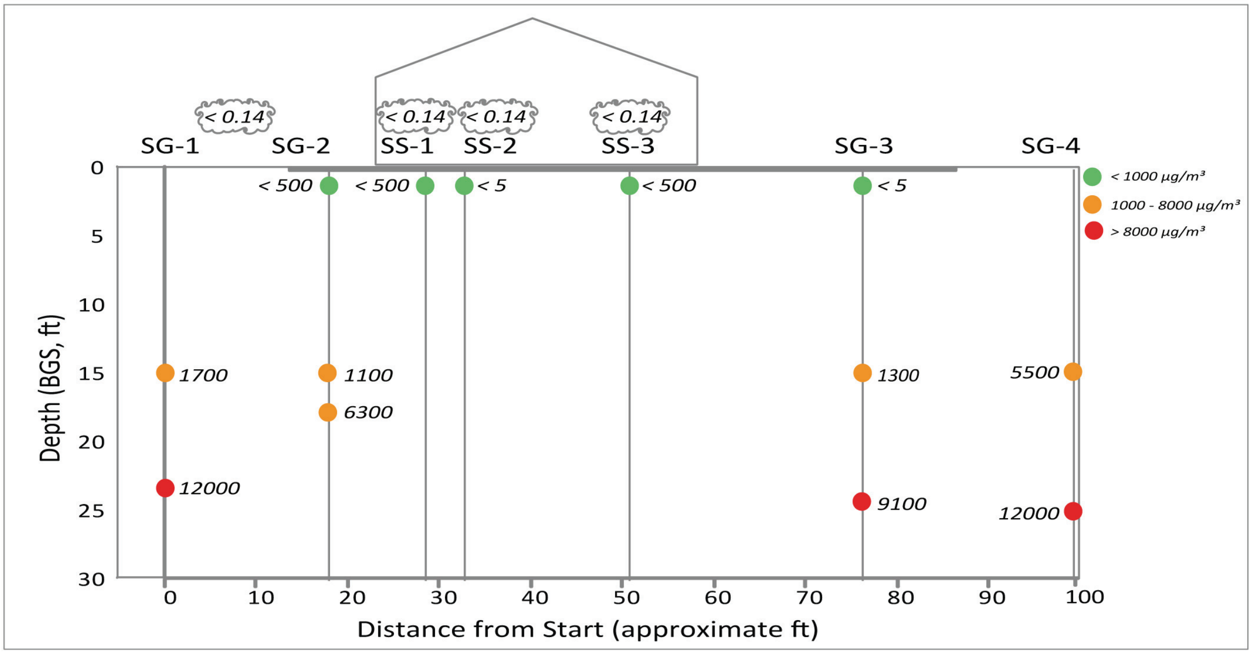


Figure 4-5
cis-1,2-DCE and TCE concentrations along transect #1



cis-1,2-DCE



TCE

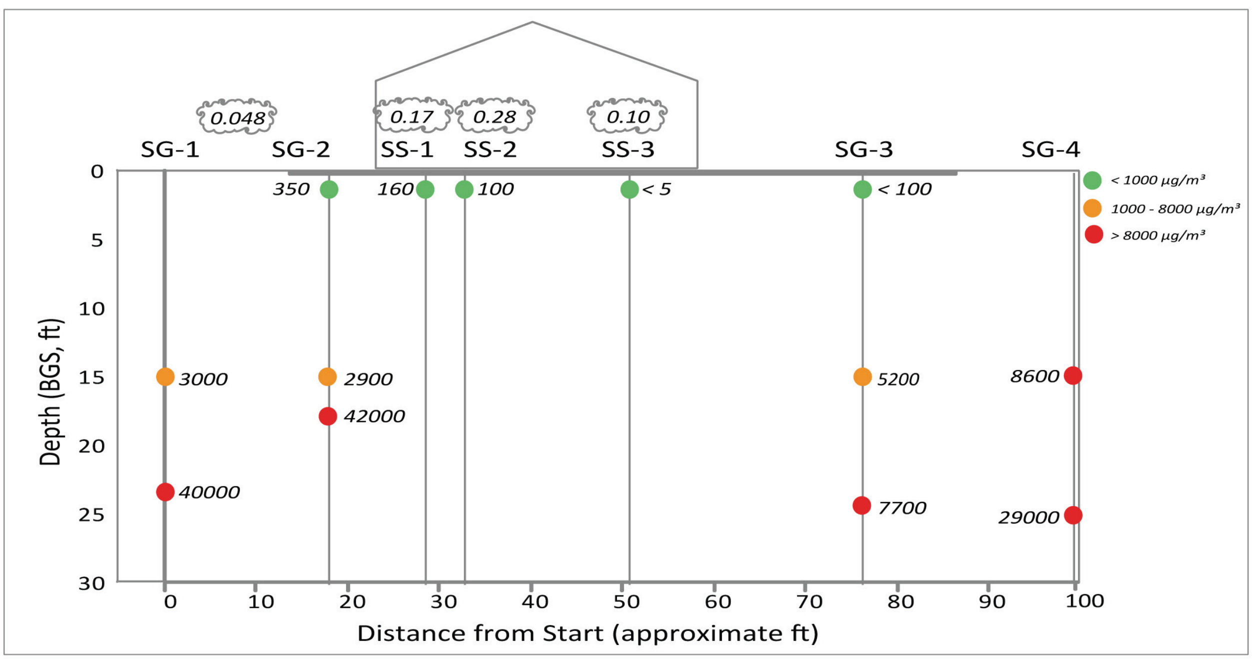


Figure 4-6
cis-1,2-DCE and TCE concentrations along transect #2

5 VAPOR INTRUSION MODELING RESULTS

5.1 Background and Approach

Vapor intrusion into Building 1416 was simulated using two modeling approaches: the J&E Model (Johnson & Ettinger, 1991) and ViM (Mills et al., 2007). Detailed descriptions of each model can be found in these two references. A summary comparison is shown in Table 5-1. The J&E model is the simpler of the two models and assumes a steady-state source term. ViM allows for a time-variable source term. Another difference in the two models is that ViM has the option of using a Monte Carlo analysis. This feature can be used to create a confidence interval about the predicted results, assuming a range of input data can be reasonably specified. This feature is used in the modeling predictions that follow.

Table 5-1
ViM and J&E Comparison

Capability	ViM	J&E/EPA
Basements, slab-on-grade	✓	✓
Crawl space	✓	
Multiple compartments	✓	
Outdoor air intrusion	✓	
Non-steady conditions	✓	
Lifetime exposure	✓	✓
Monte Carlo: Uncertainty Analysis	✓	
Chemical Processes: biodecay, adsorption	✓	
Sensitivity Analysis	✓	✓

Modeling simulations have been completed for TCE. Since ViM can simulate five different building configurations (such as one-story buildings with crawl spaces or one-story buildings with slab-on-grade foundations), the appropriate building type for Building 1416 was selected (slab-on-grade). Data used by the two models were the same when possible. Examples of the datasets are shown in Appendices F and G.

An overview of the TCE data collected at the site was shown previously in Table 4-1. Also shown near the bottom of that table are source term concentrations generated using four different metrics and alternative source configurations:

- Four alternative metrics were used for each source term:
  - arithmetic mean
  - spatially weighted mean
  - UCL_{95}
  - Maximum
- Two alternative source configurations were possible:
  - sub-slab soil gas data directly beneath the building
  - deeper vadose zone soil gas data that are not beneath the slab, combined with deeper soil gas data beneath the slab

Up to eight combinations of source terms can be generated and input to J&E and ViM. The focus here is on using deep soil gas as the source term where the source concentration is based on an arithmetic mean of the data. These analyses will later be supplemented by Monte Carlo analyses that compare ViM and JEM. JEM is a modified version of J&E developed for inclusion in the ViM modeling code. It produces identical solutions to the J&E model when identical input data are used. When tests are performed against ViM, such as thousands of Monte Carlo simulations, using JEM is the only practical way to evaluate how the Johnson and Ettinger model compares with ViM.

5.2 Model Results: Deterministic Simulations for TCE

One of the unknowns in simulating soil vapor intrusion is the time history of deep soil gas concentrations of the chemical of concern, in this case TCE. The J&E model assumes that the data collected at a point in time are representative of long term concentrations, and are at steady-state. ViM does not make that assumption and allows the source concentration to change over time as illustrated in Figure 5-1. In Figure 5-1, the source concentration is allowed to decrease slowly over a 20 year period. This decrease is small, and is intended to be illustrative; data are not available to verify this trend. To accurately configure the source term time series, concentrations are typically required at several points in time. Since such data are not available, the source of contamination was assumed to begin at year 2000, although an earlier starting point could have been chosen. Figure 5-2 shows simulated results for both ViM and the JEM model. The JEM model has been modified to account for the outdoor air TCE concentration (the original J&E model assumes this concentration is zero).

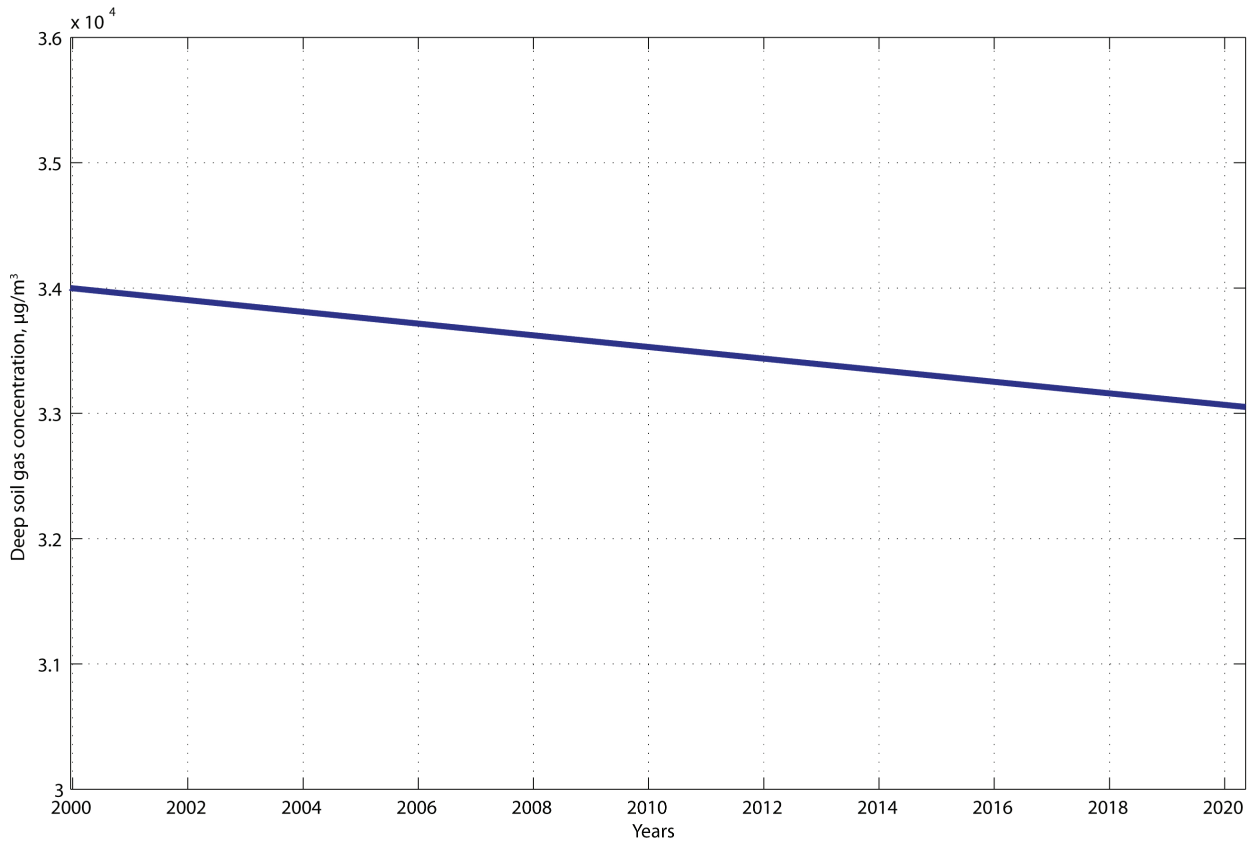


Figure 5-1
Time series of TCE deep soil gas concentrations used to model Building 1416. (Note: this time series is based on the assumption that soil gas concentrations are continuous, but slightly decreasing, over a long period of time. Data are not available to confirm this assumption.)

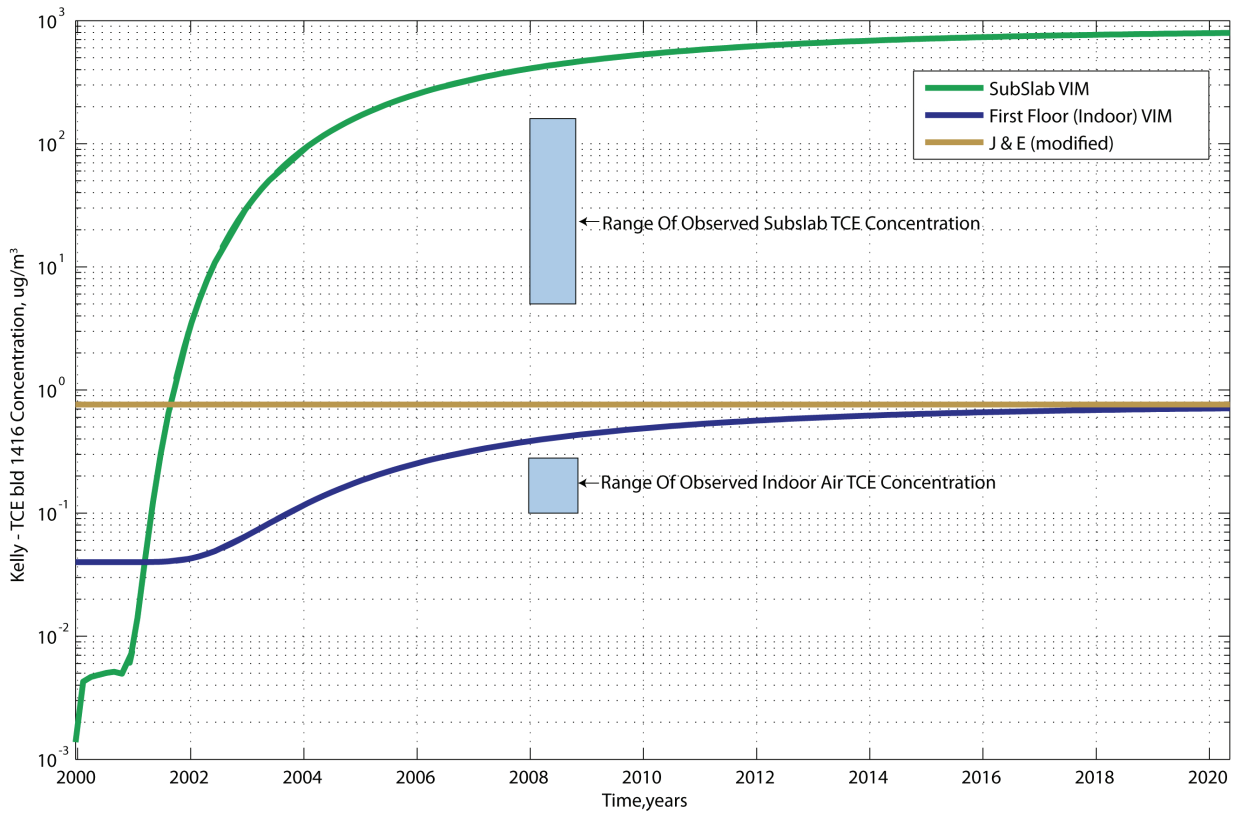


Figure 5-2
Predicted TCE concentrations for the sub-slab and indoor at Building 1416. (Note: the estimated range of observed concentrations is shown by the blue patches.)

ViM predictions for TCE are shown for both sub-slab (green line) and indoor air (blue line). Note that the indoor air concentrations predicted by ViM remain at background outdoor levels (about $4{\cdot}10^{-2}$ µg/m^3, as shown previously in Table 4-1) for about two years. In other words, it takes about two years for the deep soil vapor to travel upward and to intrude into the building at concentrations that cause indoor air concentrations to noticeably increase above background. The indoor air concentrations slowly increase to new steady-state conditions in about 12-14 years following the initiation of deep soil contamination. The steady-state J&E model is unable to show this behavior.

At the same time as indoor vapor concentrations are increasing, the sub-slab concentrations are increasing from near zero (and well below background ambient air concentrations as shown in Figure 5-2). Sub-slab concentrations are initially influenced by both deep soil vapor diffusing upward and low indoor air concentrations diffusing downward. As higher concentrations of soil vapor diffuse upward, sub-slab concentrations increase and take well over a decade to approach steady-state.

Based on the limited information available regarding the evolution of deep soil vapor over time, there is really no unique way to plot the observed data. Even though the data were collected in 2008, the data should be plotted relative to the beginning of deep soil contamination, which is not known. The modeling results suggest that deep soil gas concentrations, at the concentrations measured during this study, have been present for a number of years.

Figure 5-3 shows predicted soil vapor concentration profiles over a period of about 12 years following the assumed initiation of deep soil vapor volatilization. The plots clearly show that several years are required for the vapor to reach the sub-slab. Eventually, concentrations tend to stabilize (by about 12 years). The range of observed soil vapor concentrations is shown by the two blue patches, one at depth and the other directly beneath the slab. While there is an overlap between observed data and predicted results, in general it appears the model over predicts concentrations.

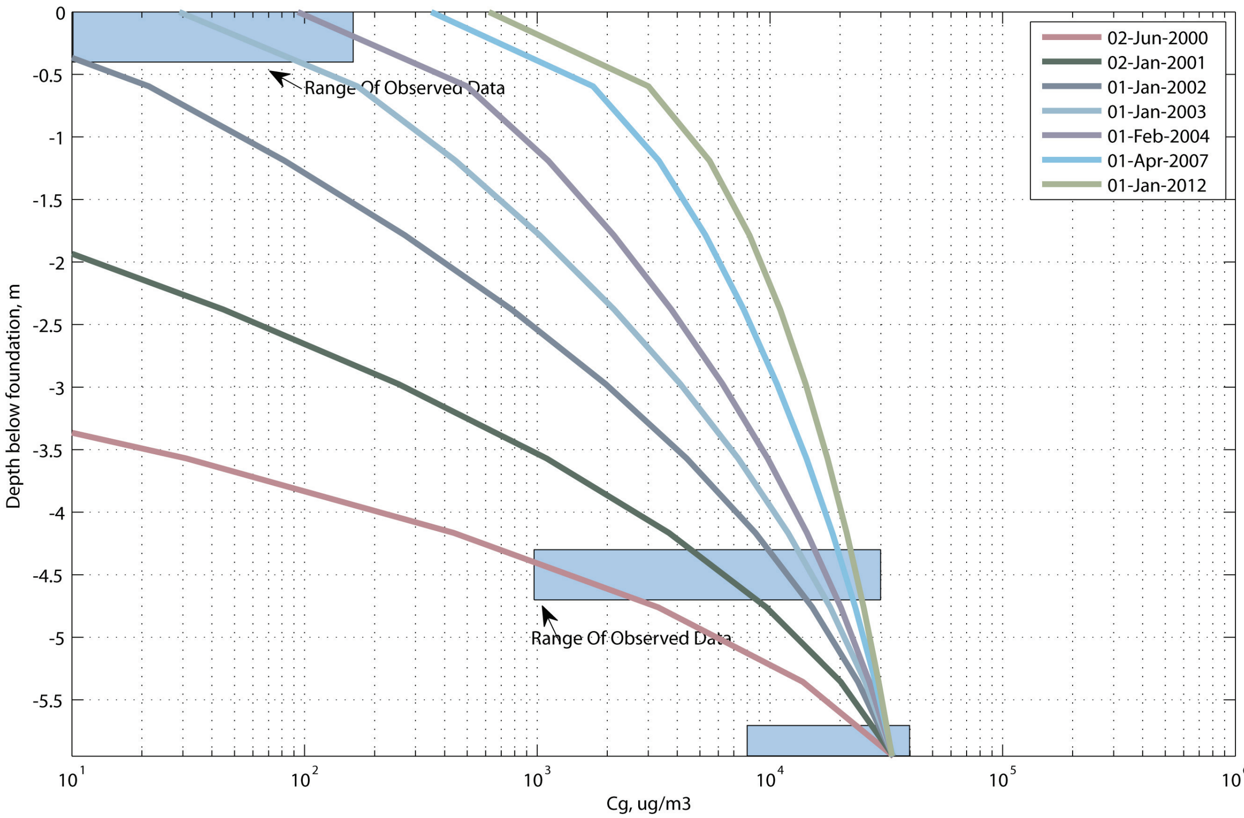


Figure 5-3
Predicted profiles of subsurface vapor phase TCE concentrations. The blue patches show the approximate range of observed data.

Figure 5-4 shows the attenuation factors predicted by ViM and JEM. For the first 10 years or so the attenuation factors increase, since higher concentrations are predicted to occur indoors and at sub-slab locations. These results indicate that using site-specific attenuation factors (that is, attenuation factors based on site data) may be problematic. Note that the attenuation factors are rapidly changing for the first six to eight years. Since it is the steady state attenuation factors that are used in models such as the J&E model, there is really no way to tell from limited site data whether the attenuation factors are at steady-state or not. A range of EPA attenuation factors (5 percentile to 95 percentile) are also plotted, and the results encompass model predictions that are near steady-state. Two calculated indoor air attenuation factors based on measured data are shown as red dots and two values of sub-slab attenuation factors are shown as green dots. One value was calculated for each transect, using average values of indoor air concentrations divided by average values of deep soil vapor concentrations or sub-slab concentrations, respectively. They are slightly lower or slightly above the predicted values.

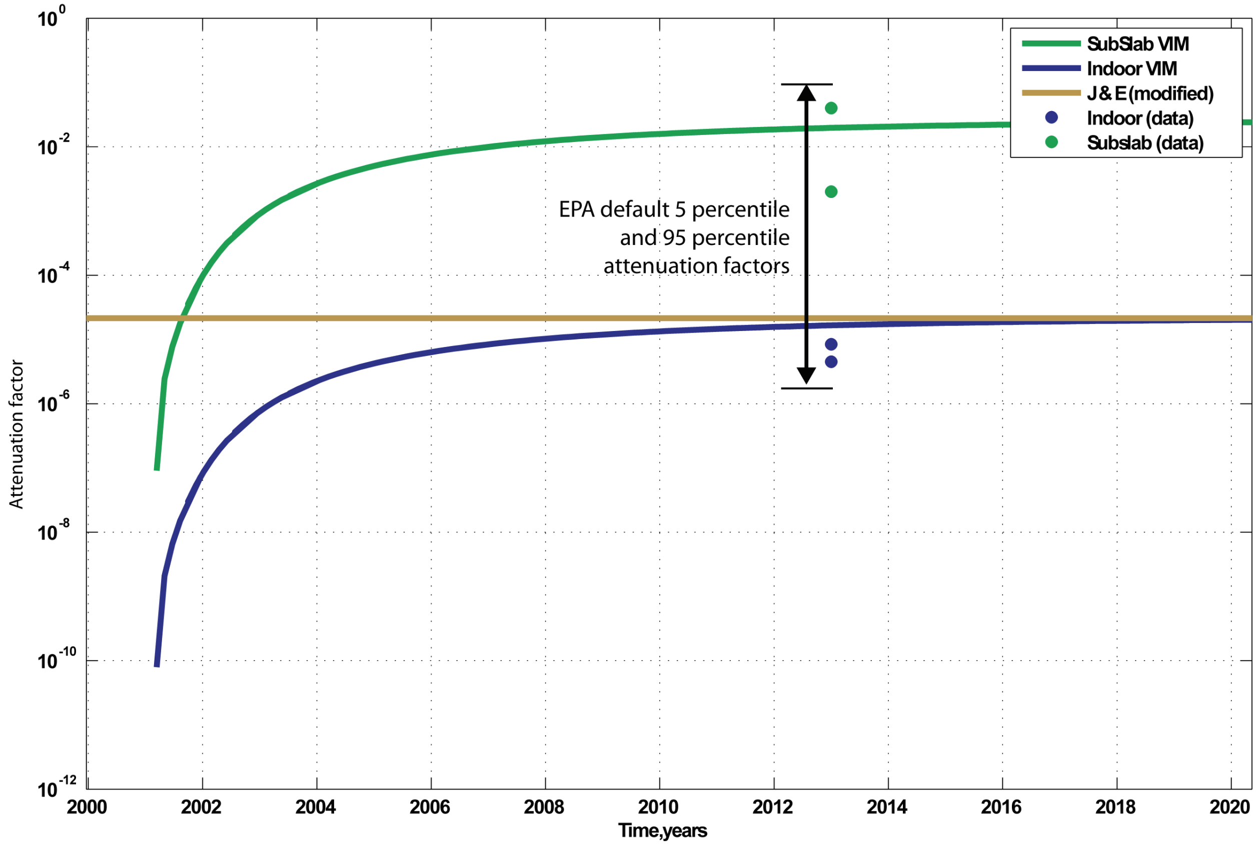


Figure 5-4
Predicted attenuation factors for TCE and calculated indoor air attenuation factors based on measured data.

One explanation for the difference in observed and predicted TCE concentrations (Figure 5-2) is that TCE, over the 20 year period of simulation, may be slowly biodegrading. The presence of cis-1,2-DCE, a degradation product of TCE decay, provides supporting evidence this is so. Even slow degradation rates, occurring over a long period of time, can reduce TCE concentrations. A typical biodegradation half life for TCE in the aqueous phase in soil is about 25 days. The predicted indoor and sub-slab concentrations for this case are shown in Figure 5-5. The blue patches are also shown. The predicted concentrations have noticeably dropped (20 to 30 fold) compared with those shown earlier in Figure 5-2. The indoor air concentrations are under predicted by a factor of four.

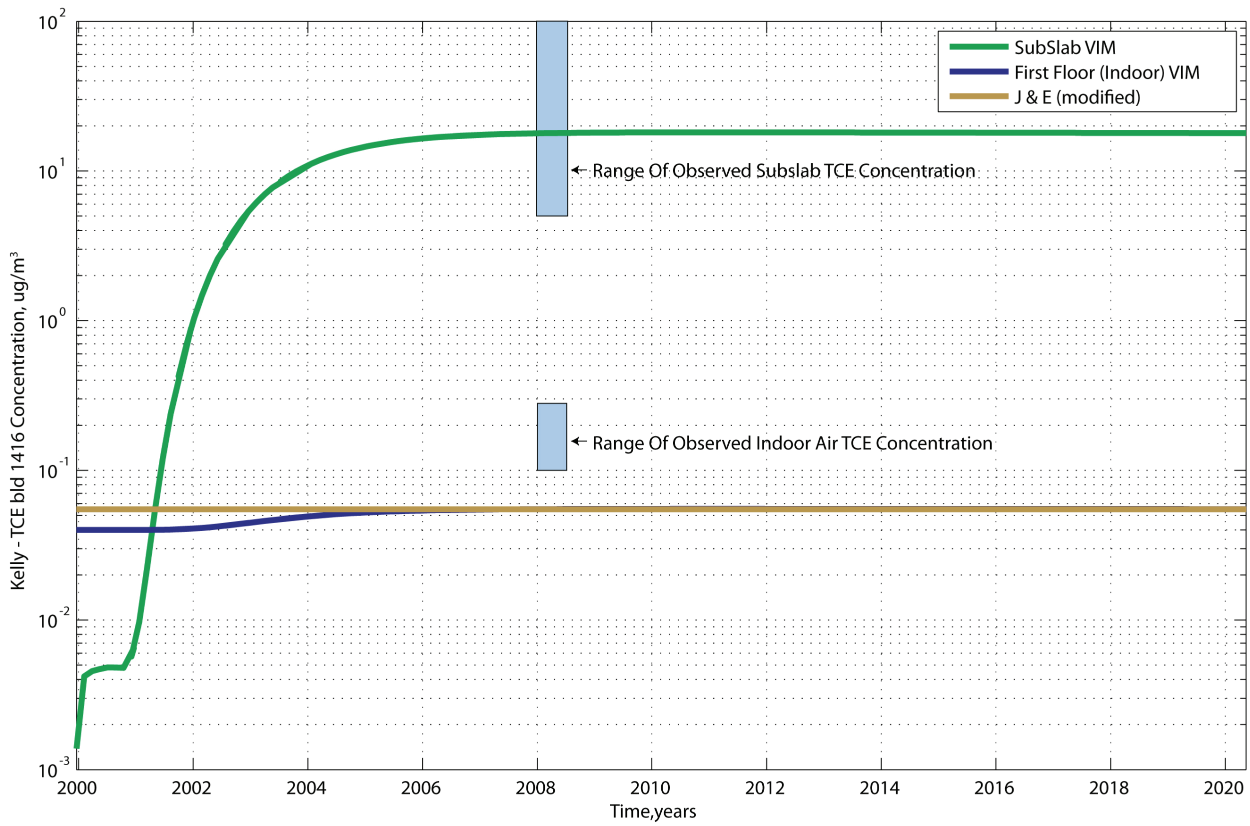


Figure 5-5
Predicted indoor and sub-slab TCE concentration, assuming a 25 day half-life.

The soil gas profiles in the presence of biodegradation are shown in Figure 5-6. For the same date, concentrations are less than before (see Figure 5-3). The observed data, shown again by the blue patches, tend to fall in the midrange of the data and provide a better agreement with model predictions than before.

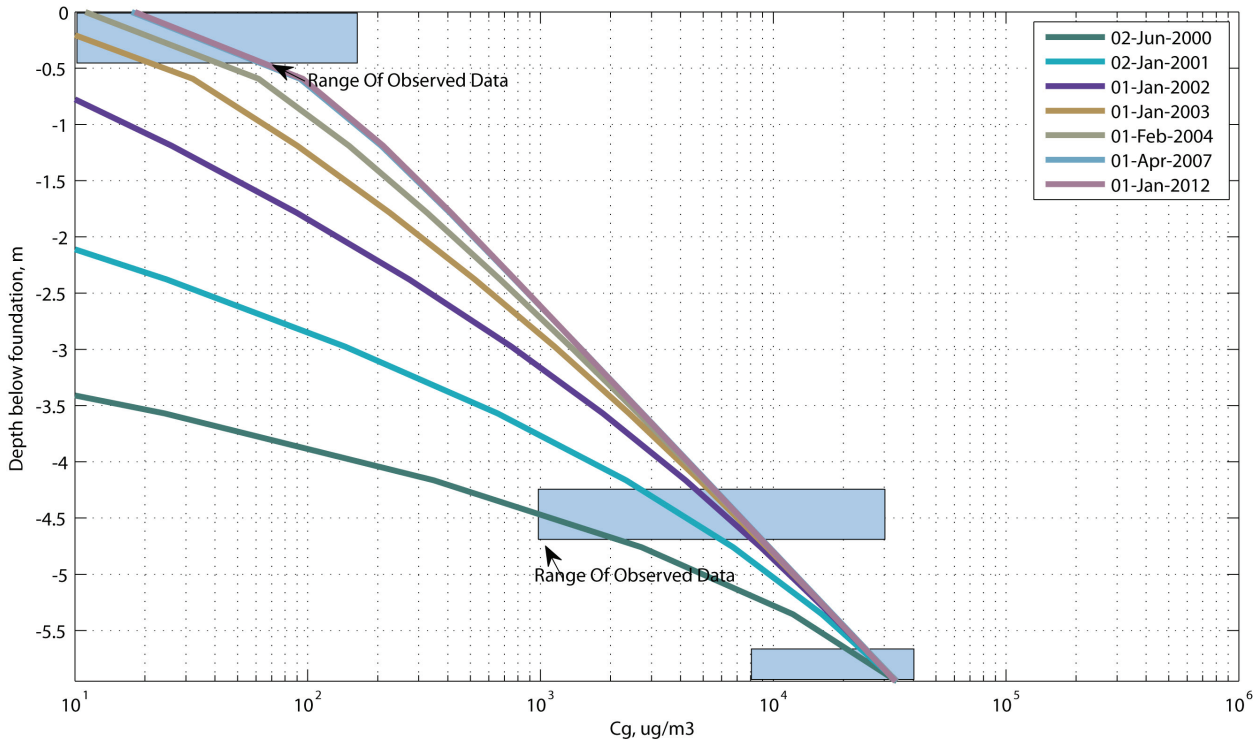


Figure 5-6
Predicted profiles of soil gas TCE concentrations, assuming TCE has a 25 day half-life.

Attenuation factors are also greatly affected by TCE decay: by a factor of 1 to 2 orders of magnitude. Figure 5-7 shows these results, which can be compared to the attenuation factors in Figure 5-4. The range of EPA attenuation factors is also shown for perspective. For the case where TCE is assumed not to biodegrade predicted steady-state attenuation factors are similar to five-percentile EPA values (Figure 5-4). For the case when TCE is assumed to biodegrade, they are not. Biodegradation causes the predicted attenuation factors to decrease.

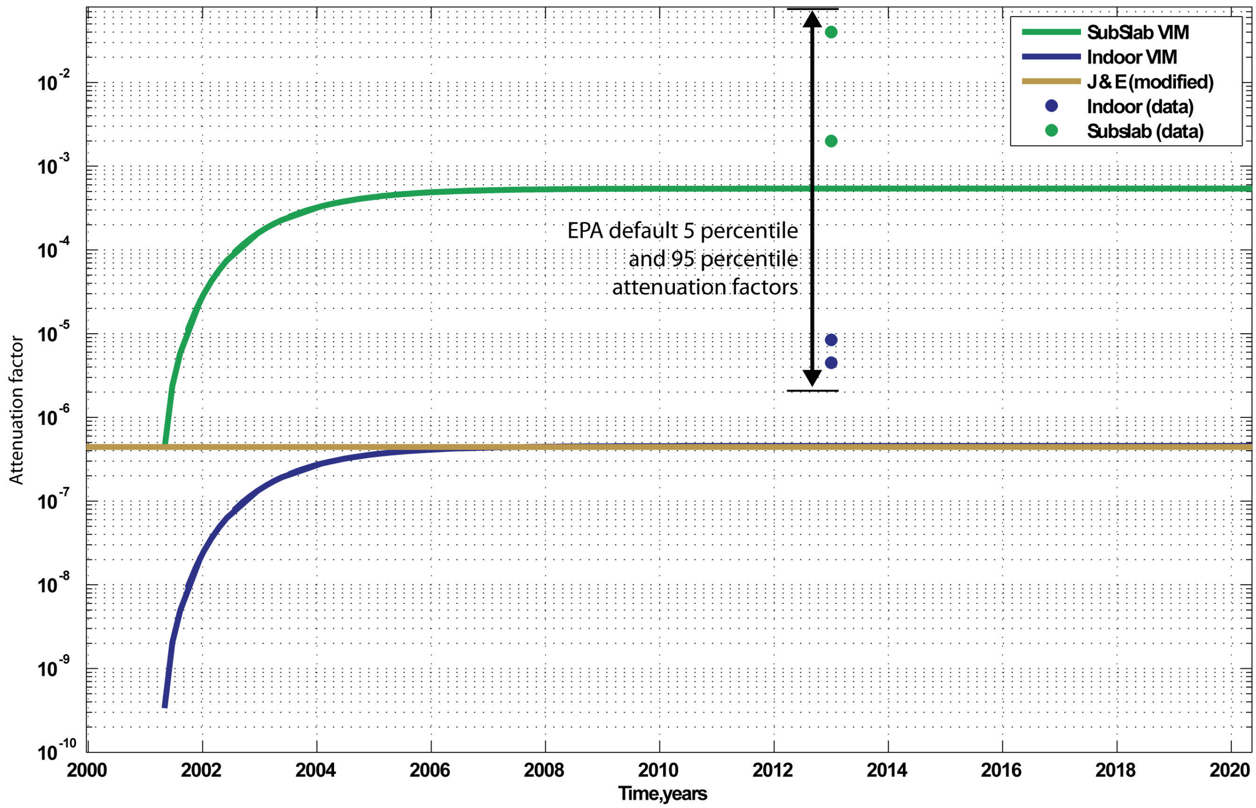


Figure 5-7
Attenuation factors assuming TCE has a biodegradation half life of 25 days and indoor air attenuation factors based on measure data.

5.3 Model Results: Monte Carlo Simulations for TCE

A Monte Carlo analysis was performed using the data shown in Appendix I. The data ranges were generated using observed data, if available, or otherwise using a realistic range about the mean value. The predicted indoor air concentrations and sub-slab concentrations are shown in Figure 5-8. Predictions are shown for median concentrations (solid lines) and 5% and 95% confidence limits (dashed lines). It is noteworthy that the confidence limits of the predicted results encompass the observed data (the blue patches), and that the median predicted values are close to the observed data. This indicates that the predicted variability associated with the Monte Carlo analyses may be close to the actual system variability.

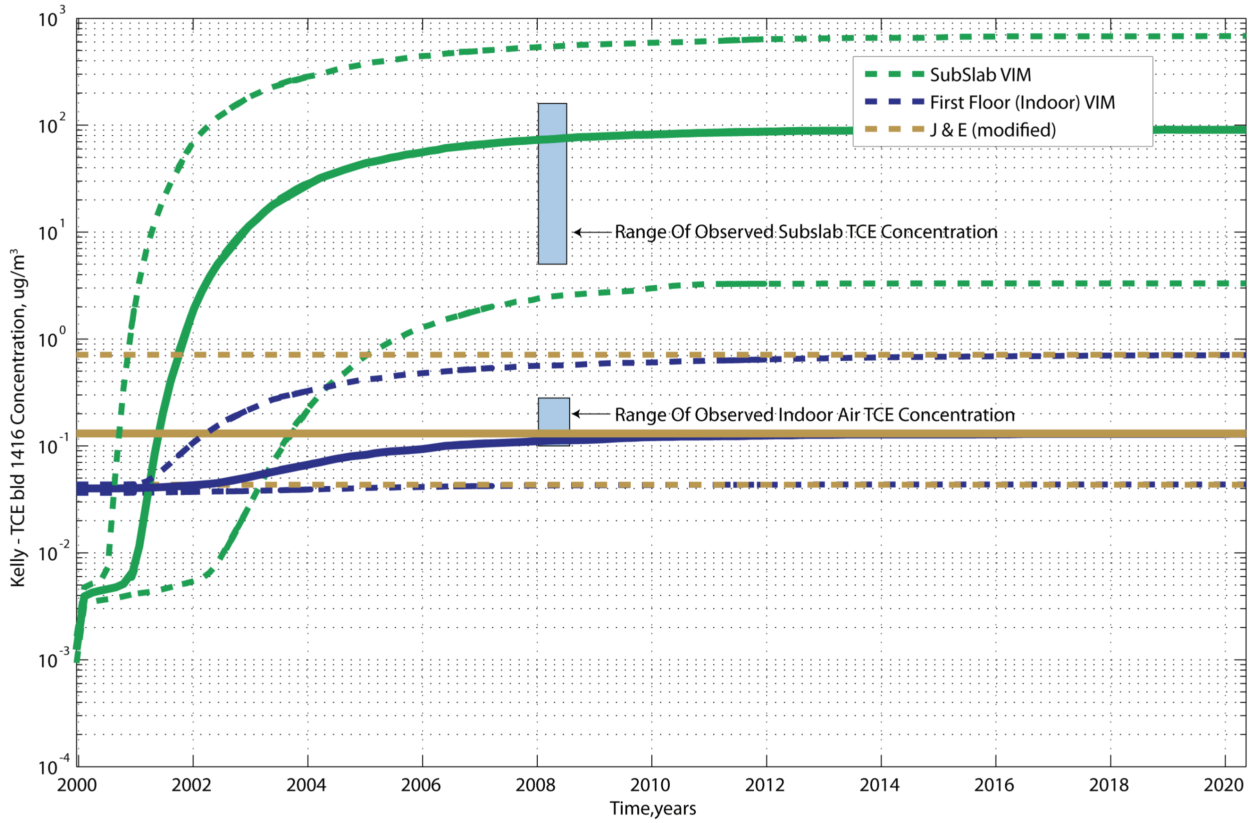


Figure 5-8
Monte Carlo predictions of TCE concentrations for sub-slab and indoor vapor concentrations at Building 1416. (Note: the estimated range of observed concentrations is shown by the blue patches.)

Figure 5-9 shows the predicted attenuation factors calculated using ViM's Monte Carlo analysis capability. Among the variables treated as random was the biodegradation rate, which was assigned a half life of 25 days to infinity. The median predicted values are about one order of magnitude less than those that assume no biodegradation. Also note the large range of predicted attenuation factors (5 percentile and 95 percentile): they range over two orders of magnitude for ViM predictions, and about an order of magnitude less for the JEM predictions. The range of EPA attenuation factors for indoor air barely include the median predicted value, and extend outside of the 95 percentile value. The calculated indoor air attenuation factors (red dots) are close to the predicted median values.

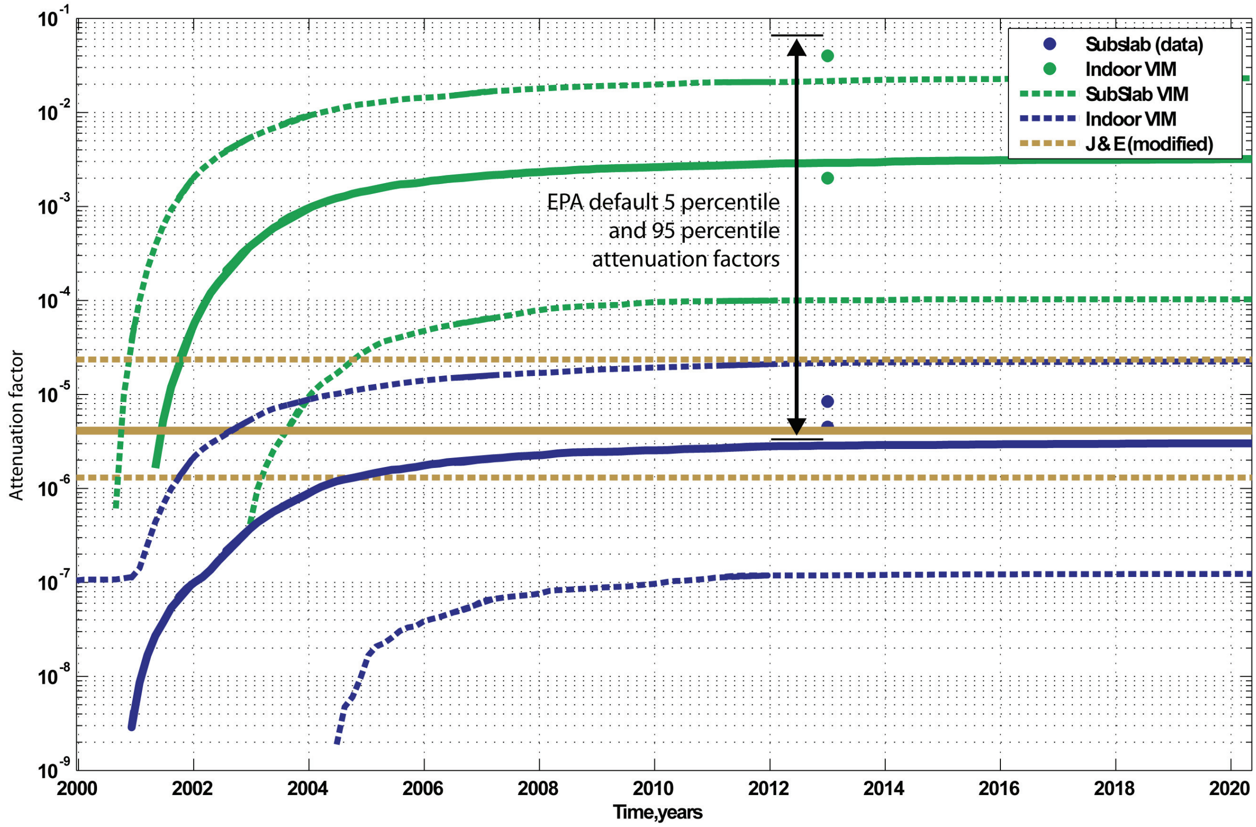


Figure 5-9
Monte Carlo predictions of attenuation factors and indoor air attenuation factors based on measured data.

6 CONCLUSIONS

The major conclusions of this work are:

1. The air exchange rate (AER) for Building 1416 was successfully calculated and ranged between 27/day to 37/day using an instantaneous release of a known quantity of helium. The methodology for doing this was developed for this project, and results to date indicate the method is reliable, easy to deploy, and inexpensive.
2. Soil gas concentrations of both TCE and cis-1,2-DCE showed rapid attenuation of concentrations, from deep soil gas concentrations to sub-slab concentrations. The rapid decrease in TCE concentrations is suggestive of possible biodegradation of TCE that would tend to reduce sub-slab concentrations and indoor air concentrations below what they otherwise might be.
3. Measured sub-slab TCE concentrations beneath Building 1416 varied by more than 30 times over five data points. This indicates that it is important to collect samples from numerous locations in order to adequately characterize the sub-slab environment. Conversely, the deeper soil gas concentrations (15 to 25 feet bgs) showed less variability, suggesting that deep soil gas concentrations can be characterized with fewer sampling points.
4. Sub-slab TCE and cis-1,2-DCE concentrations are significantly lower for those samples collected inside the footprint of Building 1416 compared to those sub-slab samples collected outside the building's footprint. The reason for this is not known with certainty, but may include differing resistance to vapor migration through the slab inside the building vs. outside, or differing impacts of vertical migration in the presence of biodegradation. An important consequence of this observation is that a conservative estimate of the sub-slab concentrations at this building could be obtained by collecting samples outside the building, without collecting sub-slab samples inside the building, which can be disruptive to building occupants and operations.
5. Simulation of TCE using ViM and JEM produced plausible results when applied in a Monte Carlo mode. However, when applied in a deterministic mode without biodegradation, the model tends to over predict; with biodegradation, the model under predicts. The advantage of a Monte Carlo analysis is that analyses can be done with many plausible sets, and results can be presented that capture the uncertainties.

7 REFERENCES

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