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March 12, 2009

SUBJECT: IPCB RULE MAKING 09-9 - RESPONSE TO PRE-FILED QUESTIONS BY MICHAEL REOTT DATED MARCH 4, 2009

To Whom It May Concern:

This letter has been prepared to address the questions that were directed to GeoKinetics in the above referenced submittal. For ease of reference, each question is repeated below followed by our response:

Question #12: What is the relative cost of using a 60 mil vapor barrier at typical sites compared to the 6 and 10 mil barriers referenced in the proposed rule and your testimony?

Answer #12: The installed cost of a 60-mil spray-applied or HDPE vapor barrier is typically on the order of \$1.50 to \$2.25 per ft^2. The installed cost of a 6 to 10 mil LDPE vapor barrier with overlapped / taped seams is typically on the order of \$0.30 to \$0.50 per ft^2. The lower unit costs are more typical of larger installations (e.g. warehouses, commercial buildings, multi-family structures, etc.) while the higher unit costs would be more typical of single family residences and small retail / commercial buildings.

Question #13: What is GeoKinetics' experience with testing indoor air quality for contaminants for vapors from subslab soil and/or groundwater contamination? Would a system of interior air quality standards (as suggested by Versar in its February 24, 2009 comment letter) be workable in Illinois?

Response #13: Measurement of the VOC levels in interior air spaces can provide a direct indication of potential exposure risks. Actionable levels for many contaminants in indoor air have been published by the U.S. EPA and other regulatory agencies based upon a 1×10^{-6} incremental carcinogenic risk and somewhat standardized exposure assumptions. This approach is useful in addressing the question "Does an unacceptable exposure risk exist?". However, interior air sampling / analysis can only identify an existing problem - it can not anticipate one in advance. It is often necessary to evaluate site conditions for a proposed building and determine if mitigative measures are required. Problems identified after the completion of construction are typically more difficult to address.

Comment #14: Has GeoKinetics ever compared its indoor air monitoring quality data to the predicted values from the Johnson and Ettinger Model?

Response #14: Yes. Where we have comparative data, the standard J&E model typically predicts higher VOC and/or methane gas levels than were actually measured in indoor air. This appears to be attributable to assumptions and simplifications utilized in the model that are generally of a conservative nature.

Comment #15: Does GeoKinetics have any experience with the costs of the various Building Control Technologies referenced in the proposed rule?

Response #15: Yes, we have installed each type of system referenced in Section 742.1210 of the draft guidelines. The cost of sub-slab and sub-membrane depressurization systems can vary significantly depending upon the site conditions and building characteristics. The installation costs for sub-slab depressurization systems are often lower than those for sub-membrane systems, although long term operating and maintenance costs are typically significantly higher. As a result, the Net Present Value costs for both systems are often comparable and typically range from approximately \$1.50 to \$3.50 per ft^2 of slab-on-grade area.

A discussion of vapor mitigation alternatives and technical considerations is attached for your reference. We hope this information is helpful to you. Please do not hesitate to contact any of the undersigned if you have any questions or comments.

SINCERELY,
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Vapor Mitigation Strategies, Alternatives and Technical Considerations

1.0 **Introduction:** There are two primary transport mechanisms that can cause vapors to migrate from the subsurface to the interior of a building - advection and diffusion. Advective flow occurs as a result of a pressure differential between the soil vapor beneath a building and the air pressure on the interior of that building. This pressure differential could be created by any of the following factors:

- Volatilization of contaminants in the subsurface and/or off-gassing from groundwater;
- Generation of a biogenic carrier gas - such as methane or carbon dioxide - in the subsurface beneath a building;
- A rising groundwater table and/or the development of a seasonal perched water zone;
- Barometric pressure fluctuations; and
- Negative pressures on the interior of a building caused by the ventilation system and/or chimney effects.

Diurnal fluctuations in barometric pressure and associated lag routinely cause soil gas pressures to exceed the air pressure on the interior of a building in many areas by up to approximately one inch of water. The passage of extreme low pressure cells through an area has been found to create short term pressure differentials of five to ten inches of water. However, these factors are cyclic or transient in nature and therefore generally do not create a significant long term bias for vapor migration to interior areas. Ventilation and/or chimney effects commonly result in small (i.e. 0.05 to 0.01 inches of water) but persistent negative pressure differentials within interior areas that can induce advective flow to interior areas.

Diffusion occurs as a result of a difference in vapor concentration between the subsurface and the interior of a building. Volatile Organic Compounds (VOCs) will have a tendency to diffuse from areas of higher relative concentration to areas of lower relative concentration. In accordance with Fick's law, the rate of diffusion is directly proportional to the concentration difference between the source and receiving areas and can proceed in the absence of any associated pressure differential.

VOCs are ubiquitous and routinely found at low concentrations in both exterior and interior air spaces. Construction materials and finishes often result in slightly elevated VOC levels within interior spaces. The objective of a vapor mitigation system is typically to reduce the rate of migration of VOCs from the subsurface such that interior VOC levels do not exceed published regulatory risk based action levels. The effectiveness of a vapor mitigation system is often expressed using an attenuation ratio referred to as an "Alpha" value. Alpha values are typically taken as the ratio of the concentration of a particular VOC in the air space on the interior of a building relative to the concentration of that VOC in the subsurface at a depth of five feet below the ground surface. The Alpha values for effective vapor mitigation systems are typically on the order of 1×10^{-4} to 1×10^{-5} or lower. Air samples can be collected from interior spaces to confirm acceptable levels are achieved. Gas probes can be installed beneath, or around the perimeter of, a building in order to estimate attenuation factors or Alpha values. However, precise determination of Alpha values can be difficult due to the resulting very low interior VOC levels and the presence of VOCs in the interior air space that did not originate from subsurface sources. Common testing or monitoring procedures to confirm or evaluate the performance of various mitigative measures are noted during the discussion of those measures in this submittal.

2.0 **Mitigative Measures:** Two general types of mitigation measures have been utilized extensively over the last several years to reduce the potential for the migration of subsurface vapors to interior spaces. These include membranes and ventilation systems installed beneath the floor of a building. The purpose and typical configurations of these systems are discussed in the following paragraphs.

2.1 **Membrane Systems:** The most common types of membranes in use today for VOC mitigation include High Density Polyethylene (HDPE) and spray applied products such as Liquid Boot^{R}. The membranes work by creating a low permeability barrier between the vapor source (i.e. the soil beneath the building) and the building interior to inhibit both advective and diffusion based transport of VOCs. For maximum effectiveness, the membranes typically extend continuously beneath the building floor slab and are either sealed against, or pass beneath, any shallow footings or grade beams that support the structure. A vapor-tight seal should be provided around any utility or conduit that penetrates the membrane. With HDPE membranes, these seals are typically provided with pre-formed boots that are slipped over the pipe or conduit and then welded to the membrane. With spray-applied products, the membrane can be applied directly to the pipe or conduit to create a seal. The relative ease and reliability of sealing penetrations generally favors the use of spray applied products for residential buildings and other structures that have a significant number of utilities or conduits that must pass through the membrane.

HDPE is highly resistive to all common solvents and has extremely low permeability and diffusion coefficients. The material is typically supplied on 10 to 20 foot wide rolls. Adjacent sheets must be overlapped and continuously welded together to create a vapor tight seal. A 60-mil thickness is used for most HDPE membranes to facilitate welding of the material. The greatest potential for VOCs to migrate across an HDPE membrane normally occurs as a result of improperly sealed membrane seams or penetrations - or as a result of construction damage to the membrane.

Spray applied membranes are typically comprised of proprietary mixtures of rubberized asphalt applied to a geotextile substrate. Due to their composition, these products are not suitable for exposure to liquid-phase solvents however they have been widely utilized for vapor phase mitigation. Long term diffusion tests have been conducted on Liquid Boot® membranes at VOC levels in excess of 100,000 μg/m^3 without any indication of degradation. The configuration of these tests is illustrated in Figures 1, 2 and 3. The diffusion testing results (Figure 4) and field performance indicate Liquid Boot® membranes provide an effective barrier against subsurface vapors at concentrations far in excess of those that are typically encountered.

Typical details for HDPE and Liquid Boot® membrane installations are shown in Figures 5 and 6, respectively. The relative advantages and disadvantages of HDPE and spray-applied membranes are summarized in Table 1.

Quality Assurance / Quality Control (QA/QC) measures are important during the installation of any type of barrier membrane. Typical QA/QC procedures include:

- Approval of the construction materials by the vapor mitigation system engineer prior to initiating the installation;
- Detailed and continuous, or near-continuous, inspection of the installation by a qualified engineer;
- The collection and measurement of coupon samples from the membrane to confirm adequate thickness and joint integrity; and
- Smoke testing of the membrane following its installation to confirm its integrity.

Typical inspection items are outlined on the sample form provided as Table 2. A completed inspection form should be provided by the vapor barrier system engineer along with a certification letter for the system at the completion of each installation.

Soil gas sampling probes can be installed above and below a vapor mitigation membrane for the purpose of monitoring vapor levels as shown in Figures 5 and 6. These monitoring probes typically consist of inert porous polypropylene tips connected to ¼-inch diameter polyethylene tubing that extends to a vault or other suitable monitoring point at the perimeter of the building. However, it should be noted that comparison of VOC levels above and below a membrane typically does not provide an accurate indication of its effectiveness when an intact floor slab is present above the membrane. This is due to the fact that the concrete floor slab also inhibits the migration of vapors. High quality (low water / cement ratio) concrete is relatively impermeable and acts as an effective barrier to the migration of VOCs. Due to the potential for cracks or separations in the concrete floor slab, it cannot be relied upon as a long term barrier. Some advective flow or diffusion will occur across all membranes or barriers. Their purpose is to significantly reduce the flux rate of VOCs to interior spaces. Where the overlying floor slab is intact and provides a similar level of resistance, elevated VOC levels should be anticipated within the membrane / floor slab interface. The level of VOCs within the air space on the interior of a building can provide a more accurate indication of the performance of the membrane. This level can be measured through the direct collection of interior air samples (which requires access to the interior) or by remotely collecting air samples through a fixed sampling train as illustrated in Figures 5 and 6. Where a cracked or deteriorated floor slab is present, the VOC levels immediately above an underlying membrane should be at low to non-detectible levels - assuming the membrane has not been breached. However, where an intact floor slab constructed of high quality concrete is present, elevated VOC levels will typically exist above the membrane. These VOC levels are often on the order of 50% of those that are present beneath the membrane. This should not be interpreted as an indication that the membrane has failed. Elevated VOC levels above the membrane are predicted by modeling and have been confirmed by monitoring under these conditions in the field.

2.2 **Vent Systems:** Sub-slab ventilation systems are routinely utilized in conjunction with membranes to further reduce the potential for vapor transmission to interior areas and to provide a greater level of system redundancy. There are three general types of sub-slab ventilation systems in common use today. These include:

1. Passive ventilation systems;
2. Active ventilation systems; and
3. De-pressurization systems.

Each of these systems is discussed separately in the following paragraphs while the typical relative advantages and disadvantages of each type of system are listed in Table 3.

Passive Ventilation Systems: Passive ventilation systems represent the most common type of system utilized in conjunction with membranes for vapor mitigation purposes. Passive ventilation systems are less expensive to install than active or de-pressurization systems. Once installed, passive systems require little or no maintenance while active and de-pressurization systems require periodic maintenance as well as a constant electrical supply to function. For these reasons, passive systems are generally more reliable than active or de-pressurization systems. In addition, there are often regulatory issues associated with air emissions with active and de-pressurization systems that can complicate their installation and significantly increase their operating costs. These issues normally do not occur with passive systems.

Passive ventilation systems consist of a network of perforated horizontally orientated vent lines installed beneath the floor slab of a building. The vent lines are typically embedded within a permeable sand or gravel blanket beneath the floor slab. The perforated vent lines are connected to vertical vent risers that extend through the walls of the structure to outlets above the roof. The system works by preventing the development of excess pressure beneath the floor slab and by purging VOC vapors from the sand or gravel blanket beneath the slab. Diurnal and weather induced barometric pressure fluctuations typically induce cyclic air flow into and out of the system. This purges and dilutes vapor that could otherwise accumulate beneath the overlying membrane or floor slab. Barometric pressure variations recorded at a southern California airport are shown in Figure 7. This pattern is typical of many coastal areas. As shown, during a typical day, the barometric pressure steadily drops as the temperature rises - while the opposite occurs during the evening hours. There is normally outflow from the vent risers during the day in response to the falling barometric pressure since the soil gas pressure at depth stays relatively constant. Conversely, fresh air typically flows into the vent risers and passive vent lines during the evening in response to the rising barometric pressure. This diurnal cycle has been found to be effective in purging the system and significantly reducing sub-slab vapor concentrations. The flow rate measured out of a passive vent system (Figures 8 and 9) installed beneath an existing single family residence in southern California is illustrated in Figures 10 and 11. Methane, oxygen, and carbon dioxide concentrations measured in the outflow from the passive ventilation system are also shown in this figure. Methane was used as an indicator due to its high initial concentration at this site and the ease and accuracy with which its concentration can be measured. As indicated, there were substantial decreases in the methane and the carbon dioxide concentrations beneath the floor slab, and corresponding increases in the oxygen levels, within two weeks of the installation of this system as a result of the purging mechanisms described above. This response is typical and has been documented at many installations.

Typical details for a passive sub-slab ventilation system are provided in Figure 12. As shown, two types of ventilation pipe are in common use - perforated round polyethylene pipe normally four inches in diameter and perforated low profile polyethylene pipe that is typically twelve inches wide and one inch thick. Both types of piping are constructed of materials that are generally inert to VOCs. The primary advantages associated with low profile vent piping include lower installation costs (it can be installed in the sand or gravel blanket without trenching), relatively high vapor collection or radial flow capacity, and the ability to place the pipe at a relatively high elevation immediately below the floor slab. High placement of the piping can improve the effectiveness of the VOC purging and reduces the potential for flooding or inundation of the system due to shallow groundwater or nuisance water associated with irrigation. The primary advantage associated with round ventilation piping is its relatively high axial flow capacity. Typical radial and axial flow head loss curves for round, 4-inch diameter perforated ADS pipe and for ADS 12-inch by 1-inch low profile vent piping are illustrated in Figure 13. As shown, low profile vent piping is generally more efficient for the collection of soil vapors, but once collected, less efficient in conveying the vapors to the vent riser. The lower axial flow capacity for low profile vent piping is generally not problematic with passive systems due to relatively low flow rates and velocities, however it is a characteristic that must be considered in the design of active systems. The relative advantages and disadvantages of round and low profile vent piping are summarized in Table 4.

As with vapor barrier membranes, diligent QA/QC is important during the installation of passive vent piping systems. The materials and components should be inspected and approved by the vapor mitigation system engineer prior to construction and the installation should be inspected and certified by that entity. Smoke testing of the sub-slab vent piping is typically performed in conjunction with the membrane testing to confirm proper flow and inter-connection of the ventilation components. A non-toxic glycerine-based smoke should be used for this type of testing.

The operational effectiveness of passive sub-slab ventilation systems can be evaluated using the following procedures:

- o Monitoring the pressure within sub-membrane gas probes (Figure 12) to confirm the absence of elevated pressure;
- o Monitoring of VOC levels within sub-membrane probes to document their reduction relative to levels measured in gas probes installed to greater depths;

- Monitoring air flow rates into, and out of, the vent risers to confirm the system is responding as anticipated to barometric pressure fluctuations; and
- Monitoring VOC levels in the outflow from the vent risers to document flux rates from the system.

Vent riser quick-connect fittings accessible from the exterior of a building are often provided for monitoring purposes as shown in Figures 5 and 6.

Active Ventilation Systems: Active ventilation systems generally have the same components as passive systems but incorporate a blower to extract air from one of the vent risers. The sub-slab vent piping with active systems often consists of two separate networks of perforated piping - an extraction network and a fresh air recharge network - each with their own vent risers. Air is removed from the extraction piping network by a blower and exhausted to the atmosphere through a vent riser that outlets above the roof level of the building. Air is drawn into separate fresh air recharge vent risers at the roof level of the building and distributed to perforated fresh air recharge piping beneath the floor slab. The perforated sub-slab extraction and fresh air recharge piping are configured to provide for the efficient cross flow of air between the two piping systems. This cross flow is intended to flush any accumulated vapors from the sand or gravel blanket. In the design of this type of system, an effort is typically made to induce only nominal negative pressures in the sub-slab vent lines. This reduces the potential for VOCs to be drawn from the soil into the sand or gravel blanket. Negative operating pressures are typically controlled by limiting the rate of air extraction and by providing a large number of fresh air recharge vent risers relative to the number of extraction vent risers. A common design objective with this type of system is to have 80%+ of the exhaust air comprised of fresh air drawn through the intake vent risers. This reduces VOC emission levels and the potential for regulatory imposition of emission permitting, monitoring and treatment requirements. Typical details for an active ventilation system are illustrated in Figure 14.

Construction QA/QC procedures for active ventilation systems are generally similar to those implemented for passive systems. Post-installation monitoring of active extraction systems also typically involve the same measurements outlined previously for passive systems. In addition, the total rate of fresh air recharge can be measured at the vent risers and compared to the discharge rate. The difference in these values corresponds to the effective rate of leakage or vapor extraction from the subgrade.

De-pressurization Systems: De-pressurization systems are generally configured similar to active systems without the fresh air recharge components. De-pressurization systems are intended to reduce the potential for VOC migration to interior areas by reducing the air pressure within the sub-slab sand or gravel blanket to a level significantly below that which exists on the interior of the building. This is done by using a blower to extract air from a vent riser that is connected to the perforated sub-slab vent piping network typically without the provision for fresh air recharge into the system. This induces relative high negative pressures beneath the floor slab of the building - often on the order of 5 to 30 inches of water. With these high negative pressures, there is little, if any potential, for VOCs to migrate through the floor slab to interior areas. De-pressurization systems are common for radon mitigation but are less common for VOC mitigation due to the following issues:

- De-pressurization is typically not considered to be necessary with the use of sub-slab membranes;
- VOC emission levels can be relatively high with de-pressurization systems increasing the likelihood that emissions monitoring, and possibly treatment, will be required;
- In the event of an equipment failure or power loss, the system becomes ineffective and the potential for VOC migration to interior areas is increased as a result of the vapors drawn into the sand or gravel blanket by the system; and
- The negative pressures created by de-pressurization systems can induce significant surcharges on the floor slabs of buildings that can cause settlement, structural issues, or damage to any overlying membrane.

For the issues outlined above, it has been our experience that de-pressurization systems are generally not desirable, and rarely used, for VOC vapor mitigation purposes. Typical details associated with a de-pressurization system are illustrated in Figure 15.

Construction QA/QC procedures for de-pressurization systems are similar to those used for passive and active systems. Post-installation monitoring of sub-slab de-pressurization systems typically involves measurement of the sub-slab pressure in gas probes relative to the air pressure on the interior of a building as shown in Figure 15. Monitoring of effluent flow rates and vapor concentrations are also often required for permitting purposes.

3.0 **Summary:** As indicated previously, the most common vapor mitigation system configuration in use today for new construction involves the installation of a continuous sub-slab vapor barrier along with a sub-slab passive ventilation system. This combination of components provides a high level of redundancy and has been found to be highly effective in reducing VOC vapor migration rates to acceptable levels. It is anticipated this will be the system configuration of choice for most proposed developments. As an additional precautionary measure, it is suggested that sub-slab passive ventilation systems be configured such that they could easily be converted into an active extraction system should the need arise in the future.

{ E N D }

Table 1 - Relative Advantages and Disadvantages of HDPE and Liquid Boot Membranes for Vapor Mitigation Applications

Item	Issue	Advantage	
		HDPE	Liquid Boot
1	Ease / Reliability of Sealing Penetrations		X
2	Ease / Reliability of Sealing Seams or Joints		X
3	Ease / Reliability of Repair When Damaged		X
4	Chemical Resistance to Liquid Phase Solvents	X	
5	Cost for Large Warehouse Type Facilities With Few Membrane Penetrations	X	
6	Cost for Typical Installation With Large to Moderate Number of Penetrations.		X

Table 2 – Typical Inspection Items

Vapor Barrier Mitigation
____-Pour Foundation Inspection Form

Mitigation Plans Dated: ________ Lot No.: ________
Project Name: ________ Project No.: ________

Materials	DESCRIPTION	APPROVED
Sub-slab vent pipe		
Sub-slab vent filter fabric		
Sub-slab vent trench back fill material		
Sub-slab vent pipe to concrete protection material		
Vapor Barrier		
Vapor Barrier bonding tape		
Vapor Barrier pipe boots		
Vent riser pipe		
Vent riser rain cap		
Conduit Sealant Material		
Utility Dam Material		

Sub-Slab Vent Piping	INSPECTOR	OK	NOT OK	NOTE #	INSPECTION DATE	CORRECTION DATE
Configuration of piping consistent with approved plans (Attach floor plan documenting any deviations)						
Proper transitions through footings						
Vent pipe installed in 2" sand layer						
End caps properly installed						
Proper connection for active venting system						
Filter fabric properly installed						
Vent piping foam taped through footings						
Vent risers properly secured to form boards						
[illegible]—OK to pour footings [illegible] sub-grade						

Vapor Barrier	INSPECTOR	OK	NOT OK	NOTE #	INSPECTION DATE	CORRECTION DATE
Geofabric Placement Acceptable						
Proper stemwall/footing finish for vapor barrier bonding						
Vapor barrier continuously bonded to perimeter footings						
Vapor barrier continuously bonded to interior footings						
Vapor Barrier seems continuously sealed						
Pipe boots properly installed and sealed						
Vapor barrier properly sealed to sewer backflow valve conduit						
Vapor barrier smoke testing successfully completed						
[illegible] vapor barrier						
Sand above vapor barrier suitability and thickness of installation (______ inches)						
Final vapor barrier inspection—OK to pour slab						
Slab pouring/finishing protocol observed and acceptable with respect to protection of vapor barrier						

Vent Risers	INSPECTOR	OK	NOT OK	NOTE #	INSPECTION DATE	CORRECTION DATE
Vent riser location consistent with approved plans						
Vent risers (do not penetrate)(properly penetrate) studs						
Vent riser holes through sill plate and top plate properly placed & dimensioned						
Structural straps properly installed on sill & top plates where required						
Nail plate properly installed on blocking where required						
Vent pipe joints properly solvent welded						
Vent pipe properly secured/strapped where exposed						
Vent pipe properly stubbed through roof sheathing						
Vent pipe outlet has proper roof clearance						
Vent pipe outlet has proper clearance with respect to windows, etc.						
Vent pipe rain cap properly installed						
Vent pipe labels properly installed						

Utility Seals	INSPECTOR	OK	NOT OK	NOTE #	INSPECTION DATE	CORRECTION DATE
Conduit Seals Properly Installed						
Native Material Compacted to 90% Relative Compaction / Or Cement And Bentonite Slurry						
Interior Air Space Vapor Level (PPM) Concetration in Parts Per Million						

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Inspecton Notes:

Inspector: ________
Inspector Signature: ________

(DOC.PUB.4.02.02)

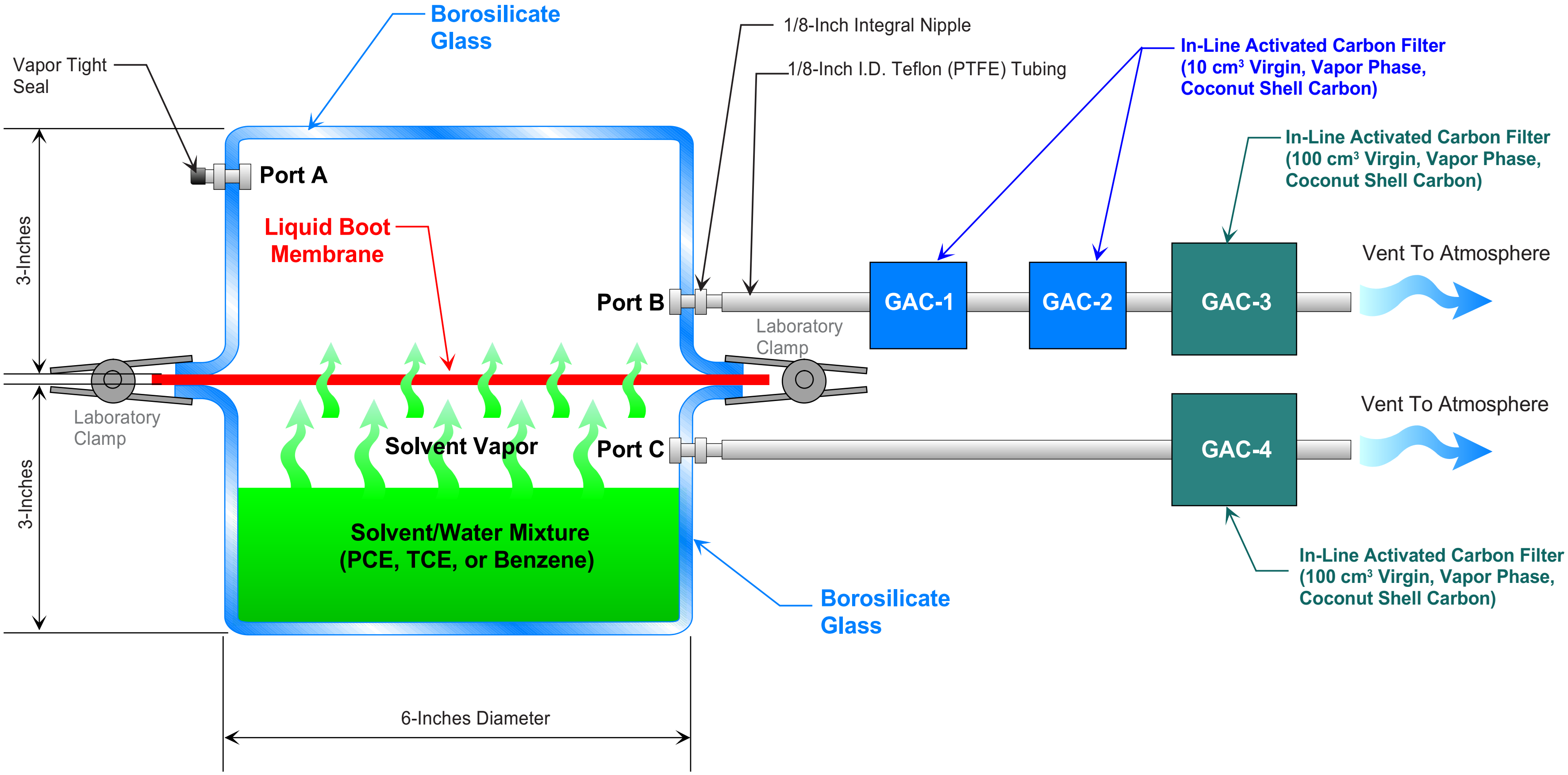
Table 3 - Relative Advantages and Disadvantages of Sub-Slab Ventilation Alternatives for Vapor Mitigation Applications

Item	Issue	Advantage		
		Passive	Active	De-pressurization
1	Ease / Cost of Installation	A	C	D
2	Ease / Cost of Operation	A	C	D
3	Reliability of Operation	A	D	D
4	Potential for Noise or Vibration That Could Disturb Building Occupants	A	D	D
5	Potential for VOC Emissions and Associated Permitting Issues	B	C	F
6	Potential For Inundation From Nuisance Water	A	C	F
7	Potential for Excessive Surcharging of Building Floor Slab	A	B	D
8	Overall Installation and Operation at Typical Sites With Low to Moderate Vapor Levels	A	B	F
9	Overall Installation and Operation at Sites With Very High Vapor Levels	B	A	D

A = Good Performance / No Issue
B = Generally Good Performance / Low Potential for Issue
C = Generally Satisfactory Performance / Possible Issue
D = Generally Poor Performance / Likely Issue
F = Generally Unacceptable Performance / Use Generally Not Recommended

Table 4 - Relative Advantages and Disadvantages of Round and Low Profile Vent Piping for Vapor Mitigation Applications

Item	Issue	Advantage	
		Round	Low Profile
1	Ease / Cost of Installation		X
2	Potential for Interference With Utilities or Other Systems		X
3	Use With Passive Ventilation Systems		X
4	Use as Collection Lines for Active Ventilation Systems		X
5	Use as Headers and Primary Flow Lines for Active Ventilation Systems	X	
6	Potential for Inundation by Nuisance Water		X



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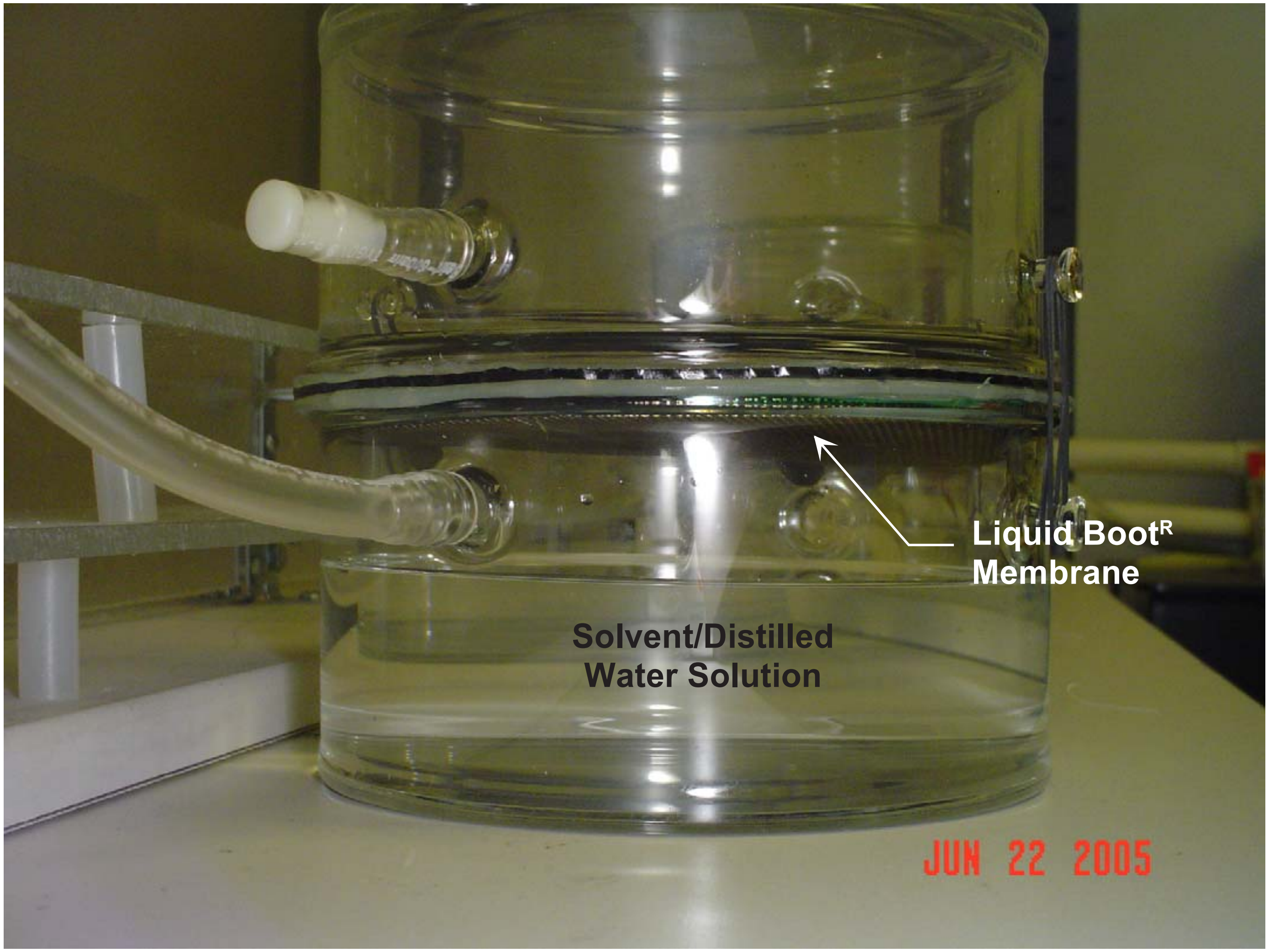
Membrane Diffusion Test Configuration

Figure 1



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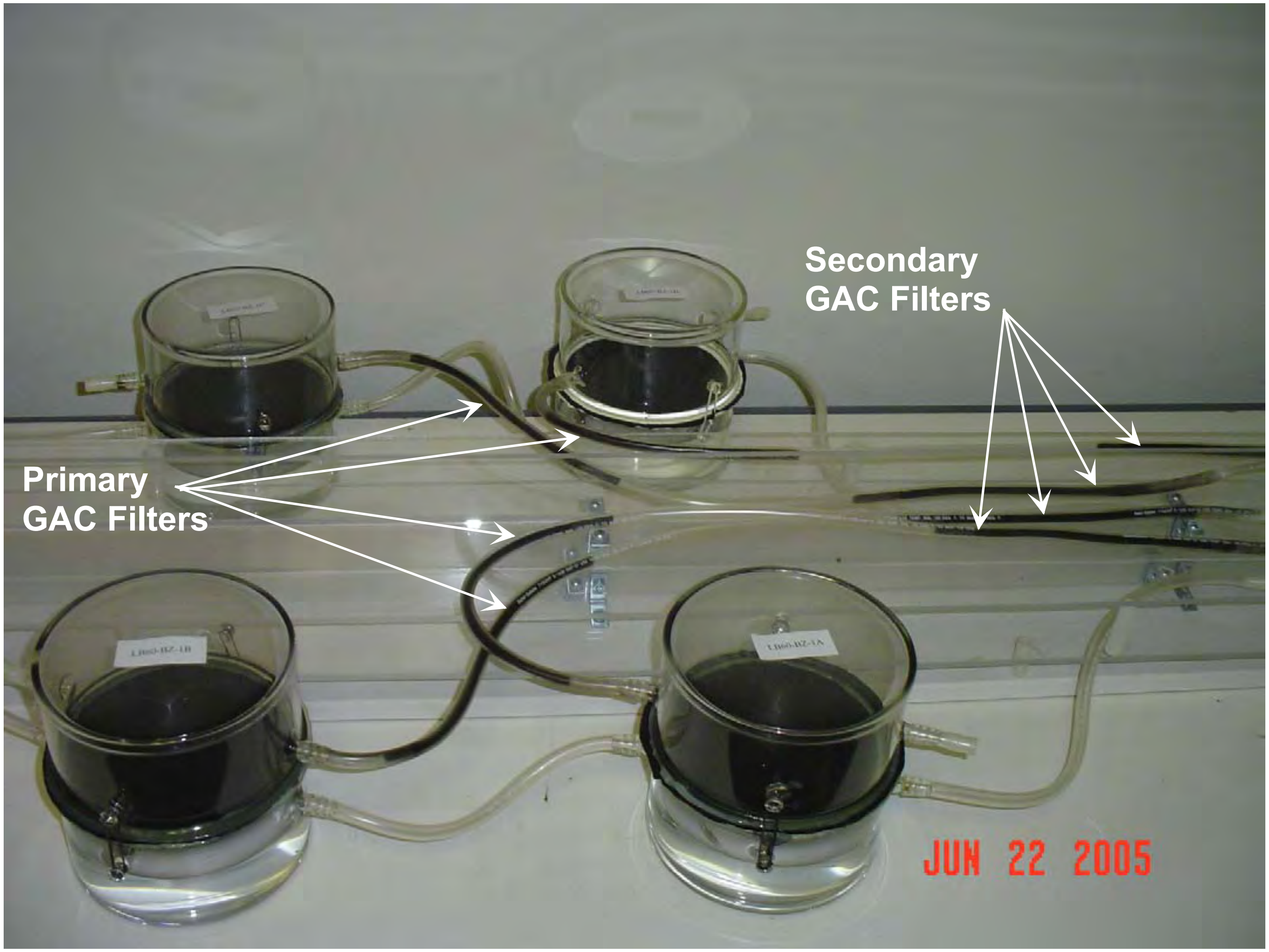
Liquid Boot Diffusion Testing

Figure 2



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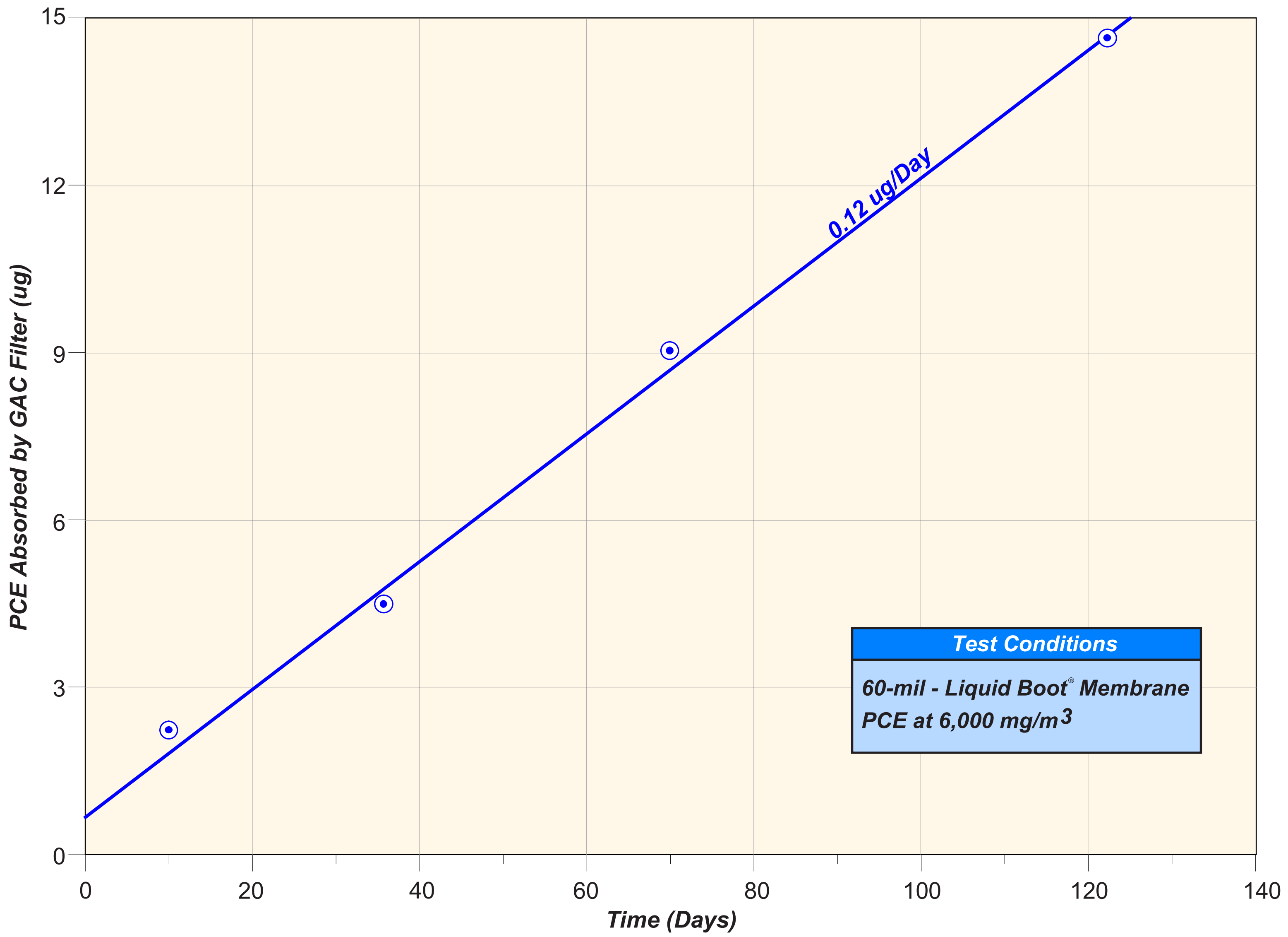
Liquid Boot Diffusion Testing

Figure 3



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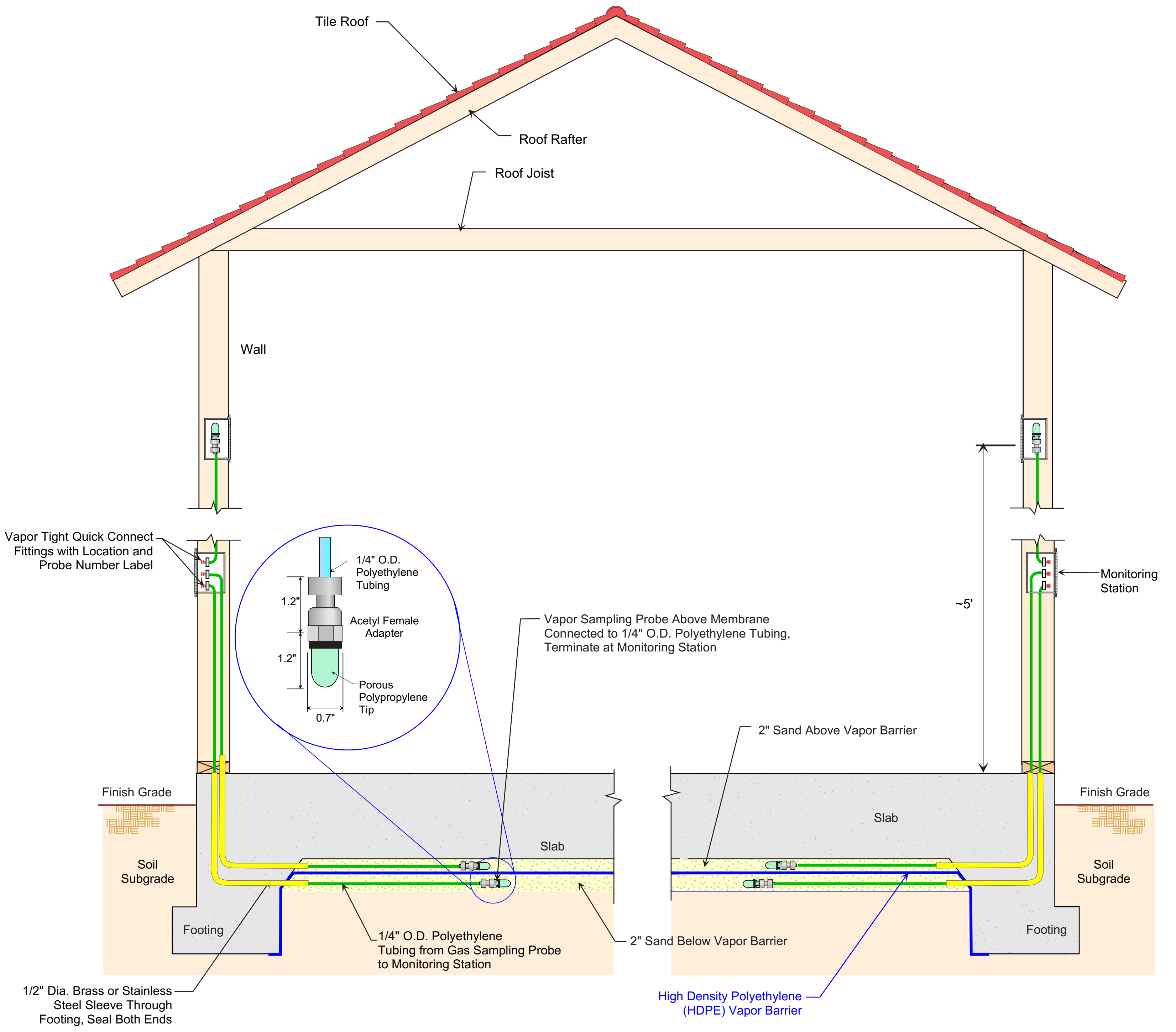
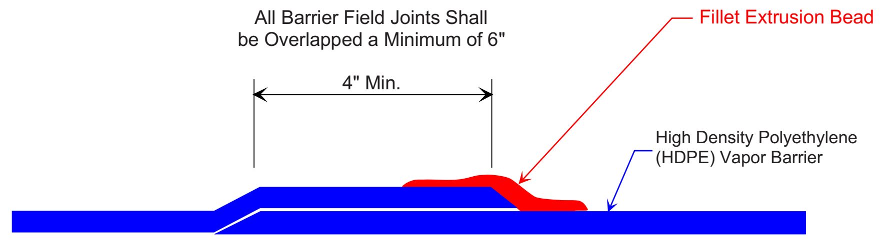
Test Results for Liquid Boot Membrane with PCE

Figure 4



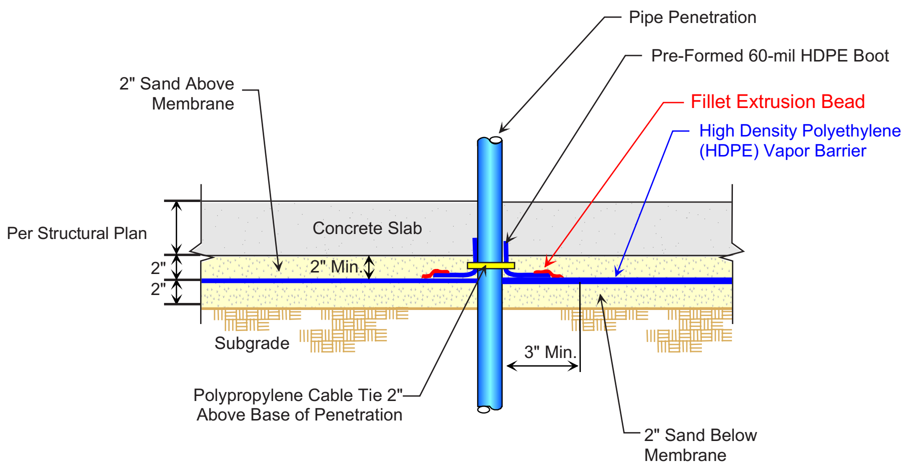
Above and Below Membrane Sub-Slab Vapor Sampling Probes

Not to Scale



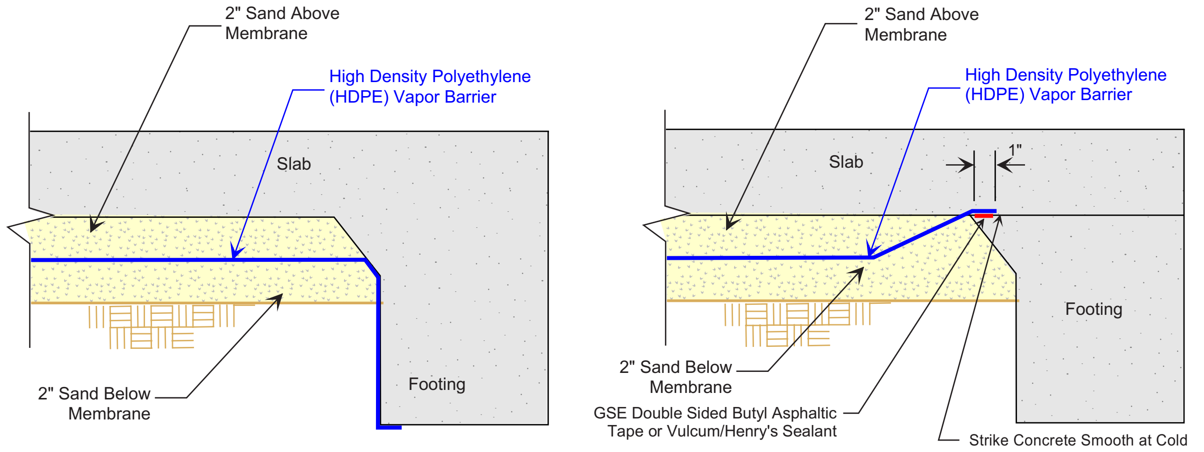
Typical Membrane Overlap Detail

Not to Scale



Typical Membrane Boot

Not to Scale



Single Pour ***Two Pour***

Typical Liquid Boot Seal

Not to Scale

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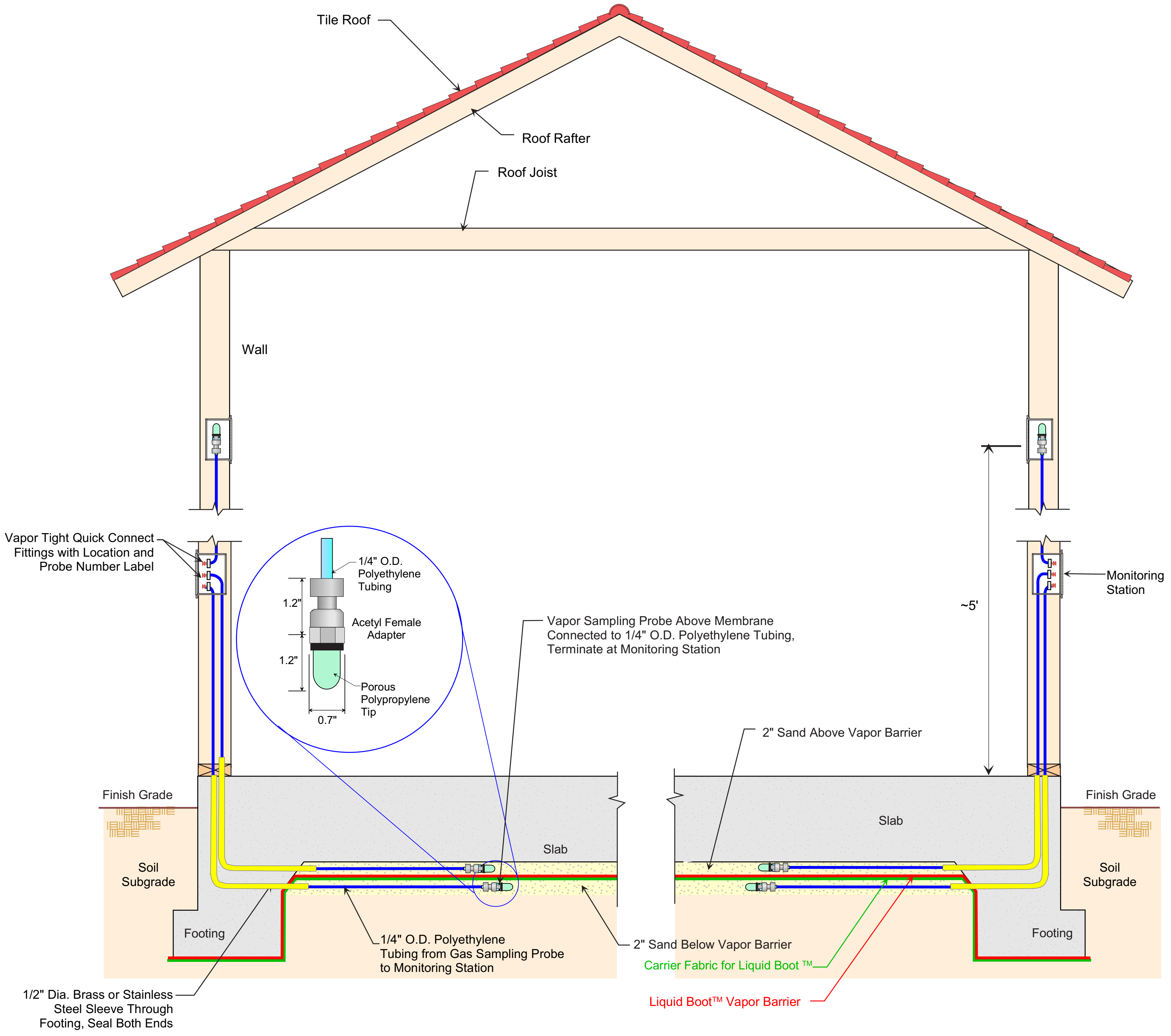
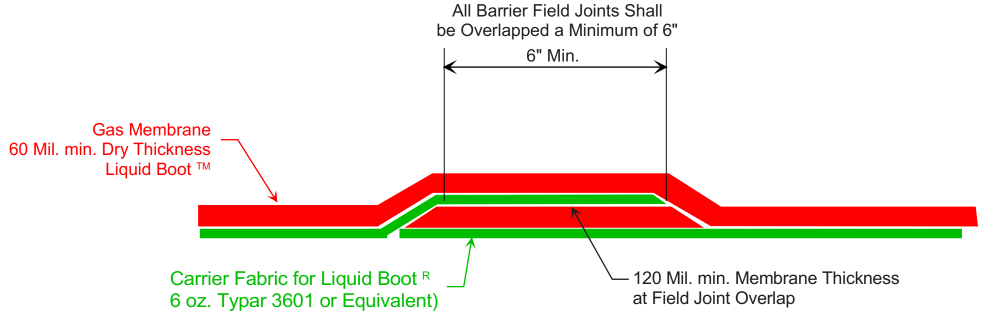
Typical HDPE Vapor Barrier Membrane Configuration

Figure 5



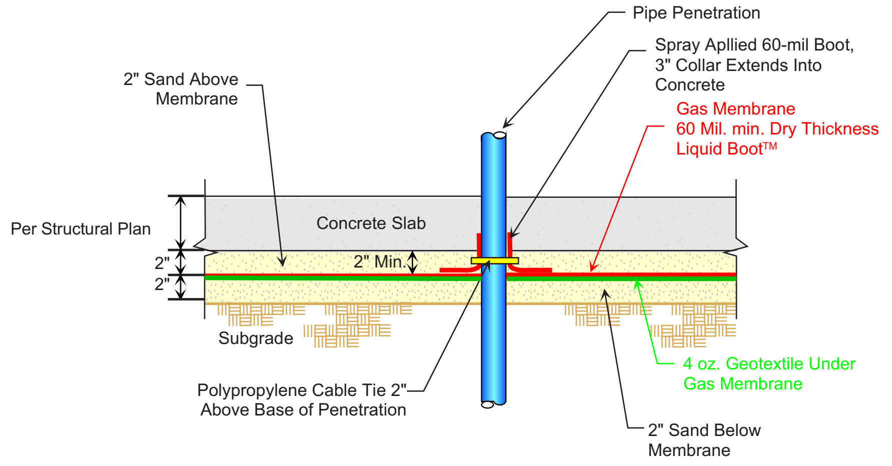
Above and Below Membrane Sub-Slab Vapor Sampling Probes

Not to Scale



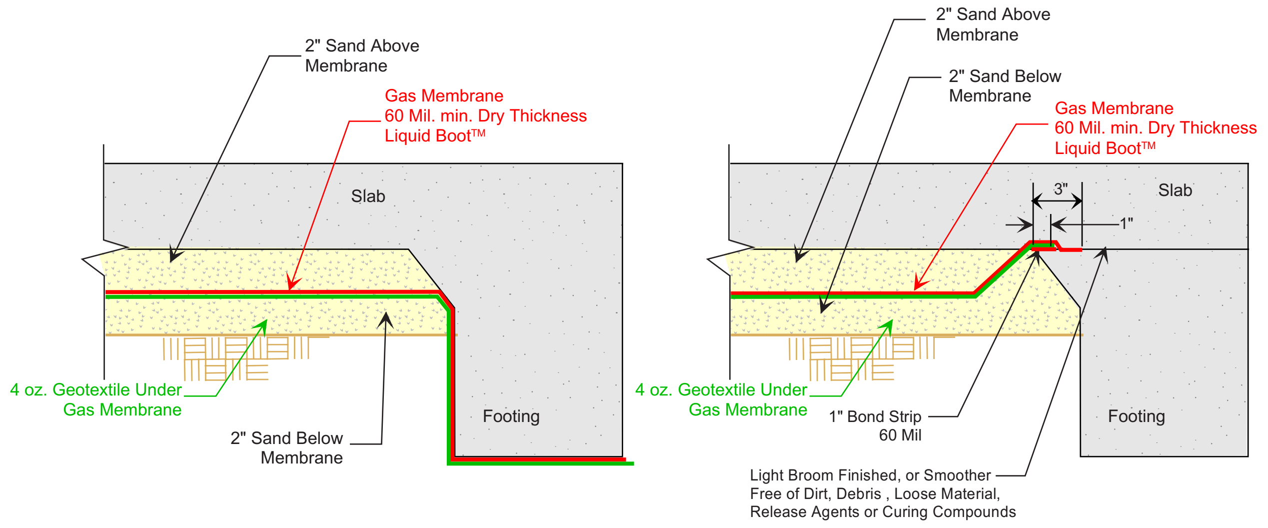
Typical Membrane Overlap Detail

Not to Scale



Typical Membrane Boot

Not to Scale



Typical Liquid Boot Seal

Not to Scale

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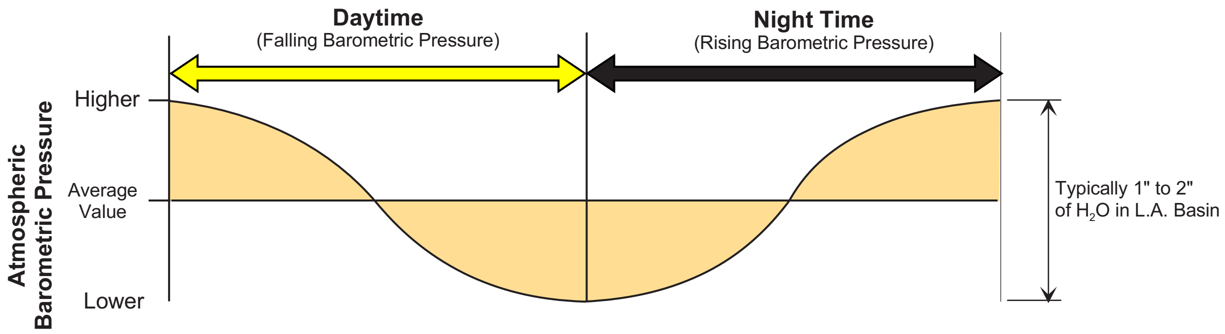
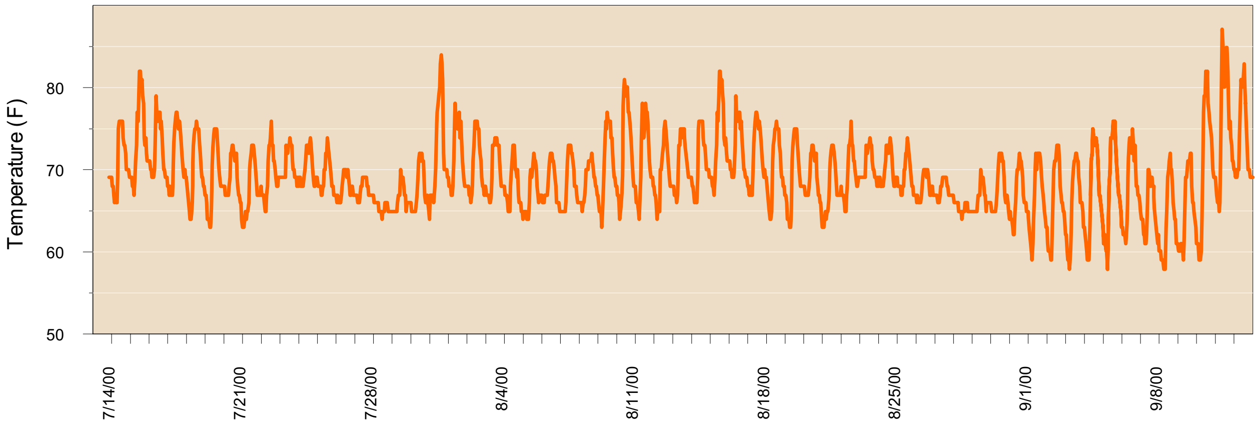
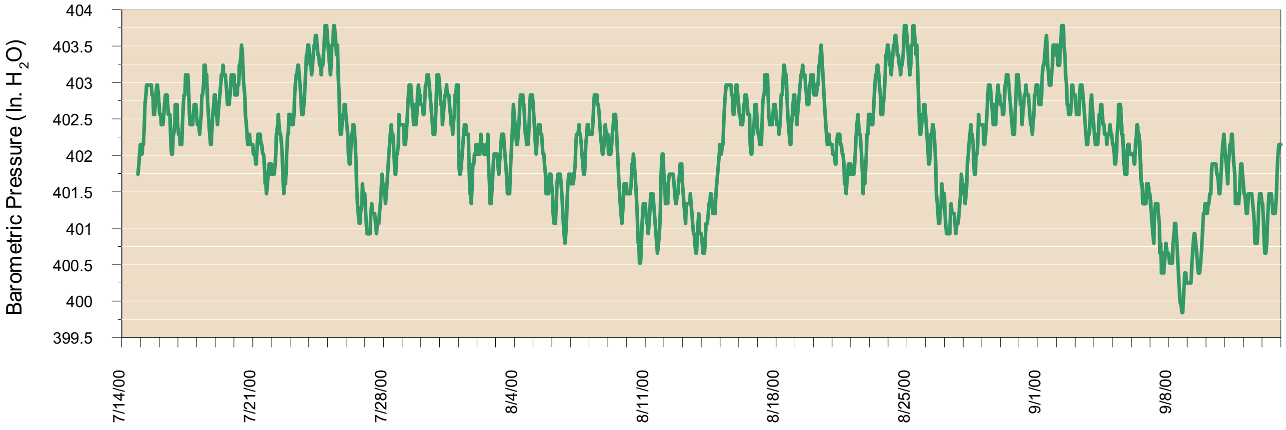
Typical Liquid Boot Vapor Barrier Membrane Configuration

Figure 6







Typical Diurnal Barometric Pressure Variation: 1" to 2" of H_2O
Typical Weather Induced Barometric Pressure Variation: 3" to 10" of H_2O

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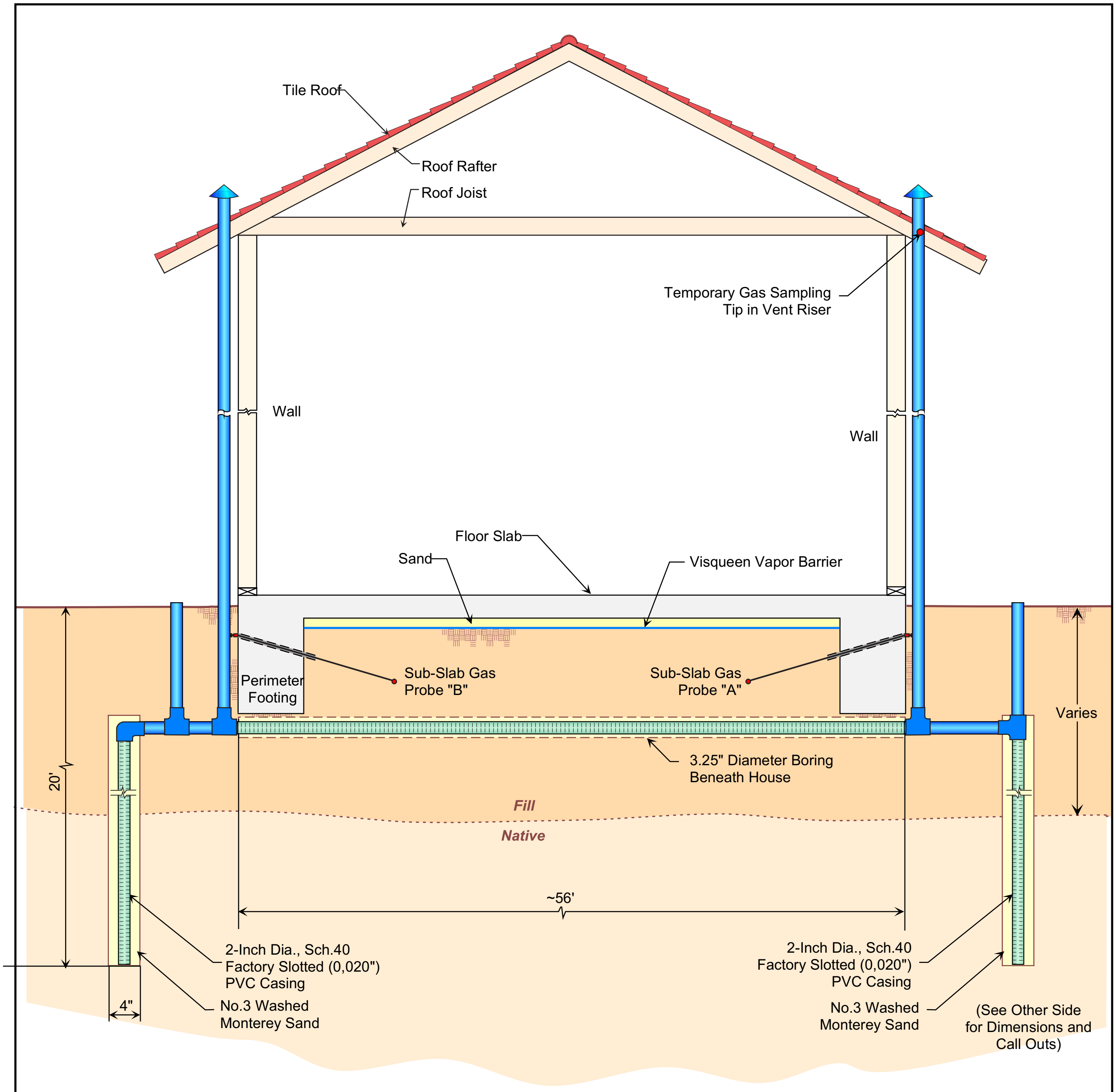
Typical Diurnal & Weather Induced Barometric Pressure Variations

Figure 7



Cross Section

Not to Scale
Vertical Scale Exaggeration

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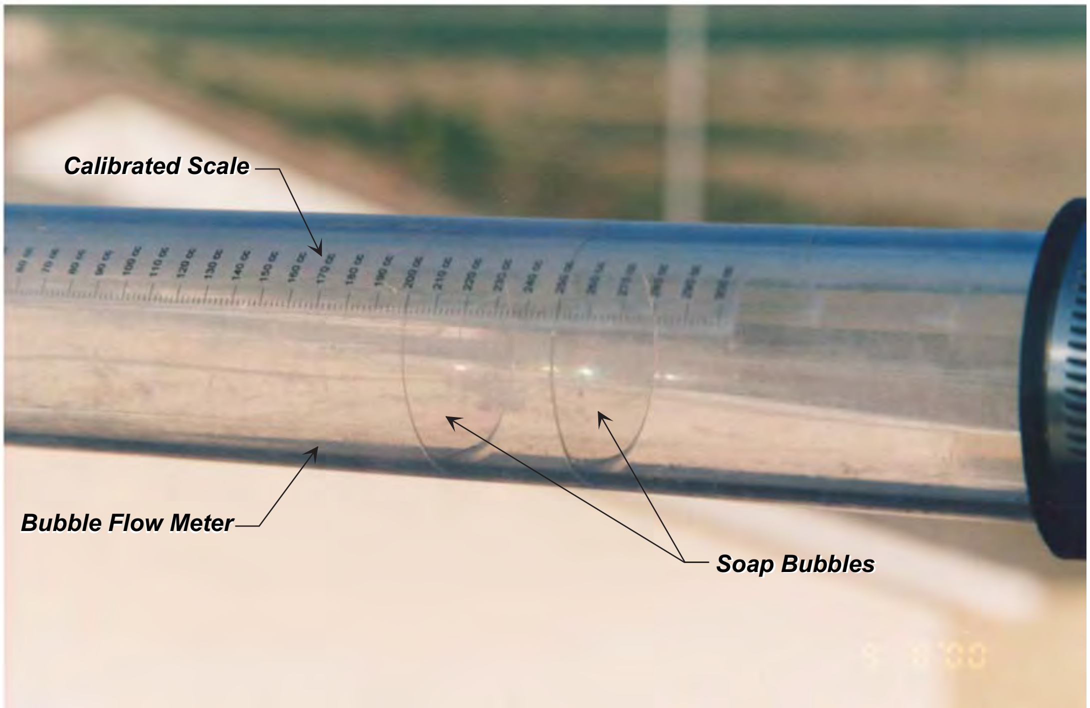
**Typical Retro-Fit Sub-Slab
Vent Configuration**

Figure 8



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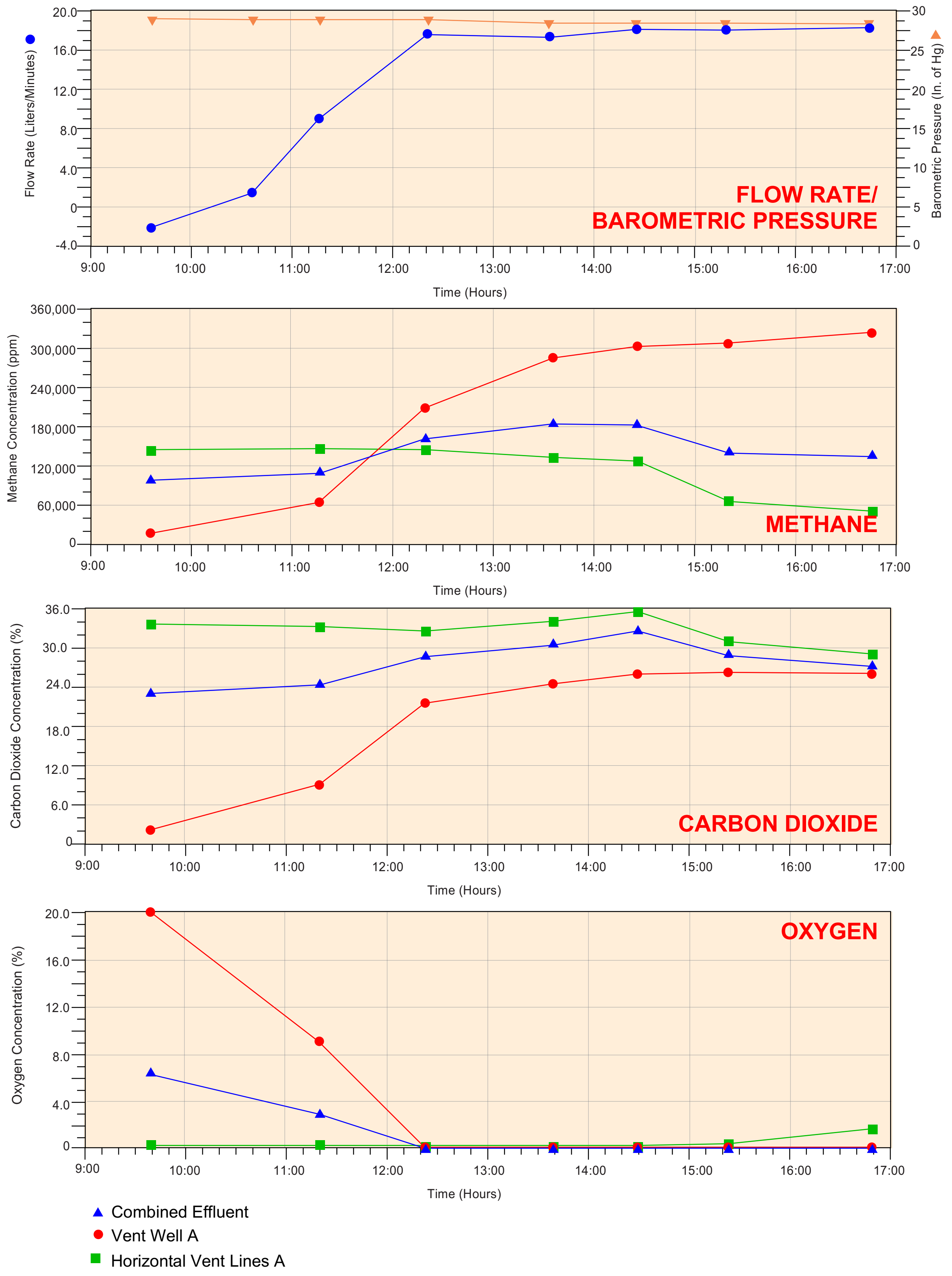
Measurement of Vent Riser Flow Rates

Figure 9



Note: Measurments Made on September 8, 2000

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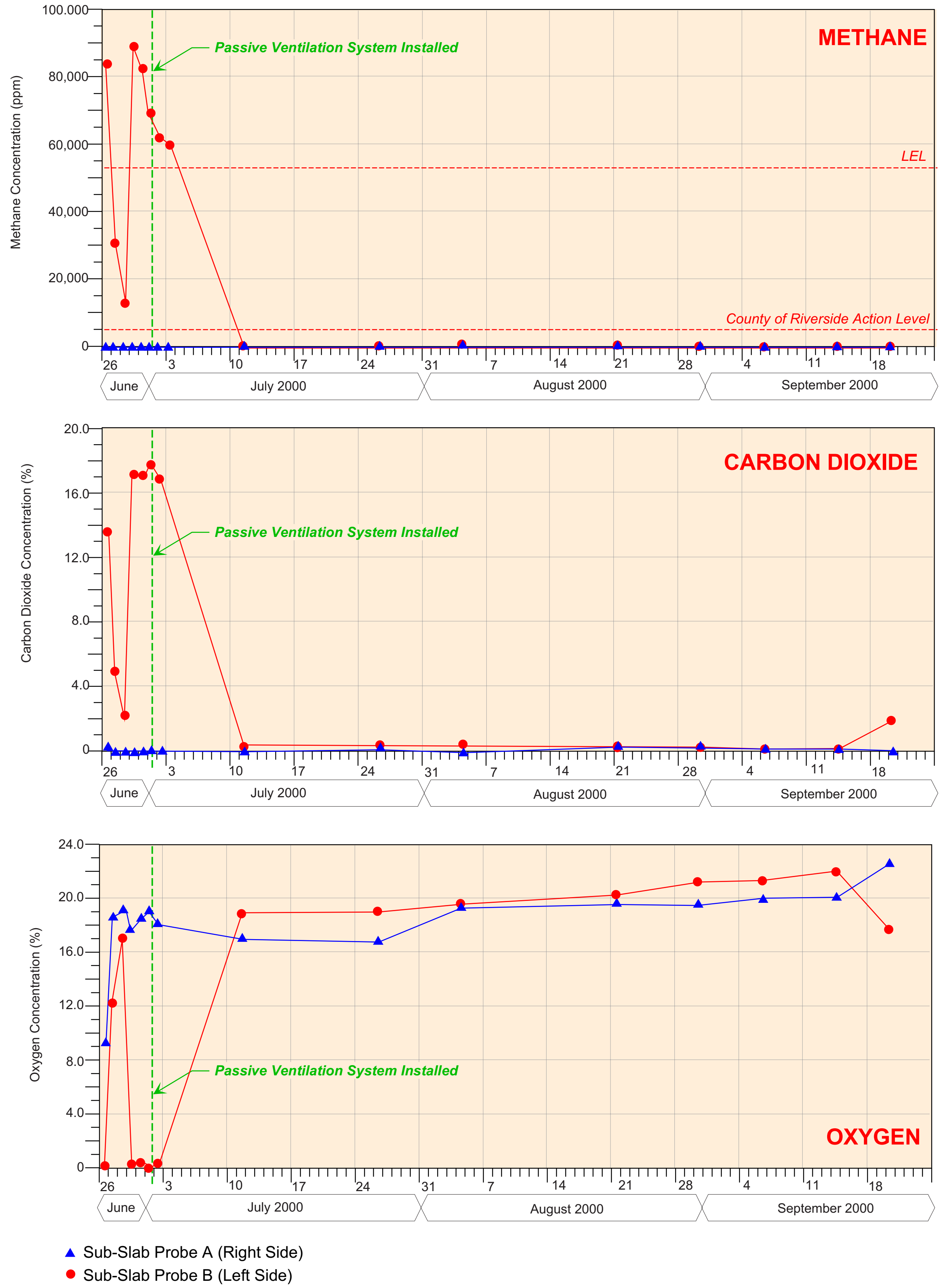
Hourly Vent Piping Flow Rate and Gas Concentrations for Passive Vent System at Lot 75

Figure 10



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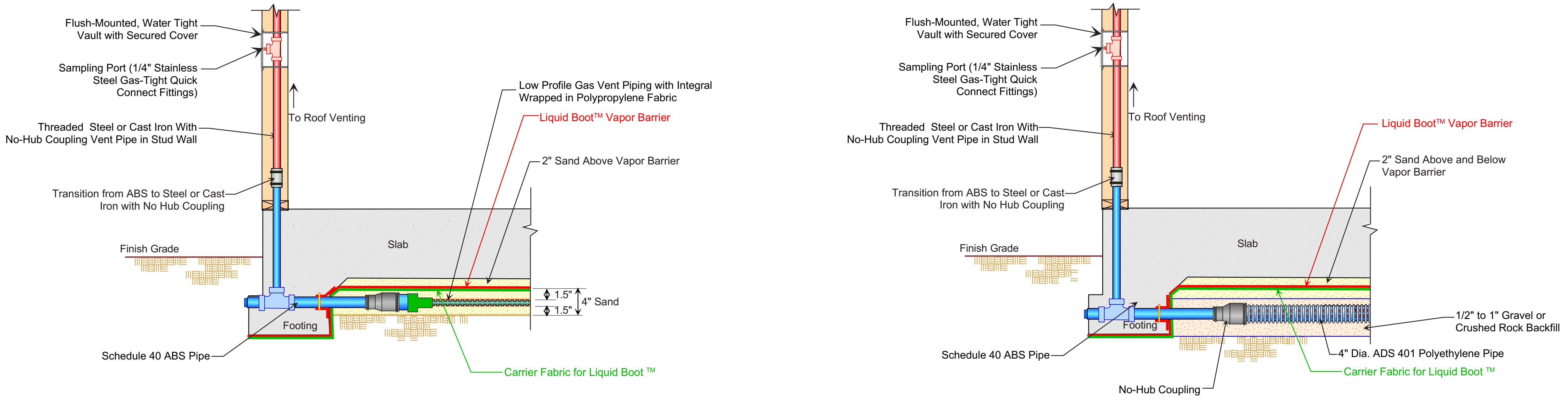
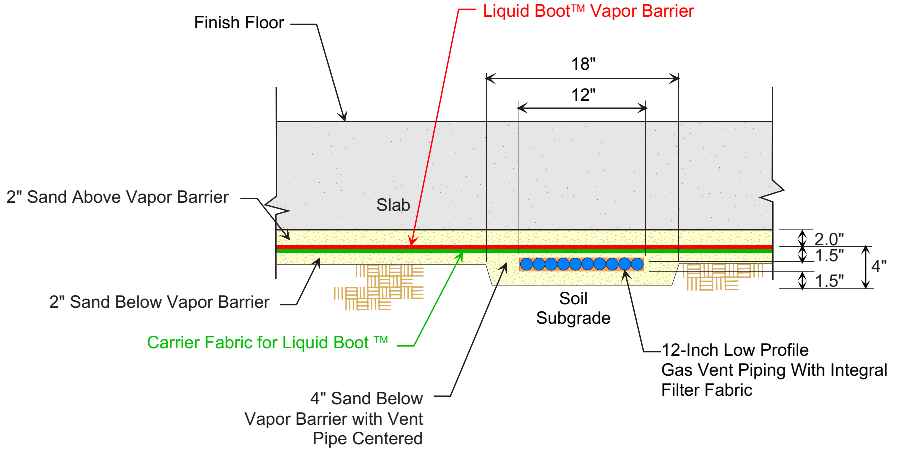
Sub-Slab Probe Monitoring Results for Lot 42

Figure 11



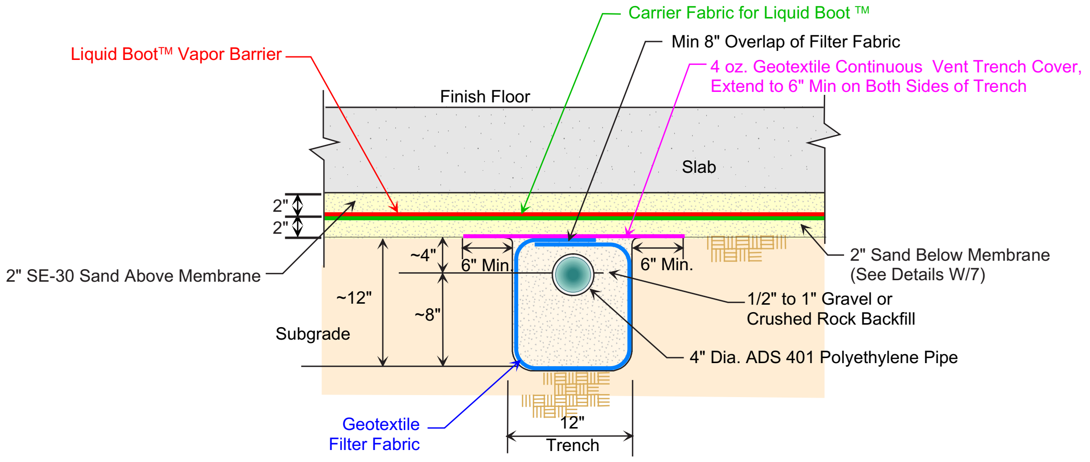
Vent Riser at Exterior Wall

Not to Scale



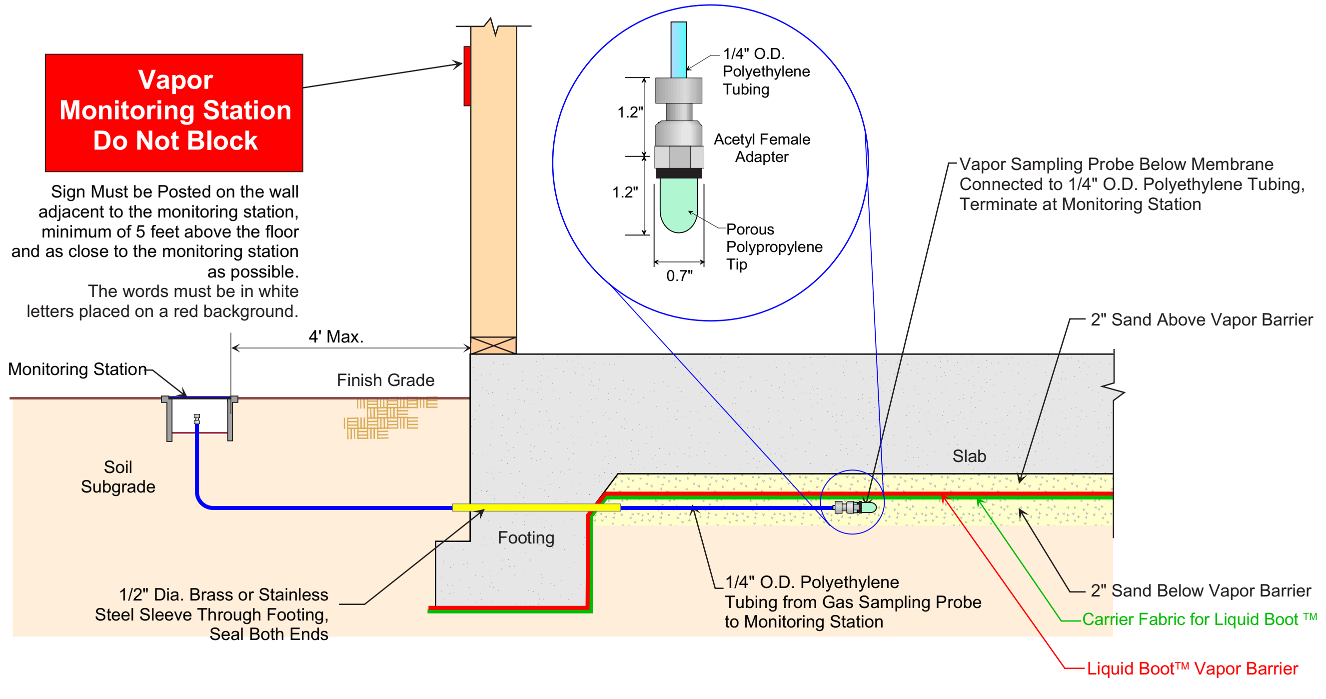
Low Profile Sub-Slab Vent System

Not to Scale



Conventional Vent Piping in Trench Detail

Not to Scale



Below Membrane Sub-Slab Vapor Sampling Probe

Not to Scale

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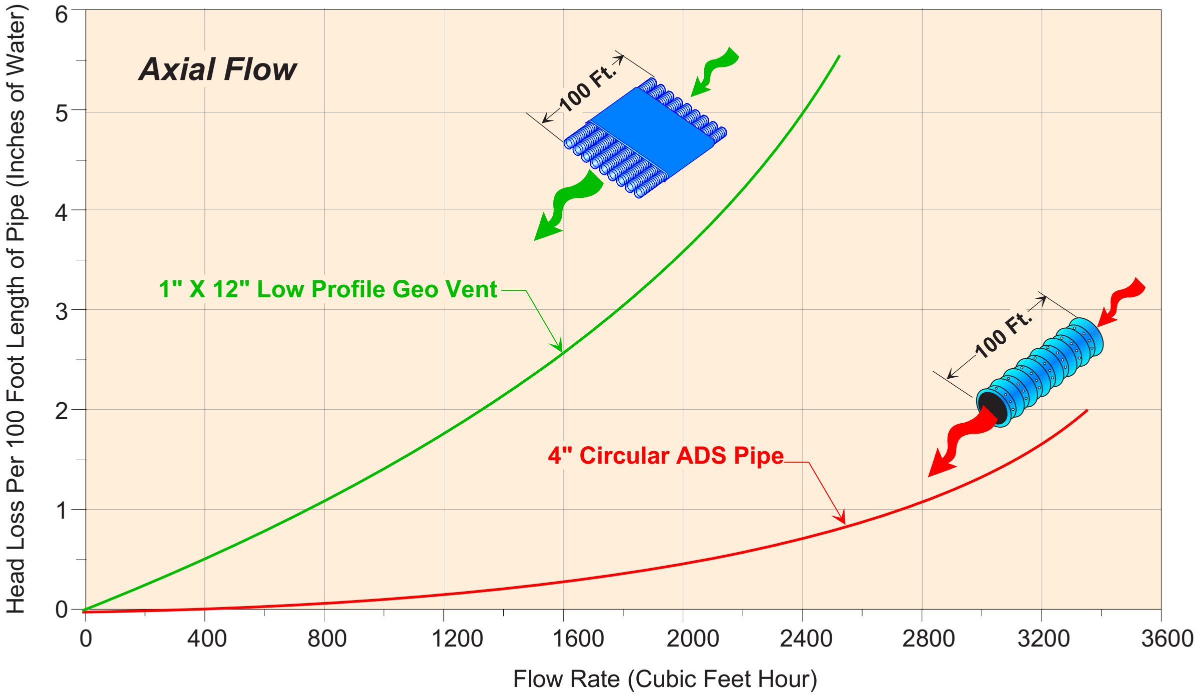
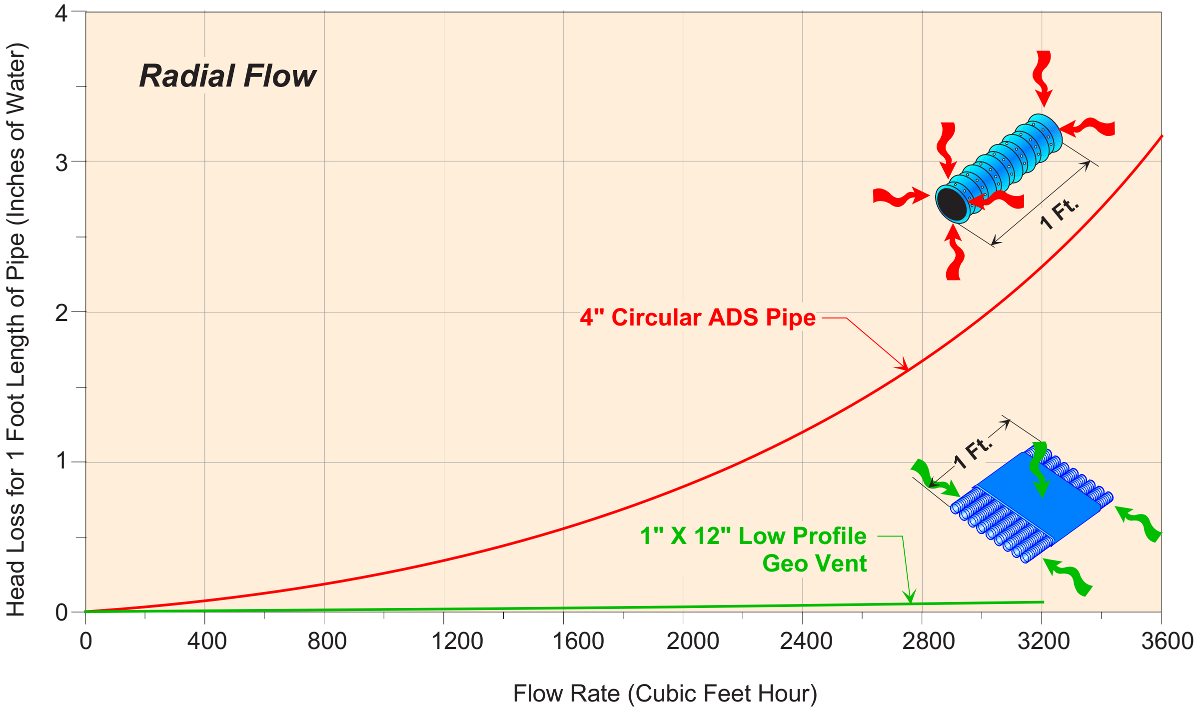
Typical Passive Sub-Slab
Vent System Configuration

Figure 12





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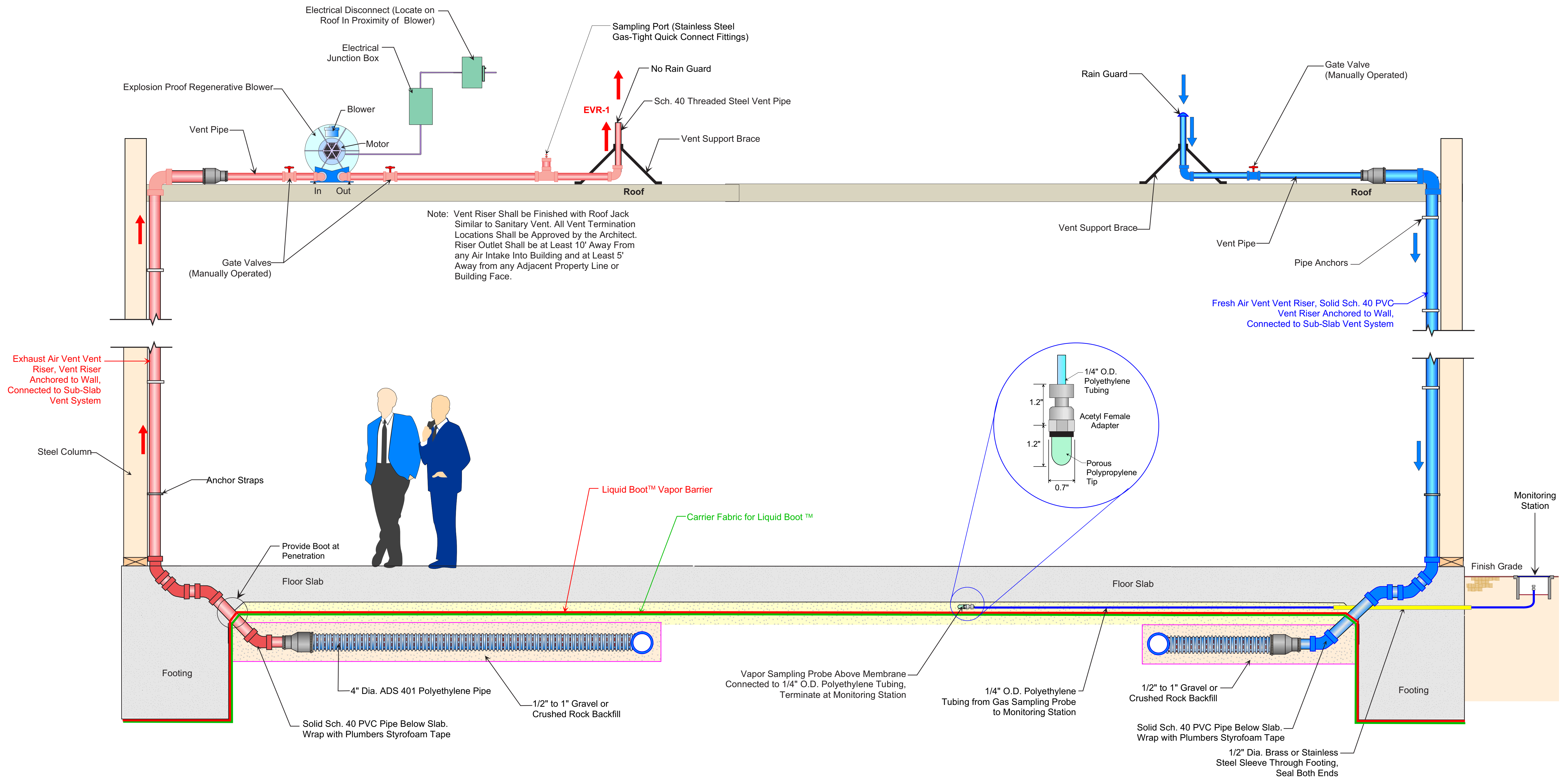
Axial and Radial Flow Characteristics of Vent Pipe

Figure 13



Note: Vent Riser Shall be Finished with Roof Jack Similar to Sanitary Vent. All Vent Termination Locations Shall be Approved by the Architect. Riser Outlet Shall be at Least 10' Away From any Air Intake Into Building and at Least 5' Away from any Adjacent Property Line or Building Face.

A ***Exhaust Air Vent Riser Configuration***
Not to Scale

B ***Fresh Air Vent Riser Configuration***
Not to Scale

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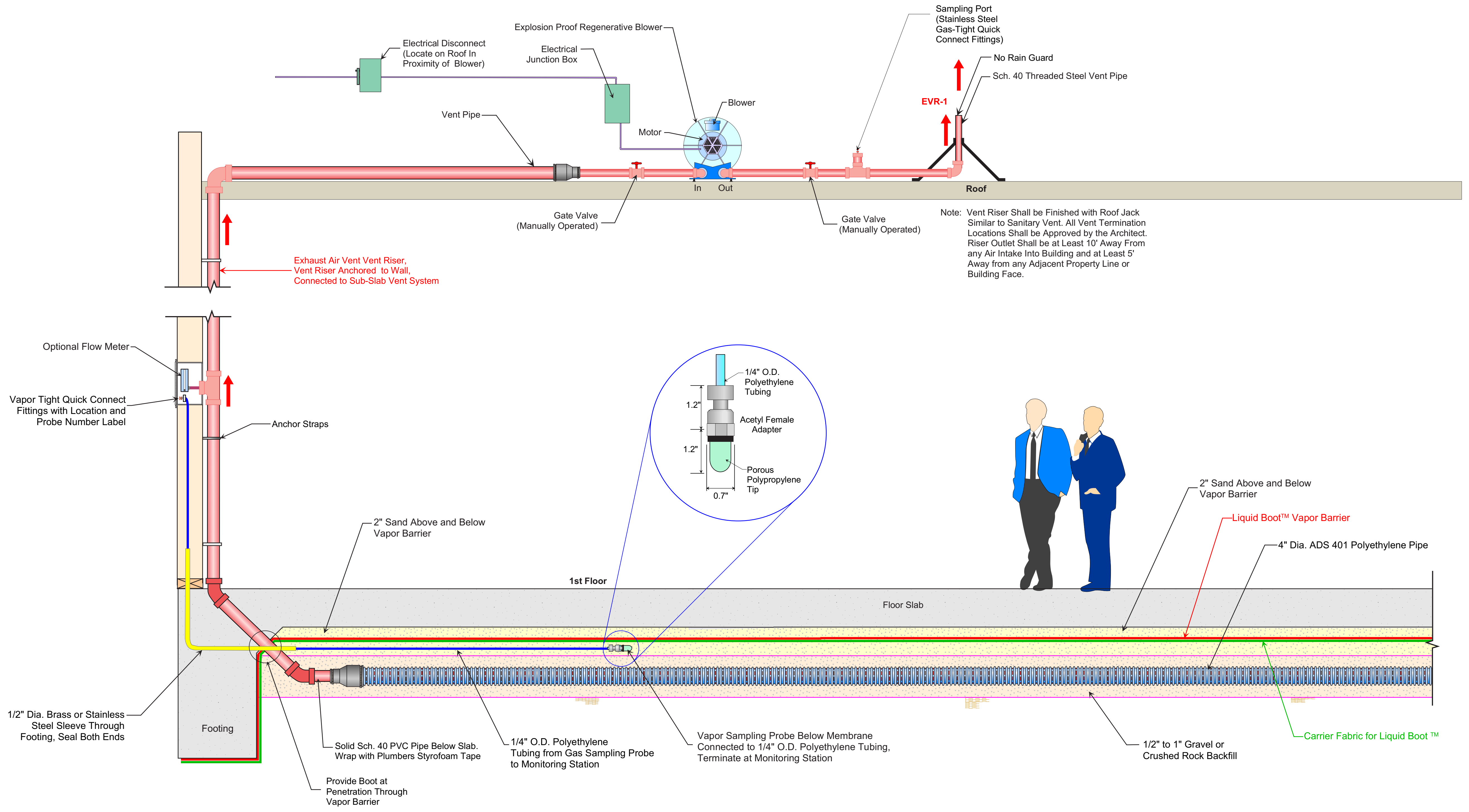
Vent Piping Details for
Active Sub-Slab Ventilation Systems

Figure 14



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**Typical Sub-Slab
De-Pressurization System Configuration**

Figure 15