Final Report P-5340/FG

# Development and Evaluation of Soil Gas Sampling Techniques

for

The Research Division
Policy Development and Research Sector
Canada Mortgage and Housing Corporation

by

Ontario Research Foundation
and
Gartner Lee Associates Limited

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Canada Mortgage and Housing Corporation, the Federal Governments's housing agency, is responsible for administering the National Housing Act.

This legislation is designed to aid in the improvement of housing and living conditions in Canada. As a result, the Corporation has interests in all aspects of housing and urban growth and development.

Under Part V of this Act, the Government of Canada provides funds to CMHC to conduct research into the social, economic and technical aspects of housing and related fields, and to undertake the publishing and distribution of the results of this research. CMHC therefore has a statutory responsibility to make widely available, information which may be useful in the improvement of housing and living conditions.

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SUMMARY

This study, conducted by Ontario Research Foundation and Gartner Lee Ltd. for Canada Mortgage and Housing Corporation, describes the development and evaluation of soil gas sampling techniques. The present study was prompted by previous research indicating a potential for significant soil gas entry into basements and crawl spaces of residential buildings.

Two types of soil gas sampling devices were fabricated and tested. To measure soil gas in-situ, soil probes manufactured with thin wall aluminum tube of 53.5 mm diameter and of varying lengths were installed in the soil surrounding the test homes. To measure pollutant levels at basement soil gas entry points, rigid accumulator containers were sealed to floor and wall cracks.

Three residences were selected for field evaluations of the probes and containers. Conditions at these residences represented a variety of soil geological and home construction characteristics. The in-situ soil probes were successfully installed and measured pressures at varying depths and locations within the soils. Soil gas pressure profiles and the resulting soil gas flow patterns were not uniform. The in-situ pressures were higher than reported literature values by several orders of magnitude. This high pressure effect was due to the confined condition of the soil. Frost sealed the ground surface while a fluctuating water table created excessive pressures.

Passive sampling of organic constituents of the soil gas in the soil probes and the entry point containers was unsuccessful because of the high moisture levels within these sampling devices. Active sampling of organic constituents from the probes located above the water table and from the entry point containers was successfully conducted. However, soil gas could not enter probes located at or below the water table and therefore the sampling pumps stalled when sampling these probes.

The low level of soil gas constituents found at the three test homes made evaluation of the sampling techniques and interpretation of the results difficult. The tests for organic compounds, pesticides and fungal growth were at or below the analytical detection limits. However, radon levels were consistently measurable.

The ratio of average indoor radon concentration to average entry point radon concentration can be used to determine the fraction of whole house air infiltration which is soil gas entry. For the three homes tested the soil gas entry was 1.1 to 3.8% of the entire home air infiltration.

## INTRODUCTION

As a consequence of the investigations on indoor radon, air infiltration and moisture in residential buildings, it has been determined that there may be a potential for significant entry of soil gas into basements or crawlspaces. This soil gas may also have the potential of containing various contaminants such as radon, methane, and other organic compounds and fungi which may have an adverse effect on indoor air quality. Considerable soil gas research has been conducted as a consequence of radon transport studies but little is known on the other potential contaminants in soil gas. In order to determine more about soil gas entry into residential building and the potential contaminants in soil gas, research programs will require the sampling and analysis of soil gas in-situ and at entry points.

This report describes the development and evaluation of soil gas sampling techniques that would be suitable for a wide soil gas entry survey of Canadian housing.

# 1. PROCEDURES

## 1.1 Background

The first step in the methodology of the study was to conduct a literature review.

A considerable amount of literature has been written on radon entry mechanisms into homes [1,2,3,4,5,6,7,8,9] but very little has been done to characterize the components of soil gas in-situ and at the entry points in basements. Some studies have investigated carbon dioxide and organics in soil gas,[10] but these have been associated with oil, gas and coal geological exploration. These soil gas references did not address methane, pesticide or herbicide residues or moulds.

### Soil Probes

The literature review completed in the initial stage of this study indicated that very few previous studies dealt with actual measurement of soil gas pressures and composition. The bulk of the existing literature dealt with sampling suspected soil gas entry points indoors. Five of the studies reviewed[2,3,11,12,13] actually installed soil gas probes in the ground outside homes. These studies dealt with narrow diameter probes driven into the ground or into a pilot hole in the ground. These studies provided some insight as to the status of current investigation techniques. However it is apparent much development is still required to handle different geological settings and home geometries.

Radon

Radon in soil gas has been measured by various techniques. Radon in-situ or in soil probes has been measured with track-etch detectors,[11,12,14] scintillation vials[12], and real-time and analyzers[2,3]. The passive, time integrating samplers (track-etch detectors and scintillation vials) are placed in the soil for periods of one week or greater. The real-time analysers measure radon continuously.

These studies found very little, if any, correlation between soil gas radon and indoor radon. Only in a Finnish study[12] was a correlation found, and then only in three of 70 soil probes surrounding a home. Further details of these studies follow.

A study conducted by the University of Pittsburgh[11] investigated the relationships between radium in soil, radon in soil gas and radon in indoor air. Soil gas radon was measured with Terradex Track-etch cups buried at depths of 37 cm in the soil adjacent to the homes. The correlations for the different factors were all very weak. The authors suspect that the Track-etch cups were not at a suitable depth to monitor soil gas representative of that which enters the homes.

During a radon entry study conducted by Lawrence Berkeley Laboratory[2,3], radon in a soil probe, radon in a basement sump, radon in the indoor living space and the building air exchange rate were all measured. The indoor radon concentration changes corresponded to changes in radon levels in the sump. Changes in radon levels in the soil probe did not correspond to changes in the sump or the indoor air. Radon in the soil probe ranged from approximately 2220 to 6290 $Bq/m^3$ (60 to 170 pCi/L), radon in the sump from 148 to 2960 $Bq/m^3$ (4 to 80 pCi/L) and in the indoor air from 37 to 260 $Bq/m^3$ (1 to 7 pCi/L). Radon was measured with real-time analyzers.

A soil gas radon study conducted in Finland in an esker area found an appreciable seasonal variation in soil gas radon concentrations.[12] Test holes in the vicinity of a home were sampled. The test holes varied in depth from 0.5m to 5m, depending on the soil conditions. The primary radon detector employed was a liquid scintillation solution placed in an open glass vial. The vials were placed in the test holes at varying depths for periods of one to three weeks. After exposure, the alpha activity of the liquid scintillation solution was determined by a scintillation counter. The vials were calibrated in a laboratory calibration chamber in order to relate vial alpha activity to average radon concentration. The error of this vial detector method was estimated to be 25%. A cellulose nitrate track-etch method was also employed, but not used as extensively as the vial method.

Because the esker was a high radon area, soil gas radon and indoor radon levels were high in this Finnish study. Soil gas radon varied from 50,000 Bq/m$^3$ (1350 pCi/L) to 430,000 Bq/m$^3$ (11,6000 pCi/L) and indoor radon from 2000 Bq/m$^3$ (54 pCi/L) to 14,000 Bq/m$^3$ (380 pCi/L). Changes in concentrations of radon soil gas in three test holes corresponded to changes in indoor radon. Based on sampling of 70 test holes, soil gas radon concentrations varied greatly within a small area. This was attributed to varying soil physical conditions.

Radon flux from surfaces has been measured by the accumulation method(15,16,17) or the charcoal canister method.(16) In the accumulation method a container is sealed onto the surface to be studied, and samples of air are taken from the container periodically and analyzed for radon. This method has been used to determine high radon flux, such as from uranium tailings, and low flux from normal soils.

The charcoal canister method involves sealing a canister of charcoal onto a surface during a collection period of two to three days. The canister is then removed and gamma spectrometry techniques used to determine the activity of radon in the canister. Charcoal canisters are not suitable for high flux sources or environments with high humidity. High radon will saturate the charcoal and high humidity will poison the charcoal so that it cannot efficiently adsorb radon.

Pesticides/Herbicides

The initial phase of the U.S. Environmental Protection Agency's ongoing study of indoor pesticide exposure measured airborne levels indoors and outdoors in close proximity to the homes tested.[18] They did not sample pesticides in the soil, vegetation or soil gas. Of 30 pesticides investigated, 22 were detected in the indoor air. Indoor concentrations ranged from 1.7 ng/$m^3$ to 15 μg/$m^3$. Outdoor levels were much lower than indoor levels. The homes of this study were known to be treated for termites or had received professional indoor pest treatments. The EPA[18] study and others were referenced to determine sampling methods, analytical methods and the expected pesticides and fungicides to be found in residential buildings.[19,20,21,22,23] In addition, the Ontario Ministry of the Environment was contacted for names of common pesticides registered for use in Ontario.[24] The Ministry schedules the pesticides that are allowed for use in Ontario. From this information, a list of candidate pesticides used in Ontario homes was assembled, Table 1.

TABLE 1

COMMON HOUSEHOLD PESTICIDES IN ONTARIO

| Location | Pesticide | Comment |
|---|---|---|
| Inside Home | Diazinon | Insecticide, Nematicide |
| | Dichlorvos(DDVP) | Insecticide, Pet Collars |
| | Pyrethrin | Insecticide, Pet Collars |
| | Chlorpyrifos | Insecticide |
| | Warfarin | Rodenticide |
| | Forexa | Rodenticide |
| | Bromadialone (Bromone) | Rodenticide |
| | Sevin (Carbaryl) | Insecticide, Pet Collars |
| Outside Home | Diazinon | |
| | Benonyl | |
| | Sevin (Carbaryl) | |
| | Dimethoate | |
| | 2, 4-D + silex | |
| | Paraquat | |

Prior to environmental pesticide regulations, chlorinated hydrocarbon pesticides were used extensively but these left residues in soil and water. In the past 10 to 15 years organphosphate and phenoxy based pesticides have replaced the chlorinated pesticides. These newer pesticides degrade quite rapidly in the top soil layers and by design are more efficiently taken up from the soil by the plants. Weed'n Feed, a common commercial fertilizer/pesticide formulation, contains 2,4-D. 2-4-D is a phenoxy herbicide which decomposes within a few days. A common indoor pesticide, Raid, contains pyrethrum which breaks down in a matter of minutes.

## Household Fungi

Methods for monitoring of airborne fungus or moulds involve the collection of particulate in a culture media and then the incubation of the media to permit the growth of colonies. Each colony represents a fungal spore. The colonies may be simply identified as total fungal or, in addition, more specific genus and species identification can be performed. The identification of species is extremely specialized and expensive.

## Soil Gas Transport/Modelling

As previously mentioned soil gas entry as a mechanism for radon entry has been studied extensively. Various researchers have investigated radon entry from both diffusion and pressure induced flows.[3,4,5,6] Basement foundations which have soil gas entry points such as dry floor drains, cracks and poor seals around utility entry points are prone to higher indoor radon levels. The movement of soil gas and in turn radon into basements is pressure induced, therefore, basements which are under high negative pressure from building stack effect, wind pressures or ventilation systems will also be prone to higher radon levels. Soil gas transport has been experimentally measured[25] and modelled.[26,27,28,29,30]

A preliminary study of soil gas transport during different residential basement pressure conditions investigated tracer gas migration, in-situ soil gas pressures and indoor radon levels.[25] The tracer gas sulphur hexafluoride ($SF_6$) was injected into the soil and its concentration over time at points in the soil and in the home monitored. During home depressurization at 30 Pascal (Pa), $SF_6$ appeared to migrate toward the basement and enter at a level close to the floor. Based on one of the experiments, a net migration velocity of $SF_6$ through the soil of 1 m/h was calculated. The influence of basement pressures in the soil was detected at distances up to 5 meters from the basement foundation. The depressurization conditions had a strong effect on the indoor radon concentration.

A computer model[26] predicted similar effects. Variations in wind speed and direction which caused pressure differentials across the building envelope were found to cause large variations in radon entry rates. The average radon entry was found to be a function mainly of soil permeability, and only secondarily of the area and resistance of the foundation entry points to the soil.

The prime elements of a predictive radon transport/entry/indoor concentration model would include hydrogeological and building technology components. The hydrogeological component would predict soil gas radon levels based on soil uranium content, soil fracture patterns, soil permeability patterns, and water table behaviour.[27] The building technology component would addresse foundation characteristics, and building envelope differential pressure patterns.[28]

One conceptual hydrogeological model[28] discusses the influence of water table movement and precipitation events on the pressure patterns that drive soil gas flow towards natural "low pressure chambers" such as houses with partially buried basements. Precipitation accompanied by substantial infiltration creates a surficial confining layer that, coupled with a rising water table, drives soil gas flow with a piston effect. Similarly, water table drawdown created by pumping wells can draw soil gas towards residences. Other investigators[17] have also noted the effect of infiltrating water raising soil gas pressure.

## 1.2 Sampling Techniques

### Sampling Techniques Selection

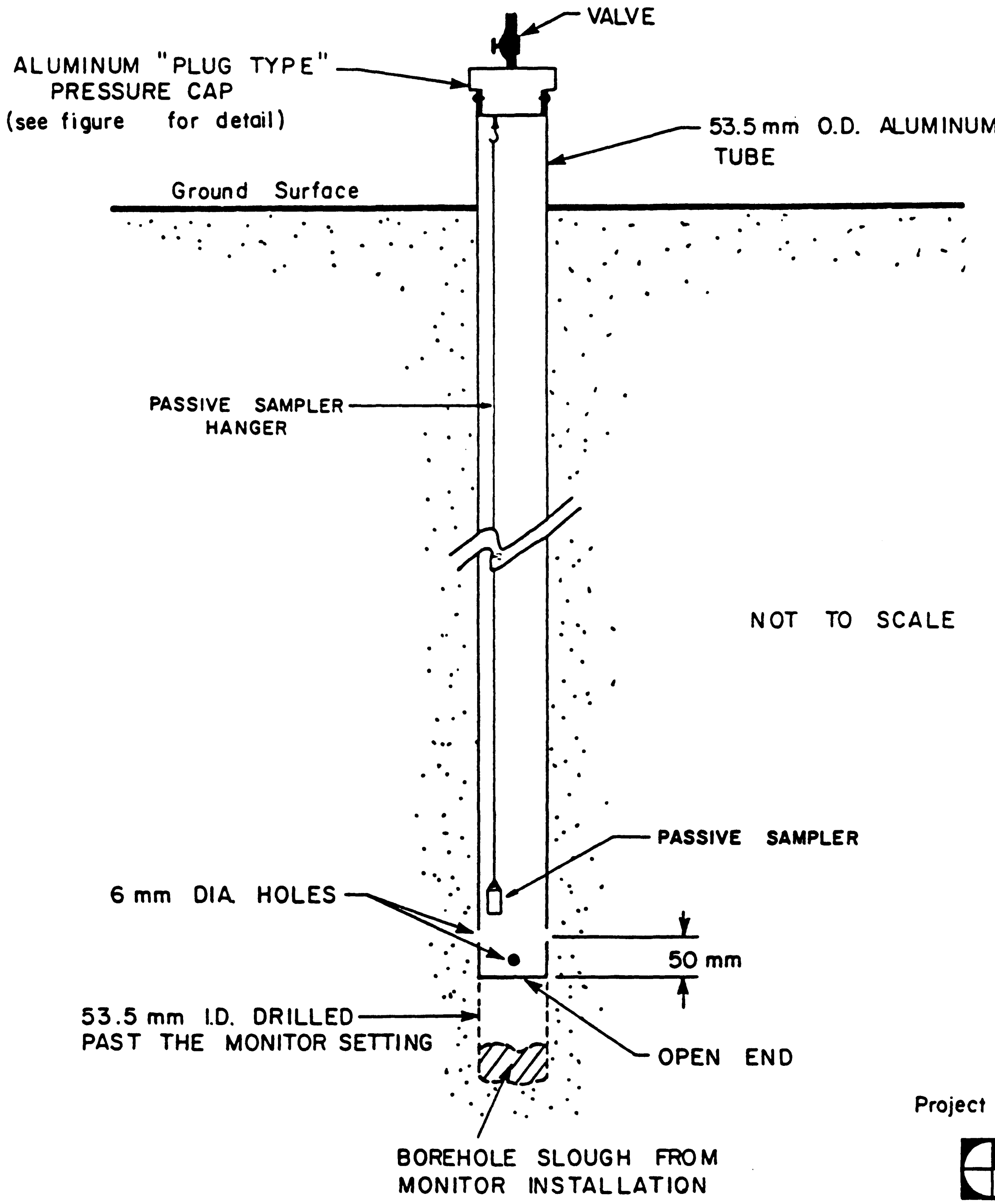
Soil gas moves from the soil, through entry points in the home foundations that are below grade into the basements and then from the basement to other living areas. In order to study the movement of soil gas from the soil into homes, measurements should be made in-situ in the soil, at the entry points and in the living areas. For this study sampling was conducted at each of the locations. Soil probes were selected to sample soil gas in-situ and rigid containers were selected to sample soil gas at the entry points.

Figure 1 shows a schematic drawing of a soil gas probe. The probe was designed to accommodate a variety of pollutant sampling techniques. It was anticipated that both low and high soil gas sampling flow rates would be used. The device chosen, and described below, incorporated features that could allow high volume sampling but also have sufficient storage capacity for low flow sampling rates.

A thin wall aluminum tube with a diameter of 53.5 mm was

# Figure 1

# TYPICAL MONITOR CONSTRUCTION

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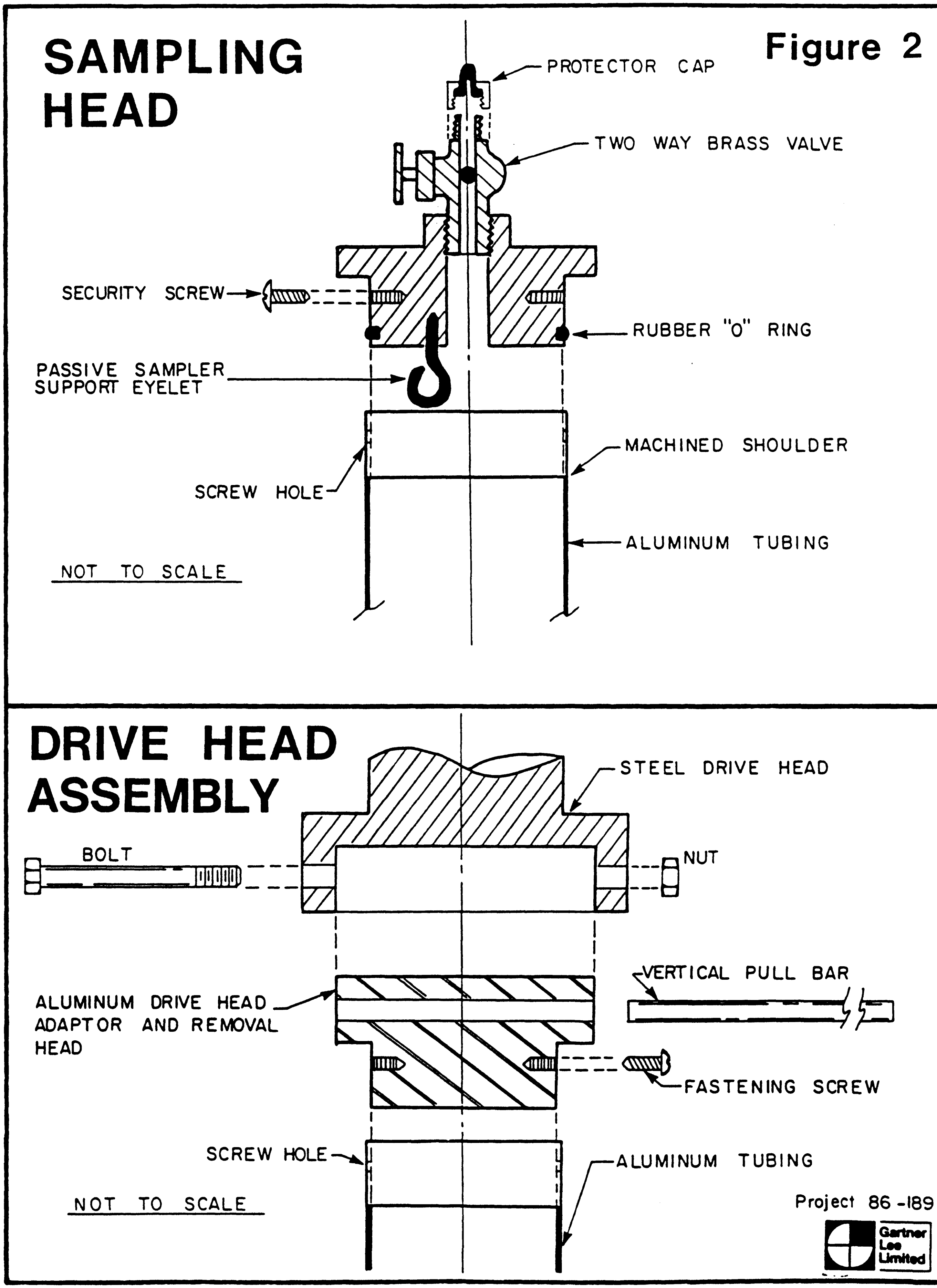
selected to provide the necessary storage capacity. The upper end was machined to allow the insertion of the sealed sampling head. The lower 50 mm was perforated with 6 mm holes to create a greater soil gas inflow area. The bottom of the tube was left open to facilitate installation.

The sampling head is shown in Figure 2. It is equipped with a rubber "O-ring" which was coated with inert teflon grease to provide an effective pressure seal. Two screws installed above this ring provided the necessary security. This head is equipped with a two-way valve and protector cap. The valve was used, first to measure pressure, and then to sample the soil gas. Underneath the head, an eyelet was installed to permit the installation of passive sampling devices. These were suspended opposite the perforations downhole using string as shown in the monitor in Figure 1.

Based on radon flux sampling of soils and uranium tailings and contaminant flux sampling of hazardous waste landfill sites, the accumulator sampling technique was chosen for entry point sampling. Rigid containers which could be placed over floor drains and floor and wall cracks and which had sufficient internal volume to contain the various passive monitoring devices were selected. Low cost, easily available, polished stainless steel baking pans of various sizes and shapes were used, Figure 3. Sampling ports with flexible tubing were installed in each container to permit active sampling. With these rigid containers both long-term passive sampling and short-term active sampling could be performed.

The containers were to be sealed onto the floor or wall surfaces with a waterproof silicon sealant. If the surfaces were irregular then duct tape was to be used to ensure a tight seal and hold the container in place. Air samples were taken and analyzed of volatile organic compounds


SAMPLING HEAD
Figure 2
PROTECTOR CAP
TWO WAY BRASS VALVE
SECURITY SCREW
RUBBER "O" RING
PASSIVE SAMPLER SUPPORT EYELET
MACHINED SHOULDER
SCREW HOLE
ALUMINUM TUBING
NOT TO SCALE
DRIVE HEAD ASSEMBLY
STEEL DRIVE HEAD
BOLT
NUT
VERTICAL PULL BAR
ALUMINUM DRIVE HEAD ADAPTOR AND REMOVAL HEAD
FASTENING SCREW
SCREW HOLE
ALUMINUM TUBING
NOT TO SCALE
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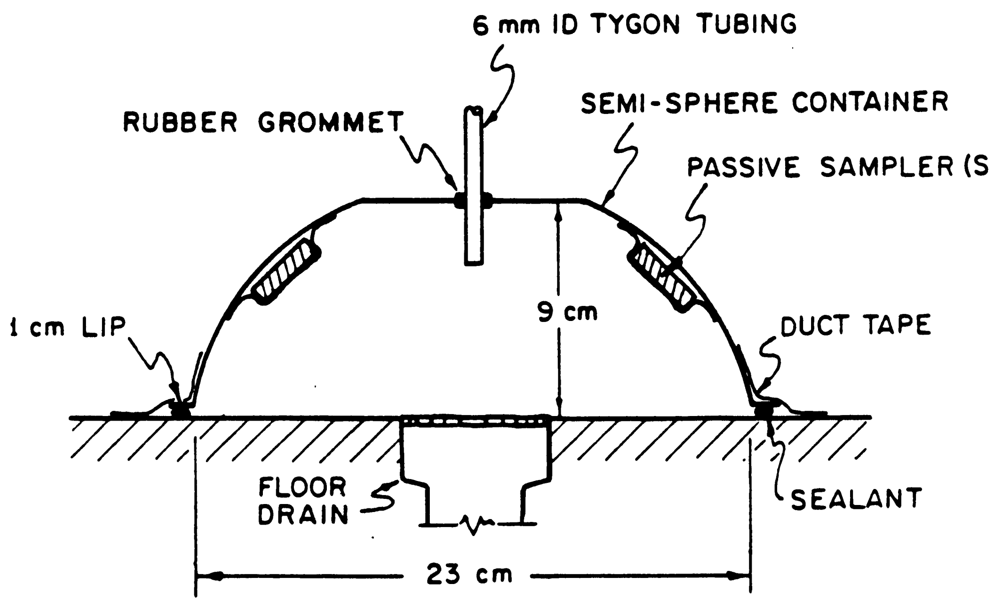



FIG. 3

ENTRY POINT CONTAINER SAMPLING CONFIGURATION released from the sealant. These compounds might also be sampled and interfere with the analyses of organic compounds in the soil gas.

Trial tests were conducted with the entry point containers to determine their suitability for field sampling. Containers were placed over cracks and openings in basement floors and walls and leakage into the containers investigated. After sealing the containers to the surfaces with caulking and duct tape, the containers were put under negative pressure by means of an air sampling pump. Leakage was tested by noting the rate of decrease in partial vacuum of the containers and the potential air flow through the seal with smoke pencils. In these trial locations of over floor cracks, floor drains and hair-line cracks on a concrete block wall, negative pressures could not be maintained after the sampling pump was turned off. This was not unexpected for the floor drain and floor crack locations as air flow entry into the containers through the floor drains and large floor cracks was anticipated. Flows of up to 4 litres per minute could be obtained. Smoke pencil tests at the floor drains and floor cracks did not indicate leakage of room air into the containers through the surface contact seal.

The inability to obtain partial vacuum in a hair line wall crack location was unexpected. Initial tests with a smoke pencil indicated leakage at the contact seal, but after this was corrected high flows, up to 4 litres/min., could not provide partial vacuum conditions. The concrete blocks and the hairline cracks must have been more porous than anticipated.

Consideration was also given to accumulator techniques which used flexible sampling bags to contain a sample of soil gas. These were rejected as it was not known whether the inward pressure of the soil gas would be capable of inflating a bag on its own pressure. There was also concern that the volume of soil gas sampled in a bag would not be sufficient to permit a large enough sample for analysis of trace levels of pollutants.

In order to identify and select soil gas pollutant sampling techniques for further development and evaluation the following criteria were established.

- Cost - The capital equipment cost, and associated analytical costs, if applicable, must not be prohibitive for a large survey where measurements in many homes are required. Capital equipment costs were classified according to the following: low - less than $100, moderate - $100 to $3000, and high - greater than $3000. Analytical costs were classified according to the following per sample costs: low - less than $50, moderate - $50 to $100, and high - greater than $100.
- Practicality of Use - The equipment must be portable, capable of being performed by one technician on-site for a maximum on-site duration of 3 hours, and cause minimal disruption or inconvenience to the home or homeowner.

Sampling techniques identified were assessed from available information using the above criteria in order to provide a rationale for selecting pollutant sampling techniques. A list of pollutant sampling techniques reviewed is presented in Table 2.

## Radon

Various techniques are available for measuring radon and radon daughters. There is no single measurement technique that will be adequate for all possible applications. To assess soil gas and indoor radon, the measurement of radon gas, not the particulate radon daughters,

TABLE 2

POLLUTANT SAMPLING TECHNIQUES REVIEWED

| Pollutant | Sampling Technique | Costs | Practicality of Use |
|---|---|---|---|
| Radon | Continuous | Moderate to High Capital | Requires trained Operator<br>Requires lengthy set-up time and daily checks |
| | Grab Sampling/ Laboratory Analysis | Moderate Capital<br>Moderate Analytical | Requires trained Operator<br>Timing constraints on Analysis |
| | Integrating/ Laboratory Analysis | Low Capital<br>Low Analytical | Very Simple to Deploy<br>Minimal Household Disruption |
| Pesticide/ Herbicide Residues | Active Samplers/ Laboratory Analysis | Moderate Capital<br>Moderate to High Analytical | Requires trained Operator |
| Methane and Organics | Portable Analyzers | High Capital | Requires trained Operator |
| | Active Samplers/ Laboratory Analysis | Moderate Capital<br>Moderate Analytical | Requires trained Operator |
| | Passive Samplers/ Laboratory Analysis | Low Capital<br>Moderate Analytical | Very Simple to Deploy<br>Minimal Household Disruption |
| Fungi | Settling Plate | Low Capital<br>Low to Moderate Analytical | Simple to Operate |
| | Liquid Impingers | Moderate Capital<br>Low to Moderate Analytical | Simple to Operate |
| | Impaction | Moderate to High Capital<br>Low to Moderate Analytical | Simple to Operate |

should be measured. It is the radon gas which is the constituent of the soil gas which enters the homes and results in indoor levels of radon gas and the decay product radon daughters.

For in depth studies of radon transport, radon behaviour and for the development of control techniques, intensive and complex measurement techniques have usually been used. These in depth research studies have used continuous monitors. These continuous monitors provide invaluable real-time data but are not suitable for large scale surveys due to lengthy on-site set-up time and cost considerations.

Grab sampling for radon and radon daughters is useful in some applications such as screening purposes on a small scale, and for guiding remedial action work. Grab samples are taken in the field and then analysis is required within a short-time period, 1/2 hours to 4 hours, depending on whether radon gas or radon daughters are being measured. This analytical timing contraint would be impractical in a large survey of homes. Grab sampling is also restricted to short-time period samples, less than 1/2 hour. This has limitations when sampling for radon because large temporal and spatial variations in indoor radon can exist. When augmented with integrating or continuous sampling methods, grab sampling is useful.

Integrating radon samplers provide a single average concentration value for an extended time period from a few days to a week or more. The sampling period depends on the anticipated radon concentration and the sensitivity of the particular technique being used. Samples usually can be analyzed later at a more convenient time and place. Integrating devices are usually simpler and less expensive than continuous reading devices and can be used to measure concentrations that are too low for grab or continuous methods. Collection of a sample can be accomplished either passively or actively. These simpler and smaller integrating devices can be used to monitor a large number of sites for both radon and radon daughters.

Based on the low cost and simplicity of use, integrating radon sampling techniques were selected for soil gas sampling development and evaluation. Passive sampling techniques are required for the in-situ soil probes, the soil gas entry point and indoor living space. The commercial passive, integrating radon gas monitoring devices are the track-etch method(30) and the charcoal cannister(31,32) method. The principle of detection of the track-etch system, manufactured by Terradex Corporation, consists of recording the damage imparted on the detector material by the alpha particles from radon and radon daughters. After exposure, the tracks on the film are revealed by etching with NaOH solution and counted manually or automatically under a microscope. The Terradex detectors can be used to detect radon in air, water or soil.

For monitoring radon in indoor air, exposure periods of 3 months or greater are required in order to obtain the required accuracy at anticipated levels of less than 148 $Bq/m^3$ (4 pCi/L). For monitoring radon in soil gas, much shorter exposure periods can be used because of the higher level of radon in soil gas, often greater than 1850 $Bq/m^3$ (50 pCi/L). Terradex offer two configurations of monitors. The small pill box size was selected for this study because its small size permitted placement in the 5 cm (2 in) diameter soil probes and the entry point containers. In order to measure radon gas in the indoor living space for time periods parallel to that of the soil probes and entry points, approximately one week, the track-etch method would not be suitable. Therefore, the charcoal adsorption technique was used. The charcoal adsorption technique operates on the principle of adsorption of radon in charcoal and then measuring the quantity adsorbed by counting the gamma-rays from the decay of radon daughters. The charcoal adsorption monitors available from Airchek, North Carolina were used for measuring indoor radon gas in this study. The pollutant sampling techniques selected for evaluation are presented in Table 3.

## Pesticides

Early methods of sampling for pesticides in air made use of air being actively drawn through liquid absorbent impingers. However, a more common method is to draw air through solid sorbents such as activated charcoal, silica gel, florisil, polyurethane foam, chromosorb 102, XAD-2 resin, and Durapak-Carbowax 400/Porasil F. The various sorbents have been evaluated for a wide variety of pesticide sampling applications. However, due to the uncertain nature of the type of pesticides present at the homes surveyed, a sorbent specific for a given pesticide category or categories could not be selected. Florisil tubes were chosen because they are a common sorbent for pesticide sampling and are readily available.

TABLE 3

POLLUTANT SAMPLING TECHNIQUES SELECTED FOR EVALUATION

| Pollutant | Sampling Technique | Sampling Location |
|---|---|---|
| Radon | Track-etch (Terradex) | In-situ Soil Probes<br>Entry Point Containers |
| | Charcoal Adsorption (Airchek) | Indoor Air |
| Pesticides/ Herbicide Residues | Florisil Adsorption/ GC/EC Analysis | Insitu Soil Probes<br>Entry Point Containers |
| Organic Compounds | Tenax Adsorption/ GC/MS Analysis | In-situ Soil Probes<br>Entry Point Containers |
| | Passive Badges (3M, Dupont)/GC/MS Analysis | In-situ Soil Probes<br>Entry Point Containers |
| Fungi | Impinger | In-situ Soil Probes<br>Entry Point Containers |
| | Centrifugal (Biotest) | Indoor Air |

Diffusion samplers were used to passively measure for any organic vapours present in the soil gas probes as well as at basement entry points. A diffusion sampler consists of a tube or disc, with one end open to the atmosphere and a trapping material located at the distant end. Two models of diffusion samplers for organic vapours were selected for use - one manufactured by 3M, the other by DuPont. In both cases, the time-weighted average concentration is measured by collection of the organic vapours present in air onto an activated charcoal absorbent. The collection of the organic vapours is defined according to physical principles of mass transport across a defined diffusion layer. Fick's law of diffusion is used to described the relationship between the vapour concentration and the weight of material collected by the monitor.

Two active methods of measuring for organic vapours were also employed. Initially, air was drawn at a fixed flow rate through charcoal tubes. However, given the low flow rate and short sampling duration (approximately 1 hour), no organic vapours could be detected. Subsequently, the pump flow rates were increased and Tenax, instead of charcoal, tubes were used. This resulted in an improved lower limit of detection.

### Household Fungi

There are three types of samplers available for monitoring airborne fungus: settling plates, liquid impingers and impaction samplers. The settling plate technique uses a petri dish containing an agar. The plate is exposed to the atmosphere for a specified time period, covered and then incubated. This technique is rather crude, since only particles of a certain size will settle on the plate, and the volume of air sampled is not known. This technique is only applicable to monitoring indoor living spaces.

Liquid impingement samplers draw air through a liquid which traps the airborne fungus. The liquid is subsequently plated and cultured to determine the quantity of fungus. This technique can be used to sample air indoors and in enclosed spaces such as the entry point containers.

There are various types of impaction samplers; sieve-type, slit-type and the centrifugal type. These samplers impact the airborne particulate fungus on agar surfaces and are applicable to sampling only indoor air.

The impinger technique was selected to obtain samples from the in-situ soil probes and the entry point containers. A centrifugal impaction device known as the Biotest sampler was monitor to test the indoor air.

## House Selection

Homes used in the study were selected on the basis of the site geology and basement foundation condition.

Two geological factors had to be considered:

1. Physical soil properties, and,
2. Parent chemical regime

The conductive properties of the unsaturated geologic media falls under the first heading. Greater flow of soil gas, assuming an equal driving pressure, is encountered in sandy soils as opposed to silty and clayey soils. However, silty or clayey soils which are fractured or dessicated exhibit significant flow through this secondary permeability. The parent chemical regime was an important second consideration. Since radon gas is of concern, a geologic setting where it was present had to be chosen. The contaminant source in this case is radium 226, which is the source of radon 222. The host soils in southern Ontario do not have naturally high radium 226. However, the crystalline rocks of the Canadian Shield have a much greater potential for hosting radium 226.

Based on these two geological factors, three study sites were chosen. The residence investigated in the most detail was selected in a sandy soil (for high potential soil gas flow), and on the Canadian Shield (to increase the chance of finding measurable radon concentrations). A second residence on the Canadian Shield was selected in silty soils in order to investigate the effect of different soil conductive properties. A third residence, in sandy soil, was selected in southern Ontario to investigate the different chemical properties of the host soils there. These latter two sites were instrumented in lesser detail.

In order to permit soil gas entry point sampling, the basement foundations must have potentially good leakage points. During initial visual inspection, sites such as floor drains, sumps, floor cracks, wall cracks and utility entry fittings were characterized to determine their suitability for sampling. Smoke pencil testing was conducted with the homes operating under natural draft in order to rank the degree of air leakage. This was not successful because of the low pressures experienced across the building envelope. Final selections were based on the number of potential leakage points, ease of access to the entry points to conduct sampling, and the willingness of the houseowner to participate in the study.

Installation of Soil Probes

An initial pilot hole was sunk at each monitor location. This was done with a 53.5 mm diameter vibratory drill. This technique recovers a core of the soil for geologic logging. The monitor tube was designed to have this exact diameter to ensure a tight fit in the pilot hole. The hole was extended 0.1 to 0.2 m past the projected monitor screen location. In this way, any soil dislodged by inserting the monitor would fall into this reservoir and not block the end of the gas monitor. If the monitor would not penetrate the required distance, a driving head was fitted to the top and attached to the vibratory drill head. By applying vibration to the actual monitor tube, it would move down hole. This technique was only applied in clayey soils during an initial test run, and was not required in the sandy and silty soils of the three study sites. The driving head was also equipped with a manual pull bar which was used for removing the monitors from the ground once the study was complete.

Once the monitor was installed, measurements were taken down hole to ensure no soil was blocking the lower end. If this was the case, a soil auger was used to remove the soil. Measurement for possible ground water levels in the tube were also taken. If the water table was intersected, the tubing was pulled up the hole to a higher level. Finally, to ensure a seal at ground surface to prevent ambient air from travelling down the borehole annulus to the screen, water was poured around the monitor on the ground and allowed to freeze.

Once the installation was complete a peristaltic pump was used to evacuate the soil probe. A final pressure measurement was taken and recorded for each probe. These measurements and subsequent measurements are recorded in Table 4.

## Field Sampling

Before sampling activities proceeded, the soil probes were routinely monitored for downhole pressures to assess the soil gas pressure profile. Taken with a portable pressure transducer, the pressures were expressed as a differential between that at the soil probe inlet and the atmospheric pressure. Table 4 lists the pressure measurements taken at each residence at different times. The first set of readings in each case represents those after each monitor had been pumped to remove ambient air and to develop the soil gas from the ground, and therefore, are not representative of ambient soil gas pressures.

Both active and passive sampling was conducted in soil probes and at the basement entry points. Radon track-etch monitors and organic vapour passive badges were suspended from the eyelet hooks and lowered down the length of the soil probes. These radon monitors and organic vapour badges were also taped on the inside of the stainless steel entry point sampling containers. All passive monitors were left in for a week, then removed and returned for laboratory analysis. Indoor radon was also measured passively using canisters containing activated charcoal as the adsorbing medium. The charcoal canisters were suspended from

TABLE 4

SOIL GAS PROBE PRESSURE MEASUREMENTS

Haliburton Residence

| Monitor/Date | 4 Mar 87* | kPa 12 Mar 87 | 19 Mar 87 |
|---|---|---|---|
| N1 | 0.00 | -0.269 | -0.207 |
| N2 | 0.00 | N.M. | -0.219 |
| N3 | 0.00 | -0.311 | 0.037 |
| N4 | 0.00 | -1.662 | -1.250 |
| N5 | 0.00 | -0.498 | -0.451 |
| E1 | 0.00 | -0.278 | -0.535 |
| S1 | 0.00 | -0.062 | -0.598 |
| S2 | 0.00 | -0.075 | -0.105 |
| S3 | 0.00 | -0.152 | -0.224 |
| S4 | 0.00 | -0.672 | -0.553 |
| S5 | 0.00 | -0.278 | -0.500 |

Dawson Road Residence

| Monitor/Date | 4 Mar 87* | kPa 12 Mar 87 | 19 Mar 87 |
|---|---|---|---|
| 1 | 0.00 | -0.647 | -0.174 |
| 2 | 0.00 | -0.373 | -0.124 |
| 3 | 0.00 | 1.071 | -0.610 |
| 4 | 0.00 | 0.032 | -0.398 |
| 5 | 0.00 | 0.00 | 0.423 |

Oak Ridges Residence

| Monitor/Date | 9 Feb 87* | kPa 18 Feb 87 | 19 Feb 87 | 25 Feb 87 |
|---|---|---|---|---|
| 1 | -0.722 | -0.916 | -0.274 | N.M. |
| 2 | 0.00 | -0.001 | 0.00 | -0.0008 |
| 3 | 0.00 | -0.001 | 0.00 | 0.00 |
| 4** | -0.871 | -1.877 | -1.096 | -1.696 |

* Measurements taken after development
** Values affected by water table
N.M. No measurement taken

bookshelves, wall panels and other indoor locations. The sampling period was originally one week; however, this was later shortened to 3 days to prevent overloading of the charcoal with moisture.

Active grab sampling for pesticides, organics and microorganisms was conducted by withdrawing air at a fixed flow rate from the soil probes via the valve in the sampling head. Sampling duration varied from 30-90 minutes. Similarily, active samples were withdrawn from the sampling ports of the stainless steel containers. Pump flow rates were varied in order to determine the minimum flow rate necessary for adequate sample collection. Sampling flow rates were maintained for the full sampling durations for all the entry point containers actively monitored for organics, pesticides and moulds. Probes which were tightly sealed in the ground and in impermeable or wet soils caused sampling problems. In four instances, the sampling flowrate could not be maintained for the duration desired. The sampling pumps could not maintain the flowrate and, consequently, stalled in these instances.

Pesticide vapours were collected by adsorption into florisil tubes. Initially flow rates of 50-180 millilitres per minute (mL/min) were utilized and sampling was conducted over a 30-60 minute period. Subsequently, flow rates were increased to approximately 1000 mL/min and sampling was extended to 90 minutes.

Organic vapours were initially collected by adsorption onto charcoal tubes. In order to increase sensitivity, charcoal tubes were replaced with Tenax tubes. Flow rates of 70-140 mL/min were utilized and sampling was conducted over a 60-90 minutes period.

Airborne fungi were collected in impinger solutions. Flow rates of 700-1600 mL/min were utilized and sampling was conducted over periods of 30-60 minutes.

Ventilation

Air-leakage tests were performed to determine the air change rate per hour (ach) at 50 Pascals (Pa), the equivalent leakage area, and the major leakage paths by CGSB CAN2-149.10 M.[33] The air leakage test is conducted by depressurizing the house using a variable speed fan mounted in an exterior door. While maintaining an house depressurization of 20 Pa, smoke pencil testing was undertaken on the building envelope to identify major air leakage paths. These paths are then subjectively identified as being high, medium or low areas of leakage. This information on potential soil gas entry points was useful in determining the actual indoor soil gas entry point sampling locations.

The air infiltration measurement system (AIMS) offered by the National Association of Home Builders (NAHB) Research Foundation was used to measure air infiltration. The AIMS test is simple, not requiring sophisticated field equipment, and easy to install. The AIMS test provides direct air infiltration determination result averaged over a period from a week to months, depending upon sampling duration. The AIMS test involves installation of sources called perfluorocarbon tracers (PFT) in different house zones (approximately 1 per 50 square meters of building floor area). There are 3 different types of inert gases used as sources. Each source is a small aluminum tube, smaller than a cigarette, which contains the perfluorocarbon tracer which is released at a known, constant rate. After the PFT sources have been installed for a few days, sampling is initiated by the installation of capillary adsorption tube (CAT) samplers. The CAT sampler is a small glass tube with a charcoal-like absorbent to trap the gas emitted by the PFT source. For this study, each home was divided into 3 different zones and 1 PFT source and 1 CAT sampler placed in different areas of the same zone. Sources and samplers were placed in areas where they are least likely to be disturbed and away from direct sun, heat sources and drafts. The sources and samplers were left in each house for a 7-day period after which time they were removed and sent to the NAHB research laboratory for analysis. Air infiltration and exfiltration rates for each zone, as well as air exchange rates between zones, were calculated.

In addition, interior/exterior pressure differentials were measured at different points in each house using a micromanometer to determine the neutral pressure plane, ie. where a zero pressure differential between inside and outside exists and thus no net leakage occurs. Above this neutral pressure plane exfiltration occurs, while below this plane infiltration occurs. The approximate location of the neutral pressure plane is presented on the home information data sheets.

### 1.3 Analytical Methods

Samples collected were either analyzed at Ontario Research Foundation laboratories or sent to other laboratories when in-house analysis could not be performed.

Radon track-etch monitors were sent to Terradex where detectors were analyzed by microscopic counting. The charcoal canisters were sent to the Airchek lab where analysis was conducted by determining gamma-ray emission.

Pesticide samples collected on florisil tubes were analyzed using gas chromatography with an electron capture (GC/EC) at Ontario Research Foundation.

Both the active samples of organics collected on charcoal and Tenax tubes, and the passive samples collected on organic vapour monitors were analyzed using gas chromatography, mass spectroscopy (GC/MS) at Ontario Research Foundation.

The fungus samples collected in impinger solutions and on the agar strips were analyzed at Ontario Research Foundation for total yeasts and moulds. Impinger samples were analyzed using the pour plate technique, while the samples collected on the agar strips were counted following incubation.

The CAT samplers used to measure air infiltration were sent to the NAHB Research Foundation for analysis. The concentrations of the gases adsorbed in each of the sampler tubes were determined using gas chromatography. This information, combined with the known rates of emission of each of the source gases and the volume of the zones was used to calculate air infiltration rates in each zone, the air exchange rates between zones and the overall air exchange rate per hour for the home. The air infiltration results are presented in Tables 5, 6 and 7.

# 2. RESULTS

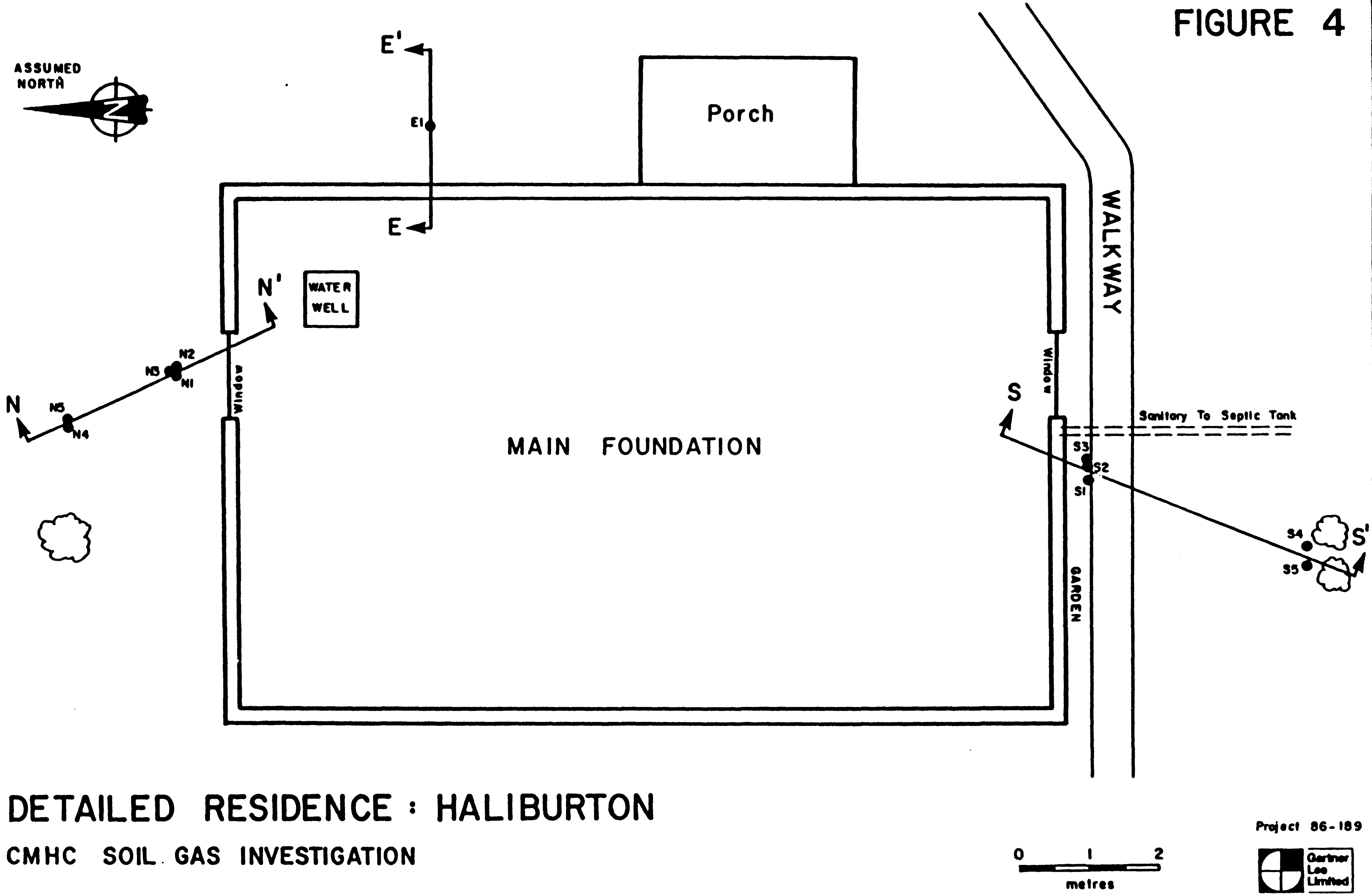
## 2.1 Field Sampling

Based on the selection procedures outlined previously, three homes were selected which were located in different soils. Two homes, Dawson Road and Haliburton, were chosen in a geological region, Canadian Shield, with the potential of moderate soil gas radon. The Oak Ridges home was chosen in a geological region suspected of low soil gas radon.

### Haliburton Residence

This residence represents the detailed study site in a sandy regime on the Canadian Shield. Figures 4 and 5 show plans of the home, including monitor locations. Figure 6 shows three cross-sections detailing the gas monitor locations in relation to the basement of the home. The entire property consists of medium sand with a trace of silt. Where this was disturbed by the excavation for the foundation and basement, the natural sand was backfilled around the home. A natural "mat" of roots was found at almost all drilling locations at a depth of approximately 1.0 m. The residential water well is located in the basement of the home as shown on Figure 4. The water level observed in this well is just below the level of the floor, since the top of the well

## FIGURE 4




# DETAILED RESIDENCE : HALIBURTON

CMHC SOIL GAS INVESTIGATION

Project 86-189

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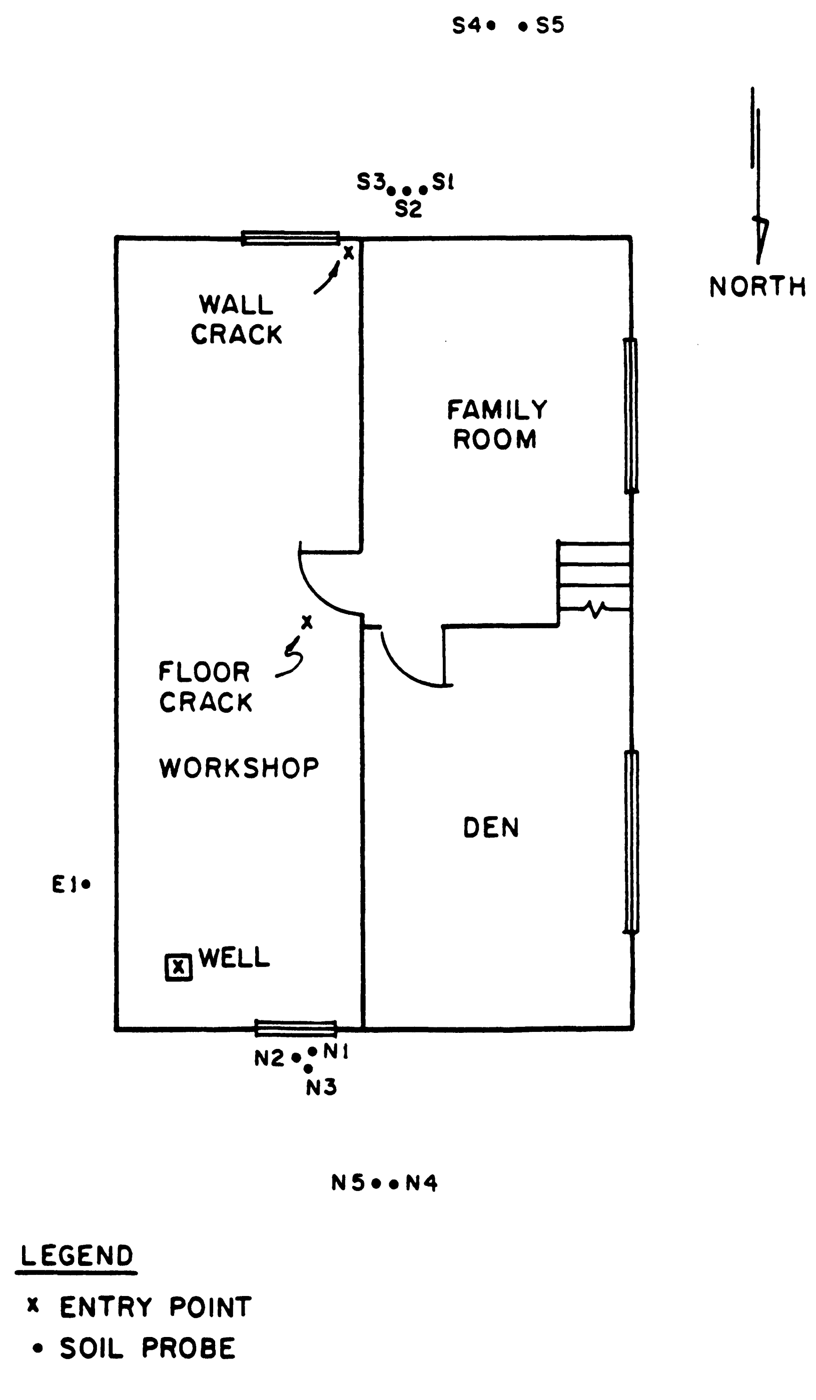
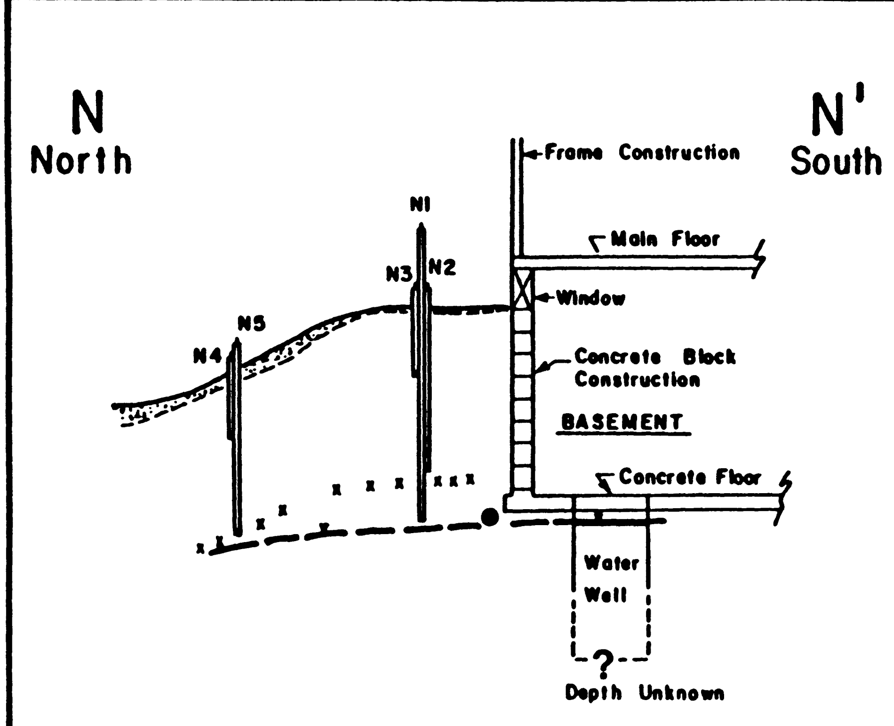
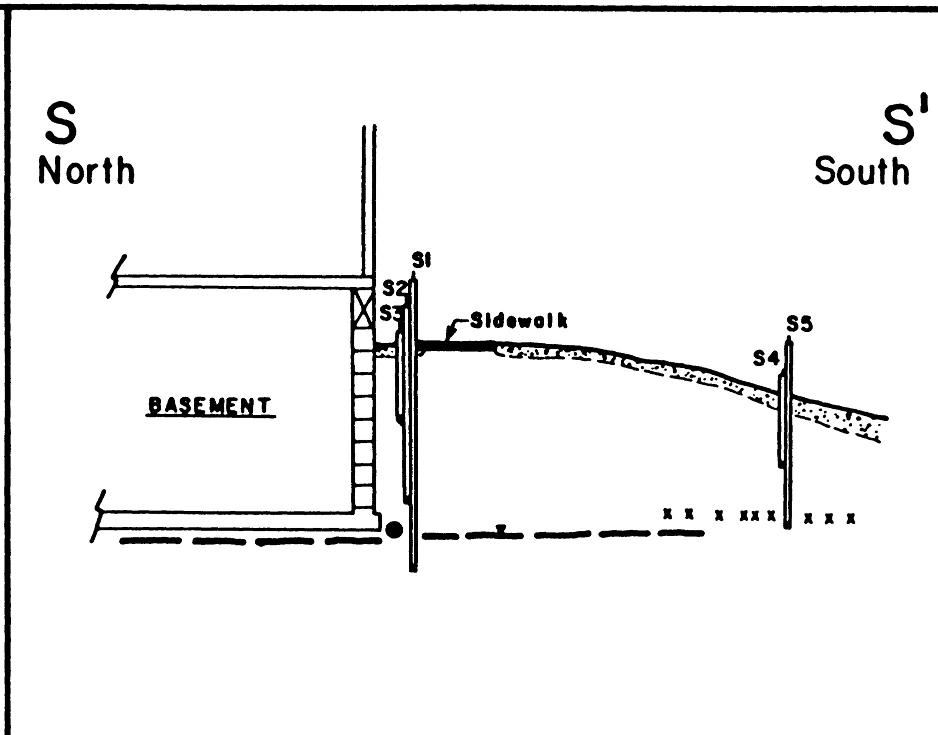
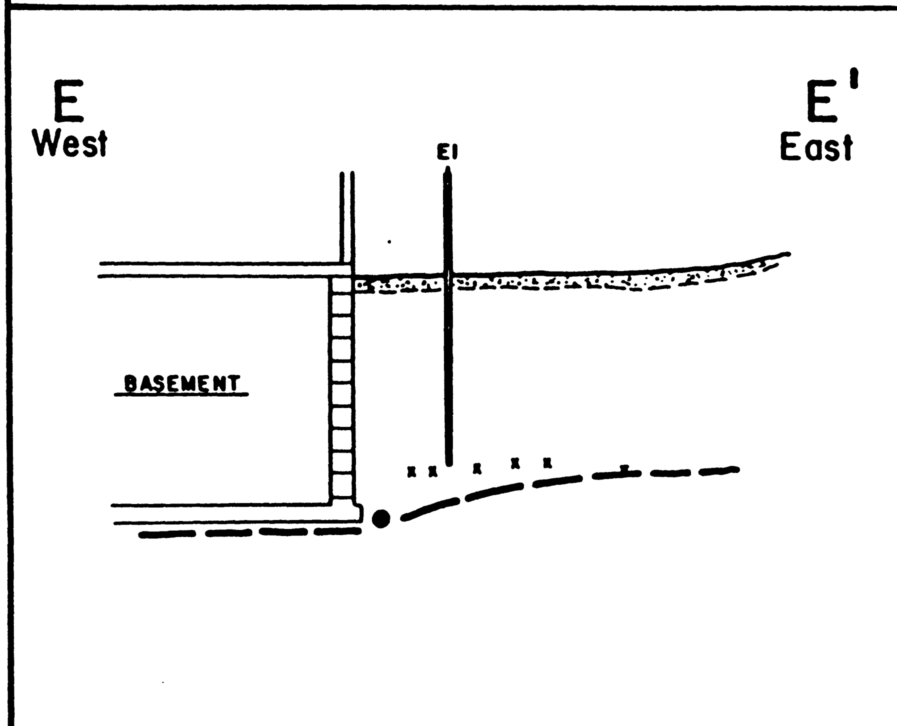



FIG. 5

BASEMENT FLOOR PLAN
HALIBURTON




# FIGURE 6

## CROSS-SECTIONS N-N', S-S', E-E'

CMHC SOIL GAS INVESTIGATION
HALIBURTON RESIDENCE

### Legend

- SANDY TOPSOIL
- MEDIUM SAND
- xxxx ROOT MAT
- ● INFERRED POSITION OF DRAINAGE TILE
- INFERRED POSITION OF WATER TABLE

0 1 2
metres

Project 86-189

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is connected to the weeping tile surrounding the house. This tile acts as a local ground water drain and effectively keeps the soils surrounding the house, and above this level, unsaturated at all times. The water table may dip to the southwest since probe S1 did not intersect the water table.

Nests of soil gas probes were placed close to the foundation on the north and south sides of the home (Figure 4). Additional nests were placed about 3 m further out on these two sides. A single monitor was placed on the east side near the level of the floor-wall interface. The west side of the building was not instrumented because the basement was partially exposed and access was difficult. The south series of monitors, in particular S1,S2, and S3, are directly opposite an interior crack in the basement block wall. The probe monitor details are presented in Table A1 of the Appendix.

This Haliburton residence is one storey with basement. The basement foundation is concrete block. The basement floor plan is presented on Figure 5 and further home details are presented on Table 5. The initial visual inspection identified the potential soil gas entry points as wall cracks, and the water supply well located in the basement floor.

During the air leakgage tests subjective recording of air

TABLE 5

INFORMATION SHEET - HALIBURTON RESIDENCE

BUILDING PARAMETERS

| | |
|---|---|
| Location: | Haliburton, Ontario |
| Construction Type: | 1 Storey, with Basement |
| Foundation: | Concrete Block |
| Floor Area: | 191.8 $m^2$ |
| House Volume: | 467 $m^3$ |
| Air Leakage: | 2.873 ach at 50 Pa |
| Equivalent Leakage Area: | 0.0434 $m^2$ |
| Air Infiltration: | 0.136 ach |
| Neutral Pressure Plane: | At Basement Ceiling Elevation |
| Heating System: | Forced Air - Oil |
| Soil Type: | Medium Sand |

INDOOR AIR QUALITY

Temperature and Humidity:

| Location | Wet Bulb(°C) | Dry Bulb (°C) | % RH |
|---|---|---|---|
| Basement | 12 | 18 | 49 |
| Main Floor | 13 | 19 | 52 |

Radon:

| Location | Analysis | Sampling Method |
|---|---|---|
| Basement | 44.4 Bq/$m^3$ | Charcoal Adsorption |
| | 48.1 Bq/$m^3$ | Charcoal Adsorption |
| | 48.1 Bq/$m^3$ | Charcoal Adsorption |

Fungus:

| Location | Analysis | Sampling Method |
|---|---|---|
| Basement - Family Room | 56 CFU/$m^3$ | Centrifugal |
| - Near Sump | 94 CFU/$m^3$ | Centrifugal |
| - Near Floor Crack | 19 CFU/$m^3$ | Centrifugal |
| - Near Wall Crack | 94 CFU/$m^3$ | Centrifugal |

TABLE 5 (cont'd)

INFORMATION SHEET - HALIBURTON RESIDENCE

SOIL GAS ENTRY POINTS

Radon:

| Location | Analysis | Sampling Method |
| --- | --- | --- |
| Well | 836 $Bq/m^3$ | Track-Etch |
| Floor crack | 1430 $Bq/m^3$ | Track-Etch |
| Wall crack | 390 $Bq/m^3$ | Track-Etch |

Organic Compounds:

| Location | Analysis | Sampling Method |
| --- | --- | --- |
| Well | Non detectable | Tenax Adsorption |
| Floor Crack and Wall Crack | Aliphatic and Aromatic hydrocarbons<br>Traces of Alcohols, ethers and ketones | Tenax Adsorption |

Pesticides:

| Location | Analysis | Sampling Method |
| --- | --- | --- |
| Floor Crack | Non-detectable | Florisil Adsorption |
| Wall Crack | Non-detectable | Florisil Adsorption |
| Well | Non-detectable | Florisil Adsorption |

Fungus:

| Location | Analysis | Sampling Method |
| --- | --- | --- |
| Well | 1972 $CFU/m^3$ | Impinger |
| Floor Crack | 0 $CFU/m^3$ | Impinger |
| Wall Crack | 0 $CFU/m^3$ | Impinger |

TABLE 5 (cont'd)

INFORMATION SHEET - HALIBURTON RESIDENCE

SOIL GAS PROBES

Radon:

| Location | Analysis | Sampling Method |
|---|---|---|
| Probe E1 | 10560 $Bq/m^3$ | Track-Etch |
| Probe N1 | 4540 $Bq/m^3$ | Track-Etch |
| Probe N4 | 9080 $Bq/m^3$ | Track-Etch |
| Probe S1 | 696 $Bq/m^3$ | Track-Etch |
| Probe S4 | 9060 $Bq/m^3$ | Track-Etch |

Organic Compounds:

| Location | Analysis | Sampling Method |
|---|---|---|
| Probes E1, N2 and S2 | Non-detectable | Tenax Adsorption |

leakage entry points were noted. The major air leakage points were the chimney/ceiling penetrations, window frames and casings, and electrical outlets located in partitions and exterior walls. Below grade air leakage paths, including the covered well, were minimal. The exception was a minor wall crack above the waste plumbing outlet. This was the tightest of the three homes investigated. The seven-day average whole home air infiltration value was very low, 0.136 ach (air changes per hour).

The indoor air quality levels indicate a typical low basement radon level, average of 46.9 $Bq/m^3$ and ranging from 44.4 to 48.1 $Bq/m^3$. Average Canada wide residential radon levels range from 5.2 to 57 $Bq/m^3$ depending on location.(34) Indoor temperatures were typical of winter residential levels. Airborne fungal levels were low, ranging from 19 to 94 Colony Forming Units per cubic meter ($CFU/m^3$). The experience of Ontario Research Foundation indicates that well ventilated, well maintained, clean buildings usually have airborne fungal levels ranging from 0 to 500 $CFU/m^3$.

Radon at the entry points averaged 885 $Bq/m^3$, and ranged from 390 to 1430 $Bq/m^3$. Airborne fungi were not detected at the wall crack or the floor cracks. At the sump, which had standing water conductive to microorganism growth, a high level of 1972 $CFU/m^3$ was measured. The analysis of the Tenax adsorption tubes for organic analysis indicated the presence of aliphatic and aromatic hydrocarbons with trace quantities of alcohols, ethers and ketones for the samples taken at a floor crack and a wall crack. The sample analysis of the tube taken at the sump did not detect any organic compounds.

Radon in five soil probes was an order of magnitude higher than that at the entry points, averaging 6790 Bq/$m^3$ and ranging from 696 Bq/$m^3$ to 10560 Bq/$m^3$. Probe S1 was located below the water table in the saturated zone and had the lowest level, 696 Bq/$m^3$. Probes S4 and N4 were at similar depths, at similar distances from the home in the medium sand soil on the south and north sides of the home. These two probes also had similar radon levels, 9060 and 9080 Bq/$m^3$. Probe N1 was located just above the water table in the unsaturated zone but below a root matt layer. The level at N1 was the second lowest at 4540 Bq/$m^3$. Probe E1 which was located just above the root matt layer and closer to the home, had the highest level, 10560 Bq/$m^3$. All probes were located in median sand soil. Organic compounds were non-detectable at the three probes sampled.

The pressures measured around this residence were consistently negative in the soil adjacent to the home (with the one time exception of probe N3) and increasingly negative with increasing distance from the foundation, on both sampling occasions. Values ranged from a high of +3.81 mm of water to a low of -169.42 mm of water. The existence of pressure differentials indicates that the soil probes were functioning correctly at this location. Section 2.3 discusses these findings and their implications.

Dawson Road Residence

This residence represents a less detailed study site in the less conductive silty soil regime on the Canadian Shield. Figure 7 shows a site plan of the home, including monitor locations. The cross section in Figure 8 detail the soil gas probe locations in relation to the basement of the home. The residence rests on a bedrock high and is keyed into the silt overburden on the eastern side of the building. Where this was disturbed by the excavation for the foundation and basement, imported silty sand was backfilled around this side of the home. The cross section in Figure 8 also shows the location of the silt-sand fill interface as delineated by drilling and hand-augering.

The silt soil was a mottled brown in colour, containing several fine sand seams, and was fractured, thus indicating a secondary porosity. It became grey in colour with depth and appeared to be saturated below about 1.0 m at probe location 5 (Figure 8). The position of the water table is inferred to be at the level of the weeping tile immediately adjacent to the foundation and likely rises to the east in the less permeable silt. The sandy fill is unsaturated, an effect caused by the weeping tile.

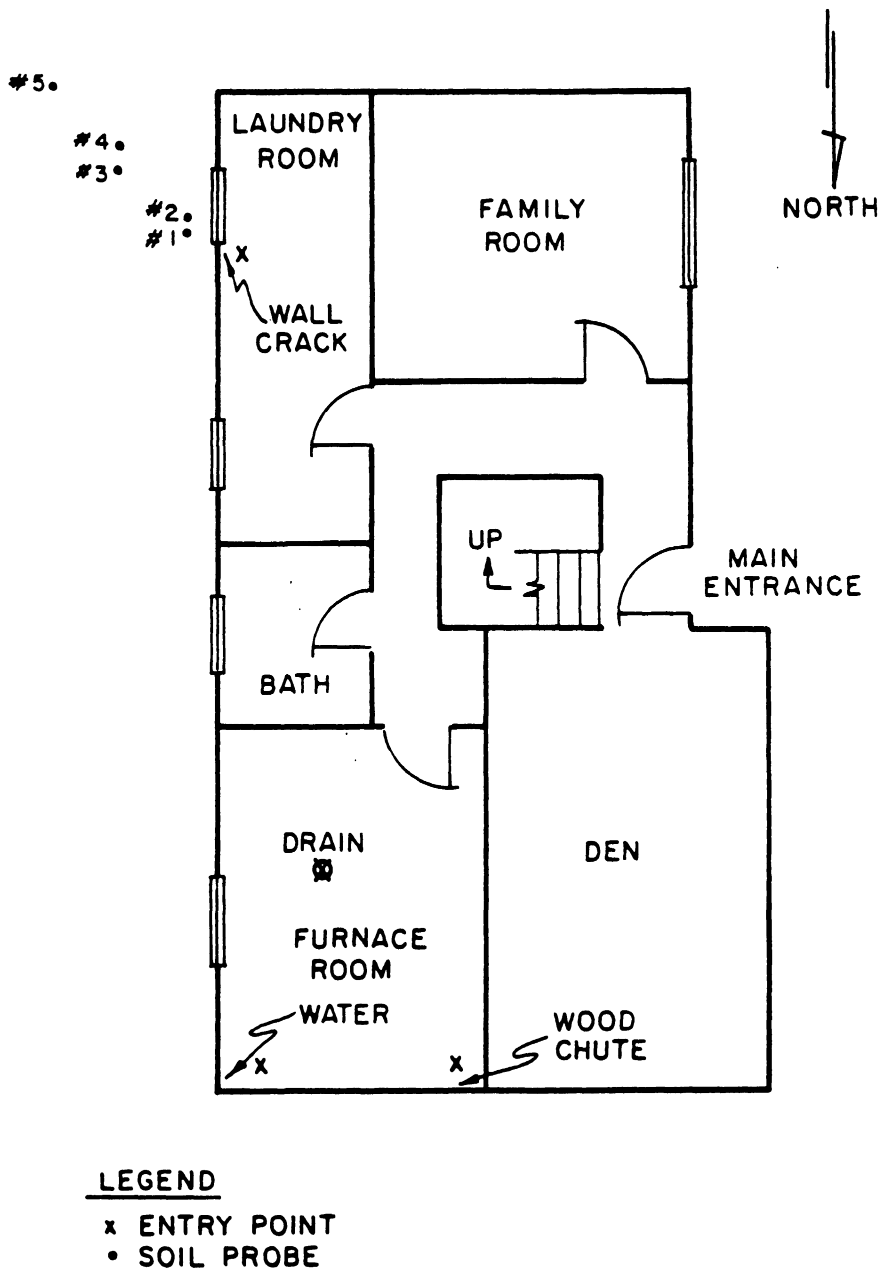
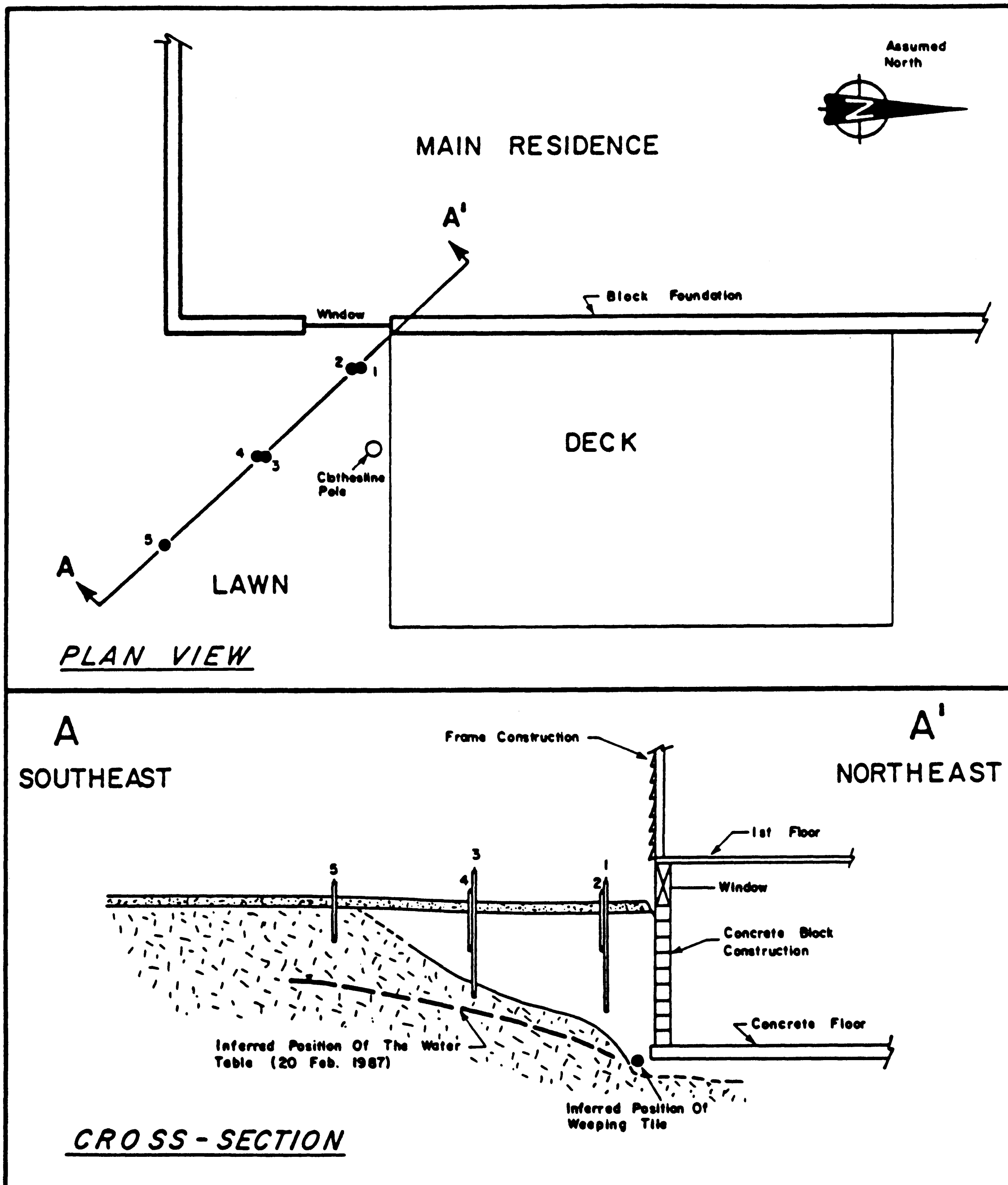



FIG. 7

BASEMENT FLOOR PLAN
DAWSON ROAD




# DAWSON ROAD RESIDENCE

# FIGURE 8

## CMHC SOIL GAS INVESTIGATION

Legend

SILTY TOPSOIL

SILTY SAND FILL

SILT (natural)

0 1 2 metres

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Three nests of soil gas probes were placed diagonally out from the basement wall (Figure 8). They are directly opposite an interior crack in the basement block wall. Probes 1, 2, and 4 are in the unsaturated sandy fill, while 3 and 5 are in the unsaturated portion of the natural silt overburden. The probe details are presented in Table A2 of the Appendix.

The Dawson Road residence is a one storey home with basement entrance or walk out. The basement foundation construction is concrete block. The basement floor plan is presented in Figure 7 and further home details on Table 6. Initial inspection identified potential soil gas entry points as floor drains, floor cracks and wall cracks.

During the air leakage tests, subjective recording of air leakage entry points was noted. The major air leakage points were the window frames, basement family room sliding glass exterior door, basement exterior wall opening in furnace room, and electrical outlets located in partitions as well as in exterior walls. Below grade air leakage paths were the basement floor drain, minor wall cracks and around the water supply pipe. The seven-day average air infiltration value for this home was low, 0.236 ach.

The indoor air quality levels indicate a typical low basement radon level, averaging 46.9 $Bq/m^3$, and ranging from 44.4 to 48.1 $Bq/m^3$. Indoor temperatures indicated typical winter residential

TABLE 6

INFORMATION SHEET - DAWSON ROAD RESIDENCE

BUILDING PARAMETERS

| | |
|---|---|
| Location: | Minden, Ontario |
| Construction Type: | One Storey, Basement Entrance |
| Foundation: | Block |
| Floor Area: | 322 $m^2$ |
| House Volume: | 787 $m^3$ |
| Air Leakage: | 4.46 ach at 50 Pa |
| Equivalent Leakage Area: | 0.1307 $m^2$ |
| Air Infiltration: | 0.236 ach |
| Neutral Pressure Plane: | At 1st Floor Elevation |
| Heating System: | Forced Air - Oil with wood supplement |
| Soil Type: | Silt |

INDOOR AIR QUALITY

Temperature and Humidity:

| Location | Wet Bulb(°C) | Dry Bulb (°C) | % RH |
|---|---|---|---|
| Basement | 11 | 17 | 46 |
| 1st Floor | 10 | 17 | 44 |

Radon:

| Location | Analysis | Sampling Method |
|---|---|---|
| Basement | 62.9 Bq/$m^3$ | Charcoal Adsorption |
| | 48.1 Bq/$m^3$ | Charcoal Adsorption |
| | 59.2 Bq/$m^3$ | Charcoal Adsorption |

Fungus:

| Location | Analysis | Sampling Method |
|---|---|---|
| Basement - Playroom | 200 CFU/$m^3$ | Centrifugal |
| - Den | 0 CFU/$m^3$ | Centrifugal |
| - Laundry | 275 CFU/$m^3$ | Centrifugal |

TABLE 6 (cont'd)

INFORMATION SHEET - DAWSON ROAD RESIDENCE

SOIL GAS ENTRY POINTS

Radon:

| Location | Analysis | Sampling Method |
|---|---|---|
| Floor Drain | 3060 $Bq/m^3$ | Track-Etch |
| Wall Crack Furnace Rm | 614 $Bq/m^3$ | Track-Etch |

Fungus:

| Location | Analysis | Sampling Method |
|---|---|---|
| Floor Drain | 0 $CFU/m^3$ | Impinger |
| Wall Cracks - | | |
| Laundry Rm | 123 $CFU/m^3$ | Impinger |
| Furnace Rm a) | 237 $CFU/m^3$ | Impinger |
| Furnace Rm b) | 0 $CFU/m^3$ | Impinger |

Organic Compounds:

| Location | Analysis | Sampling Method |
|---|---|---|
| Floor Drain | Non-detectable | Tenax Adsorption |
| Wall Crack and Wood Chute | Aliphatic and Aromatic Hydrocarbons Traces of Alcohols Ethers and Ketones | Tenax Adsorption |

Pesticides:

| Location | Analysis | Sampling Method |
|---|---|---|
| Floor drain | non-detectable | Florisil Adsorption |
| Wall cracks | | |
| Laundry Rm | non-detectable | Florisil Adsorption |
| Furnace Rm a) | non-detectable | Florisil Adsorption |

TABLE 6 (cont'd)

INFORMATION SHEET - DAWSON ROAD RESIDENCE

SOIL GAS PROBES

Radon:

| Location | Analysis | Sampling Method |
| --- | --- | --- |
| Probe 1 | 7650 $Bq/m^3$ | Track-Etch |
| Probe 3 | 12400 $Bq/m^3$ | Track-Etch |

Organic Compounds:

| Location | Analysis | Sampling Method |
| --- | --- | --- |
| Probe 1 | Non-detectable | Tenax Adsorption |

levels. Airborne fungal levels were low, ranging from 0 to 275 CFU/$m^3$ for three samples.

Radon at two entry points were different, 3060 Bq/$m^3$ at the floor drain and 514 Bq/$m^3$ at a wall crack. Moulds were low at two wall cracks, 123 and 237 CFU/$m^3$ and non-detected at another wall crack and the floor drain. As in the Haliburton residence, trace levels of alcohols, ethers and ketones were detected at two of the three entry points. At the floor drain, the levels were non-detectable.

Soil probe 3 located at 1.25 meter depth in the natural silt above the water table, had a radon level of 12400 Bq/$m^3$. Soil probe 1, located closer to the home at 1.38 meter depth in silty sand fill above the water table, had a radon level of 7650 Bq/$m^3$. Organic compounds were non-detectable at the one soil probe monitored.

Soil gas pressures around this residence were both negative and positive on March 12 and mainly negative with the exception of probe 5 on March 19. Values ranged from a high of +109.22 mm of water to a low of -62.23 mm of water. The existence of pressure differentials indicates that the soil probes were functioning correctly at this location. Section 2.3 discusses these findings and their implications.

<u>Oak Ridges Residence</u>

This residence represents a less detailed study site in a sandy regime in southern Ontario. Figure 9 shows a site plan of the home, including soil gas probe locations. Cross-sections detailing the soil gas probe locations, in relation to the home basement are presented in Figure 10. The home has been built on natural silty fine sand. It appears that the original excavation was not very deep because a layer of topsoil was found buried at about 0.6 m which likely represents the original ground level. The fill above it and adjacent to the foundation is composed of the same silty fine sand.

The soil gas probe locations were chosen opposite a sump installed in the basement of the home. The water level in this sump is assumed to be that of the water table below the monitors. The sump is connected to the drainage tile below the home which in turn drains to a ditch running parallel to the main road in front of the house. It is suspected that a weeping tile is present around the perimeter of the house as well. These foundation drains, in general, act as a local ground water drain and effectively keep the soils adjacent to the home unsaturated.

The Oak Ridges residence is a split level detached with a block foundation. The basement floor plan is presented in Figure 9 and further home details on Table 7.

Initial inspection identified potential soil gas entry points as a floor drain, a sump, and various cracks in the block basement foundation walls below grade. The living area of the basement was furnished with access to the sump and household water supply pipe restricted. A box was built around the sump and water meter in the basement living area corner. Access to the sump and water meter was by a removable top on the box.

Subjective recording of air leakage entry points during the air leakage tests identified the major air leakage points as the window frames, exterior wall outlets of the first and second floor, ceiling fixtures and the basement header area from the blocks and the outside above grade. Below grade air leakage paths were minimal. Two exceptions were that around the water supply pipe and a crack in the foundation wall in the crawl space. The seven-day average air infiltration value was 0.606 ach.

The indoor air quality levels indicate a typical low basement radon level, 55.5 $Bq/m^3$. Indoor temperatures are also typical for

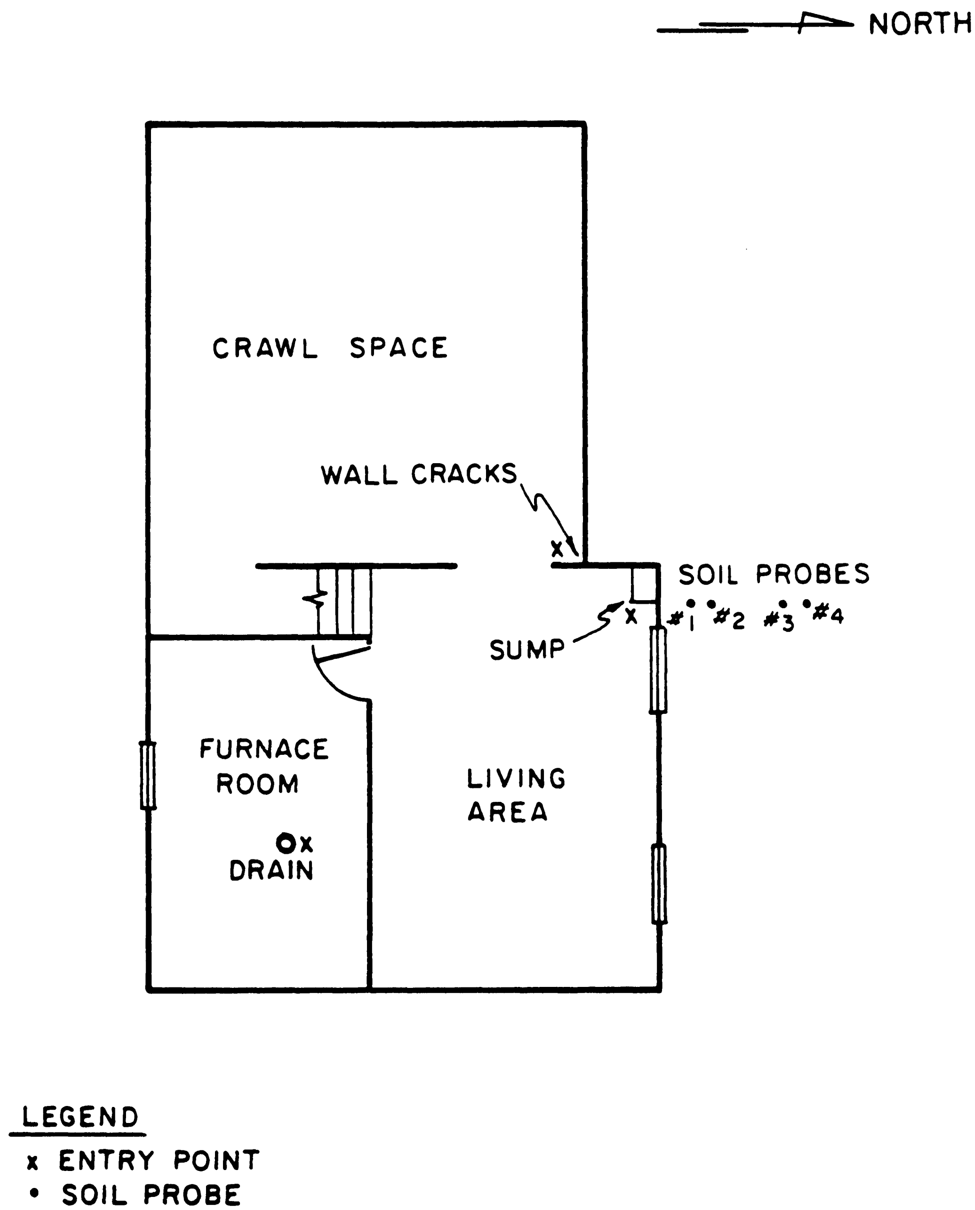
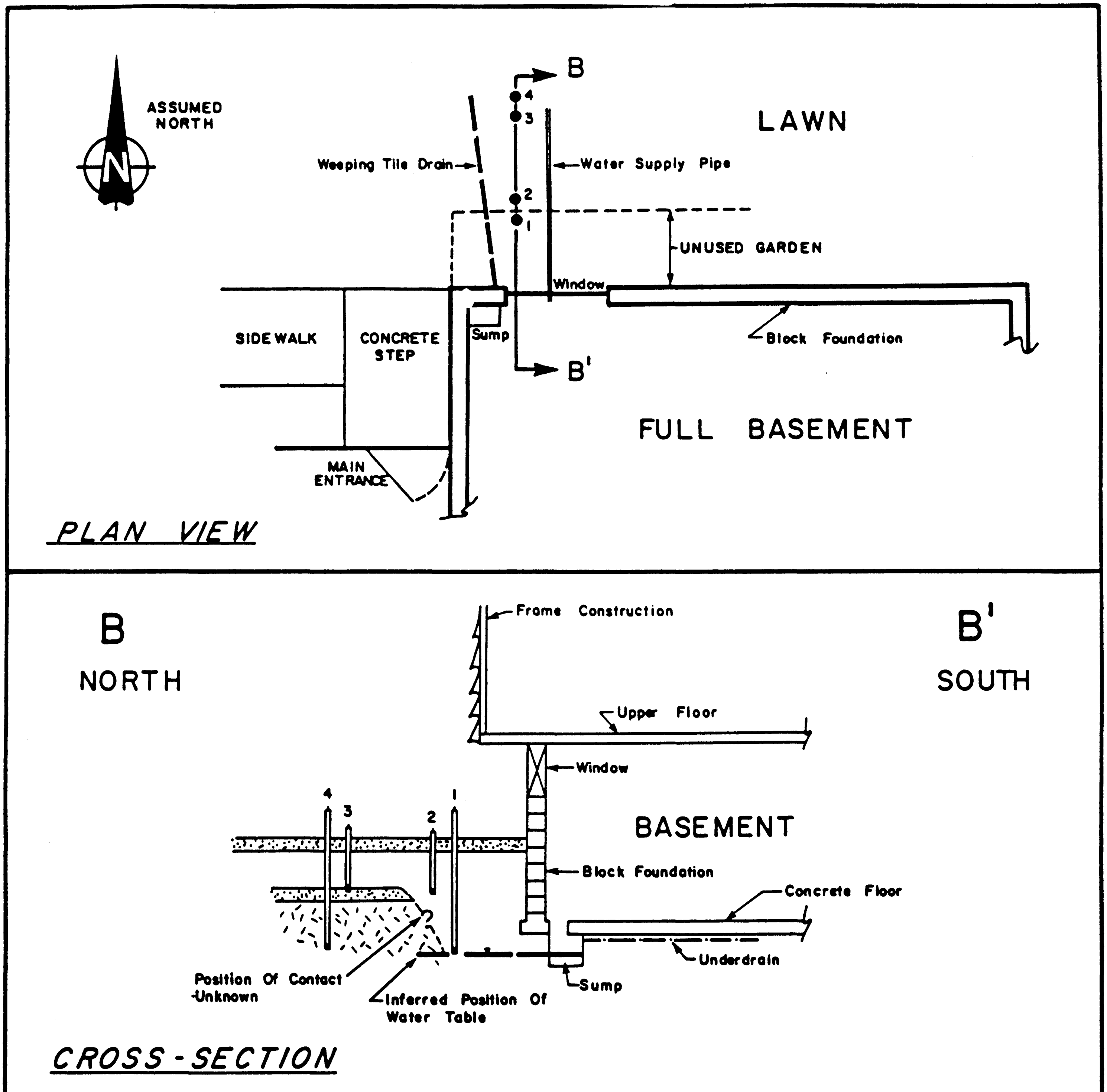



FIG. 9

BASEMENT FLOOR PLAN
OAK RIDGES




# OAK RIDGES RESIDENCE

## FIGURE 10

CMHC SOIL GAS INVESTIGATION

0 1 2
metres

Project 86-189

Legend

SILTY SAND TOPSOIL

SILTY FINE SAND (fill)

SILTY FINE SAND (natural)

Gartner Lee Limited

TABLE 7

INFORMATION SHEET - OAK RIDGES RESIDENCE

BUILDING PARAMETERS

| | |
|---|---|
| Location: | Oak Ridges, Ontario |
| Construction Type: | Split Level Detached |
| Foundation: | Concrete Block |
| Floor Area: | 169.28 $m^2$ (+ crawl space of 40.96 $m^2$) |
| House Volume: | 425 $m^3$ |
| Air Leakage: | 9.934 ach at 50 Pa |
| Equivalent Leakage Area: | 0.1987 $m^2$ |
| Neutral Pressure Plane: | 0.5 m below 2nd Floor Ceiling |
| Air Infiltration: | 0.606 ach |
| Heating System: | Forced Air - Gas |
| Soil Type: | Silty Fine Sand |

INDOOR AIR QUALITY

Temperature and Humidity:

| Location | Wet Bulb($^oC$) | Dry Bulb ($^oC$) | % RH |
|---|---|---|---|
| Basement | 11.0 | 19.0 | 38 |
| Main Floor | 10.5 | 17.5 | 42 |
| 2nd Floor | 12.0 | 21.0 | 34 |

Radon:

| Location | Analysis | Sampling Method |
|---|---|---|
| Basement Living Area | 55.5 Bq/$m^3$ | Charcoal Adsorption |

Pesticides:

| Location | Analysis | Sampling Method |
|---|---|---|
| Basement | non-detectable | Florisil Adsorption |
| Living area | non-detectable | Florisil Adsorption |

TABLE 7 (cont'd)

INFORMATION SHEET - OAKRIDGES RESIDENCE

Fungus:

| Location | Analysis | Sampling Method |
|---|---|---|
| Basement - Living Area | 50 CFU/$m^3$ | Centrifugal |
| | 161 CFU/$m^3$ | Impinger |
| | 326 CFU/$m^3$ | Impinger |
| - Near Sump | 0 CFU/$m^3$ | Centrifugal |
| - Crawl Space | 238 CFU/$m^3$ | Centrifugal |
| - Near Drain | 38 CFU/$m^3$ | Centrifugal |
| - 2nd Floor | 0 CFU/$m^3$ | Centrifugal |

SOIL GAS ENTRY POINTS

Radon:

| Location | Analysis | Sampling Method |
|---|---|---|
| Crawl Space | $<$160 Bq/$m^3$ | Track-etch |
| Floor Drain | 1070 Bq/$m^3$ | Track-etch |
| Sump | 240 Bq/$m^3$ | Charcoal Adsorption |

Pesticides:

| Location | Analysis | Sampling Method |
|---|---|---|
| Crawl Space | non-detectable | Florisil Adsorption |
| Floor Drain | non-detectable | Florisil Adsorption |

Organic Compounds:

| Location | Analysis | Sampling Method |
|---|---|---|
| Floor Drain | Non-detectable | Tenax Adsorption |
| Wall Cracks | Non-detectable | Passive Charcoal Adsorption |
| Floor Drain | Concentrations too low to permit identification | |

TABLE 7 (cont'd)

INFORMATION SHEET - OAKRIDGES RESIDENCE

Fungus:

| Location | Analysis | Sampling Method |
|---|---|---|
| Crawl Space | 0 CFU/$m^3$ | Impinger |
| | 37 CFU/$m^3$ | Impinger |
| Floor Drain | 0 CFU/$m^3$ | Impinger |
| | 0 CFU/$m^3$ | Impinger |

SOIL GAS PROBES

Radon:

| Location | Analysis | Sampling Method |
|---|---|---|
| Probe #1 | 210 Bq/$m^3$ | Track-etch |
| Probe #2 | 3190 Bq/$m^3$ | Track-etch |
| Probe #3 | 5510 Bq/$m^3$ | Track-etch |
| Probe #4 | 160 Bq/$m^3$ | Track-etch |

Organic Compounds:

| Location | Analysis | Sampling Method |
|---|---|---|
| Probes 1 and 3 | Non-detectable | Tenax Adsorption |
| Probes 1, 2, 3 and 4 | Non-detectable | Passive Charcoal Adsorption |

winter, approximately 19$^{o}$C. Airborne fungal levels ranged from 0 to 326 Colony Forming Units per cubic meter (CFU/$m^3$). The higher levels in the basement living area and the crawlspace may be explained by the activities of sampling personnel. Airborne fungal levels are strongly influenced by resuspended dust from furniture, rugs and unswept floors.

Radon varied considerably at the three entry points monitored. The floor drain was the highest at 1070 Bq/$m^3$, then the sump enclosure at 240 Bq/$m^3$, followed by a level of less than the detection limit at the crawl space wall crack. The detection limit for 7 days of sampling, for the Track-etch detector is 160 Bq/$m^3$.

Airborne fungi levels at the soil gas entry points were zero or very low, 37 CFU/$m^3$. This would indicate that if soil gas is entering at these points it contains low levels of particulate and fungus.

Organic compounds for the active Tenax adsorption tubes and the passive badges were non-detectable at all entry point and soil probe sampling locations.

Radon in the soil gas probes indicates two conditions. The shallow probes above the water table, had moderate soil gas levels, 3190 and 5510 Bq/$m^3$ while the deeper probes at or below the water table had low soil gas radon levels, 210 and 160 Bq/$m^3$. The shallow probes were located in silty fine sand fill (3190 Bq/m$^3$) and a layer of silty sand topsoil (5510 Bq/m$^3$).

The soil gas pressures measured around this residence were consistently negative in the soil adjacent to the home (with the exception of zero pressures measured occasionally in probes 2 and 3). They became increasingly negative with increasing distance from the foundation, on two sampling occasions. Non-zero values ranged from a high of -0.08 mm of water to a low of -191.52 mm of water. The high negative pressures coincided with the deep monitors located above the water table. The existence of pressure differentials indicates that the soil probes were functioning correctly. Section 2.3 discusses these findings and their implications.

## 2.2 Analytical Results

### Radon

Analysis of the track-etch and charcoal adsorption samples were conducted by external laboratories, Terradex and Airchek respectively. Even though the charcoal adsorption samples must be analyzed within 3 days of the end of sampling, this constraint did not present a problem for this study. All indoor charcoal adsorption results were above the detection limit. Even though the track-etch samplers, which were located in the soil probes and entry point containers, were used in a manner not as intended by the manufacturer, they were capable of providing results in general agreement with those from other studies.

Fungi

As previously mentioned, the sampling and detection of airborne fungus is strongly dependent on resuspended dust concentrations and sampling times. In a few instances indoor air sampling was conducted for too long a sampling period with the Biotest sampler. In these instances, after incubation of the culture media, the growth of the agar fungus was such that the accurate counting of colony forming units could not be performed. When the sampling time was correct, problems were not encountered in analysis. Problems were not encountered in analysis of the impinger liquid samples.

Organic Compounds

No organic vapours could be detected in either the soil probes or at basement entry points over a week-long sampling period using 3M and DuPont G-AA passive monitors.

However, organic vapours were detected in entry point samples for sampling durations of approximately 1 hour using Tenax tubes. The compounds detected at levels above background belonged to the aliphatic and aromatic classes of hydrocarbons.

Comparison of head space analysis of organic compounds released from the containers sealant with the Tenax tube sample analysis did not reveal any contamination of soil gas sample with sealant compounds.

Pesticides

In only one house, the Minden residence, the homeowner had treated his lawn with a commercial pesticide/fertilizer mixture, containing 2,4-D. The treatment had been applied the previous summer. Analysis of pesticide samples taken in this house at the basement entry points as well as in the soil probes showed no evidence of 2,4-D. Furthermore, compounds belonging to the organochlorine class of pesticides, for example DDT, chlordane, dieldrin and methoxychlor were also not detected. Samples taken from the soil probes and from basement entry points at the other two residences also showed non-detectable levels of phenoxy acid herbicides such as 2,4-D and non-detectable levels of the organochlorine pesticides listed above.

Air Infiltration

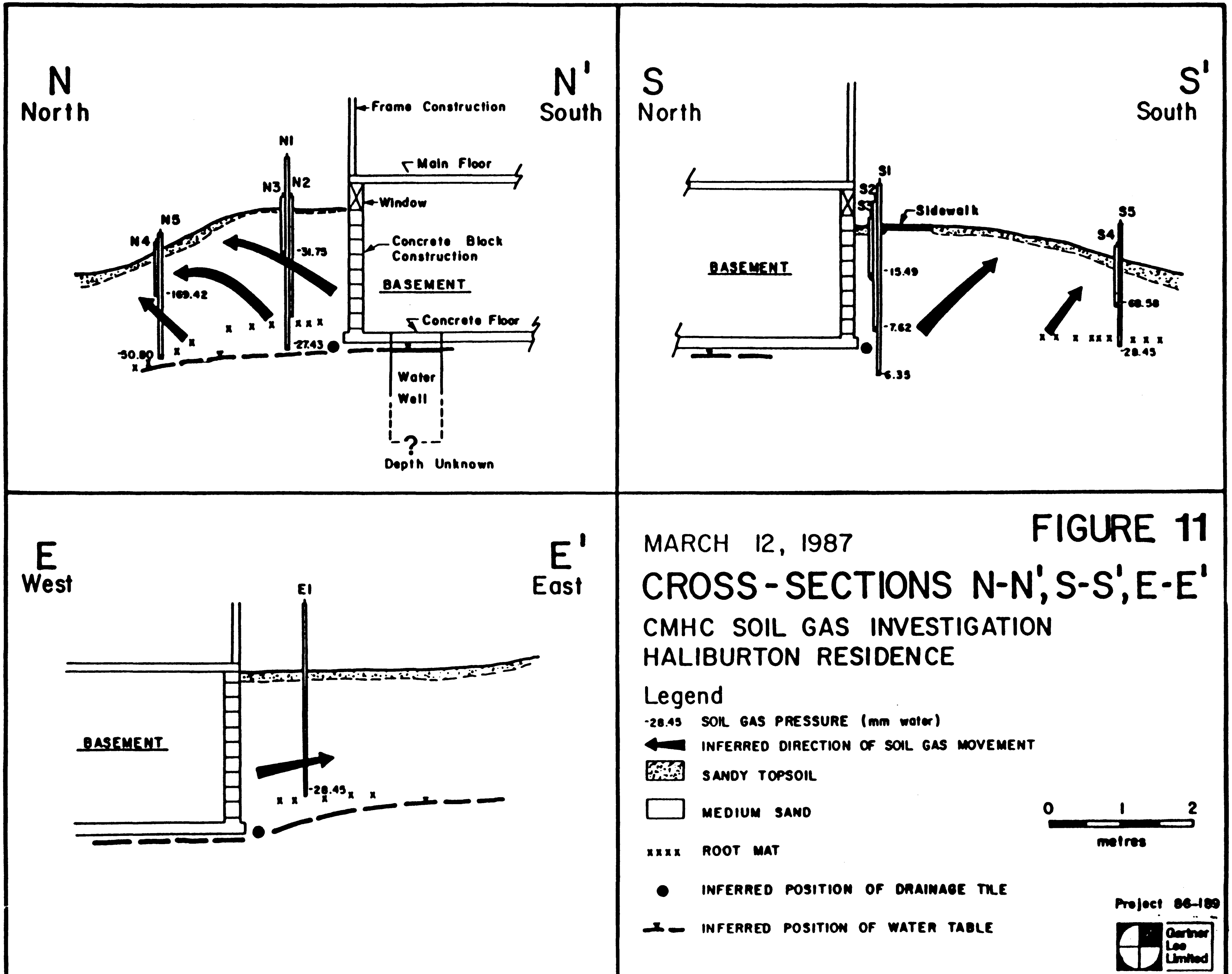
The capillary tube samples (CATS) were analyzed by NAHB. Of the three types of perfluorocarbon tracers used, the measured air concentrations of only one tracer could be used to calculate accurate entire home air infiltration values. As a consequence, separate zone air exchange rates are not presented. NAHB did not provide an explanation for this except that in future residential 3-zone studies, two sources per zone should be deployed.

## 2.3 Discussion of Results

Figures 11, 12, 13 and 14 show the inferred direction of soil gas movement around the subject homes on selected dates. In general, the soil gas pressure profiles measured before sampling yielded variable results. Soil gas flow was both towards and away from the residence foundations on different occasions and pressure gradients varied considerably. The measured pressures were in the order of kPascals whereas those reported in the literature were in the order of only Pascals. This fact is attributed to the confined condition of the soil gas. The presence of a frost layer at the ground surface did not allow natural venting of the soil gas to the atmosphere and, hence, allowed high negative and positive pressures to build. All cases reported in the literature review did not encounter these confined conditions.

The lower confining condition is the water table. Although no physical measurement of the position of the water table was made at each monitor nest location, it has been inferred on the cross sections presented for each residence. Fluctuation in the water table due to pumping is a concern for the two Canadian Shield residences where shallow private wells serve each home.

As expressed earlier, the Haliburton residence was instrumented in the most detail because of its uniform geology and symetrical geometry. As may be expected, it yielded the most consistent set of soil gas pressure measurements. Soil gas flow was away from the foundation on both sampling occasions (Figures 11 and 12). This contradicts the hypothesis that flow should be towards the home based on both the stack effect and measured radon levels in the homes. Examination of atmospheric pressure fluctuations show that it was dropping for a period of two days prior to both sets of measurements. Therefore, it would be expected that soil gas pressures should be positive and flow towards the residence. It is concluded that the water table fluctuations created by periodic and non-uniform pumping events in the well could induce the observed negative soil gas pressures by drawing down the water table. Other authors[28] have proposed this as a mechanism for soil gas flow.




MARCH 12, 1987

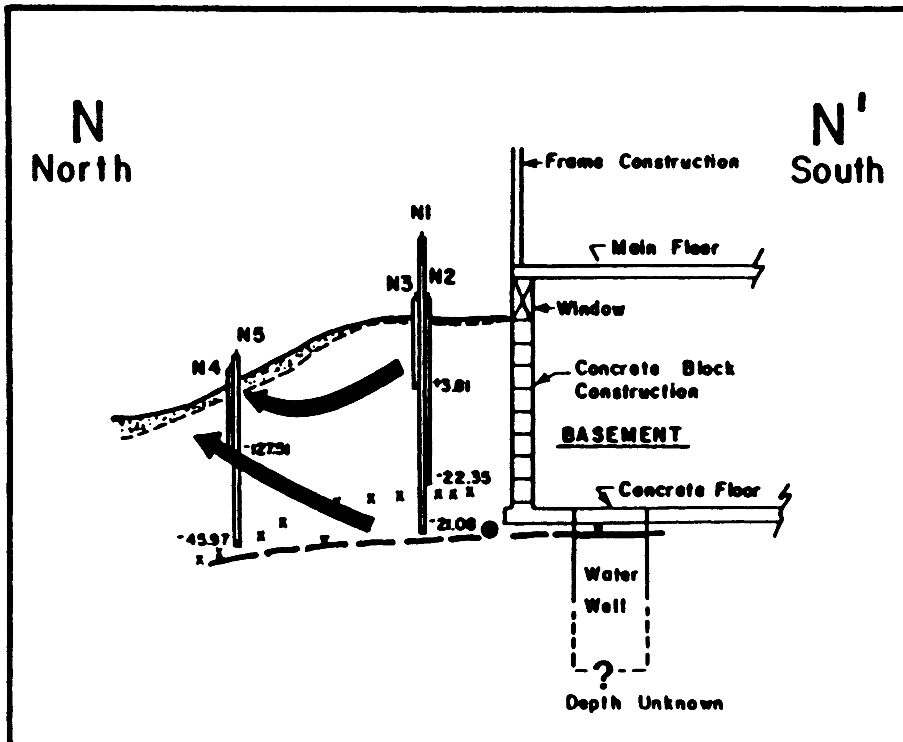
# FIGURE 11

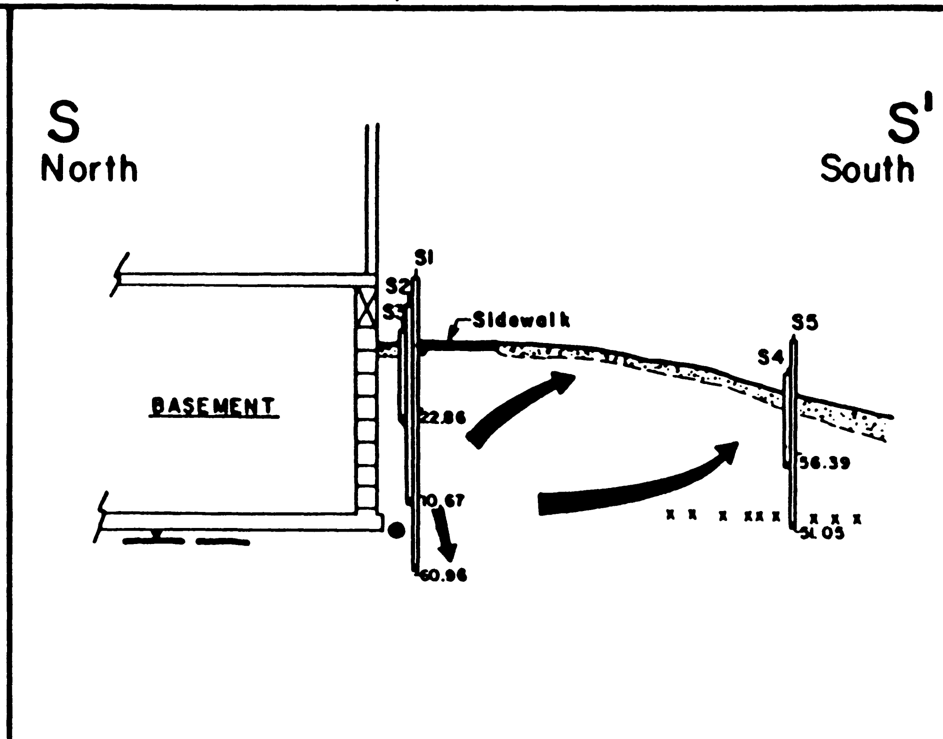
## CROSS-SECTIONS N-N', S-S', E-E'

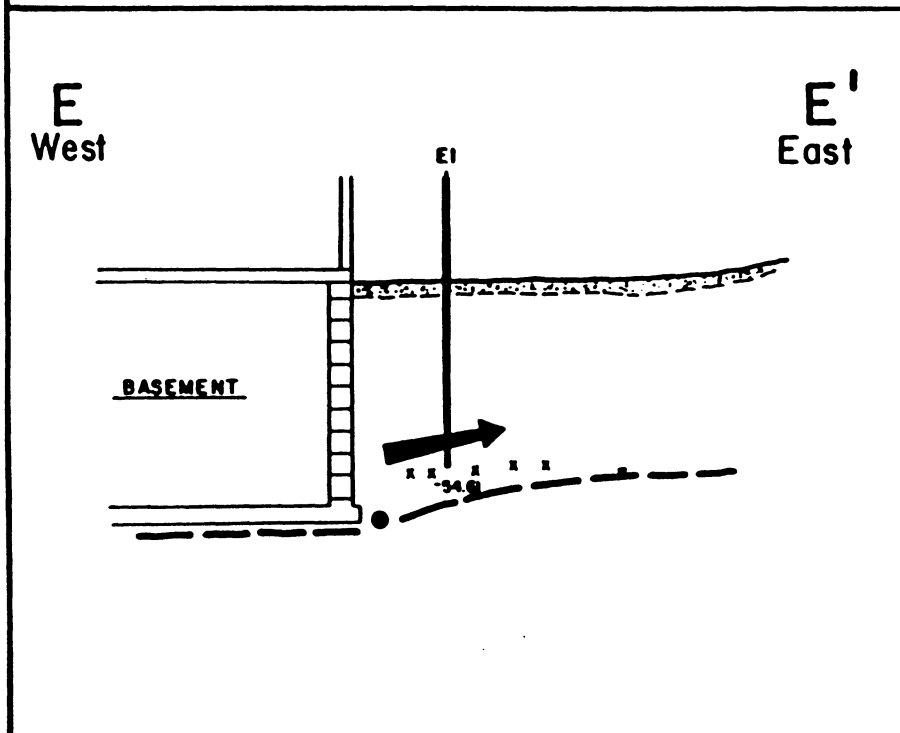
CMHC SOIL GAS INVESTIGATION
HALIBURTON RESIDENCE

Legend

- -28.45 SOIL GAS PRESSURE (mm water)
- INFERRED DIRECTION OF SOIL GAS MOVEMENT
- SANDY TOPSOIL
- MEDIUM SAND
- xxxx ROOT MAT
- INFERRED POSITION OF DRAINAGE TILE
- INFERRED POSITION OF WATER TABLE




MARCH 19, 1987

# FIGURE 12

## CROSS-SECTIONS N-N', S-S', E-E'

### CMHC SOIL GAS INVESTIGATION
### HALIBURTON RESIDENCE

Legend

- -54.61 SOIL GAS PRESSURE (mm water)
- INFERRED DIRECTION OF SOIL GAS MOVEMENT
- SANDY TOPSOIL
- MEDIUM SAND
- xxxx ROOT MAT
- ● INFERRED POSITION OF DRAINAGE TILE
- INFERRED POSITION OF WATER TABLE

0 1 2
metres

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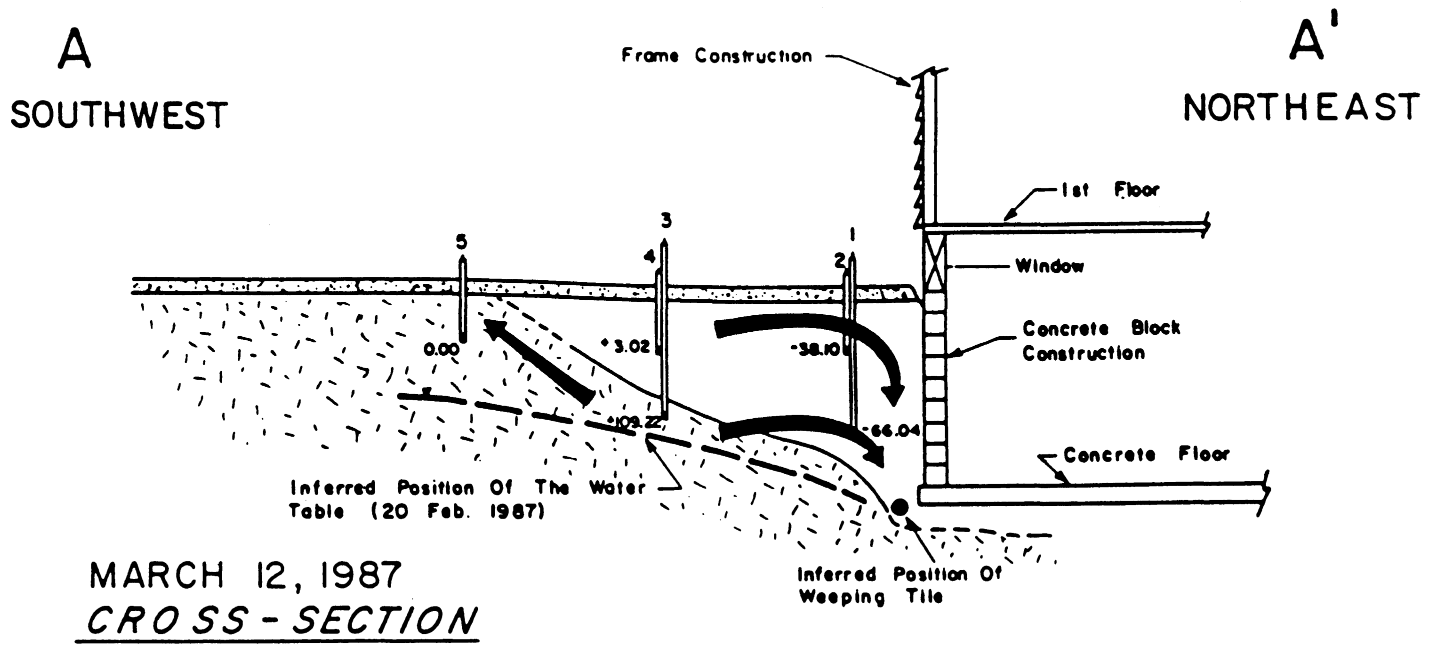


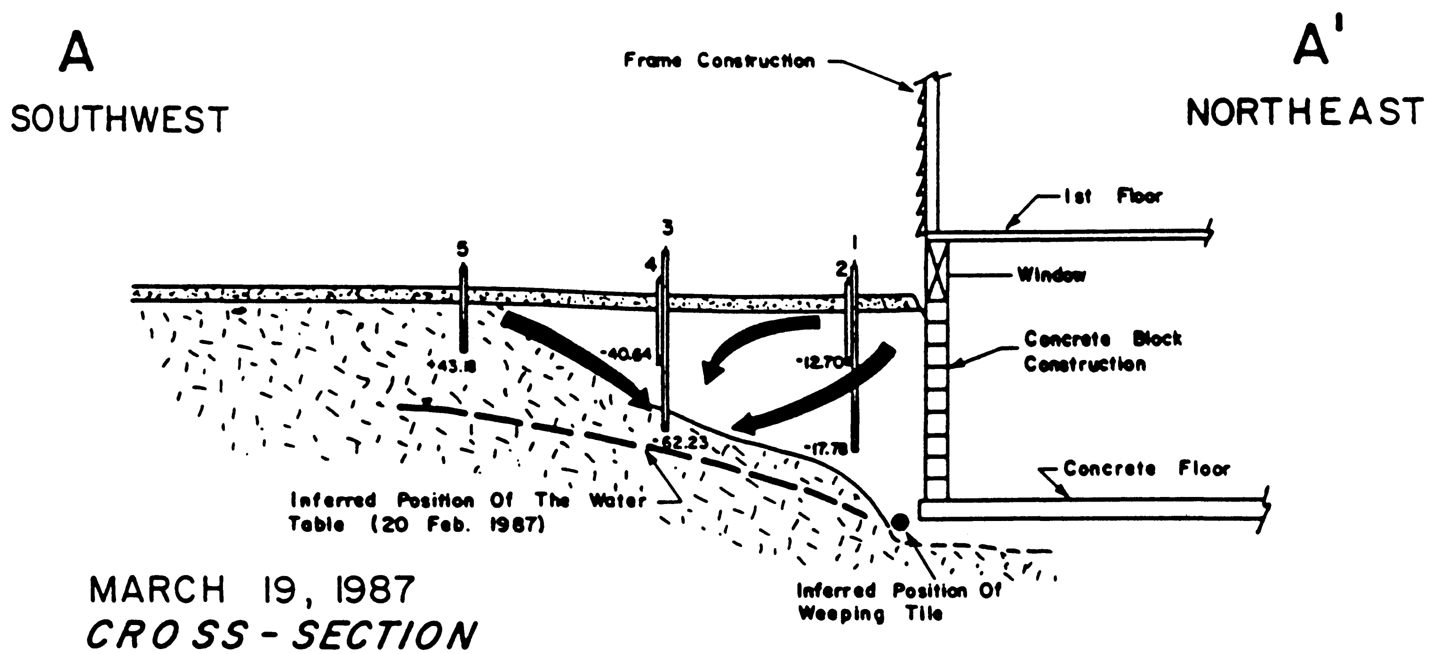


# DAWSON ROAD RESIDENCE

# FIGURE 13

## CMHC SOIL GAS INVESTIGATION

**Legend**

-17.78 SOIL GAS PRESSURE (mm water)

INFERRED DIRECTION OF SOIL GAS MOVEMENT

SILTY TOPSOIL

SILTY SAND FILL

SILT (natural)

0 1 2 metres

Project 86-189

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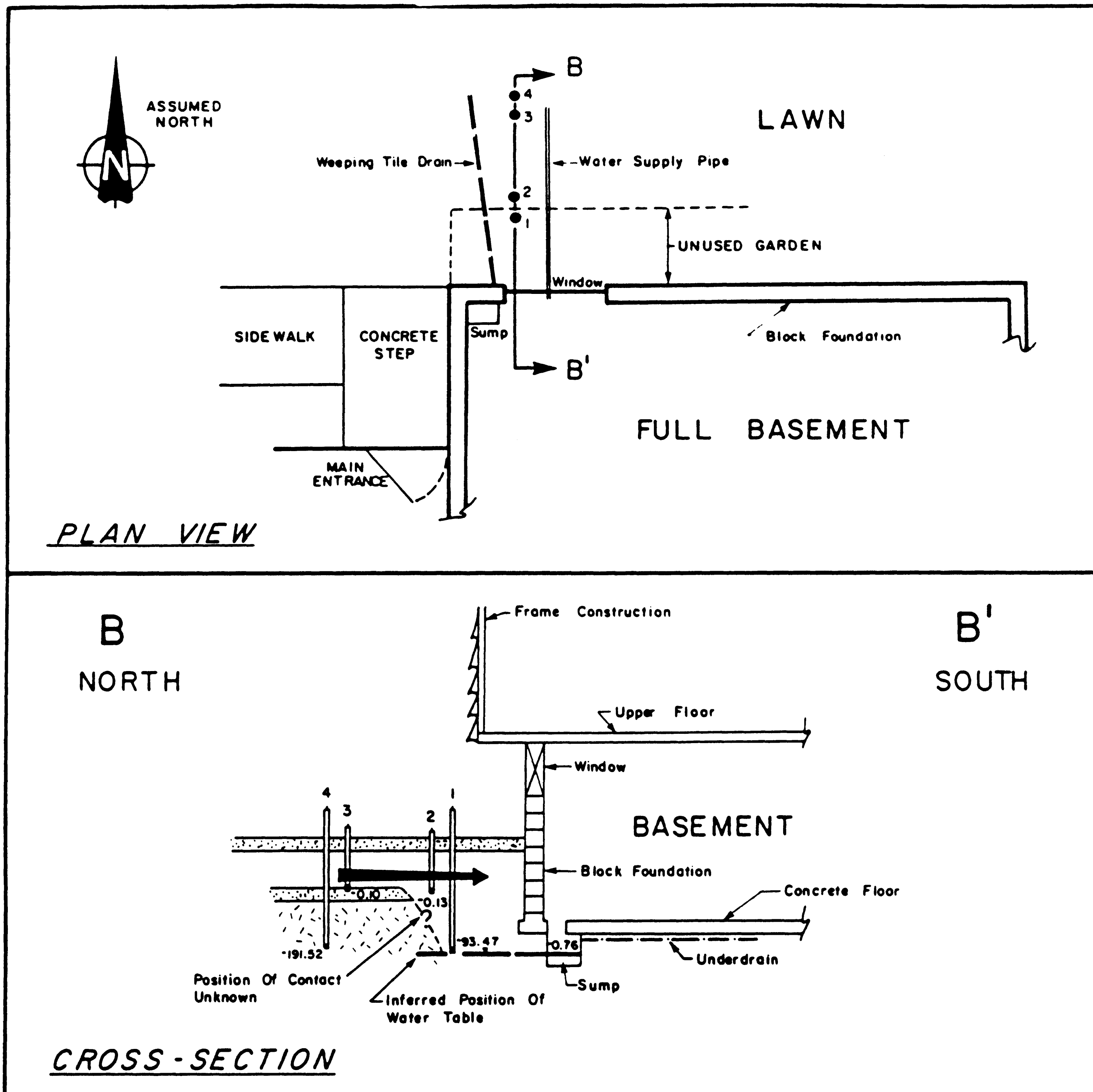


# OAK RIDGES RESIDENCE — FIGURE 14

CMHC SOIL GAS INVESTIGATION
FEBRUARY 18, 1987

0 1 2 metres

Project 86-189

**Legend**

- -62.23 SOIL GAS PRESSURE (mm water)
- INFERRED DIRECTION OF SOIL GAS MOVEMENT
- SILTY SAND TOPSOIL
- SILTY FINE SAND (fill)
- SILTY FINE SAND (natural)

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As expressed earlier, the Haliburton residence was instrumented in the most detail because of its uniform geology and symetrical geometry. As may be expected, it yielded the most consistent set of soil gas pressure measurements. Soil gas flow was away from the foundation on both sampling occasions (Figures 11 and 12). This contradicts the hypothesis that flow should be towards the home based on both the stack effect and measured radon levels in the homes. Examination of atmospheric pressure fluctuations show that it was dropping for a period of two days prior to both sets of measurements. Therefore, it would be expected that soil gas pressures should be positive and flow towards the residence. It is concluded that the water table fluctuations created by periodic and non-uniform pumping events in the well could induce the observed negative soil gas pressures by drawing down the water table. Other authors[28] have proposed this as a mechanism for soil gas flow.

The Dawson Road Residence shows two completely opposite pressure profiles (Figure 13). The profile measured March 12, 1987 infers soil gas flow towards the residence. There also seems to be a component of flow in all directions away from the silt interface at probe 3. The second profile, March 19, 1987, shows that exact reverse flow directions, that is flow away from the residence and radially towards monitor three. This apparent source/sink at probe 3 indicates flow transverse to the cross section as it is drawn. Therefore, it is concluded that some soil gas flows parallel to the foundation in these instances. Since the flow here does not seem to be driven by the stack effect of the residence, and is isolated from atmospheric effects by the frost layer, it is concluded that the pressure fluctuations are driven by water table fluctuations created from periodic operation of the water supply well.

The position of the deep monitors with respect to the water table is also an important factor to consider. Above the water table there exists a partially saturated zone, referred to as the capillary fringe. The thickness of the capilliary fringe is dependent on the pore size of the soil. A silt, for example, may have a capillary fringe that extends 200 mm above the water table, yet a clean medium sand will have one that extends only 20 mm. If the open end of a soil probe is in the capilliary fringe there may exist some soil gas, but none that is interconnected with the unsaturated soil above. Therefore, the pressures recorded in such a probe will reflect the negative pore pressure of the water phase. There will also be very little soil gas flow for sampling purposes. Since radon is soluble in water, it can also be expected that radon levels would also be lower than might be found in fully unsaturated soils.

Observations consistent with this were made at the Oak Ridges Residence (Figure 14). Probes 1 and 4 are at approximately the elevation of the water level in the sump, although no water was observed in the bottom of either monitor. When these probes were developed after installation, they maintained their negative pressures without bleeding off. The silty fine sand here would have a capilliary effect of about 150 mm. Varying strong negative pressures were always measured at these two probes, varying from -.274 kPa to 1.88 kPa (-28 mm to -192 mm of water). Finally, the radon levels measured here were more than one order of magnitude less than that measured in fully unsaturated soil above. Therefore, it is concluded that these two monitors are water locked in the capillary zone above the water table.

As anticipated, radon in soil gas was the highest in-situ in the soil probes, Table 8. Levels were higher in the unsaturated zone than at or below the water table by an order of magnitude. Unsaturated zone radon levels at the Canadian Shield sites were twice as high as the Oak Ridges site. These trends are as expected. Radon measured at the soil gas entry points was an order of magnitude less than that of that of the soil probes. Radioactive decay and dilution are most likely the main causes of this reduction in soil gas radon concentrations. As in the soil probes, the radon levels at the entry points of the Canadian Shield sites were greater than the Oak Ridges site.

Radon in the basement indoor air decreased from the entry point levels by an order of magnitude. Therefore, the total reduction of radon from soil gas in-situ to basement indoor air appears to be two orders of magnitude, or from approximately 6700 $Bq/m^3$ to 50 $Bq/m^3$. There was no apparent difference between indoor levels in the Canadian Shield sites and the Oak Ridges site. Based on the air leakage tests, the Oak Ridges residence was the leakiest home. Even though the concentration of radon at the entry points was less at Oak Ridges, there may be a greater quantity of soil gas entering this home than the Canadian Shield homes. A greater quantity of soil gas would explain why resultant indoor radon levels are the same.

Indoor levels of airborne fungi are affected by several factors including humidity, the level of organics present, immediate outdoor air quality and the level of contamination of the recirculated indoor air. Sources of contamination are the occupants, pets and plants and these are also influenced by household cleaning habits. The entry point airborne fungal samples were drawn through floor cracks and adjacent soil. The soil and cracks will filter fungus spores from the soil gas. In addition, the floor or wall surface immediately surrounding the entry point sampling was not sterilized prior to placement of the containers and floor or wall contamination could have contributed to the measured fungal levels. The open well sample at the Haliburton residence has a characteristically high fungal count. This is due primarily to the high humidity and accessible organics which support fungal growth.

Neither trace organic compounds nor pesticides were measured in all the in-situ soil gas probes sampled. This is also as expected. One of the three homes had fertilizer/herbicide lawn treatment. This was applied five months prior to sampling.

TABLE 8

SUMMARY OF RADON MEASUREMENTS

SOIL PROBES:

| | |
|---|---|
| Unsaturated zone | 3190 to 12400 Bq/m$^3$, median 8355 Bq/m$^3$ |
| At or Below Water Table | 160 to 696 Bq/m$^3$, median 210 Bq/m$^3$ |

UNSATURATED ZONE:

| | |
|---|---|
| Canadian Shield | 4540 to 12400 Bq/m$^3$, median 9060 Bq/m$^3$ |
| Oak Ridges | 3190 to 5510 Bq/m$^3$, median 4350 Bq/m$^3$ |

ENTRY POINTS:

| | |
|---|---|
| Canadian Shield | 390 to 3060 Bq/m$^3$, median 836 Bq/m$^3$ |
| Oak Ridges | <160 to 1070 Bq/m$^3$, median 240 Bq/m3 |

INDOOR AIR:

| | |
|---|---|
| Canadian Shield | 44 to 63 Bq/m$^3$, median 48 Bq/m$^3$ |
| Oak Ridges | 55.5 Bq/m$^3$ |

The organic content of the soils sampled was low, therefore, decomposition products such as methane were not anticipated, particularly in winter. Trace quantities of organic compounds were detected in four of the seven entry points sampled. The compounds detected were typical of those found in background indoor air and most likely originated from inside the homes and not from the soil gas. They may have entered the containers when the containers were sealed onto the cracks. The containers were neither cleansed nor purged with inert gas prior to sampling. The compounds may have also entered into the cracks by diffusion from the indoor air prior to sampling and then the sampling removed them from the cracks and into the containers.

## 3. CONCLUSIONS

### Soil Probes

The 53.5 mm diameter aluminum soil probe configuration designed for this study successfully satisfied the purposes for which it was designed. The probes could be used for both active and passive methods of pollutant monitoring to sample soil gas surrounding residences. They were also successfully used to measure pressures at varying depths and locations within soils. The sinking of an initial pilot hole with a vibrating drill and then probe installation by hand or with vibratory drill assistance was a successful method of probe installation. The probes were successfully installed in a trial clay soil and the three test sites which were medium sand, silt and silty fine sand. Caution should be taken when installing the probes to ensure the ends are above the water table and in the unsaturated zone. If the probes are below or at the water table in the saturated zone, soil gas cannot enter the probes. This restriction of soil gas flow into the probes restricts the sampling rate of probes located at or below the water table.

The capital cost of fabrication of these probes was approximately $100 . The installation method which requires vibratory drill equipment, may render these soil probes unreasonable for a large survey of homes.

Soil gas pressure profiles and the resulting soil gas flow patterns were not uniform. The pressures were higher than previously reported values in the literature by several orders of magnitude. This effect was found to be due to the confined nature of the unsaturated zone. Frost seals the ground surface during winter while a water table fluctuating from well pumping events creates these excess pressures. This phenomenum effectively masks the stack effect which usually drives soil gas flow towards structures, particularly in winter. To understand these effects in more detail, it is recommended that an assessment be made of water table fluctuations in the vicinity of homes to further define the gas flow in the unsaturated zone.

Soil Gas Entry Point Containers

The entry point containers proved to be suitable for covering floor drains and floor and wall cracks. The sealant and duct tape held the containers firmly in place for the 7-day sampling periods. Seals between the containers and floors and walls were leak proof. Sampling airflow rates and time durations required by active sampling techniques could be maintained. Both detectable and non-detectable levels of organics, pesticides and fungi were measured with active sampling techniques. It is recommended that active sampling for larger durations be undertaken in future applications of this technique. This will increase the sample volume and provide a lower level of detection for organics and pesticides.

These entry point containers were not suitable for the use of passive dosimeter badges for organic compound sampling. Moisture and low face velocities were most likely the causes for the lack of success.

The investigation of below-grade air infiltration requires inspection of floor slab and wall surfaces. Finished basements are difficult to investigate when walls are covered with panelling or floors have coverings such as tiles or rugs. Homeowners may also erect partitions, place furniture or store belongings in such a way as to make access to bare floor and wall surfaces very difficult. The use of these entry point sampling containers assumes readily accessible cracks and drain holes.

Basement sump pits could not be covered with the containers. In the two sumps encountered, both were enclosed and samplers were installed within the enclosures. No attempts were made to seal the sump enclosures as it would not have been practical to attain a tight seal without modification to the enclosures. Since this modification would require further permission from the homeowner, sealing of the pump enclosures was not undertaken.

### Radon Sampling

The track-etch passive technique for radon sampling was successfully used in the soil probes and entry point containers. It was found that radon gas levels were higher in the soil gas sampled from the soils on the Canadian Shield. Other investigators have found similar results from crystalline rocks elsewhere. In addition, those soil probes closest to the ground water table exhibited lower radon levels than those further above. This is possibly due to the solubility of radon produced from the soil in the ground water, although this has not yet been confirmed. Radon levels decreased by one order of magnitude from the soil probes to the entry point containers. This is most likely due to radioactive decay and dilution.

Fungus

The impinger method for sampling airborne fungi from the entry point containers and the centrifugal method for sampling the indoor air were successfully employed. Based on the findings of this study, soil gas is not a major source of indoor fungus. Fungus spores originate from within the home and moisture introduced through cracks below grade contribute to their growth in basements.

It should be noted that monitoring of indoor air quality for moulds or fungi is a new field, and as such, monitoring techniques and results interpretations are in the developmental stage. In this study, total fungal counts were undertaken as a screening technique. In order to determine more about airborne fungi, genus and species identification would be required, at considerably greater analytical cost.

Organic Compound Sampling

Organic vapours were detected with the short-term active samples using Tenax tubes but not with the passive organic vapour monitors. The analysis of the 3M and the DuPont G-AA monitors did not detect any organic vapours at levels greater than the blank samples. These monitors were placed in the soil probes and at basement entry points for periods of 7 days. The reasons for lack of detection could be:

1. Concentrations of organic vapours at the sampling points were below the lower detection limits of the monitors.

2. The relative humidity was greater than the recommended upper limit, thus severely decreasing the adsorption capacity of the monitors.

3. The face velocities were below the minimum value resulting in starvation of the monitors.

It is unlikely that the concentrations of organic vapours were less than the lower detection limit of the monitors. The analysis of the short-term active Tenax tube samples indicated various compounds at or slightly above those of the blank Tenax tube sample. The lower detection limit for the DuPont G-AA monitor for a 7-day exposure is reported to be 0.001 parts per million (ppm), well below trace levels.

Humidity was most likely a problem in the case of samplers placed in the soil probes. Most of the monitors showed evidence of condensation when they were removed at the termination of sampling. Because water vapour competes effectively with organic vapours for the monitor charcoal adsorption sites, the retention of organic vapours would be severely decreased.

Because the organic vapour monitors are enclosed in sampling containers both in the basement at source entry points and within the soil probes, the air velocity at the face of each monitor may be less than the minimum design requirement. Thus, the monitor performance would have been compromised.

As previously mentioned, organic vapours were detected in the short-term active samples using Tenax tubes. Although more success was achieved using Tenax tubes, the main drawback of this method is that it represents a grab sample taken over a one-hour period. In contrast, the organic vapour monitor may have provided an integrated value taken over a 7-day period, and hence, a more representative sample. The sensitivity and degree of representativeness of the Tenax method, however, can be improved by increasing sampling duration and taking a greater number of samples over several days.

## Pesticides

Due to the rapid degradation in soil of most commonly used pesticides, concentrations in excess of trace amounts were not anticipated. In addition, because sampling was conducted during the winter period, any pesticides detected would have been a result of application during the previous spring or summer.

Time and cost constraints imposed by the pesticide analytical procedure necessitates that all pesticides used in and around the house be identified prior to analysis. Although this can be accomplished by questioning the homeowner as to the pesticides used, it is confounded by problems in homeowner recall.

## Air Infiltration

Radon measurements can be used to determine the fraction of the entire home air infiltration which is soil gas. This fraction is determined by the ratio of the average indoor home radon concentration to the concentration of radon at the entry points. This determination assumes that all the radon which enters the home is by soil gas flow through cracks and openings and the radon entry by diffusion is negligible. For the three homes studied, the monitoring results can be used to determine the following soil gas entry rates.

| | |
|---|---|
| Haliburton Residence: | 3.8% of 0.138 ach<br>or 0.0061 ach |
| Dawson Road Residence: | 1.1% of 0.236 ach<br>or 0.0026 ach |
| Oak Ridges Residence: | 2.5% of 0.606 ach<br>or 0.015 ach |

Details of the calculations are presented in Appendix A-4.

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# APPENDIX

PROJECT NO. 86-189
FIGURE A-1

DAWSON ROAD RESIDENCE

SHEET 1 OF 1

# MONITOR DETAILS SUMMARY

| BOREHOLE | | | MONITOR | | | | SCREENED INTERVAL | FILTER PACK | SEAL | BACKFILL |
|---|---|---|---|---|---|---|---|---|---|---|
| No. | Diameter (mm) | Dpth (m) | Type | Diameter (mm) | Stick-up (m) | Length (m) | | | | |
| 1 | 53.5 | 1.57 | G | 53.5 | 0.29 | 1.67 | 1.32 - 1.38 | | | |
| 2 | 53.5 | 0.89 | G | 53.5 | 0.13 | 0.75 | 0.57 - 0.62 | | | |
| 3 | 53.5 | 1.44 | G | 53.5 | 0.42 | 1.67 | 1.20 - 1.25 | | | |
| 4 | 53.5 | 0.88 | G | 53.5 | 0.12 | 0.75 | 0.58 - 0.63 | | | |
| 5 | 53.5 | 0.85 | G | 53.5 | 0.18 | 0.75 | 0.52 - 0.57 | | | |

P - Piezometer S - Standpipe G - Gas Monitor
(t.o.p.m.) - Top of Pipe in Metres

Gartner Lee Limited

PROJECT NO. 86-189

FIGURE A-2

HALIBURTON RESIDENCE

SHEET 1 OF 1

# MONITOR DETAILS SUMMARY

| BOREHOLE | | | MONITOR | | | | SCREENED INTERVAL | FILTER PACK | SEAL | BACKFILL |
|---|---|---|---|---|---|---|---|---|---|---|
| No. | Diameter (mm) | Dpth (m) | Type | Diameter (mm) | Stick·up (m) | Length (m) | | | | |
| N1 | 53.5 | 2.00 | G | 53.5 | 0.72 | 2.58 | 1.81 - 1.86 | | | |
| N2 | 53.5 | 1.52 | G | 53.5 | 0.21 | 1.67 | 1.41 - 1.46 | | | |
| N3 | 53.5 | 0.81 | G | 53.5 | 0.16 | 0.75 | 0.54 - 0.59 | | | |
| N4 | 53.5 | 1.22 | G | 53.5 | 0.16 | 0.75 | 0.54 - 0.59 | | | |
| N5 | 53.5 | 1.46 | G | 53.5 | 0.22 | 1.67 | 1.40 - 1.45 | | | |
| E1 | 53.5 | 1.67 | G | 53.5 | 0.96 | 2.58 | 1.57 - 1.62 | | | |
| S1 | 53.5 | 2.28 | G | 53.5 | 0.58 | 2.58 | 1.95 - 2.00 | | | |
| S2 | 53.5 | 1.48 | G | 53.5 | 0.26 | 1.67 | 1.36 - 1.41 | | | |
| S3 | 53.5 | 1.00 | G | 53.5 | 0.10 | 0.75 | 0.60 - 0.65 | | | |
| S4 | 53.5 | 1.09 | G | 53.5 | 0.12 | 0.75 | 0.58 - 0.63 | | | |
| S5 | 53.5 | 1.18 | G | 53.5 | 0.49 | 1.67 | 1.13 - 1.18 | | | |

P - Piezometer    S - Standpipe    G - Gas Monitor

(t.o.p.m.) - Top of Pipe in Metres

Gartner Lee Limited

PROJECT NO. 86-189

FIGURE A-3

OAK RIDGES RESIDENCE



# MONITOR DETAILS SUMMARY

| BOREHOLE | | | MONITOR | | | | SCREENED INTERVAL | FILTER PACK | SEAL | BACKFILL |
|---|---|---|---|---|---|---|---|---|---|---|
| No. | Diameter (mm) | Dpth (m) | Type | Diameter (mm) | Stick-up (m) | Length (m) | | | | |
| 1 | 53.5 | 1.46 | G | 53.5 | 0.31 | 1.67 | 1.31 - 1.36 | | | |
| 2 | 53.5 | 0.76 | G | 53.5 | 0.10 | 0.75 | 0.60 - 0.65 | | | |
| 3 | 53.5 | 0.76 | G | 53.5 | 0.15 | 0.75 | 0.55 - 0.60 | | | |
| 4 | 53.5 | 1.45 | G | 53.5 | 0.36 | 1.67 | 1.26 - 1.31 | | | |

P - Piezometer S - Standpipe G - Gas Monitor

(t.o.p.m.) - Top of Pipe in Metres

Gartner Lee Limited

## FIGURE A-4

## DETERMINATION OF SOIL GAS ENTRY RATIO

Derivation of Equation:

If AHR = (ER X EA)/HA

where AHR = Average home radon concentration, $Bq/m^3$
ER = Entry point radon concentration, $Bq/m^3$
EA = Entry point airflow, $m^3/h$
HA = Entire house air infiltration, $m^3/h$

then $$\frac{EA}{HA} = \frac{AHR}{ER}$$

For the three test homes:

| Home | Average Home Radon ($Bq/m^3$) | Average Entry Point Radon ($Bq/m^3$) | AHR/ER | Home ach | Soil Gas ach |
|---|---|---|---|---|---|
| Haliburton | 34 | 900 | 0.038 | 0.136 | 0.0061 |
| Dawson Road | 34 | 1000 | 0.011 | 0.236 | 0.0026 |
| Oak Ridges | 25 | 3000 | 0.025 | 0.606 | 0.015 |