APPENDIX A
Report on Panel of Experts Meeting and Recommendations

Exploratory Study of Basement Moisture During Operation of ASD Radon Control Systems

Contractor Report to EPA

December 6, 2007

Report on Radon Moisture Study Design Meeting
Washington, D.C.

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On June 26, 2003 a panel of experts was convened in Washington, D.C. to discuss proposed investigations of controlling moisture entry into buildings from the soil by using active soil depressurization (ASD). The one-day workshop was hosted by the Radon Team of the U.S. Environmental Protection Agency's (EPA) Indoor Environments Division, with support from the Scientific Analysis Team. Participants included building scientists, radon mitigators and instructors, mold investigators, soil scientists, and administrative and research staff of the U.S. Environmental Protection Agency (EPA). A participant list is attached.

EPA's Perspective

<u>Background</u>

The EPA has been aware of anecdotal information on the perception of moisture problem reduction as a result of ASD operation since the beginning of residential radon mitigation in the mid-1980s. Typical comments from occupants of houses with ASD installed pointed out that musty odors in basements were reduced, dehumidifiers operated less frequently, and wood in paneling, furniture and cabinets had shrunk.

Also, researchers conducting mitigation field studies during this period discovered that certain soils below concrete slabs were drying out from continuous operation of ASD systems. In many situations the drying of soil under slabs created void spaces which enhanced the pressure field extension of the ASD system, the differential pressures across the slab and the overall performance of the system.

There are about 750,000 ASD systems in place in the U.S., most of which are in residential dwellings. There are also more than 1,000,000 homes built with radon resistant new construction (RRNC) features, including a passive stack. If ASD systems can be shown to provide other benefits besides mitigation of indoor radon levels, then activation of this large number of passive systems may significantly reduce the risk potential to the public.

Finally, some new home builders and radon mitigators indicate that they are already installing ASD systems for the purpose of controlling moisture entry from the soil. There is little information or data available to better understand the impacts of this activity (benefits or drawbacks) on the indoor environment.

<u>Literature Review</u>

In 2002, EPA contracted to conduct a literature/model search on published documentation pertaining to a relationship between indoor moisture levels and the use of ASD. The search did not reveal any relevant documentation. A limited number of interviews were also conducted

with authors from published papers that might contain some unpublished information or potential leads to other sources. Again, no specific information was obtained.
As a result of this lack of information, some in the EPA's Radon Team became more interested in the usefulness of exploring a limited field study.

Unsolicited Proposals
Within the last two to five years, the EPA (Region 4 and Headquarters) has received unsolicited proposals from the Southern Regional Radon Training Center at Auburn University (Southern Training Center) to research the effect that radon ASD systems have on moisture in homes.

Limited Resources
Current EPA resources for any kind of a radon field study are limited, and do not approach the funding levels of 12-15 years ago when numerous field studies were underway. A front end workshop was envisioned as a way to explore the feasibility of a small study with limited resources in mind. In order to leverage additional benefits from their investment, EPA has also considered the possibility of packaging a successful small field study so that it could be replicated by individual states that wanted to conduct their own study.

EPA's Goals for the Workshop

EPA's overall goal for the workshop was to obtain ideas, suggestions and information from a panel of experts on design parameters for a field study on the potential to control moisture in residential substructures by the use of a radon active soil depressurization system.

EPA is not necessarily interested in moisture per se, but in its role in promoting microbial growth. Although a proposed exploratory study may not be able to include microbial measurements because of time scale and measurement difficulties, a focus on moisture as a surrogate for microbial growth is probably appropriate.

The panel of experts was given a table of measurement parameters and a possible project outline before the workshop as a straw for a starting point of discussions. However, the panel was instructed not to be limited by the information in these supplied materials. The outline and table originated from a proposal by the Southern Training Center. The panel was encouraged to present additional information and data during the workshop. EPA is willing to be convinced by this additional information and data to the extent to which it is compelling.

EPA was interested in the panel's feedback on the measurement parameters listed in the straw, with specific interest in:

- prioritized measurement parameters (i.e., are they essential parameters, are they reasonable but not essential enhancements, or are they are superfluous)
- time period sampling should take place in a house
- how many samples should be taken
- how many soil types should be included
- how many houses should be included

- cost estimates
- existing protocols or guidelines
- other considerations, and
- areas in which the panel lacked experience, and names of individuals with that experience

Broad Study Interests

A proposal from the Southern Training Center included goals and objectives for a study that would examine larger topics areas than that to be included in the limited study discussed at the workshop.

1) Quantify the change in building moisture levels and dampness indicators caused by soil depressurization control techniques
2) Characterize microbials in and near building structures during baseline conditions and control system operation
3) Improve our understanding of moisture (and possibly microbial) transport from the soil, and microbial amplification by this moisture
4) Examine the effect of soils and building characteristics on control system performance (i.e., identify the construction, soil, and environmental conditions where the problem is significant and can be remedied by the control technique)
5) Investigate the implications to occupant health and structural soundness
6) Develop guidelines for the application of these techniques

Specific Goals and Objectives of a Field-Based Exploratory Study

Also included in the Southern Training Center proposal were goals and objectives for a limited, exploratory, field-based study. The overall goal of this exploratory effort is 'Proof-of-Concept' testing that soil depressurization/ventilation techniques can change building dampness indicators, and moisture entry and accumulation in buildings. Specific objectives were:

- Improve our understanding of moisture transport and accumulation from the soil, and microbial amplification by this moisture
- Identify the parameters that characterize the changes to be monitored
- Refine protocols for measurement and data collection, and house identification and selection
- Gather preliminary data to define the expected range of the key parameters
- Recommend additional work based on study findings

Brief Synopsis of Workshop Activities and Discussion

After brief introductions and presentations of pertinent experience and information, the panel used the documents distributed before the workshop as starting points for discussion. In general, the participants supported the concept of a project to investigate control of moisture entry by ASD. The benefits and concerns that could accompany the operation of an ASD system for moisture control were discussed. Some examples of possible benefits included drying of foundation materials, energy savings compared to operating dehumidification equipment, reduced exposure to microbial contaminants and to other soil gas-borne pollutants, and improved building durability. Potential drawbacks included drying of materials that could cause structural or superficial movement or settling, backdrafting of combustion appliances, increased life-cycle costs compared to other moisture control techniques (drainage layers installed during initial construction), and increased moisture entry into some buildings.

Modeling vs. Field-based Study

The merits of a modeling versus a field measurement study were discussed. The group suggested several possible modeling approaches: adaptation of existing numerical models, application of conceptual models, and use of simple calculations to design experiments and measurement protocols and to bound measurement parameters. Some panelists suggested that soil models may be useful for predicting water balance in substructure materials,. and that standard, already-validated, advanced hygrothermal modeling could be very useful for exploratory studies. Participants discussed that there is little information and measurement data available on moisture movement in and around substructures under the influence of an ASD system, and that there is a limited budget for an initial study. Therefore, the group suggested that a reasonable approach would be to rely on conceptual models supplemented by computational modules (e.g., mass balance calculations, moisture movement by diffusion and capillarity, effective resistance of foundation surfaces and soils) to assist in the design of measurement protocols and to predict boundary conditions of important parameters. Field measurement data could be collected to validate initial assumptions and employed to modify protocols. Conceptual models were loosely defined to be expanded hypotheses on moisture sources and moisture sinks, moisture transport and accumulation, air movement in and around soils and buildings, etc.

Moisture Entry and Accumulation

There was a wide-ranging discussion on factors affecting moisture entry into buildings through the substructure. Moisture accumulation in microclimates in, or at, substructure surfaces was mentioned as probably having greater importance than moisture levels in the general air of the space. Apparently little data is available on conditions in these small regions.

Microbial Measurements

Although an interesting and affordable biosensor was introduced to the panelists, most of the group expressed the opinion that, for an initial project with limited resources, moisture was the key parameter to monitor. If time and money is available, then some of these sensors should be deployed in a pilot situation. These devices incorporate three different fungi as separate sensors that will grow when exposed to suitable moisture conditions. They are inspected by microscope to determine the amount of growth that has occurred. This is related to moisture available in the exposure environment. Unfortunately, few labs are currently trained to produce and analyze the sensor. Other microbial measurements were considered to be too costly and unlikely to provide meaningful results for the study considered here.

Other Techniques for Moisture Control

Other techniques for controlling moisture entry from the soil and comparisons of their effectiveness with ASD were briefly discussed, but it was decided that they should not be included in this limited study.

Recommendations

The group's recommendations are described in more detail, below

Pertinent Questions and Comments

Participants in the workshop raised a number of provocative and relevant questions, and offered insightful comments on issues related to the proposed study – some are listed below. It is intended that many of them will be addressed in the design of the study.

- What are the important sources of moisture entering the foundation and how do they change?
- How does ASD control 'musty' odors and dry foundation materials and surrounding soils in some homes?
- Could ASD aggravate moisture entry?
- What are the soil/foundation air flow pathways?
- What is the response time in substructure moisture levels after a change in a moisture source or moisture removal process?
- What is soil moisture gradient across slab?
- Value of fungal sensors?
- Value of MVOC markers?
- What is the source(s) of the 'damp basement' odors?
- Can microbials (particles and gases) that originate in the soils near a building enter the building?
- Are there health effects associated with exposure to these microbials and those growing in the construction materials of the foundation?
- Is ASD system design different for radon and moisture control?
- What is the energy cost comparison of ASD vs. dehumidification?
- What is the water activity at slab/wall surface?
- How much moisture in a house derives from soil gas entry?
- Do the measurements affect the parameter being measured?
- What other parameters are important for studies in other type of buildings?
- Key information is to be found at interior surfaces of slabs and walls
- Identify unknowns which cannot be addressed before beginning study
- Must distinguish changes caused by seasonal variations
- Need a new device to measure moisture in the top few centimeters of the concrete

Workshop Panel's Recommendations

The group discussed and provided recommendations on overall study design considerations, including selection criteria for buildings, length of study, and installation and operation of ASD systems. Some of the most important parameters to be measured as part of a field study were identified, and an attempt was made to assign priority to other supporting measurements and data.

Overall Study Design

The following overview of a possible study design has been drafted based on comments and recommendations made by panelists at the workshop. The group discussed the elements of a study design but did not agree on a design in its entirety. Some of the design elements are described in more detail, below.

1. *Develop Conceptual Model(s) and Calculate Boundary Conditions* to confirm key measurement parameters and expected range of measured values.
1. *Select One of Three Houses* (see below).
2. *Collect Structure and Occupant Information.* Although this activity may be part of the house selection process, information on building and occupants would be gathered during an early site visit (e.g., size, number of stories, construction materials, heating, cooling, ventilation equipment, occupant activities).
3. *Conduct Evaluation of Testing and Measurement Protocols in One House.* Test and measurement protocols would not only be evaluated on the bench (where necessary) during this element, but also on-site at one house. Include several preliminary periods of ASD cycling (step 8).
4. *Modify Model(s), and Test and Measurement Protocols* based on results from previous stage.
5. *Begin Extended Monitoring in One House* with test and measurement instrumentation and protocols as refined during the previous stage. Monitoring would continue for Priority/two to four weeks. If funding permits, additional, more extensive testing and measurements could be performed in this house.
6. *Design and Install ASD in One House.* Perform system design diagnostics and install system components as described below and attached.
7. *Continue Monitoring as ASD System is Cycled*. The houses will act as their own control (returning to non-intervention conditions) during the 'off' period of each cycle.
    - initially perform short cycles (days to week) to identify problems quickly, then proceed to longer cycles as determined experimentally by the equilibration time of key parameters
    - cycle systems for a full year over all seasons
8. *Select Two Additional Houses* based on information gathered from the first house.
9. *Begin Extended Monitoring in Two Additional Houses*.
10. *Design and Install ASD in Two Additional Houses*.
11. *Continue Monitoring in All Houses as ASD Systems are Cycled.* Changes in basement moisture levels and the resulting impact on small areas of wall and floor finish materials would be evaluated.

12. *Reporting of Results and Recommendations of Future Steps*

House Selection Criteria

The group recommended that residential structures be studied first, since these buildings tend to have simpler designs, construction, and accompanying ASD systems, and people spend most of their time in dwellings. Residences should be selected to provide a strong 'signal', and optimize the opportunity of observing any changes due to operation of the ASD systems. If no effect is observed in these homes, then it unlikely to be seen elsewhere.

Number of residences - A minimum of three buildings for each foundation type (slab, basement, crawlspace). The structures should be between five and ten years of age.

Owner-occupied (or unoccupied) single-family residence - It is important to simplify occupancy conditions and agreements/understandings with the occupants. Therefore, vacant houses are preferred if available (some possibilities include rentals, Minnesota research houses or other test facilities). If desired, occupancy effects can be simulated for vacant houses. If occupied houses must be selected, then it is preferable that there not be pets or children.

Geographical location - To reduce costs for this initial study and to reduce climatic variability, buildings should all be located in close proximity. The recommendation was for the dwellings to be located in a cold climate or mixed-climate area that has a dependable driving force for soil gas entry and moderately uniform underlying soils and geology.

Permeable soils around the building - Permeable native soils (e.g., glacial tills) tend to have better uniformity in radon levels (and perhaps moisture levels?) surrounding the substructure and have more consistent air flow pathways.

Unoccupied and mostly unfinished basement - The initial study should focus on a single foundation type – the panel recommended basements. Basement homes have greater surface contact with the soil and tend to be influenced more by conditions in the soils and materials around the building. Basement walls should be poured concrete to avoid complicated air flow pathways in blocks. The requirement for an unoccupied and minimally unfinished basement reduces variability in moisture response due to occupant activities and different finishes and furnishings. An unfinished basement also affords better access to basement surfaces for investigators. 'Unfinished' is a loosely defined requirement, since unfinished basements often have some equipment or activities (laundry). However, many of the meeting participants recommended the selection of houses with small areas of finish assemblies (e.g., framed wall with gypsum board and paint, carpeted floors, etc.) already installed, or that these assemblies be constructed during the cycling phase of the study. The assembled components would be representative of typical areas of concern where: (1) moisture would be more likely to accumulate due to the microclimate in the spaces created by these assemblies, and (2) the growth of microbials would be supported. Houses that have very small finished areas may also be suitable in order to investigate the impact of these areas on moisture accumulation. Basements should be able to be isolated from upper levels of the building, for example by a door. For similar reasons, residences without HVAC equipment or ducts in the basement would be preferred.

Gravel that forms a capillary break below the slab floor - As with permeable soils, a gravel layer generally results in more uniform conditions below the floor.

Musty, moldy, or earthy odors in the basement - An indicator of existing moisture problems.

Evidence of persistent moisture entry into the basement - Short-term variations in moisture entry can confound analysis of the effectiveness of the intervention technique. Therefore, homes that appear to have less fluctuation in moisture entry would be better candidates for this study.

No drainage problems or unusual moisture sources - Homes with significant liquid water entry due to leaks, major drainage problems, or very high water tables should not be selected since ASD is unlikely to be successful in these conditions. Houses where the water table is greater than 25 feet below the basement slab are preferred.

Pre-mitigation basement radon levels greater than 4 pCi/l and less than 10 pCi/L, while upstairs levels are no more than 4 pCi/l. Radon concentrations and entry rates may be useful as an approximate indicator for soil gas (and soil gas-borne water vapor) movement into a building while ASD systems are cycled on and off. Radon levels must be sufficiently elevated to indicate changes in soil gas entry rates, yet must be low enough in occupied areas so that exposure is minimized when the ASD systems are cycled off.

Buildings without an ASD installed are preferred, although homes with an installed passive stack could be considered. Homeowners must be willing to have an ASD system installed, or a passive system activated. They must also be willing to have the system cycled on and off for certain periods.

Tests, Measurements, and Data Collection

The panel provided considerable guidance and recommendations for various tests and measurements to be performed during the study. They were asked to consider and respond to the following questions and issues during their discussion of methods and measurement protocols. Complete responses were not generated for each method or protocol.

1. Do we already know the answer or have information on the measurement parameter or protocol?
2. Is there a protocol or professional agreement that can be referenced?
   - If not, what procedures/methods should be employed to address the measurement parameter or protocol?
   - Group to develop preliminary recommendations for approaches and protocols.
3. Group to assign a priority for each measurement parameter or protocol (high,

medium, low)
- For the importance of including it in this 'exploratory' project, and the importance of including in subsequent phases.
- To assist in configuring the project to the available budget.

Based on relevance and importance to the study, the panel's information has been assigned to one of three categories: priority/primary tests and measurements, supporting data and measurements, and low priority tests and measurements.

Priority/Primary Tests and Measurements
The following measurements were either identified by the panelists as essential, high priority tests and measurements, or have been included as primary measurements based on the group's discussion and the author's professional opinion.

- Moisture at several locations at the surface of slab, below slab, and several depths within slab, plus walls. High Priority.
  - To perform these measurements, the panel recommended relative humidity (RH) sensors with high sensitivity, accuracy and precision. The devices would be used to measure the relative humidity in a small head space above or within the subject material. Vaisala manufactures such instruments.
  - Exact protocols and methods would need to be developed and evaluated on the bench or in the field.
  - European standards should be referenced for in-slab moisture measurements (ASTM is also reported to be looking into this).
  - Uncertainty of measurement is not known.
  - A good seal around measurement location is important.
  - Allow sufficient equilibration time.
  - Avoid other sources of surface moisture.
- Differential pressure measurements at several locations to identify pressure orientations and gradients that drive air flow: above and below slab, inside and outside basement walls, basement inside and outdoor air. High Priority.
- Flow and pressure measurements of ASD system to characterize performance, including diagnostic measurements and pressure field extension for system design. See detail below and attached. High Priority.
- Distance to water table by boring – if distance is greater than 25 feet, then water table is probably not an important influencing factor. Most useful for selecting houses. High Priority.
- Temperature and RH in upstairs air, basement air (3 locations – look for spatial variation), below slab (directly below slab and below gravel), ASD exhaust, and outdoors plus one set of duplicate measurements. Not Prioritized. High Priority.
  - The relative humidity measurements described here may overlap with those conducted for moisture in and below the slab (above).
- Standard meteorological measurements (wind speed and direction, precipitation,

snowfall/snow cover, barometric pressure) of environmental conditions that may impact moisture movement and levels. Solar insulation was not discussed. Not Prioritized. High Priority.

- Radon gas measurement. Assess ASD performance and to assist in tracking soil gas movement and entry into the building: below slab, around walls, in soil around building, in building air (upstairs and basement), and ASD exhaust. Radon entry is not a direct stand-in for soil gas (and moisture) entry because of the spatial and temporal variations in radon concentrations in the soil around a building. However, radon is a traceable constituent in the soil air and generally causes elevated indoor levels when soil air with high concentrations of radon convectively/advectively flows into buildings. Not Prioritized.
- Determine fraction of ventilation air from soil gas entry into building using radon or other tracer gas. Not Prioritized.
- Determine fraction of basement/soil air in ASD exhaust by injecting a tracer into the basement air. Not Prioritized.
- Perform measurements of effective resistance to air flow of slab and soil around slab to assist in identifying soil gas entry locations, and to better understand air flow dynamics. Not Prioritized.
  - A blower door is used to depressurize the basement while flows and pressure differentials are measured at test holes bored through various locations in the walls and slab floor.
- Blower door test of basement and whole house leakage area. Not Prioritized.
- Information on characteristics of building and nearby surroundings. Not Prioritized.
- Maintain an occupant diary of house conditions. Not Prioritized.
- Occupants would be asked to track their perceptions of odor and air quality, and record unusual activities that might impact measurements.
- Field data collected and analyzed will meet EPA QA/QC requirements including appropriate data quality objectives (DQO), standard operating procedures (SOP) and protocols.

Supporting Data and Measurements

The following measurements and data collection were usually not assigned a priority because of disagreement among the panelists as to their importance to the study, but were considered by some panelists to be important additions to the study.

- Establish confidence intervals of measurement data to describe precision.
- Moisture in soil around and below building. Use gypsum blocks if they are appropriate and affordable.
- Characterize flow paths of moisture and air around and into basement. Discussions didn't clarify a suitable protocol for doing this, other than testing with tracer gas into surrounding soils.
- Blower door test with tracer gas to identify air movement pathways.
- Diffusion of moisture through concrete slabs and walls, to monitor diffusion contribution to indoor moisture. Diffusion coefficients from other sources

(NIST, DOE) to be used in model estimations, and to compare with field measurements.

- Develop device/protocol for measuring surface moisture (possibly paper/other industry has already developed?) Heated head RH and lithium chloride dew point sensors will be considered.
- Passive microbial volatile organic compound (MVOC) dosimeter on two week cycles to determine if moisture changes are reflected in indicators of microbial activity. Consider performing some pilot these measurements with these sensors, depending on time, cost and QA issues – or consider odors as substitute indicator.
- MVOCs or mold in settled dust – high cost, so only measure if there is reduction in other parameters (e.g., moisture) – medium priority
- Biosensors (fungal detector with sensors for 3 molds) to measure water activity levels necessary for mold growth. Would require approximately 100 detectors.
- Perform survey of slab moisture with non-invasive instrument (such as Tramex) to determine if this method would be a suitable low-cost alternative to more intensive measurement methods.
- Soil air permeability in surrounding native soil, around foundation, and below slab.

Low Priority Tests and Measurements

- Moisture emissions from slab and walls surfaces using commercially-available calcium chloride test kits. A number of panel members mentioned that this measurement technique can be unreliable due to variations in surface preparation, sealing to the surface, nearby finishes and structural components, etc. However, if the technique could be refined, it would provide an affordable method for quickly monitoring and surveying large areas.
- Tracer gas measurements of ventilation and interzonal air movement. Multiple tracers (e.g., perflourocarbon tracers - PFT) would be necessary for careful characterization of interzonal flow, including soil gas flow into building (position PFTs in soil if viable). No consensus on this issue.
- Soil air permeability in surrounding native soil, around foundation, and below slab.
- Multi-tracer gas test of interzonal flows with and without HVAC operation.
- Sampling of mold in the air – too many would be required, interpretation could be difficult, cost would be high
- Develop protocol for using dehumidifier during study - recommendation is to not use a dehumidifier during the study.

<u>ASD System Design and Operation</u>

A straw protocol for ASD system diagnostics, design, and installation is attached. Other comments from the panel include:

- Systems should preferably be routed through the heated space and exhaust above the roof, although this requirement may not be necessary for fan-driven systems
- There was disagreement on whether to simplify system design vs. performing

comprehensive design diagnostics (note: the attachment outlines the latter)
- Information on system performance should be collected so as to provide guidance for future ASD system designs for controlling moisture entry.
- Differential pressures should be measured at all corners and every wall during system cycling
- Perform suite of measurements with sealed and unsealed slab while system is cycled.

Estimated Costs for an Initial Limited Field Study

A limited field study outline should at least include the items listed below. Some activities can be conducted simultaneously.

Prepare QA/QC Plan
Equipment Identification, Procurement and Costs
Develop Conceptual Model(s) and Calculate Boundary Conditions
Select Three Houses
Collect Structure and Occupant Information
Select One House for Initial Evaluation of Testing and Measurement Protocols
Modify Model(s), and Test and -Measurement Protocols in field/bench tests
Begin Extended Monitoring in One House
Design and Install ASD in One House
Continue Monitoring as ASD System is Cycled
Begin Extended Monitoring in Two Additional Houses.
Design and Install ASD in Two Additional Houses.
Continue Monitoring in All Houses as ASD Systems are Cycled.
Reporting of Results and Recommendations of Future Steps

Estimated Total: $100,000 - 175,000

Straw ASD Diagnostic/Design Protocol (Jack Hughes)

General system performance requirements

ASD systems intended to depressurize under slabs shall be capable of producing a sub-slab pressure field with a minimum of 5 Pa (0.020" WC) negative pressure relative to the basement with the basement pressure neutral to outside.

ASD systems intended to depressurize soil adjacent to basement walls shall be capable of producing the required negative pressure field (minimum pressure to be determined) without adversely impacting the minimum required performance of any sub-slab depressurization systems present which may need to be operated simultaneously. [i.e., if combination sub-slab/outside-the-wall systems are installed, the system must have the capacity to adequately depressurize both areas simultaneously. A dedicated system(s) for each area may be necessary to meet this requirement.]

General system configuration requirements

Each suction point leg shall be equipped with a valve which, when fully closed, reduces the air flow from that suction point effectively to zero, and which, when fully open, does not offer resistance sufficient to reduce the air flow below the required minimum.

Each suction point leg shall be equipped with a manometer installed to continuously monitor read the indoor-to-pipe pressure differential in the pipe leg below the above-mentioned valve.

Provision shall be made for continuous air flow measurement in each suction point leg.

Diagnostic Procedures

Quantitative ASD diagnostic procedures sufficient to ensure that installed systems meet minimum performance requirements shall be performed. These procedures shall include, but shall not be limited to:

- -- basic communication testing at each proposed suction point;
- -- quantitative determination of resistance characteristics at each installed suction point and calculation of friction loss in proposed pipe run from that suction point;
- -- quantitative prediction of pressure/air flow at each suction point for any proposed system configuration (pipe runs and fans), including multiple suction point systems;
- -- simulation of operation of any proposed system to verify its capability to meet minimum performance (pressure field) requirements;
- -- verification of extent and strength of pressure field by measurement of pressure differential across slab at holes located so as to provide adequate pressure field

profile, particularly near known potential soil gas entry points, but not less than one hole per 200 square feet of slab area. Additional characterization of pressure field extent and strength can be achieved by use of chemical smoke at existing openings. Pressure fields outside walls can be similarly characterized.

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