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DEVELOPMENT AND DEMONSTRATION
OF INDOOR RADON REDUCTION MEASURES
FOR 10 HOMES IN CLINTON, NEW JERSEY

Prepared for

Office of Radiation Programs

Prepared by

Air and Energy Engineering Research
Laboratory
Research Triangle Park NC 27711

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Development and Demonstration of Indoor Radon Reduction Measures for 10 Homes in Clinton, New Jersey

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ABSTRACT

In the spring of 1986, the New Jersey Department of Environmental Protection located a cluster of homes with extremely high radon levels in the town of Clinton, New Jersey. Research Triangle Institute was contracted to develop and demonstrate radon reduction techniques in 10 of these homes. The work was to be completed before the 1986-87 winter heating season began.

The demonstration homes were selected from among 56 homes in the subdivision of Clinton Knolls. All of these homes had shown radon concentrations in excess of 64 pCi/l when monitored in the spring of 1986. Each of the homes was inspected and a representative sample of 10 homes was selected for the radon reduction demonstration project.

Following intensive diagnostic work and monitoring in each of the homes, a radon reduction plan was developed. With the agreement of the homeowners, installation of radon reduction systems was carried out during the summer of 1986. All of the 10 homes had radon concentrations reduced significantly by the fall of 1986. The average cost of radon reduction was $3,127.

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1.0 INTRODUCTION

The discovery of high indoor concentrations of radon gas in the Reading Prong area of New Jersey, New York, and Pennsylvania, and in other locations in the United States, has raised serious concerns about a large number of people being exposed to the radioactive gas. In response, the U. S. Environmental Protection Agency (EPA) issued a guidance booklet, "A Citizen's Guide to Radon: What It is and What to Do About It" (EPA, 1986a). EPA guidelines recommend initiating corrective action in homes with radon concentrations in excess of 4 picocuries per liter (pCi/l), or 148 Becquerels per cubic meter, of air. At radon concentrations of 200 pCi/l, temporary relocation is recommended.

In the early spring of 1986, a preliminary survey of homes in Clinton, New Jersey, conducted by the New Jersey Department of Environmental Protection (DEP), identified more than 50 homes with indoor radon concentrations greater than 100 pCi/l in the subdivision of Clinton Knolls. Many of these homes had radon concentrations of 600 pCi/l or higher.

The primary purpose of the work described in this report was to develop and demonstrate cost-effective radon reduction techniques in 10 representative Clinton Knolls homes. Radon reduction measures were to be completed before the beginning of the 1986-1987 heating season to keep the exposures of residents to a minimum. Additional data were collected to add to the general body of information on radon transport and its control in homes; however, this data collection was secondary to the pressing need to demonstrate effective radon reduction techniques by the Fall.

2.0 BACKGROUND

The subdivision of Clinton Knolls is located near the center of the town of Clinton, New Jersey. The neighborhood is dominated by frame houses with floorplans of approximately 139 m^2 (1500 ft^2). This uniformity is due to development of the subdivision by a single builder. Some custom-built homes, similar in style and size to the developer-built homes, are scattered among those built by the prime contractor. While most of the houses are approximately 18 years old, many of the 56 volunteer homes that were surveyed were still occupied by their original owners, making this neighborhood a stable one.

The development is built on a dolomitic limestone hill that rises above Main Street and ends at the edge of an abandoned quarry. The hill crests at the interior streets of the subdivision with bedrock rising to the surface in the area. Several homeowners reported that the bedrock beneath their homes had to be blasted before basements could be built or before sewer lines could be placed. Residents also reported the appearance of sinkholes throughout the neighborhood where the formation of underground caves had caused the earth to subside.

3.0 SELECTION OF DEMONSTRATION HOMES

One hundred three homeowners who had participated in the DEP radon survey in March and April of 1986 were asked to volunteer their homes for the radon reduction demonstration effort. Fifty-six of the homeowners who volunteered were selected for screening. Figure 1 demonstrates the proximity of the 56 homes participating in EPA's radon screening effort and Table 1 shows the range of radon concentrations among the 103 homes participating in the DEP radon survey.

Three basic floorplans repeated throughout the subdivision are reproduced from the original developer's promotional brochure in Figure 2. In addition, a small number of diverse floorplans built by independent contractors were also investigated. For the purposes of this report, the floorplans have been assigned the following letter designations:

- Split level with half basement (combination of slab-on-grade and block basement) - A
- Bi-level (slab-below-grade) - B
- Two story with no basement (slab-on-grade) - C
- Two story with basement (concrete block basement) - D
- Independent builder floorplans (variety of substrates) - E

During a one week period, each of these homes was investigated by a diagnostic team of EPA and RTI personnel. Figure 3 reproduces the checklist that was used to assess each of the homes. The objective of EPA's home screening effort was to characterize the pool of homes and select 10 homes as representative of the Clinton housing stock which could be used to demonstrate radon reduction measures. Table 2 is a summary of findings; Table 3 shows the distribution of survey houses by floorplan. Selection of 10 demonstration homes from among the volunteers homes was done using the criteria below:

- The ability to identify and to access the location of radon entry into the house.
- The ease of worker access to the home during the workday.
- The ability to reduce radon levels in the home with few potentially unknown factors affecting the outcome, such as fireplaces, woodstoves, etc.

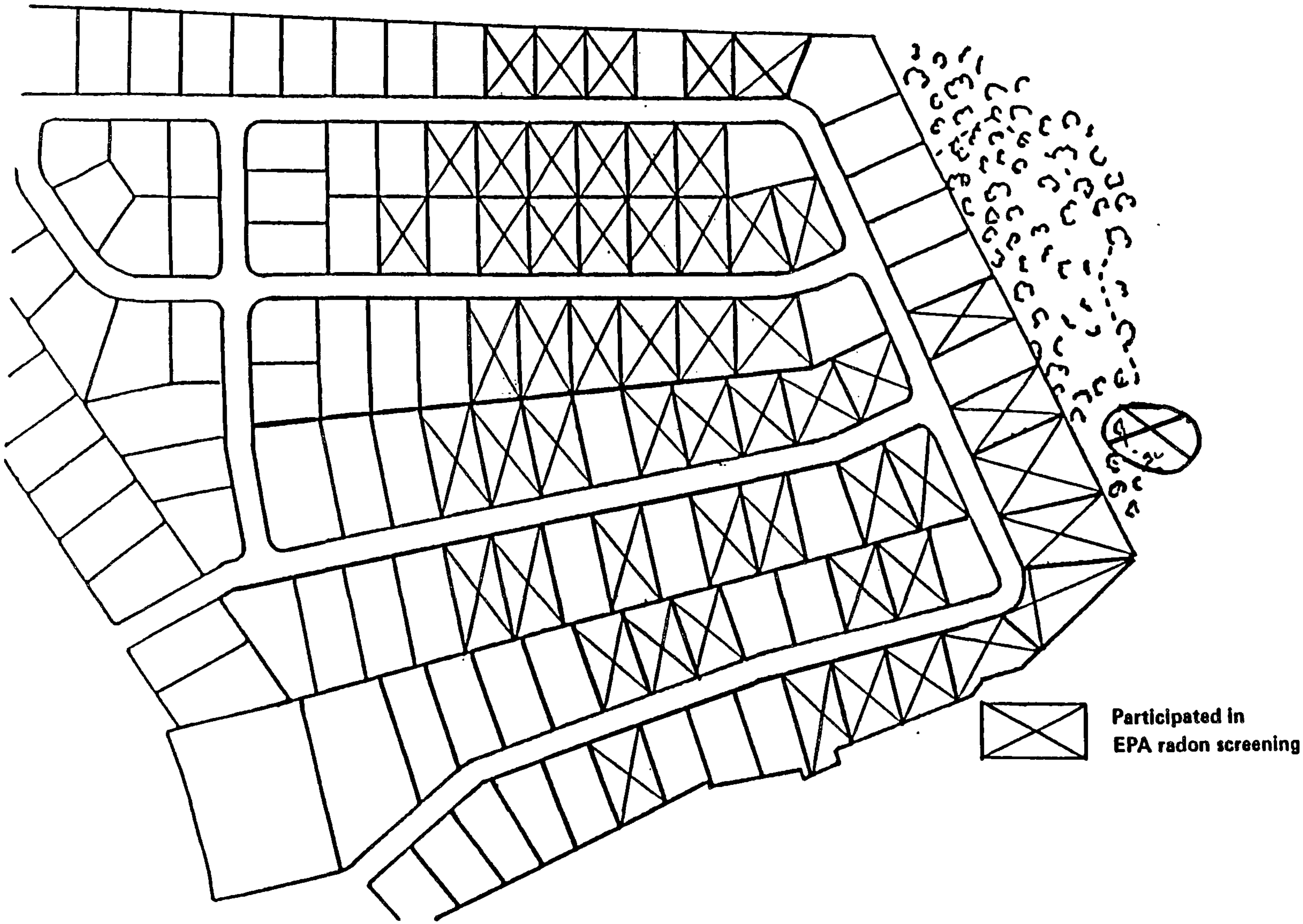
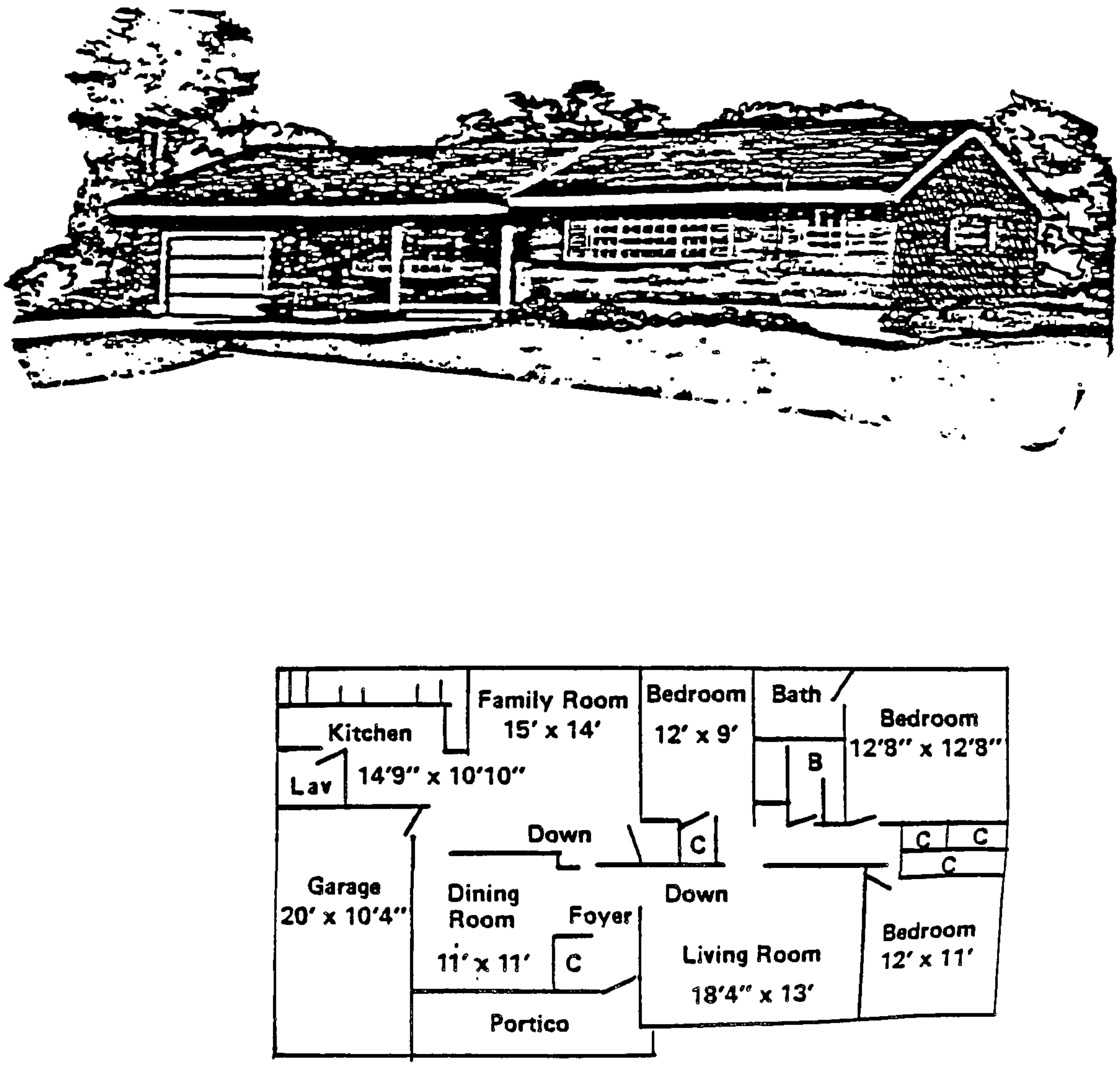


Figure 1. Houses selected for radon screening.

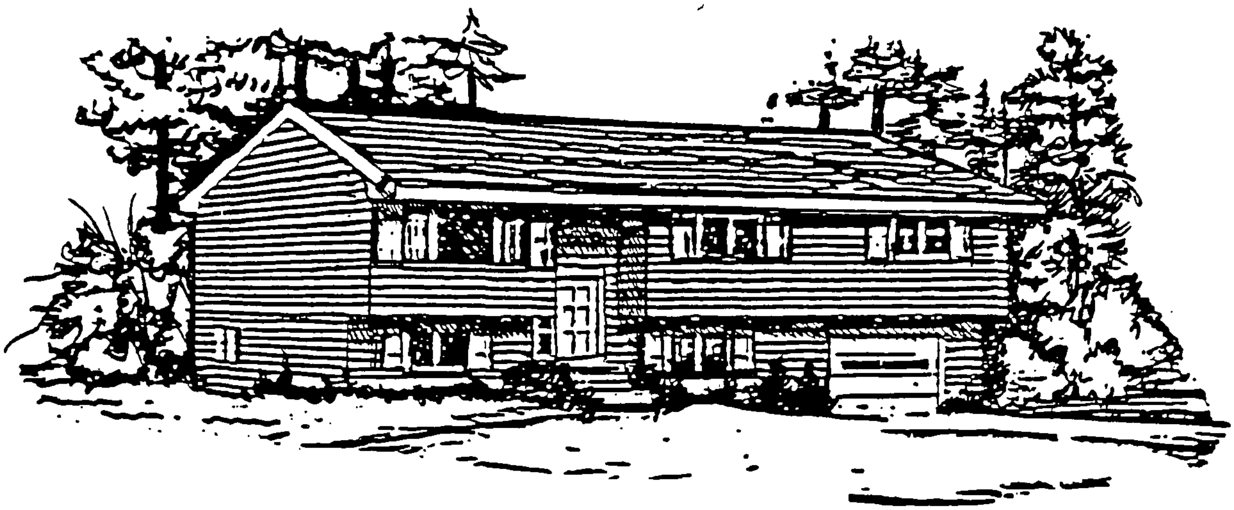
TABLE 1. CLINTON RADON LEVELS

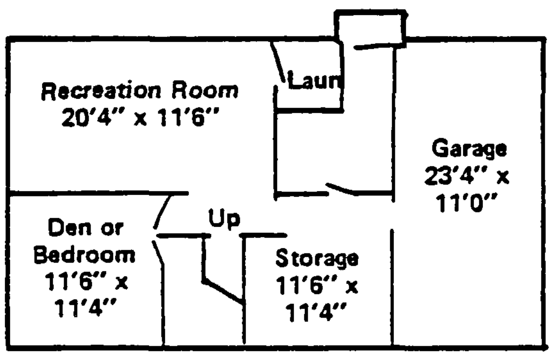
Concentration pCi/l	No. of Houses	% of Sample
>2048	2	1.9
1024-2047	3	2.9
512-1023	13	12.6
256-511	17	16.5
128-255	17	16.5
64-127	12	11.7
32-63	12	11.7
16-31	14	13.6
8-15	5	4.9
4-7	6	5.8
<4	2	1.9
	103	

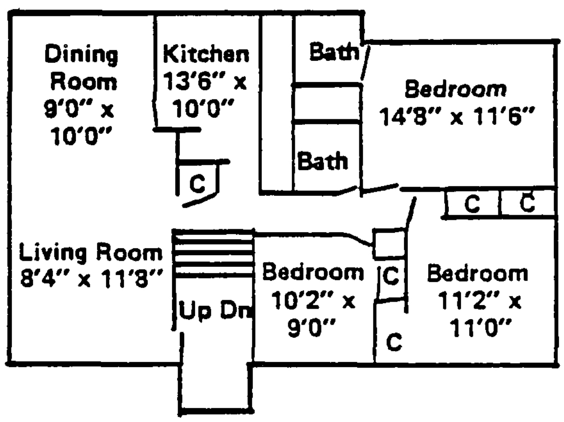


Source: Clinton Knolls subdivision advertising brochure

Figure 2-a. Floorplan "A".

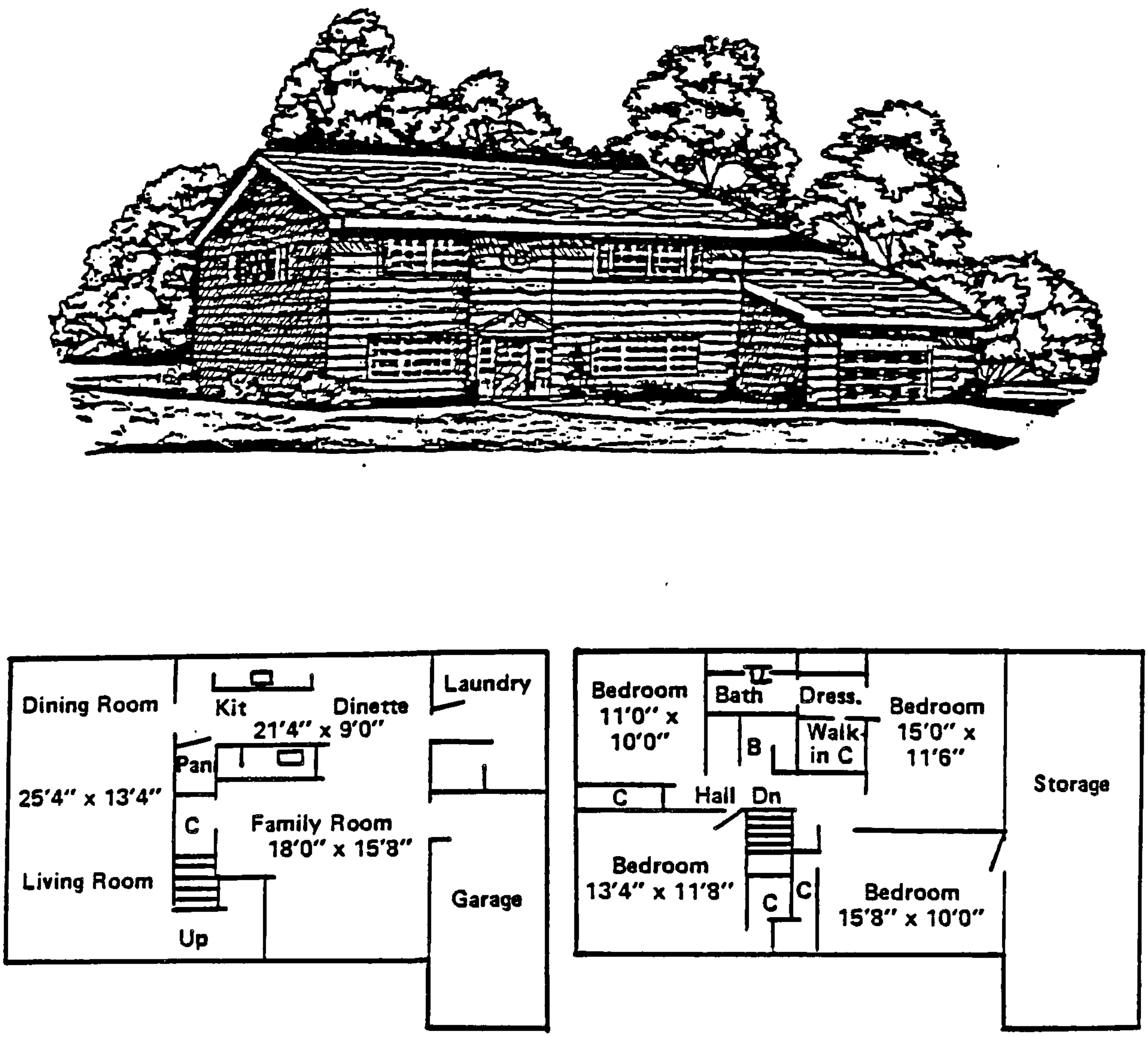






Source: Clinton Knolls subdivision advertising brochure

Figure 2-b. Floorplan "B".



Source: Clinton Knolls subdivision advertising brochure

Figure 2-c. Floorplan "C" and "D".

House Address ____

House Number S-_____

Date ______________

Time ______________

Survey Crew Members ____

General Instructions

This checklist is designed to ensure that each house is thoroughly evaluated. FILL IN ALL SPACES ON THIS CHECKLIST. All sketches, notes, and measurement results should be recorded in the field notebook along with the house address and survey number, date, time, and names of the crew members.

I. Sketch a floor plan of the house. Also provide a sketch of the house elevation. If a house lacks one of the features listed then write "NA" in the space provided. Otherwise sketch the dimensions of the Basement and/or Crawl Space. Check off each item as it is completed.

____ Floor plan

- ____ Basement
- ____ Crawl Space
- ____ Fireplace(s) and Chimneys
- ____ Stairwell(s)
- ____ Bathrooms
- ____ Overall floor plan dimensions (length x width)
- ____ Basement dimensions (length x width)

____ Elevation

____ Interior block walls

____ Structures penetrating basement slab

____ Exterior slabs: patios

____ Exterior slabs: attached garage

Figure 3. Pre-selection site survey checklist.

II. Provide a detailed sketch of the Basement and/or Crawl Space. Check off each item as that has been included or write "NA" if it is not present.

____ Sump pump

____ Floor drain

____ Windows/vents

____ Pipe penetrations

____ Cracks in floor/walls

____ Outside door to basement

____ Crawl space door to inside

III. Miscellaneous Information. Answer as indicated or write "NA" if the question is not appropriate.

Is the basement finished? (Y/N) ____

Is the water supplied from a well? (Y/N) ____

How many children under 7 yrs old live in this house? ________________

How many adults live in this house? ________________

How many smokers live in this house? ________________

What type of heating system does the house have? ________________________

____

Building materials:

Basement:

Walls____

Floor____

House exterior ____

Is there drain tile under the foundation? (Y/N) _____

Figure 3 (continued)

IV. Measurement checklist. Check off each measurement as it is taken or write "NA" if not applicable. Record the time and location of each measurement in the field notebook.

Integrated Samples (Charcoal cannisters/bags)

- ____ Basement
- ____ Crawl Space
- ____ Living/Family Room
- ____ Other: ____

Grab Samples

Air samples (Scintillation cells)

- ____ Sump pump
- ____ Floor drain
- ____ Wall/Floor cracks
- ____ Crawl space
- ____ Other: ____

Working Level measurements (Filter samples)

- ____ Sump pump
- ____ Floor drain
- ____ Wall/Floor cracks
- ____ Crawl space
- ____ Other: ____

Figure 3 (continued)

TABLE 2. ASSESSMENT SUMMARIES--CLINTON

House number	Radon concentration lowest floor (pCi/l)	Number of adults	Number of smokers	Number and ages of children	Type	Features
C1D*	160	2	0	16, 19	two-story colonial, no basement	standard
C2A	103	2	1	18, 20	split level with basement--unfinished	sump with pump; attic fan; open block-plaster
C3B	89	2	1	17, 14, 10	bi-level	has photos of house being built; block halfway up front and one side; good access to block wall from closet; water closet leak; negative pressure hot air furnace/dryer/bath fan upstairs; thermal bypass-kitchen soffits/chimney/bath chase (tub); pipe penetrations with wood stakes
C4A	676	3	0	0	split level--unfinished	addition over patio; many cracks in poured concrete floor
C5B	114	2	0	15, 13	bi-level	concrete block; whole house fan
C6A	255	2	0	0	split level	eight months in house; many wall cracks and floor/wall seam/floor cracks; some open blocks/poles (support); no sump at floor drain

* C-denotes Clinton study
number (1-56) denotes assigned project number
letter (A-E) denotes floor plan

(continued)

TABLE 2. ASSESSMENT SUMMARIES--CLINTON (continued)

House number	Radon concentration lowest floor (pCi/l)	Number of adults	Number of smokers	Number and ages of children	Type	Features
C7E	250	2	0	6, 9	bi-level	homeowner capable of doing variation remediation work has repaired rotted sill; all at grade level
C8A	791	2	0	6, 7, 10, 13	split level--finished	basement finished but owner willing to remove wall paneling, etc.
C9B	186	2	1	6	bi-level	standard
C10B	418	2	0	0	bi-level	owners both work--willing to vacate house to have work done
C11B	250	2	1	0	bi-level	block front; wood stove in family room; closet access to block
C1D2	608	2	0	12, 9	colonial with basement--unfinished	whole house fan; several large cracks and openings; coal stove; bedrock in northeast corner of lot
C13E	165	2	1	0	other-multilevel--finished with crawlspace	woodstove; all abovegrade; slab poured against 4 inch block; 2 ft x 3 ft chase at head of bathtub

(continued)

TABLE 2. ASSESSMENT SUMMARIES--CLINTON (continued)

House number	Radon concentration lowest floor (pCi/l)	Number of adults	Number of smokers	Number and ages of children	Type	Features
C14B	437	2	0	7	bi-level	coal stove in basement; penetration (water pipe/toilet/perimeter crack)-closet access to 1/2 block wall; negative pressure (furnace/dryer/ bath fan/coal stove); bypasses: whole house fan/chimney/kitchen soffit/bath chase; stone wall behind brick surround for coal stove
C15E	411	2	0	6, 10	bi-level, but not Lackland;	owners scheduled to relocate soon; block wall to grade
C16E	495	2	0	0	other, finished basement	standard
C17A	150	2	1	4,5	split level with unfinished basement	basement entry from first-level garage penetrations: open blocks (1/2), jackposts, cracks in floor, two oil lines; negative pressure-boiler/ dryer/chimney bypass/whole house fan; AC in attic; may be easy to isolate attic

(continued)

TABLE 2. ASSESSMENT SUMMARIES--CLINTON (continued)

House number	Radon concentration lowest floor (pCi/l)	Number of adults	Number of smokers	Number and ages of children	Type	Features
C18A	79	2	0	0	split level on slab, no basement	slab on grade; penetrations: main in laundry/outside faucet from bath/two toilets; dishwasher/bath sinks/kitchen sinks/shower and tub drains; negative pressure-one bath fan/dryer/attic scuttle soil vent/ kitchen soffit
C19A	163	2	1	17, 16, 13, 7	split level, partially finished basement	hot water heater; two sump holes; finished garage (two steps down); horizontal break in block at back of house approximately 1/4 inch
C2A0	150	2	1	19, 17, 8	split level with basement	finished basement; added on garage and basement for garage
C2A1	122	2	0	1, 4	split level with basement	block open at top; fan moves air from basement to upstairs; basement partially finished; wood stove
C2A2	101	2	1	18, 14	split level, basement under addition, unfinished	two bathtubs on slab (currently being renovated); wood stove and fireplace; no expansion joint; garage converted to bedroom; HV ducts above slab

(continued)

TABLE 2. ASSESSMENT SUMMARIES--CLINTON (continued)

House number	Radon concentration lowest floor (pCi/l)	Number of adults	Number of smokers	Number and ages of children	Type	Features
C23B	423	2	0	0	bi-level	coal stove; block in front; renovating lower level; all ventilated
C24E	426	2	1	18, 26	bi-level	different from Lackland houses; a true split with earth floor crawlspace
C25B	252	2	1	0	bi-level	crawlspace
C26B	249	1	1	4	bi-level	wood stove and recirculating exhaust fan; French drain approximately 12 feet from front; block front; two-story addition on patio; electric heat
C27B	93	2	2	7, 12, 17	bi-level	one bath upstairs (not two)
C28C	720	2	1	2	colonial, no basement	wood stove
C2A9	148	2	0	3 months	split level	finished basement
C30A	2,254	2	0	0	split level	duct under slab upper level; two elderly people do crafts in basement; several top of block openings/sump hole/wall cracks; high pitched roof; windows never opened, some sealed; owners not likely to do much on own

TABLE 2. ASSESSMENT SUMMARIES--CLINTON (continued)

House number	Radon concentration lowest floor (pCi/l)	Number of adults	Number of smokers	Number and ages of children	Type	Features
C3B1	691	2	1	8, 6, 4, 2	bi-level	block front, partially below grade
C32D	1,357	3	0	0	colonial unfinished basement, added crawlspace	add on room with crawlspace; concrete slab; original owner; a good candidate to confirm the effectiveness of remediation methods at Boyestown
C33C	1,190	3	0	3 grown	colonial, no basement	remedial measures begun
C3B4	619	3	1	17, 10	bi-level	concrete patio slab; music teacher's house; block front, partially below grade
C35A	1,250	2	0	0	split level	transite all along back wall behind garage
C3B6	360	3	0	1, 5	bi-level	ten-year residents both work; wood stove in corner; 1/2 block in front (front only, approximately 1/3 dirt or block); blocks exposed under front foyer; open stone patio off family room; only central opening to wall, no side closet

(continued)

TABLE 2. ASSESSMENT SUMMARIES--CLINTON (continued)

House number	Radon concentration lowest floor (pCi/l)	Number of adults	Number of smokers	Number and ages of children	Type	Features
C3B7	440	3	1	none under 7	bi-level	bath tub on slab; sample taken at water stake hole through slab; block on front; wall to grade
C38A	321	2	1	10, 12	split level	12 ft x 16 ft addition behind family room with crawlspace and vents; sump open; attic fan (not whole house) typical basement openings; typical subfloor ductwork; coalstove in addition
C39A	1,500	2	1	15, 12, 9	split level, unfinished	daycare, two children under age 7
C40B	120	2	0	9, 5 respiratory problems	bi-level	laundry slightly different
C41E	500	3	1	17	large, old, custom house	interior block walls under fireplace; root cellar
C4A2	265	4	1	0	split level	attic fan; basement door to outside with concrete; steps to cellar door-inside door cut through block

(continued)

TABLE 2. ASSESSMENT SUMMARIES--CLINTON (continued)

House number	Radon concentration lowest floor (pCi/l)	Number of adults	Number of smokers	Number and ages of children	Type	Features
C43B	99	2	1	4	bi-level	1/2 block wall on front with closet access; entry points-toilet/ showers/water pipes (two stakes); negative pressure (furnace/dryer/ cold air return/bath fan/gas DHW/ normal bylead bypasser; lived here 2 years; asbestos shingles
C4A4	451	3	0	0	split level	fireplace (but not a significant factor)
C45B	226	2	1	0	bi-level	fireplace
C4C6A	635	1	0	0	split level	original owner; partially finished basement
C47B	686	3	0	21, 16	bi-level	original owner, witnessed construction; bedrock close to surface; block wall grade
C48B	936	2	0	19, 18, 14	bi-level	fifteen-year resident; plan with back-to-front family room; raised bi-level; 15x15 foot patio; asphalt drive and carport to wall; son sleeps in basement; cracks on concrete slab visible on patio

(continued)

TABLE 2. ASSESSMENT SUMMARIES--CLINTON (continued)

House number	Radon concentration lowest floor (pCi/l)	Number of adults	Number of smokers	Number and ages of children	Type	Features
C4A9	823	2	0	0	split level, unfinished basement	one adult works at home; 1/2 bath off kitchen removed; leakage and cracks in basement-house and garage-house; open sump
C50C	135	4	1	0	colonial, no basement	subslab heat ducts; whole house has wallpaper and paneling; garage converted to bedroom; stone fireplace; potentially many entries; slab penetration-toilets/ductwork/water main; negative pressure-furnace/fireplace/bath fan/bypass
C5B1	157	2	0	1 month, 2	bi-level	block in front
C5B2	411	1	0	0	bi-level	fireplace-raised hearth with ashpit, outside access; block at front
C53A	403	3	0	0	split level, finished basement	fireplace; renovated both bathrooms covered register in bathroom off kitchen; no chase in bathroom

(continued)

TABLE 2. ASSESSMENT SUMMARIES--CLINTON (continued)

House number	Radon concentration lowest floor (pCi/l)	Number of adults	Number of smokers	Number and ages of children	Type	Features
C54A	400	2	0	0	split level with unfinished basement	owner attempting subslab vents (5); has garage in 1/2 of basement; basement penetrations but solid top course; runs coal stove in winter (added room up on posts, open beneath); negative pressure furnace; has soil pipe and AC drain
C55A	131	2	0	0	split level	full basement and garage under house; floor drain-to daylight-fan currently sucking; fan on kitchen hood; whole house attic fan; plaster gap; pipes sealed
C56B	252	2	0	0	bi-level	similar construction details to house C23B

TABLE 3. DISTRIBUTION OF HOMES INCLUDED IN RADON SCREENING BY FLOOR PLAN

	Floorplan A	B	C	D	E
Number of houses	22	22	3	3	6

- The radon concentration in the home must be above 64 pCi/l according to the DEP screening measurements.
- The 10 homes should show an even distribution of substructures, that is, approximately half should be slab-on-grade construction and half should have basements. At least one of the demonstration homes should have a crawlspace.
- A high degree of homeowner cooperation.
- Homes with young children whose lungs are still developing should be well represented in the selection.
- Special consideration should be given to homes that are occupied a large portion of the day, especially if a basement or slab level is used as a play area or sleeping area. Duration of residency is also considered.
- The presence of smokers is considered as a positive factor in home selection because of possible synergistic effects.
- Some of the selected homes should be more difficult to achieve radon reduction in because of finished lowest floor space.

Table 4 shows the distribution by floorplan of the homes selected for the demonstration study. All of these homes had radon concentrations in excess of 200 pCi/l in the DEP screening, and four of the houses had concentration in excess of 1000 pCi/l.

TABLE 4. DISTRIBUTION OF HOMES SELECTED FOR DEMONSTRATION

Construction Design (substructure)	House Number
Split Level (combination slab-on-grade and block basement)	C8A C39A C30A C46A
Bi-level (slab-below-grade)	C31B C10B C48B
Two-story	
(slab-on-grade)	C33C
(block basement)	C32D
Other (combination slab-on-grade and dirt crawlspace)	C24E

4.0 DIAGNOSTIC PROCEDURES USED PRIOR TO RADON REDUCTION

At the time work was initiated on the homes in Clinton, only a small amount of experimental data was available to assist in selecting techniques for assessing suitable radon reduction methods in homes. The EPA guidance document, "Radon Reduction Methods: A Homeowner's Guide" (EPA, 1986b) and publications describing similar radon reduction efforts (NYSERDA, 1985; EPA, 1983; Nazaroff, 1985; Turk, 1986; Henschel, 1986; Nitschke and Brennan, 1986) provided a basis for the development of diagnostic and radon reduction approaches. Diagnostic techniques focused on the detection and isolation of three main mechanisms of radon entry and transport in a structure:

- Simple transfer through substructure openings. Radon enters into a house through openings connecting the house substructure to the soil. These entrance ways need not be very large to constitute a significant radon pathway. Small slab-cracks, hollow pipes, sump holes, or any other features that penetrate the foundation of the house are likely sources.

- Negative pressure driven transport. Negative air pressure over the portion of the structure with soil contact results in a pressure-driven transport of radon and other soil gases into the house. Negative pressure can be induced by the use of fans, appliances, and natural ventilation in the house.

- Thermally driven transport. Differences in temperature between the soil-contacting portions of the building and the rest of the structure due to normal heating of the home may give rise to the thermally driven transport of radon from the soil into the house.

Although numerous sources have confirmed these general mechanisms, little information is available on the effect on indoor radon levels as the three mechanisms interact with one another in a house, nor are there data describing the interactive effects of other factors such as the tightness of a house or the operation of an assortment of common indoor venting devices such as a whole house fan.

Consequently, diagnosis of the 10 homes in Clinton was performed using two approaches. The first approach was to identify and characterize all possible sources of in-leakage, negative pressure, and thermally induced transport in each house. The second approach was to simulate, in isolation, conditions that might enhance or reduce radon transport and then measure the actual effect. The second approach was used in a small number of homes. Experiments in this latter category include:

- Measuring the effect of whole house fan operations
- Investigating the negative pressure induced on the basement by the use of various household appliances
- Using a high volume fan to simulate winter-time stack effect
- Measuring the effect that furnace operation has on basement pressure.
- Experimenting with supplied outdoor makeup air to reduce negative pressure.

In all cases, the objective of the diagnostic procedure was to understand the mechanism and identify sources of radon infiltration to develop a low-cost and effective radon reduction strategy for each of the demonstration homes.

4.1 RADON GRAB SAMPLE MEASUREMENTS

Radon grab samples were obtained using a Pylon scintillation cell in conjunction with a Pylon AB-5 fitted with a Lucas cell adapter. Procedures as described in the EPA document "Interim Indoor Radon and Radon Decay Products Measurement Protocols" (EPA, 1986c) were followed. Grab samples were used to identify suspected soil gas entry routes. In all homes with sump holes, grab samples were taken in the stream of air exiting the footer drain pipe. Other common locations for effective grab sample collection were:

- Air spaces in unpaved crawlspaces
- Wall cavities
- Inside open cinder blocks
- Air exiting a hole drilled in a concrete block wall or slab floor
- Air in subslab heating ducts.

Although grab sampling can be misleading, in combination with other measurements, it proved very useful in identifying major soil gas entry routes. Appendix A provides a detailed summary of each of the 10 demonstration homes and lists the results of individual grab samples taken in each of the homes in the "Diagnostic Investigation" section of the summary.

If the grab sample concentration can be combined with the measurement of soil gas flowrate from an opening to the soil, then a source strength can be calculated (for the conditions under which the measurement was taken). The concentration and flowrate are dynamic and are affected by air pressure differentials, snow cover, precipitation, and even by time of day. An example source term calculation was made for house C30A. A soil gas flowrate of 2,550 pCi/l was measured entering the building from the footer drains in the sump hole. The radon concentration in a grab sample of the air from the sump hole was 36,000 pCi/l. Under the measurement conditions (approximately 2 to 3 pascals of negative pressure due to both the furnace and clothes dryer operation), this measurement corresponded to a source term of over 91 million pCi/l and would account for an indoor concentration of between 600 to 1,200 pCi/l given an air exchange rate from 0.5 to 1.0 air changes per hour (ACH). Because air concentrations of radon were from 1,400 to 2,700 pCi/l in this home, the sump hole was considered to be the largest but not the only source of soil gas infiltration to the house.

Efforts were made to measure the difference in pressure between the inside and outside of the house while grab samples were being taken. Because factors such as windspeed, and furnace or fan operation can affect the flow of soil gas substantially, pressure difference information allows a reasonable interpretation of seemingly anomolous radon grab sample results and results from other techniques designed to determine the rate and location of radon entry. Pressure difference measurements were made using low range 1.24 to 62.0 pascals (0.005 to 0.25 inches of water) magnahelic gauges.

4.2 QUALITATIVE MEASUREMENTS OF SOIL GAS ENTRY

In all cases, extensive visual examinations were made of the floors, joints, and undergrade walls of each home to identify potential entry points. A simple smoke tube test was then made at any potential site of entry to determine the direction of airflow. If the smoke was blown back into the room, the opening was considered to be a possible point of radon entry. Although this test does not determine the radon content of the incoming air stream, it does locate potential influx sites. Because factors such as windspeed and direction can greatly affect smoke tube results, outdoor and indoor conditions were noted and pressure difference measurements were made wherever possible.

4.3 CHARACTERIZATION OF SUBSLAB AGGREGATE

Because of the high radon concentrations encountered in the 10 demonstration homes, it seemed likely that soil depressurization techniques would be necessary. Consequently, all houses were inspected in an attempt to determine the composition of the subslab aggregate.

The subslab material was inspected visually by drilling holes in the slab with a hammer drill. A flashlight through a 1-inch hole was frequently sufficient to view the subslab material.

When an actual visual inspection of the subslab was impossible or uninformative, several indirect methods were used to determine if the material was porous enough to allow effective soil depressurization.

With a hole drilled through the slab and negative pressure applied to the basement using a fan or some other technique, a smoke tube over the hole was used as a visual inspection technique. If the smoke was forced out of the hole, subslab entry of soil gases was suspected. At this point, an additional technique might be used.

To determine the subslab characteristics, a second slab hole was drilled. At one hole, a vacuum cleaner was sealed over the hole to apply suction on the subslab material. At the other hole, a smoke tube was used to determine the effect of suction through the aggregate. More quantitative results were achieved with the substitution of an inclined manometer for the smoke tube to actually measure the pressure gradient through the subslab material.

A more elaborate method of assessing subslab material was developed using freon gas (standard 15-pound cylinder) as a tracer and a halogen detector (TIF model 5500: TIF, 9109 N.W. 7th Ave., Miami, FL, 33150) to follow the freon transfer into the building. Freon is injected through a hole in the subslab, and the detector is used as a sniffer to locate relative changes in freon concentrations in the building. A low concentration of the gas is sufficient, and the lowest detectable concentration should be used at all times. This technique was particularly useful in detecting problems in already installed radon reduction systems.

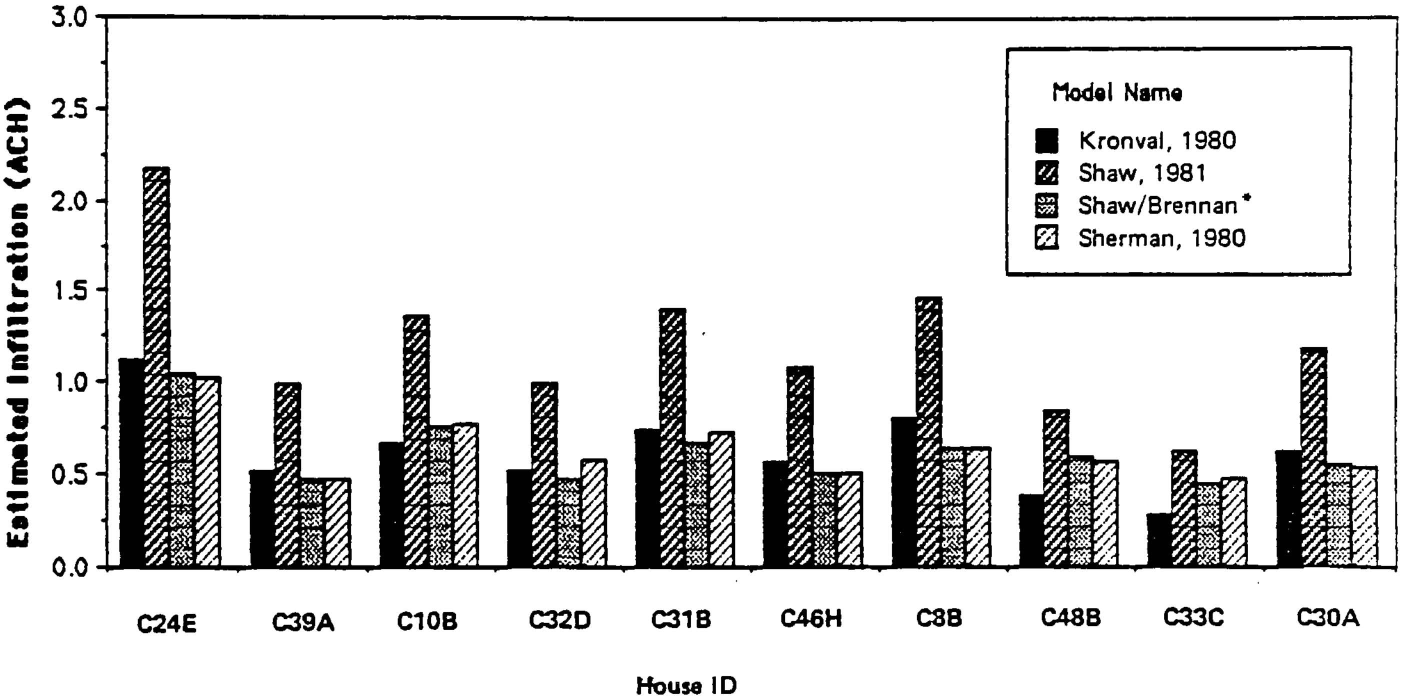
4.4 MEASUREMENT OF HOUSE "TIGHTNESS"

House tightness is used, in the context of this report, to indicate relative leakage area in a house. Air exchange rate measurements were made on each of the 10 homes in Clinton using a standard blower door test (ASTM Method No. E779-81). The measurement results, forming part of each home's profile, are presented in Appendix A. One purpose of these measurements was to determine if high indoor radon levels in the Clinton homes could be attributed to the tightness of the structure. The major objective, however, was to determine the extent of leakage into the house. If the leakage was extensive, structural rebuilding might have been necessary in order for the radon reduction efforts to be effective. If tightness showed a good correlation with high radon levels, radon reduction measures might concentrate on compensating for the low volume of available dilution air in a house.

Data from blower door measurements were fitted using various models for the prediction of air exchange rates. Figure 4 compares the results of four of these models using data from the 10 demonstration homes. A brief description of each of the models used is provided in "Indoor Air Quality, Infiltration and Ventilation in Residences" (NYSERDA, 1985). Predicted air exchange rates using the Shaw model were higher in all cases and considerably higher for eight of the ten homes than were the air exchange rates predicted by the three other models. Consequently, the Shaw model results air exchange rates were not used in the following dicussion.

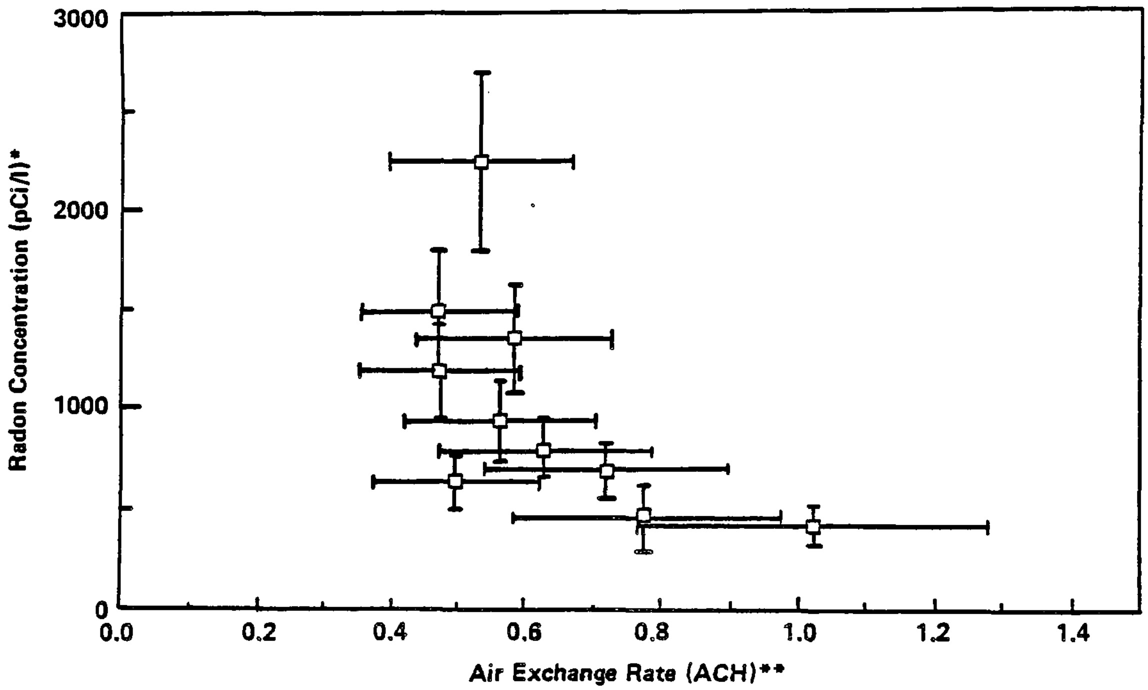
Infiltration rates predicted by the models range from 0.4 to 1.1 ACH with an average of 0.62 ACH (excluding results from the Shaw combined model). Figure 5 shows a plot of the estimated air exchange rates in the ten houses using the results of the Sherman (1980) model versus the DEP screening study charcoal canister radon concentration results for each home. Figure 6 shows the same plot, superimposing a curve that represents the best fit to the data. Correlation was low with a coefficient of correlation value of 0.60.

On the basis of these results, it was concluded that the extremely high radon concentrations encountered in the Clinton homes were not due to the tightness of the structures, but were more likely due to the unusually high source strength. For dilution ventilation alone to provide a sufficient reduction in radon concentrations, the airflow through these homes would have



* in NYSERDA, 1985

Figure 4. Estimates of air infiltration rates by home using four different models.



*Activated carbon detectors from New Jersey DEP.
**Infiltration estimates from LBL model.
Error estimation for air exchange rates. Personal communication with Andrew Persily, NBS

Figure 5. Radon concentration vs. air exchange rate for Clinton homes.

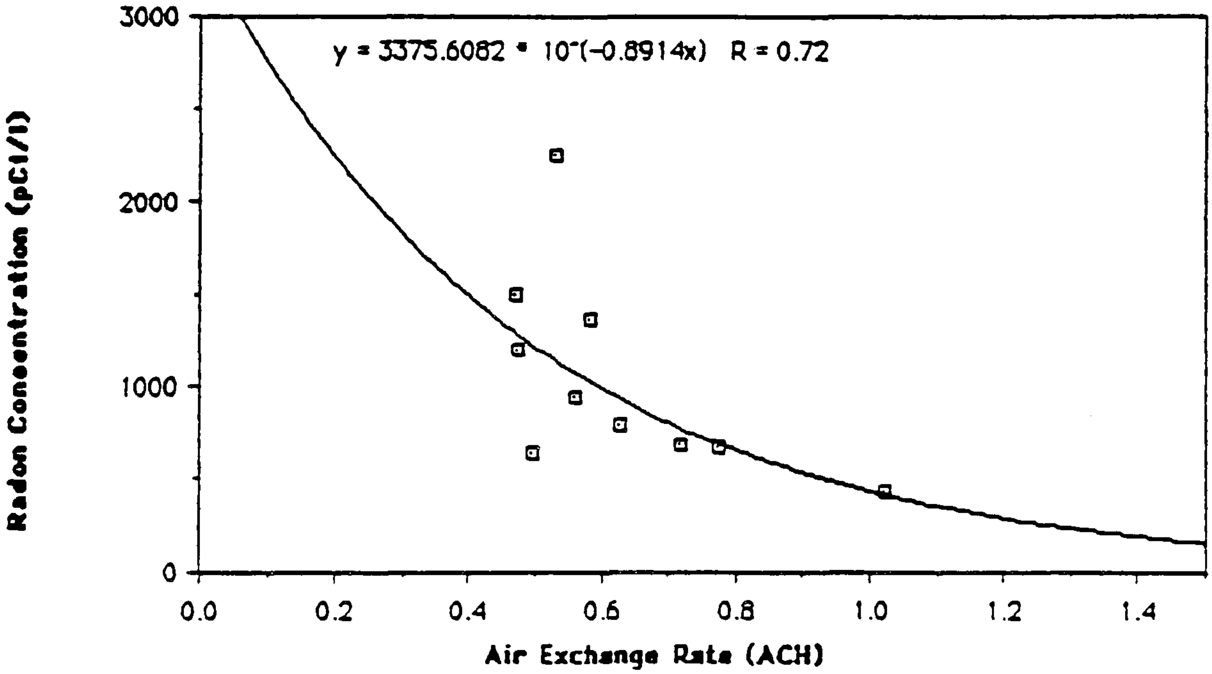


Figure 6. Radon concentration versus air infiltration rates for Clinton homes.

to be increased from approximately 5.66 m^3/min (200 cfm) to a rate of 707.9 m^3/min (25,000 cfm). The cost and discomfort presented by this option indicated that radon reduction methods that concentrated on lowering the entry rate of gas to the homes would be more effective and practical.

4.5 WHOLE HOUSE FAN TEST

A test was made to gain some insight into the potentially competing effects of increased soil gas entry versus added dilution air when a whole house fan was used to ventilate a building. The results are shown in Figure 7. Although the fan dramatically increased ventilation (in the neighborhood of 57% [2,000 cfm]) the large negative pressure differential (~28 pascals) increased the rate of soil gas entry sufficiently to overwhelm the diluting effect. This test was made in only one house and the results depend upon factors that may be peculiar to the individual building, soil gas and soil characteristics.

4.6 INVESTIGATIONS OF NEGATIVE PRESSURE INDUCED ON BASEMENTS

In the majority of houses, differential air pressure measurements between basement air and outside air were made. Temperature-driven stack effects and mechanical equipment effects were isolated and the induced pressure differences measured. It was found that:

- Dryers and bathroom fans resulted in a 1 pascal or less negative pressure on a basement.
- Furnaces in the 17,612 to 21,134 joules/sec (100,000 to 120,000 British thermal units per hour [Btu/h] range put 2 to 3 pascals (0.008 to 0.012 inches water) negative pressure on a basement.
- Differential temperatures of -6.7 to -1.1 °C (20 - 30 °F) resulted in 1 - 3 pascals (0.004 to 0.012 inches water) of negative pressure on a basement.

During the ΔP measurements described above with a furnace running, makeup air was drawn from the attic down the cavity around the chimney. In building C48B, this amounted to approximately 1.42 m^3/h (50 cfm). Measurement of the airflow from the furnace exhaust at the chimney top showed airflow rates of between 2.8 and 5.7 m^3/h (100 and 200 cfm). Figure 8 (a fan-flow curve for House C48B) shows an induced negative pressure of 1 to 2 pascals (0.004 to 0.009 inches water) at 5.7 m^3/h (200 cfm), reflecting the pressure difference actually measured in the house when neither the furnace nor the clothes dryer

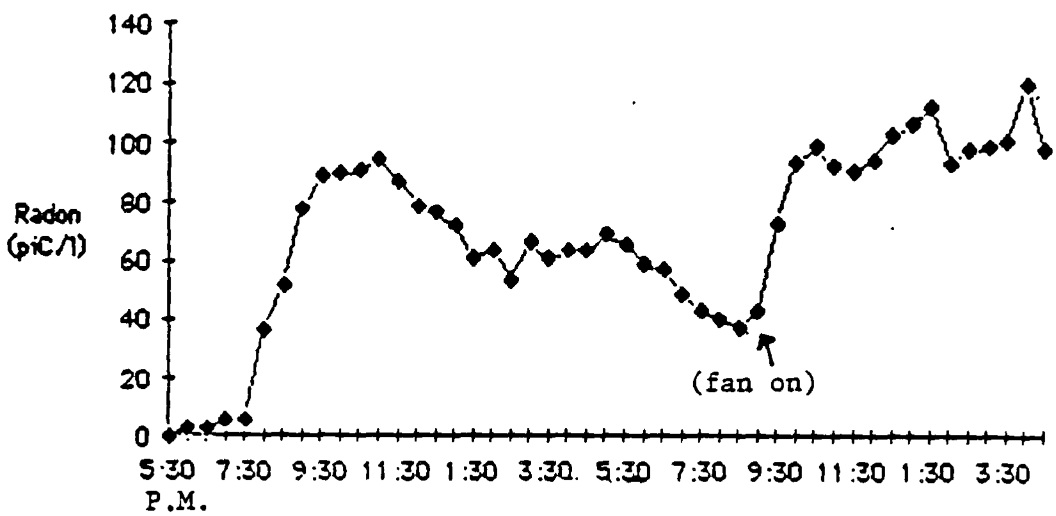


Figure 7. Effect of whole house fan use with all windows open on radon concentration.

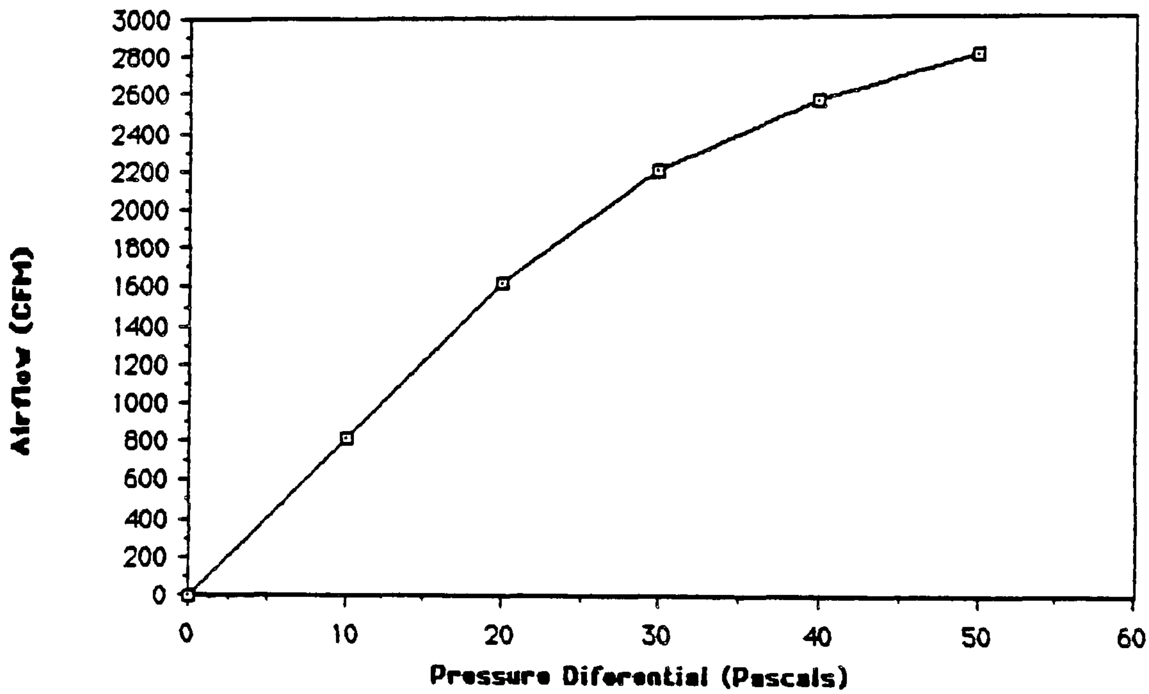


Figure 8. Fan flow curve for house C48B.

were in operation. Blower door generated fan-flow curves (as measured with blower door tests) were found to be useful in estimating the volume of makeup air required to compensate for basement negative pressures. The curves, when put to this use, were most accurate when generated from data collected with the blower door placed in a basement access door.

To reduce a negative pressure of 3 to 4 pascals (0.012 to 0.016 inches water) to 0 pascals (0 inches water), it was found that between 0.65 and 0.93 m^2 (7 ft^2 to 10 ft^2) of window area must be opened to the outside.

It is difficult to make low ΔP measurements in the field. Field instruments are only reliable to a lower limit of about 1 pascal (0.004 inches water). Even low windspeeds have a large impact on the pressure fields surrounding a house. Measurements were made when windspeeds were undetectable to avoid the confounding effects of wind. Toward the end of the diagnostic work, these measurements were made using a more sensitive electronic device assembled using standard pressure transducer and digital display components purchased from Modus Instruments (481 Gleason Rd., Stow, MA, 01775). This system has a lower detection limit of 0.25 pascals (0.001 in water).

4.7 SIMULATION OF WINTER CONDITIONS

Data from a variety of sources have confirmed that winter-time indoor air concentrations of radon are higher than even those taken under closed house conditions in other seasons (Turk, 1986). It has been speculated that elevated winter concentrations may result from:

- The formation of a nearly impermeable cap of either frost in the upper soil or a layer of melting snow inhibits diffusion of radon into the air from the ground surface and results in high concentrations of radon in the soil gas.

- Combustion heating equipment and a temperature-induced stack effect in a house produces a negative pressure on the basement. Makeup air for this suction is drawn into the house from outside above grade, but some fraction of it is drawn through cracks and holes in the belowgrade foundation (Turk, 1986).

Pre-radon reduction continuous monitoring measurements in the 10 homes were made in the early to late summer. Post-radon reduction continuous monitoring measurements were made in the early to late fall. Because these measurements spanned a variety of weather conditions but never winter conditions, an attempt was made to simulate winter conditions during some of the pre-radon reduction monitoring. It was not possible to induce ground-freezing conditions; however, it was possible to simulate basement depressurization and a temperature-induced stack effect.

A 50.8 cm (20-inch) diameter three-speed window fan was placed in a livingspace window while radon was monitored continuously using a Pylon AB-5 and passive scintillation cell. For one-third of the monitoring period, the house was in closed conditions with the fan off; during the second third of the sampling period, conditions were identical except with the fan on; and during the third part windows were opened with no fan operating.

In the first house monitored C48B (Figure 9), the fan was on with the house closed, followed by the fan off with the house open. The sampling on this house did not include a period when the house was closed and the fan was off. The average concentration for the first period was approximately 700 pCi/l, which compares favorably with the values of 964 and 542 pCi/l measured with activated carbon in the same location by DEP two months earlier (April 6 to 9 and April 16 to 19). During monitoring in June, the outside temperature averaged approximately 22.8 °C (73 °F). DEP monitoring periods were 9.4 °C and 10 °C (49 °F to 50 °F). The fan induced 7 pascals (0.03 inches water) of negative pressure across the building shell. When the fan was shut off, the concentration dropped quickly to less than 10 pCi/l, then for the remainder of the fan off, house open period, radon concentrations varied in a distinctive diurnal cycle with peaks in the early part of the day and minimum levels in the late afternoon. Control homes, selected for proximity and construction detail similarity to a demonstration home, were monitored simultaneously. As can be seen in Figure 10, this same diurnal cycle was observed over the same time period in the control house C31B.

The second house, C30A, was monitored from June 7 through 14 using the Pylon passive radon monitor. Samples were taken during three monitoring periods (fan off, house closed; fan on, house closed; and fan off, house open). The results are shown in Figure 11. During the first period, the concentration rose quickly after the windows were closed and peaked at 1,300 pCi/l near 5:00 a.m. on June 8, followed by a drop until 11:00 a.m. on June 8 when the window fan was turned on, producing a negative pressure of 8 pascals (.032 inches water) on the building. At this point, the level of radon increased very quickly to a much higher peak of 2,600 pCi/l and averaged

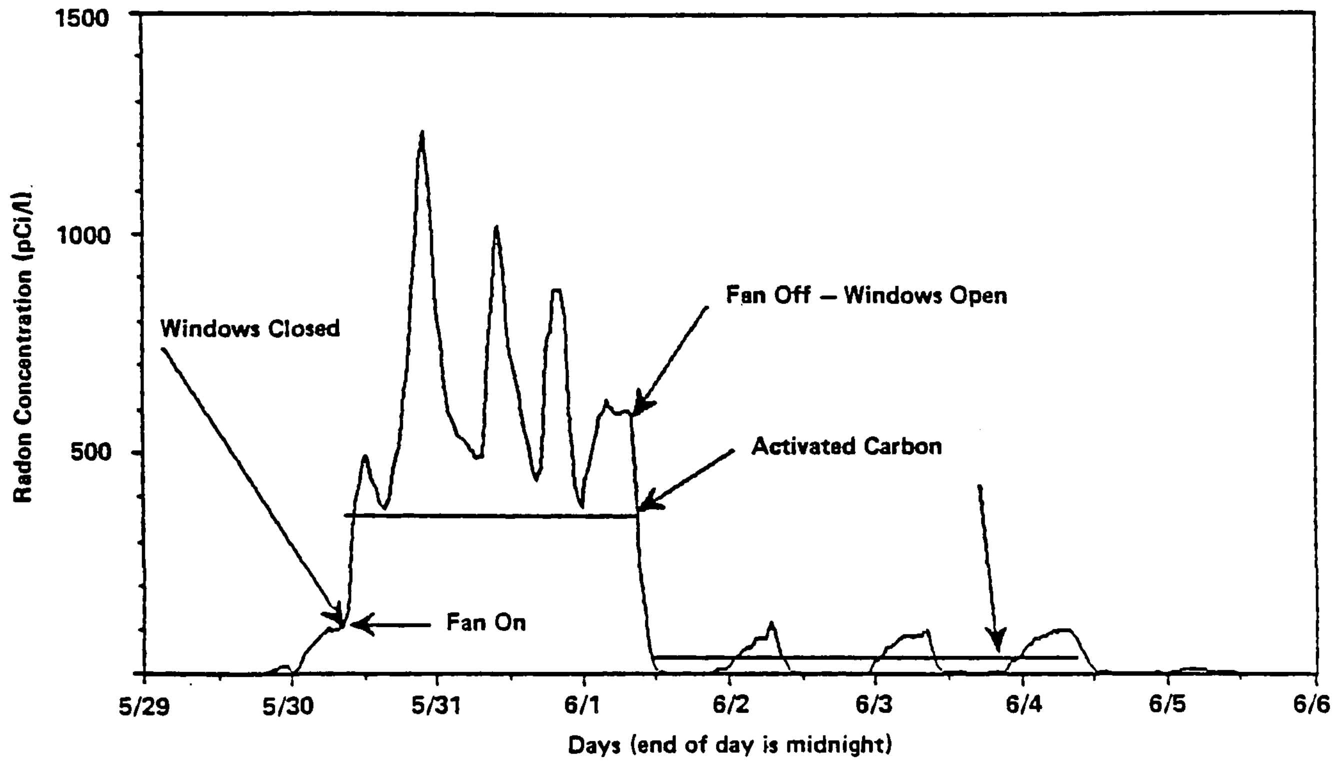


Figure 9. Premitigation radon concentration, house C48B.

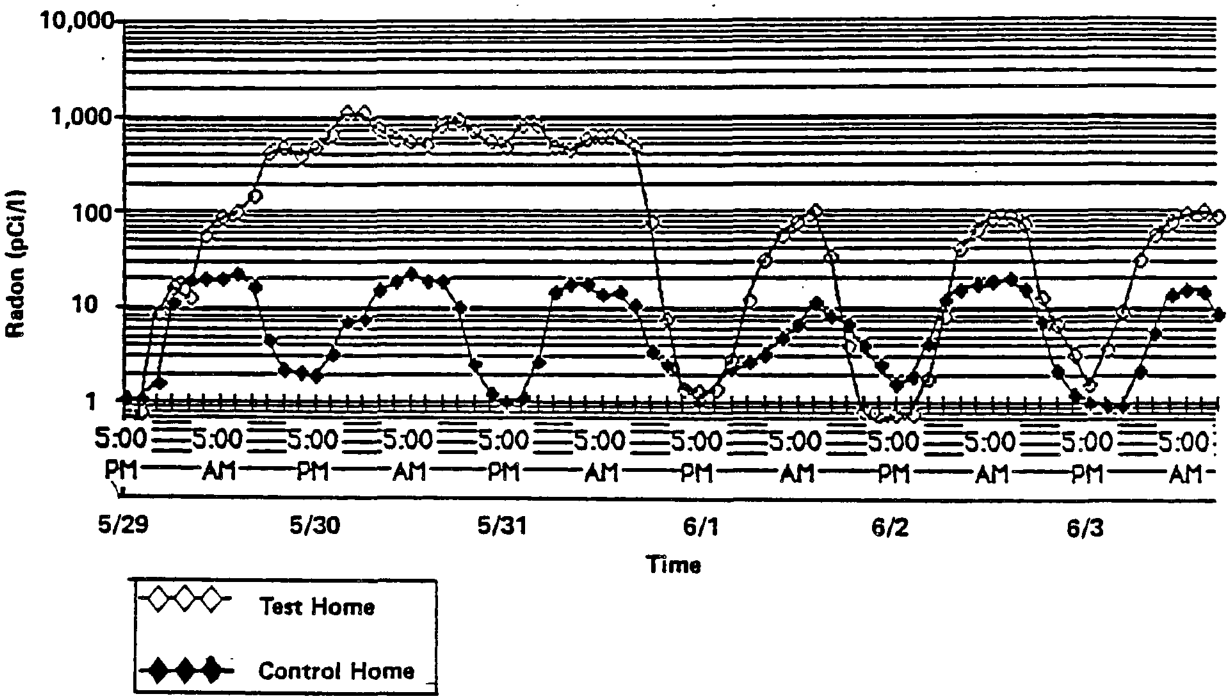


Figure 10. Premitigation radon concentrations, house C48B and control house C31B.

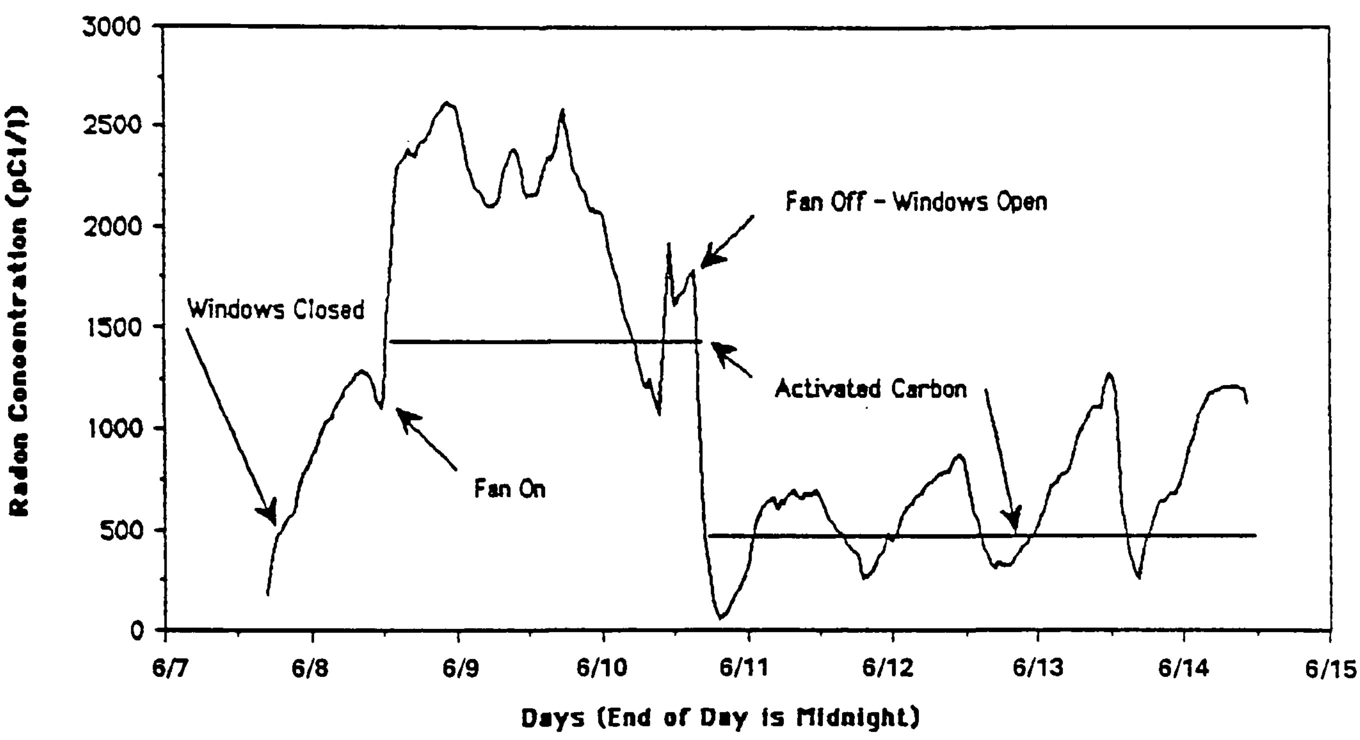


Figure 11. Premitigation radon concentration, house C30A.

approximately 2,075 pCi/l for the monitoring period. This compares well with the DEP (activated carbon) values of 2,254 and 2,141 pCi/l for the same locations on April 7 to April 14 and April 16 to April 19, respectively. At 3:00 p.m. on June 10, the fan was removed and the windows opened. The radon level in the house plummeted to a low of 60 pCi/l at 7:00 p.m. and then showed the familiar diurnal cycle seen in all the houses monitored in Clinton.

The third house, C33C (Figure 12), was monitored June 16 to June 24 using three monitoring periods--fan off, house closed; fan on, house closed; and fan off, house open. The effect of the fan-induced negative pressure was dramatically different in this house from that in either of the first two homes monitored. When the fan was turned on, it caused very wide radon concentration excursions, ranging from a low of 100 pCi/l to a maximum of 2,500 pCi/l over a period of 12 hours. The average concentration during the fan-off, house-closed periods was about 1,375 pCi/l as compared with 1,530 pCi/l measured by DEP (activated carbon) in the same location on March 14 to 17. For the fan-on, house-closed period, the average was 922 pCi/l. In this house, the floor was a slab-on-grade with heating ducts under the slab. When examining the holes in the slab made for the warm air grills, it was found that all of the soil beneath the slab had subsided, leaving a 2.5-10.2-cm (1 to 4 inches) cavity between the bottom of the slab and the earth surface (except where there were grade beams under the load-bearing walls). A polyethylene vapor barrier was found in very good condition stuck to the bottom of the concrete slab. This left a large surface area of exposed earth in direct convective contact with the living space air. When the fan was shut off and the windows opened, the average concentration dropped to about 300 pCi/l and the familiar diurnal cycle was seen, even in this unoccupied house.

The results from house C8A are shown in Figure 13. The average concentration for the fan-on, house-closed period was 465 pCi/l compared to DEP measurements of 791 and 1650 pCi/l taken at the same location on March 22 to 25 and March 28 to 31. The average concentration for the fan-off, house-closed period was 415 pCi/l. After the fan was turned off and the windows opened, the average concentration dropped to 250 pCi/l and the diurnal cycle reappeared.

An experiment to simulate thermally driven effects was also made. The temperature in one of the buildings was raised to induce stack effect negative

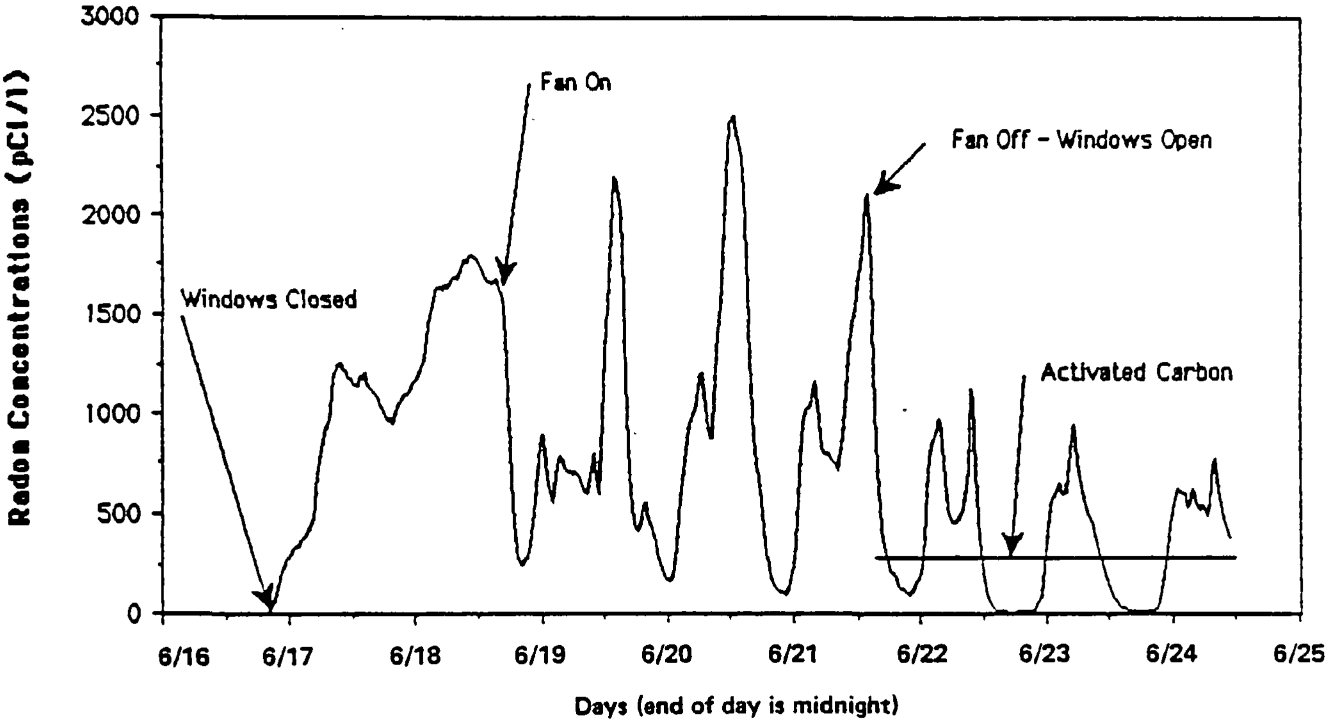


Figure 12. Premitigation radon concentration, house C33C.

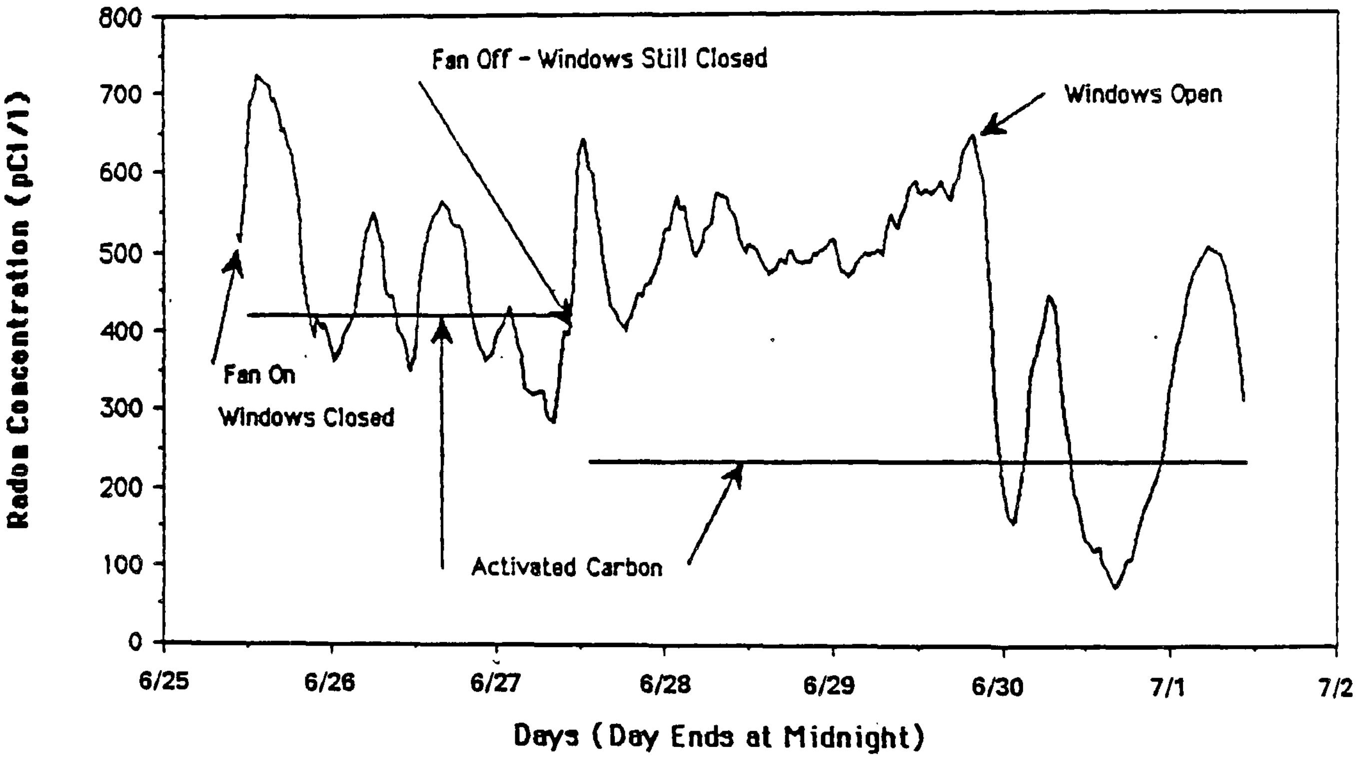


Figure 13. Premitigation radon concentration, house C8A.

pressures by running the furnace simulating combustion appliance draft. The results are shown in Figure 14. Radon concentrations were continuing to rise when the experiment was interrupted.

Negative pressures were induced by both the furnace and the temperature differential in house C48B as shown in Table 5. Essentially, the furnace produced on indoor/outdoor temperature differential of 22 °C (71.6 °F) resulting in approximately 4 pascals (0.016 inches water) negative pressure on the basement. Opening the 0.65 m^2 (7 ft^2) of attic hatch in the ceiling appeared to increase the negative pressure 1 or 2 pascals (0.004 or 0.008) from 4 pascals (0.016 in water) to 5 or 6 pascals (0.020 to 0.024 in water). Due to the difficulties in measuring small pressure differences across building shells, these measurements are preliminary.

It is clear that a fan-induced negative pressure on a house has an impact on the radon concentrations in that house. In some houses, the technique appears to adequately simulate winter-time entry rates even in the summer, while in others there is little to distinguish a house monitored under simulated winter conditions from the same house monitored under closed-house conditions. Winter conditions cannot be uniformly simulated during the summer. The ground is not capped with snow or frost. A fan induces a negative pressure over the entire building shell whereas in typical winter conditions the basement is under the highest negative pressure and the top of the house is under positive pressure due to the buoyancy of the warmed air that is driving the stack effect. A fan will bring in approximately twice as much dilution air as the temperature-driven stack effect for the same negative pressure put on the basement. Running the house at 22 °C (71.6 °F) warmer than the outside air will reduce the artificial introduction of dilution air. However, the method is impractical for summer use because of comfort and possible damage to temperature-sensitive plants, furniture, or musical instruments.

4.8 INCREASING MAKEUP AIR

Additional negative pressure in basement areas produced by the normal operation of furnaces can result in increased indoor radon levels. One approach to controlling this effect is the introduction of makeup air to the basement or the furnace itself. Several methods of providing makeup air were tested in house C30A.

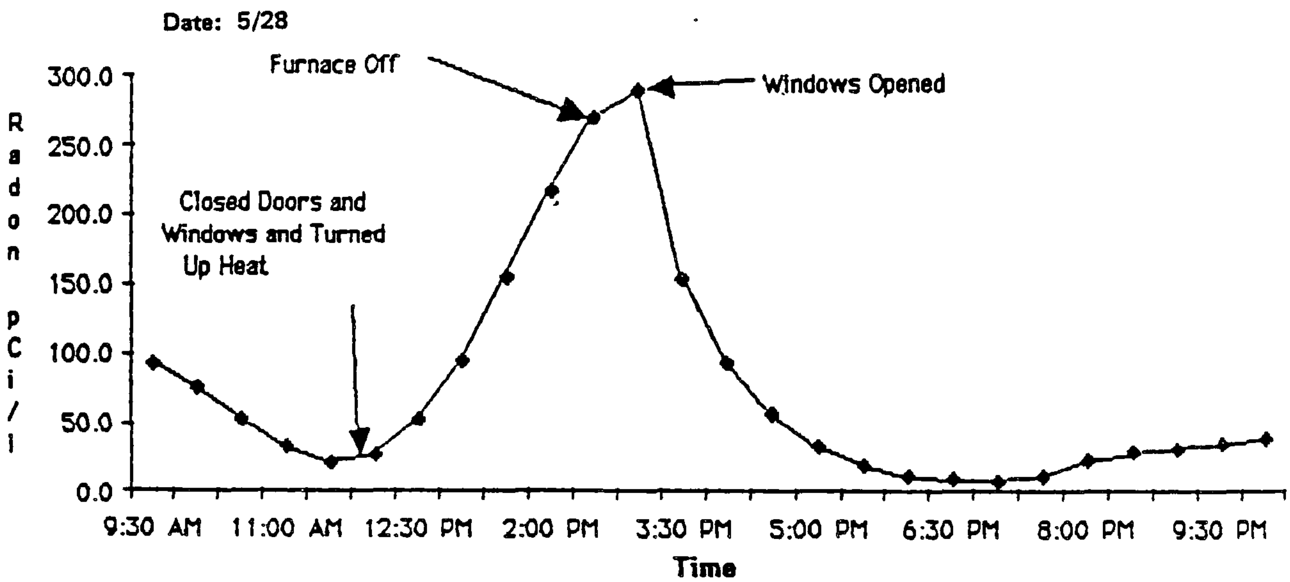


Figure 14. The effect on radon concentration of producing a heat differential to simulate winter conditions.

TABLE 5. PRESSURE DIFFERENCE MEASUREMENTS FOR TWO HOMES

Condition	ΔP
House C30A	
House closed, outside temperature = 16.6 C (62 F) inside temperature = 19.4 C (67 F)	0 Pascals
Dryer + bath fan on	1 Pascals
Furnace + dryer + bath fan on	2 Pascals
Furnace + dryer + bath fan on inside temperature = 26.7 C (80 F)	3 to 4 Pascals
House C48B	
House closed, outside temperature = 16.6 C (62 F) inside temperature = 17.8 C (64 F)	0 Pascals
Furnace on	3 Pascals
Furnace on, inside temperature = 33.8 C (92 F)	4 Pascals
Furnace on, inside temperature = 33.8 C (92 F) + attic hatch open	5 to 6 Pascals
Furnace on, inside temperature = 33.8 C (92 F) + attic hatch open	4 Pascals

A fan 2.27 m^3/h (80 cfm in free air) was used to push air down the thermal bypass surrounding the chimney. This size fan had an almost imperceptible impact on the negative pressure between the basement and outside air.

A second effort involved blowing air directly into the basement with a fan mounted in a basement window. This method was marginally more successful but required the use of a fan which had to be switched on and off by the homeowner.

A third method used a 6-inch insulated duct to supply intake air to the return air plenum of the furnace distribution system. When the furnace blower was running, about 2.83 m^3/h (100 cfm) of outside air was introduced into the 34.0 m^3/h (1,200 cfm) flow in the plenum. The simplicity, effectiveness, and passive nature of this technique make it preferable over the use of active methods of supplying makeup air. Active introduction of outside air into a house may produce excessive basement cooling when operated in the winter; consequently, the passive technique was adopted for use in the 10 homes when the reduction of negative pressure using dilution air was required.

5.0 RADON MONITORING

Two radon monitoring techniques were used during this program: continuous radon monitoring using a Pylon AB-5 monitor together with a passive radon scintillation cell detector (PRD) (Pylon Model AB-5 & Accessories Instruction Manual Pylon Instruments, Ottawa, Canada) and an integrating short-term technique using charcoal canisters (George, 1984). Protocols for the use of these techniques are detailed in the project Quality Assurance Project Plan (QAPP) and will not be repeated in this report.

5.1 CONTINUOUS RADON MONITORING

Continuous monitoring results were helpful in understanding the daily variations in radon concentration in a house and how this pattern, as well as overall radon levels, were affected by natural and powered ventilation, heating systems, and other factors that might influence radon levels.

The ability of the passive monitoring system to respond to temporal variations in radon concentration was tested in the Department of the Energy, Environmental Measurement Laboratory (EML) exposure chamber. The results of this test are shown in Figures 15 through 18 for each of the PRD scintillation cells. The lower curve in each of these figures is the radon concentration recorded by the chamber monitoring devices (four 2-liter active scintillation cell-based monitors). The upper curve is the response, in counts per minutes (cpm), of the AB-5 and PRD monitoring system. In all cases, the field monitoring device was able to track the laboratory equipment response to concentration changes reliably (on the basis of visual inspection of the superimposed curves).

The continuous monitoring system was set to count collected air samples at 30-minute intervals. Three 48-hour sampling periods were used to monitor pre- and post-radon reduction gas concentrations.

5.2 CHARCOAL CANISTER MONITORING

Short-term integrating monitoring, using activated charcoal monitors, is the method most commonly used in radon screening and assessment studies. In

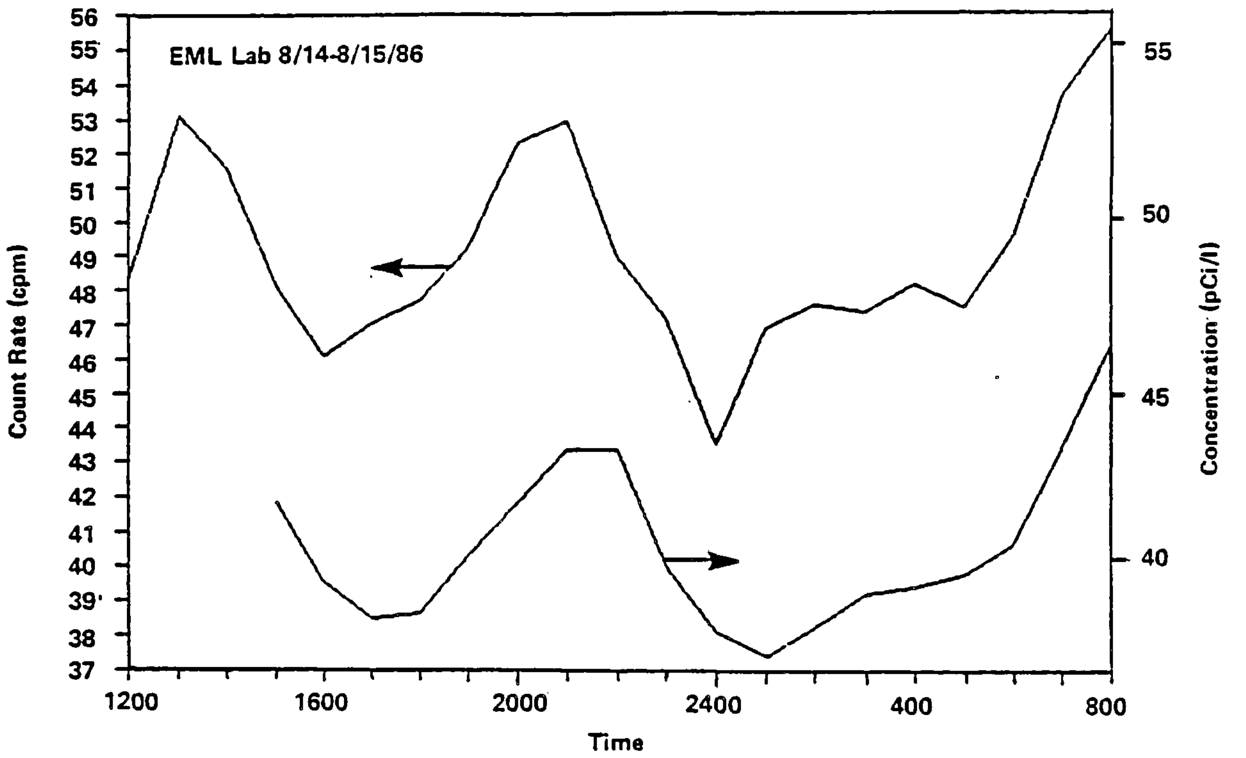


Figure 15. PRD#123 response to temporal variations.

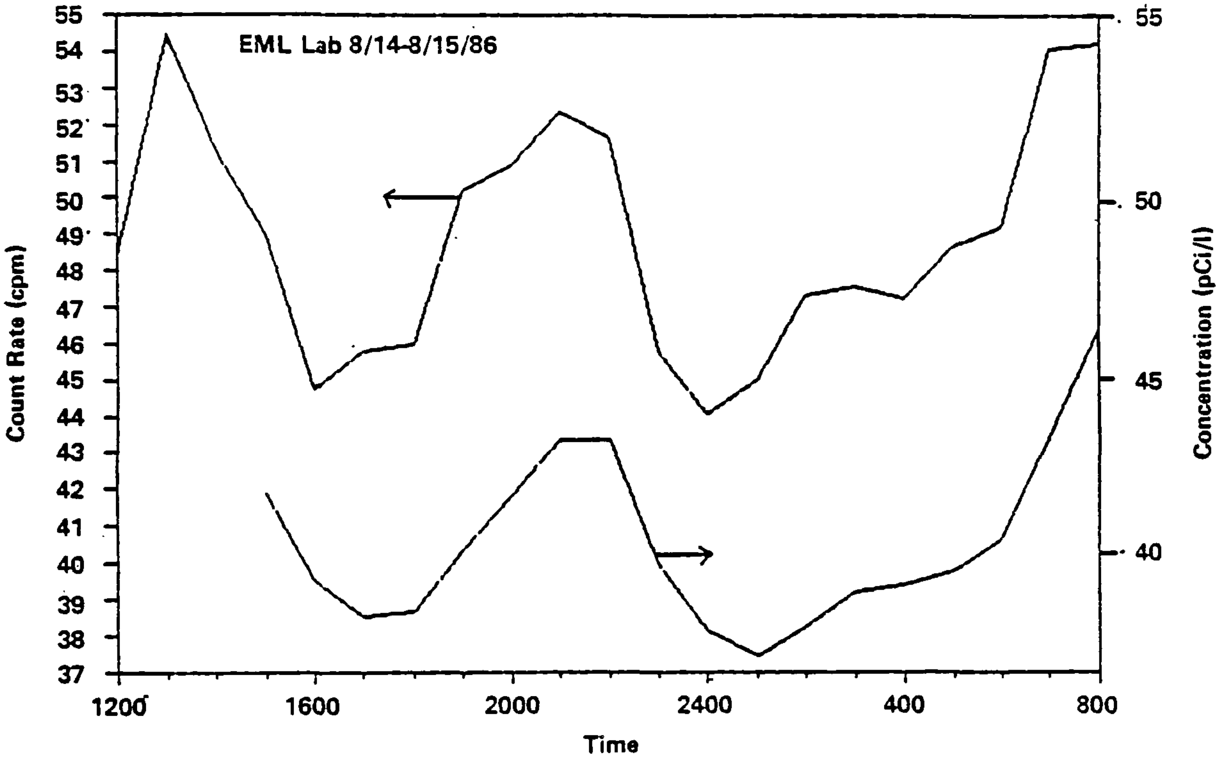


Figure 16. PRD #124 response to temporal variations.

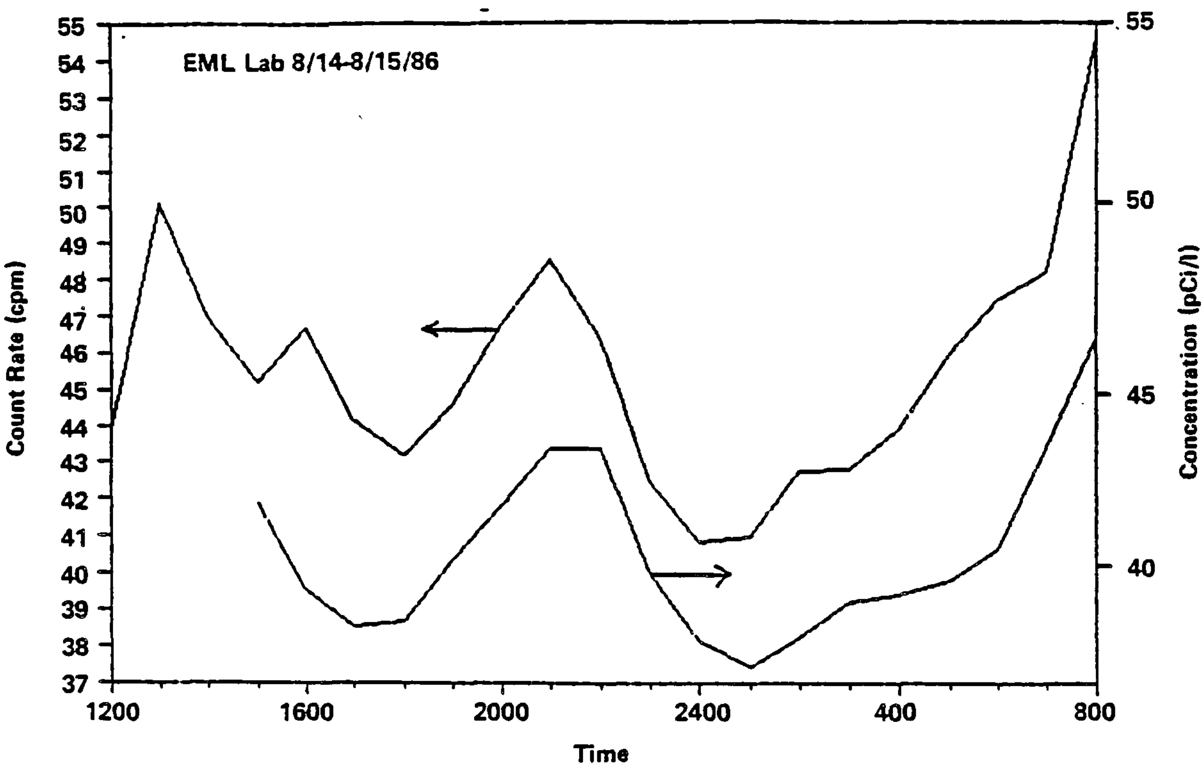


Figure 17. PRD #125 response to temporal variations.

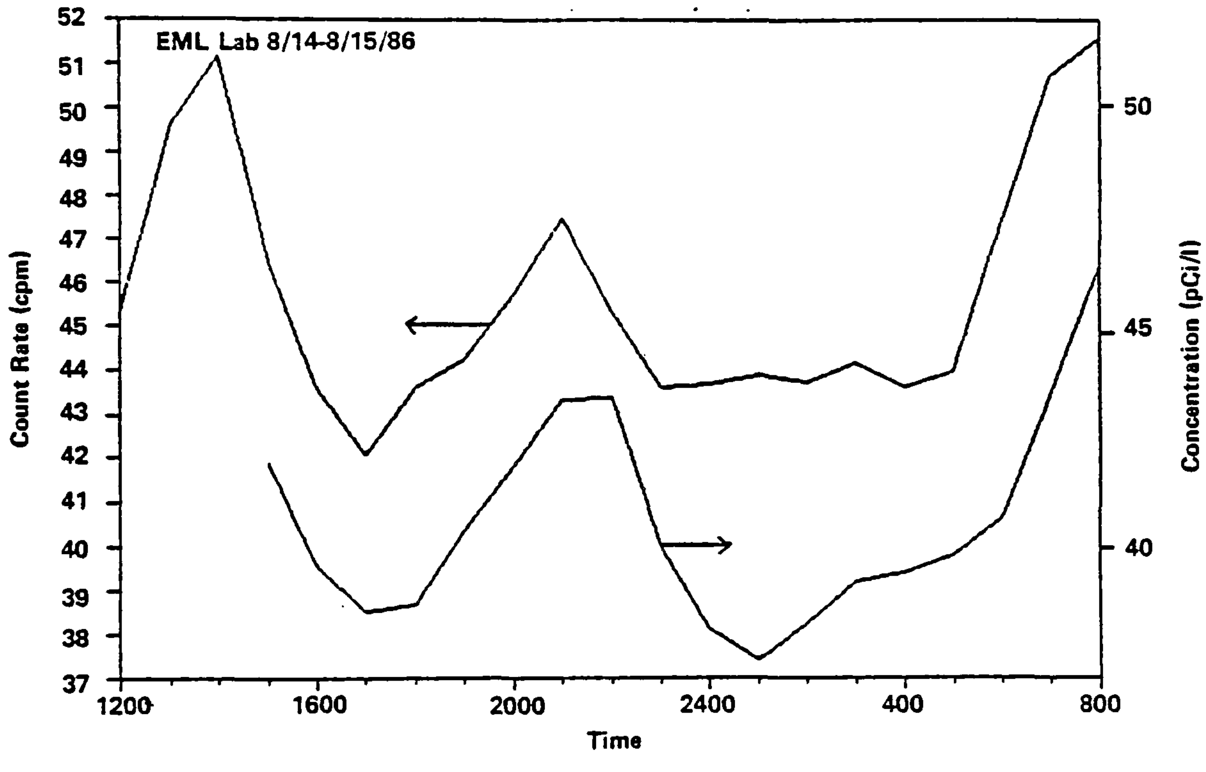


Figure 18. PRD #127 response to temporal variations.

addition, the simplicity and low cost of charcoal canister monitoring made it an attractive confirmatory measurement technique in the current work. The canisters and continuous monitoring devices were routinely deployed simultaneously in the same locations to allow comparison of monitoring results.

In the Clinton homes, radon concentrations varied by as much as a factor of 20 in a 24-hour period prior to the installation of radon reduction equipment. Similar wide swings in radon concentration have been observed in other locations found to be in close proximity to significant soil concentration of radon. Figure 19 illustrates this phenomenon in house C33C. The ability of charcoal canisters to provide reliable measurement information under these conditions is uncertain. George (1984) describes tests of the response by charcoal canisters to radon concentrations that varied by two times the lowest concentration during the monitoring period. Analyses of the canisters found radon concentrations to be representative of the average chamber concentration. However, no reports of tests at the larger concentration differences encountered in Clinton were located in a review of the literature.

5.3 MONITORING CONDITIONS

The concentration of radon measured in a house is strongly dependent on the condition under which the measurement is made. The most reproducible conditions are those found in winter, when doors and windows are closed for long periods and thermally driven negative pressure is applied at soil contact points. A statistical study of available monitoring data conducted by the EPA found that radon measurement variance was lowest when houses were monitored in the winter (Ronca-Batista, 1986). This study led to the recommendation that winter conditions be simulated when monitoring for radon. As discussed in Section 4 of this report, efforts to simulate winter conditions using a variety of techniques were at best unreliable.

Radon concentrations in houses show both a daily and seasonal variation. Measurements were taken within the 2-week period immediately preceding installation of radon reduction equipment wherever possible. Post-radon reduction measurements were made as soon after installation of the radon reduction equipment as possible. It was hoped that this short time delay between pre- and post-radon reduction measurements would reduce the effect of seasonal variation on the measurement; however, in some of the homes requiring three

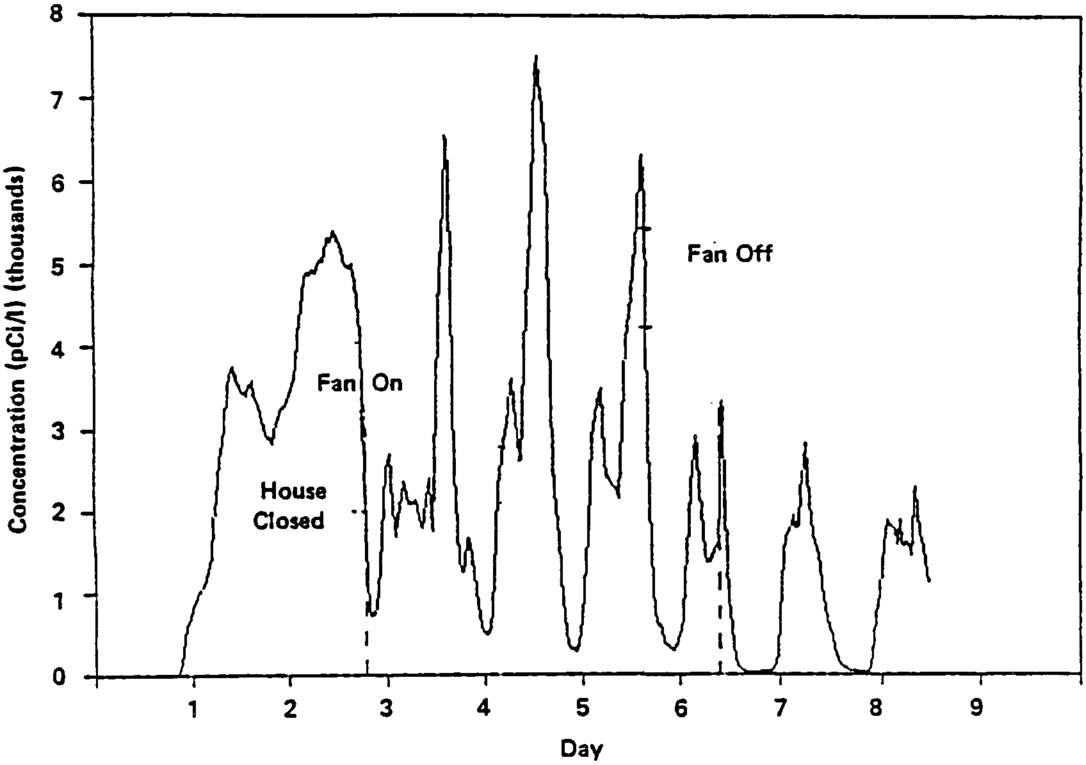


Figure 19. Preradon reduction monitoring results, House C33C.

levels of radon reduction, this was not possible. Pre-radon reduction continuous monitor measurements were made in full summer while post-radon reduction continuous monitor and charcoal measurements were made under the conditions shown in Figure 19 during the November through January timeframe. In most cases, baseline data collected under attempted simulated winter conditions did not produce radon levels comparable to those measured during the DEP radon survey. Initial continuous monitor data were collected when radon levels were at a seasonal low and the data after radon reduction were collected when indoor radon levels were increasing due to the onset of winter. Consequently, in some cases, interpretation of radon reduction effectiveness via continuous monitor data was inconclusive.

5.4 CONTROL HOMES

In an effort to differentiate between random fluctuations in concentration levels and any real reductions due to the radon reduction efforts, control homes were selected for simultaneous monitoring with radon reduction demonstration homes to be mitigated. Control homes were chosen on the basis of proximity and similarity in floorplan to the radon reduction demonstration home. An ideal control home would not receive radon reduction techniques until work was completed on its corresponding demonstration home. The demonstration home would, in addition, have similar baseline radon concentrations to those found in the corresponding control home. Unfortunately, equipment and time constraints together with some concern about the high radon exposures that might occur in control homes where radon has not been reduced led to the selection of control homes from among the 10 demonstration homes. Consequently, no control home was left in an undisturbed state for the full duration of the project. Table 6 shows the actual schedule of control home pairings to demonstration homes.

Figure 20 is a log plot showing the before radon reduction measurements on house C48B and its corresponding control home, house C31B. House C48B was closed and unoccupied during the first three days of monitoring. For the remainder of the time it was monitored under normal living conditions. House C31B was occupied and monitored under normal living conditions for the entire time period plotted. The pattern of diurnal radon concentration buildup and decline can be clearly seen in this plot. This phenomenon appears to be

TABLE 6. CONTROL HOMES PAIRED WITH DEMONSTRATION HOMES

House Code	Sample Dates	Control House
C30A	06/07 to 06/09	C39A
	06/09 to 06/14	C39A
	06/27 to 07/02	C46A
	07/03 to 07/09	C46A
	08/07 to 08/11	C46A
	11/17 to 11/20	C39A
C31B	06/06 to 06/13	C30A
	06/07 to 06/11	C30A
	08/07 to 08/13	C30A
	08/09 to 08/13	C46A
	08/15 to 08/17	C8A
	09/21 to 09/24	C39A
	11/17 to 11/21	C30A
C33C	06/16 to 06/24	C32D
	06/19 to 06/22	C32D
	06/22 to 06/24	C32D
	09/11 to 09/16	C32D
	11/17 to 11/20	C32D
C39A	06/06 to 06/13	C30A
	06/07 to 06/11	C30A
	08/09 to 08/12	C30A
	08/07 to 08/13	C8A
	09/21 to 09/24	C46A
	11/04 to 11/12	C48B
	11/17 to 11/21	C30A
C46A	06/25 to 07/01	C8A
	06/25 to 06/27	C8A
	06/27 to 06/29	C8A
	07/15 to 07/18	C8A
	08/07 to 08/09	C39A
	08/07 to 08/13	C39A
	11/21 to 11/23	C32D
	12/09 to 12/11	C24E
C48B	05/29 to 06/05	C31B
	05/30 to 06/01	C31B
	06/01 to 06/04	C31B
	06/04 to 06/05	C31B
	07/10 to 07/13	C31B
	11/07 to 11/20	C31B

(continued)

TABLE 6. CONTROL HOMES PAIRED WITH DEMONSTRATION HOMES (continued)

House Code	Sample Dates	Control House
C24E	08/15 to 08/17	C8A
	08/17 to 08/19	C8A
	08/19 to 08/21	C8A
	12/09 to 12/11	C46A
C8A	06/25 to 07/01	C46A
	06/25 to 06/27	C46A
	07/15 to 07/19	C46A
	08/15 to 08/17	C24E
	08/19 to 08/21	C24E
C10B	08/15 to 08/17	C31B
	08/19 to 08/21	C31B
	09/14 to 09/17	C31B
	09/11 to 09/23	C31B
C32D	06/16 to 06/25	C33C
	06/19 to 06/21	C33C
	06/21 to 06/24	C33C
	09/21 to 09/24	C33C
	11/17 to 11/21	C33C

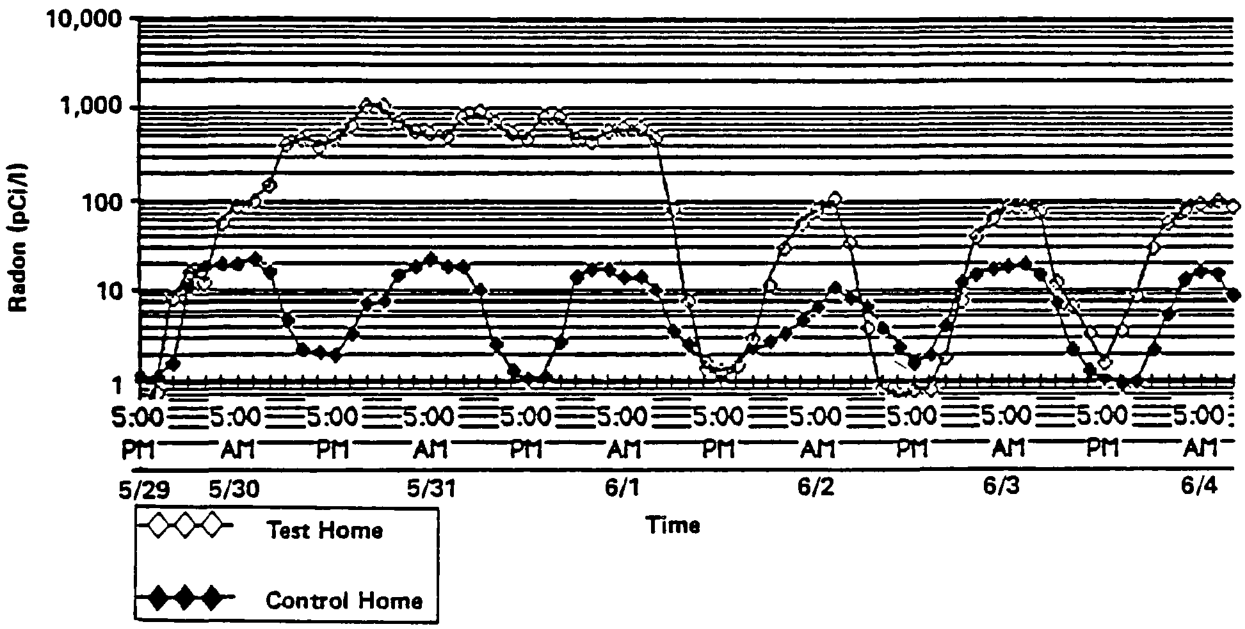


Figure 20. Premitigation monitoring results for house C48B and control house C31B.

independent of the building structure. The synchronicity of this pattern is striking and it was repeated throughout demonstration-control home sampling in Clinton, New Jersey.

Figure 21 is a plot of ambient radon concentration versus time, reproduced from the report, "Evaluation of Radon Sources and Phosphate Slag in Butte, Montana" (EPA 1983). The same pattern showing gas concentration peaking near 6 AM, followed by a minimum concentration reached roughly twelve hours later is seen in outdoor air. This diurnal cycle may be useful in fingerprinting soil gas radon sources in the diagnostic phases of future radon reduction work if other sources do not show a similar daily outgassing fluctuation.

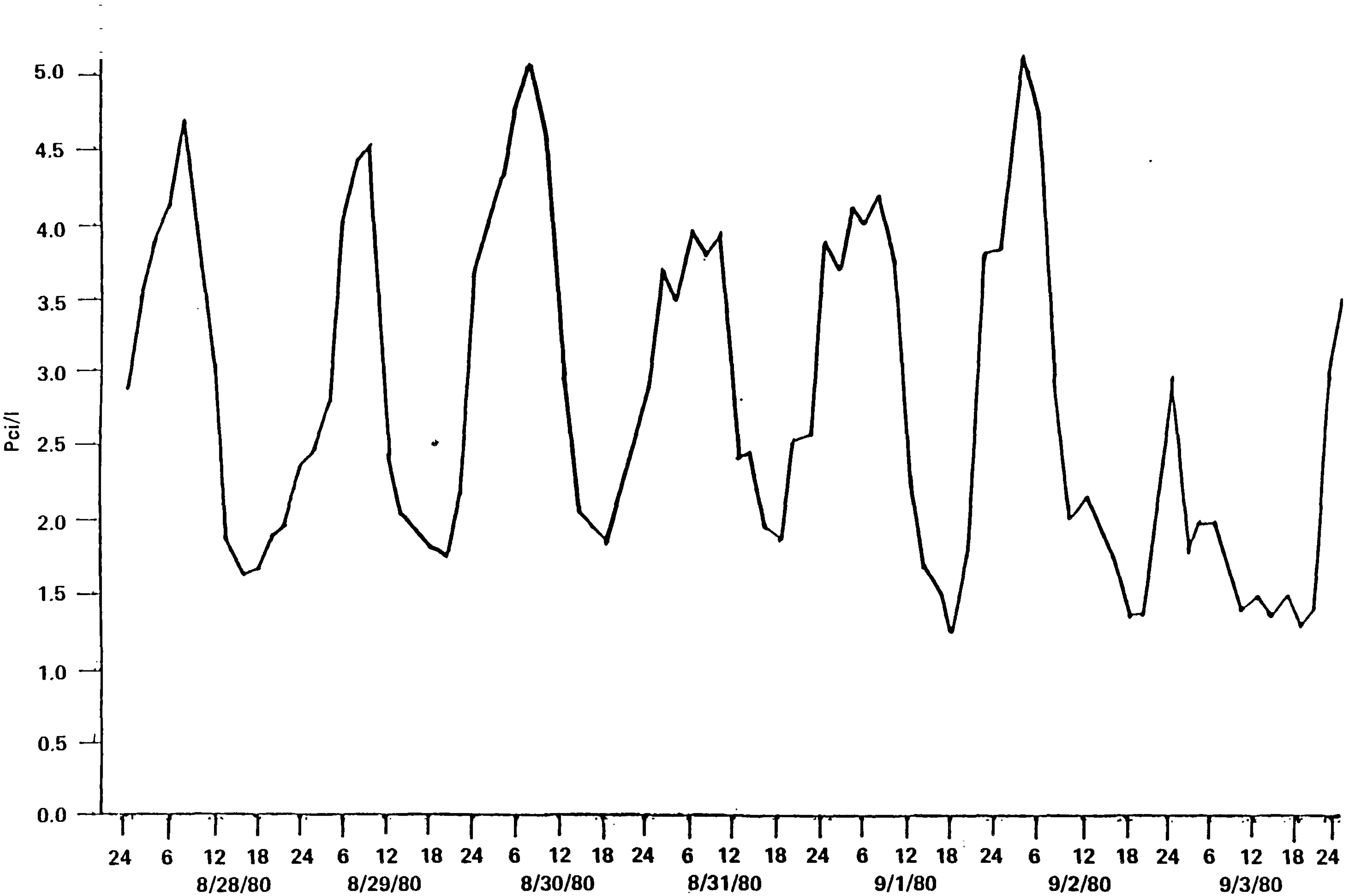


Figure 21. Ambient radon concentrations, Hebgen Park Monitoring Station, August 8-September 4, 1980.

6.0 DEVELOPMENT OF RADON REDUCTION PLANS

Radon reduction plans were developed for each of the 10 homes based upon the prior diagnostic assessment, discussions with the homeowners and construction contractor, and available information about effective radon reduction techniques.

Summary radon reduction plans were prepared for discussion with the homeowner and construction contractor to describe the installation that would be necessary. Appendix A includes copies of the radon reduction plans for each house. The plans included three levels of radon reduction. The first level was the lowest cost technique considered likely to succeed. Levels two and three were upgrades from level one. The contractor was to complete level one before monitoring began. On the basis of post-level one monitoring, a decision would be made concerning the need for further radon reduction. When radon concentrations remained elevated, additional diagnostic measurements were performed to determine the effectiveness of the installation. The second level of radon reductions was revised based on the results of these diagnostic measurements. The levels of the radon reduction plan were installed, monitored, and diagnosed in this manner until either the radon concentration was reduced to an acceptable level or the third level of the plan had been completed.

Homeowner involvement in the selection, development, and implementation of the plan was encouraged. A homeowner permission form, reproduced in Appendix B, was discussed with each of the homeowners before proceeding with the installation.

Table 7 is a summary matrix showing the important construction features and the general radon reduction options selected for each of the 10 homes.

TABLE 7. SUMMARY OF RADON REDUCTION PLANS

	House Type				
Radon Reduction Method	Bi-level (totally finished) slab below grade	Split level 1/2 basement, below grade heating duct under slab	Two-story, no basement, subsided subslab heating duct under slab	Two-story, basement sump hole-drain tile	Split level 1/2 slab on grade earth crawl-space
Perimeter suction	C48B		C33C		
Sump hole suction		C39A C30A		C32D	
Subslab suction (exterior)	C10B C31B				
Subslab suction (interior)	C48B	C46A C8A	C33C	C32D	C24E (also on block above footer)
Seal perimeter crack-no suction on crack	C31B C10B	C39A C46A C8A C30A			
Rerouting, sealing subslab ducts, and applying suction to the ducts		C30A C39A C46A C8A	C33C		

(continued)

TABLE 7. SUMMARY OF RADON REDUCTION PLANS (continued)

Radon Reduction Method	House Type				
	Bi-level (totally finished) slab below grade	Split level 1/2 basement, below grade heating duct under slab	Two-story, no basement, subsided subslab heating duct under slab	Two-story, basement sump hole-drain tile	Split level 1/2 slab on grade earth crawl-space
Supplied makeup air to furnace (dilution)		C30A C46A C39A	C33C		
Ventilation and isolation of crawlspace					C24E

7.0 INSTALLATION OF RADON REDUCTION MEASURES

7.1 INSTALLATION MATERIALS

Installation of radon reduction measures in each of the 10 homes followed the development of radon reduction plans as shown in Appendix A and the techniques generally documented in the literature. Table 8 is a summary of principle materials used in the 10 home radon reduction demonstrations.

7.2 ESTIMATE OF INSTALLATION COSTS

Table 9 shows the estimated cost of installation by home. The goal of an average cost of $2,500 per home was exceeded. This was due primarily to the cost associated with the radon reduction of house C33C.

Two factors contributed to this large excess. House C33C had essentially no subslab aggregate. The soil had subsided to from 1 to 4 inches below the slab. Depressurizing the soil was complicated by the existence of this air space.

The two highest cost houses shared a common feature--the subslab aggregate was poor. In the case of C48B, little aggregate was found and airflow from the central hole punched in the slab was only partially successful. House C48B had an incomplete foundation in a small crawlspace accessed through the back of a closet. Radon concentrations in the crawlspace were found to be elevated. The repair of the foundation was not anticipated in the cost estimate.

Another cause for elevated cost can be attributed to the use of a novel method of perimeter suction that was used in both house C33C and house C48B (the second highest cost house). This technique required the labor-intensive work of cleaning out the perimeter crack and filling it with backer rod and sealing with pourable polyurethane. The perimeter wall was then ventilated. The cost of this method was excessive; therefore, other houses, specifically C10B and C31B, had their radon levels reduced with an alternative, novel system.

TABLE 8. STANDARD PARTS USED IN INSTALLATION OF RADON REDUCTION SYSTEMS

* Duct Fans

Supplier: RB Kanalflakt Inc.
1121 Lewis Avenue
Sarasota, Florida 33577

(813) 366-7505

Cost: K4 ~ $ 87 each
K6 ~ $100 each

* Ducts

- 6 in. oval ducts - exterior - sheet metal
- 6 in. flue ducts (insulated) - ceiling runs (flexduct plastic film inside; vinyl core)
- 3 in. x 12 in. ducts - ceiling traverses

* Duct Accessories

- 6 in. ceiling diffuser boxes and plates for air outlets

- 4 in. dryer vents with wire mesh screen to direct outlet airflow on exterior of house

- 4 in. rain cap to cover open exterior ducts

- 4 in. dripless roof flashing to seal around roof exiting ducts

* Sealants

Acryl 60 by ThoroSeal for sealing voids-following manufacturer's instructions, was used for sealing larger openings, such as the cavity around electrical outlets; sealing voids and cracks-used primarily to seal dug out perimeter or patching block and slab holes.

To fill dug out perimeter, hardware cloth was rolled and then crushed. It was placed in the dug out perimeter so that a 5 to 7 cm cavity was maintained in the crack. The perimeter was then sealed with Acryl 60 cement.

Urethane caulking for general sealing-urethane caulking was used for sealing around fans, ducts, pipes, and slab penetrations.

TABLE 9. COST OF RADON REDUCTION INSTALLATIONS
(breakdowns by house are estimates)

House Code	Radon Reduction Methods	Labor*	Materials	Heating System**	Electrical	Total
C30A	sump hole suction sealed subslab duct suction sealed perimeter crack supplied makeup air to furnace	2,460	200	490	150	3,300
C39A	sealed perimeter crack sump hole suction sealed subslab duct suction supplied makeup air to furnace	1,560	300	490	120	2,470
C8A	interior subslab suction sealed perimeter crack sealed subslab duct suction	1,150	150	490	140	1,930
C46A	sealed perimeter crack supplied makeup air to furnace interior subslab suction	1,700	400	490	150	2,740
C10B	exterior subslab suction sealed perimeter crack	1,040	400	---	400	1,840
C31B	sealed perimeter crack exterior subslab suction	1,250	400	---	220	1,870
C48B	perimeter suction subslab suction	3,000	1,000	170	360	4,530

(continued)

TABLE 9. COST OF RADON REDUCTION INSTALLATIONS (continued)
(breakdowns by house are estimates)

House Code	Radon Reduction Methods	Labor*	Materials	Heating System**	Electrical	Total
C33C	perimeter suction interior subslab suction sealed subslab duct suction supplied makeup air to furnace	6,650	400	1,310	140	8,500
C32D	sump hole suction interior subslab suction	2,860	150	---	170	3,180
C24E	interior subslab suction ventilation and isolation of crawlspace	900	400	---	200	1,500
		22,568	3,509	3,453	1,737	31,267.00

* This is only installation cost (subcontractor).

** Rerouting ducts and addition of dilution air.

These two houses had their floor/wall cracks sealed, but the primary radon reduction technique was applied from the exterior of the houses. Along one side of the two houses, a trench was dug to the level of the first hollow core foundation block. Three different penetrations were made in blocks along this wall. Two penetrations made at the corners of the side wall, entered the void space in the foundation blocks on the front and rear walls. These penetrations permitted block-wall suction on the front, side, and rear walls. In the center of the side wall, a penetration was made through the block and into the loose backfill soil near the floor/wall crack beneath the house floor slab. By tying all three penetrations along the side wall into a common vertical plastic vent pipe equipped with an in-line fan, suction could be applied simultaneously to three walls and the sub-slab. This method was found to be one of the fastest, least disruptive, and most cost-effective of the methods used.

A learning curve is evident in the distribution of costs per house. Houses C30A, C33C, and C48B were the first three houses where radon reduction techniques were applied. All subsequent houses show a lower cost for radon reduction than do these three. The radon reduction plan employed in house C30A for $3,300 was virtually repeated in houses C8A, C46A, and C39A at reductions of $500 or more per house.

House C32D was originally considered to be one of the least costly to demonstrate radon reduction. Simple sump hole suction and good sealing of openings and cracks in the basement slab were recommended. When the work was completed, monitoring indicated that the radon concentration was still excessive. Measurement of pressure differences between room air and sub-slab air in the basement showed that suction did not extend to the side of the house opposite the sump hole. A second sub-slab suction system was installed to correct this. When monitoring showed that radon levels in the basement had doubled after installation of the second fan, intensive diagnostic examination of the basement was begun. Two factors contributed to the elevation in radon concentration after radon reduction techniques were applied: (1) a tiny fan leak was allowing radon-rich sub-slab air into the basement and (2) the fan exhausts on the outside of the house had been placed at ground level allowing radon-rich air to leak back into the basement. When these two problems were remedied, basement air radon was significantly reduced.

7.3 DIAGNOSTIC PROCEDURES USED FOLLOWING RADON REDUCTION EFFORTS

Additional diagnostic procedures were required when radon concentrations were considered to be excessive following the completion of any radon reduction plan level. Initially, diagnostic procedures focused on the function of the installed system checking ducts, fan, seals, and airflow through the system. If elevated radon concentrations could not be linked to a failure or weakness in the installed system, post-diagnostic procedures were directed toward the identification of secondary radon routes that may have been missed during earlier inspections. This process involved a repetition of the basic pre-radon reduction diagnostic efforts.

In many cases, secondary sources of radon infiltration were discovered and the subsequent radon reduction plan level was re-evaluated. In some cases, particularly in homes with finished basements or slab-on-grade levels, no secondary sources were located, and installed soil depressurization systems were functioning to specifications. In these cases, the addition of dilution air was required to produce any further reduction in radon concentration.

8.0 QUALITY ASSURANCE

The Quality Assurance Project Plan (QAPP) dated June 11, 1986, was approved by the AEERL Project Officer and Quality Assurance Officer prior to initiation of data-gathering activities. The objective of this project was to demonstrate radon reduction by use of low-cost mitigation techniques in up to ten homes. Charcoal canister and passive scintillation cell measurement methods were identified as the methods of choice for determining the extent of radon reduction in the homes. Data quality objectives (DQOs) for the quality of these two methods were established in the approved QAPP. The DQOs are shown in Table 10.

Precision, accuracy, and completeness objectives were met for measurements made using charcoal canisters and passive scintillation cell radon monitors. Tables 11 and 12 show the actual performance with respect to the DQOs. Details are provided in Sections 8.1 and 8.2. Sections 8.3 through 8.5 detail other QA information including results of audits, the impact of seasons on radon concentration, and the use of control homes.

8.1 QUALITY ASSURANCE OBJECTIVES FOR PASSIVE SCINTILLATION CELL RADON MONITORING

Four Pylon AB-5 radon monitors fitted with Pylon passive radon detector cells were used in the course of the project. Protocols detailed in the QAPP were followed at all times. Monitoring is discussed in Section 6 of this report.

The instruments were calibrated in the radon chamber at the EML twice during the project. Two of the monitoring systems were used only for post-radon reduction sampling and were calibrated once during the course of the project. The calibration procedure is described in the QAPP. Figures 22 through 25 show the calibration curves for the four devices. Table 11 shows the calibration constants and a calculation constant over the period between calibrations. Accuracy is calculated to be well within the objective of ±20 percent bias.

This measurement technique relies on the counting of radon events (alpha particle scintillations) and can therefore be described by Poisson statistics.

TABLE 10. QUALITY ASSURANCE OBJECTIVES

Measurement Method	Conditions	Precision (RSD)	Accuracy (Percent Bias)	Completeness
Passive scintillation cell radon monitor	indoor atmospheres (living conditions pre- and post-radon reduction)	20%	+/- 20%	90%
Charcoal canisters	indoor atmospheres (living conditions pre- and post-radon reduction)	10%	+/- 10%	90%

TABLE 11. PASSIVE SCINTILLATION CELL RADON MONITOR CALIBRATION CONSTANTS

Equipment ID#	Calibration: 6/4 to 6/5/86 (Correction factor: $\frac{cpm}{pCi/l}$)	Calibration: 8/14 to 8/15/86	Percent Bias
AB-5 #250			
PRD #123	1.270		
PRD #124		1.197	5.7%
AB-5 #244	1.278		
PRD #125		1.204	
PRD #123			5.8%
AB-5 #255	not in use		
PRD #125		1.117	n/a
AB-5 #258	not in use		
PRD #127		1.116	n/a

TABLE 12. CHARCOAL CANISTER QUALITY ASSURANCE SAMPLES

	Blanks	Field Blanks	Colocated		Spiked		
Number of samples	6	3	8				
Concentration (pCi/l)	1) <detection limit*	1) <2.9	1) <4.0	2) <4.0	Spiked Value	Analysis Result	
					Group #1		
	2) <detection limit	2) <1.0	3) 4.7	4) 4.7	40.4	**41.6	
	3) <1.0	3) <1.0	5) 6.5	6) 5.4	40.4	**41.9	
	4) <0.6		7) 15.5	8) 21.7	40.4	41.7	
	5) <detection limit				Group #2		Using Correct Humidity Factor
					31.8	**21.0***	27.6
	6) <detection limit		Precision (RSD)		31.8	**21.4***	28.8
			1) 0%		31.8	21.6***	27.9
			2) 0%				
			3) 13.1%		Precision	Percent Bias	
			4) 23.6%		7.8 RSD	Group #1 +0.6%	
			5) 0.5%**		1.4 RSD	Group #2 -12.3%	
			6) 1.3%**				
			average 6.3%				

* Detection limit depends upon interval between sampling and analysis.
If this interval is 2 days d.l. = 0.5 pCi/l.
If this interval is 4 days d.l. = 1.0 pCi/l.
If this interval is 6 days d.l. = 2.0 pCi/l.
If this interval is >6 days d.l. = 4 pCi/l.

** These RSD values are for two "spiked" samples colocated in the chamber.

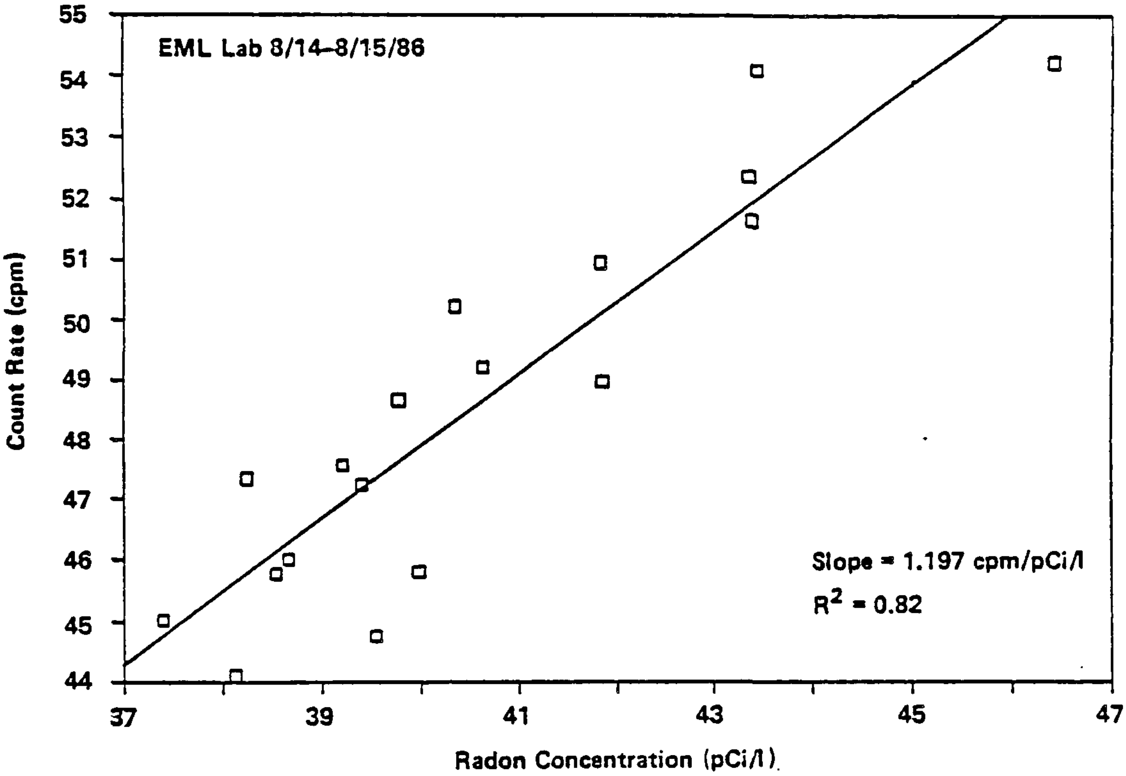


Figure 22. Calibration data: AB-5 #250, PRD #124.

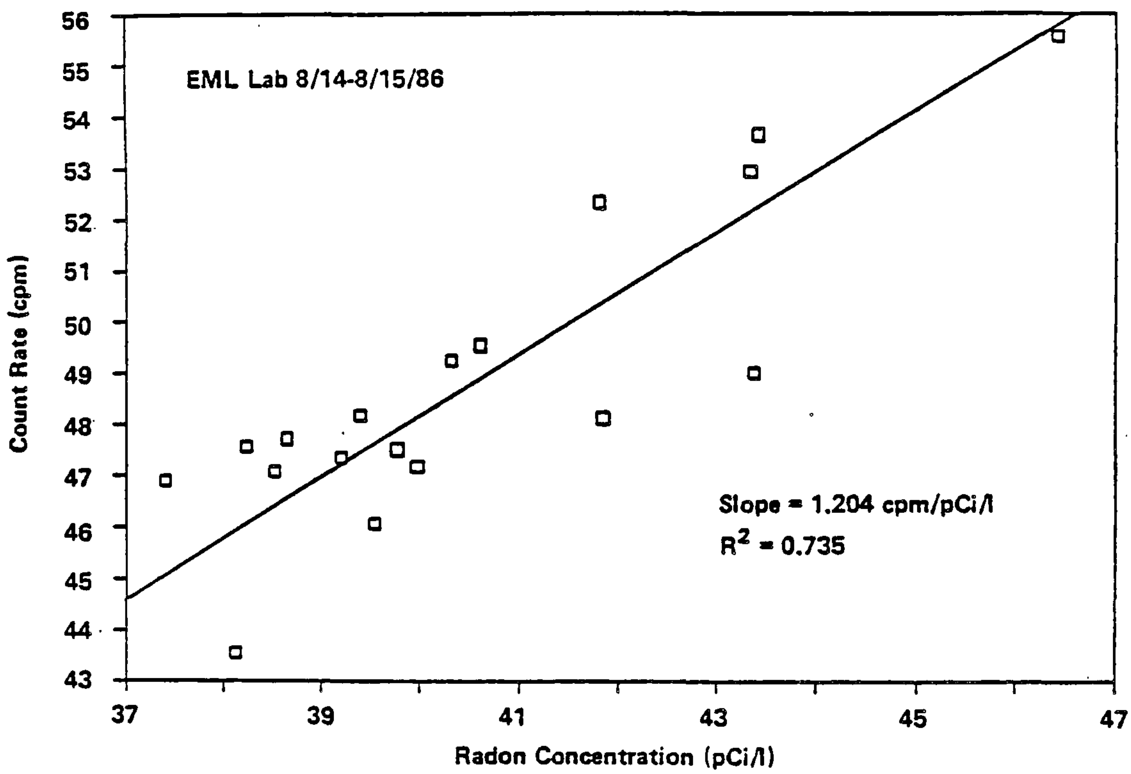


Figure 23. Calibration data: AB-5 #244, PRD #123.

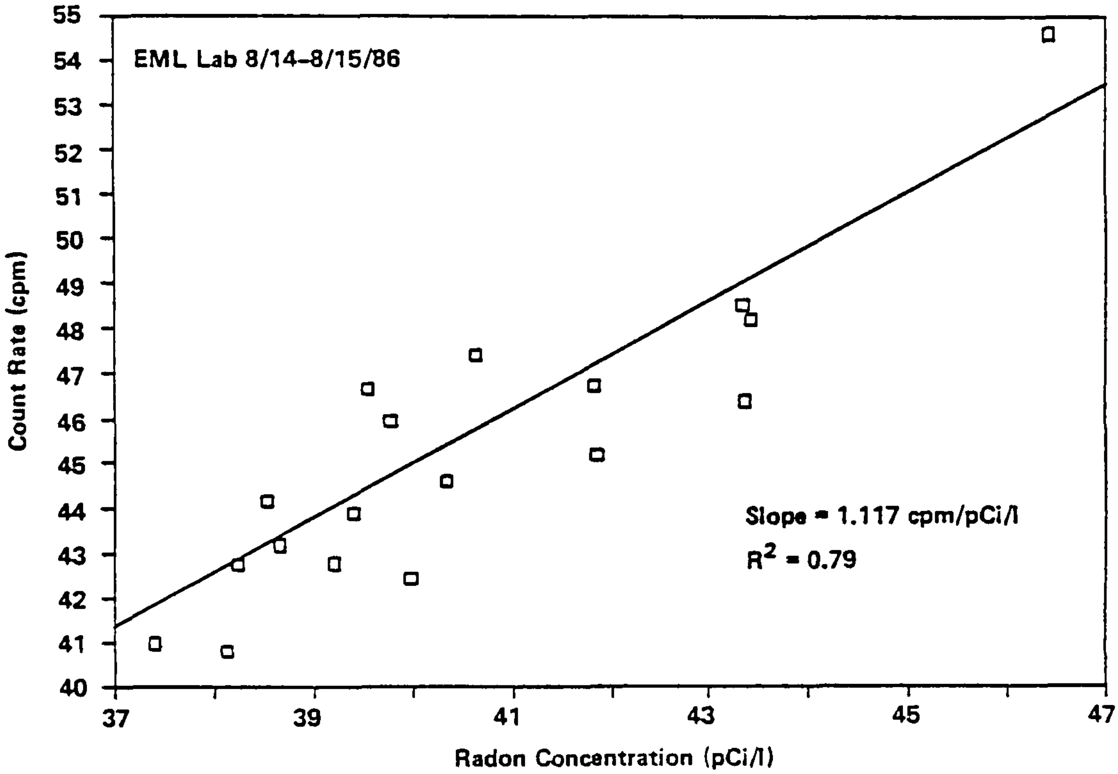


Figure 24. Calibration data: AB-5 #255, PRD #125.

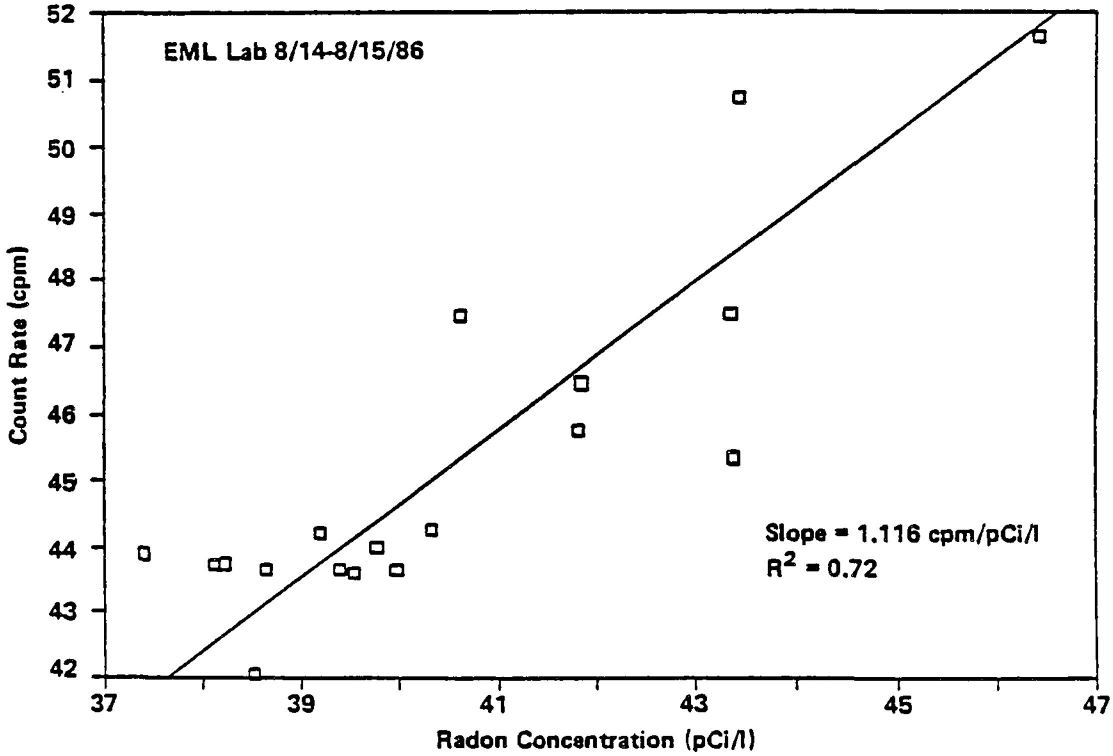


Figure 25. Calibration data: AB-5 #258, PRD #127.

For a Poisson distribution, the variance of a population is equal to the mean of that population. If single measurements are made from a Poisson distribution, then it must be assumed that the measured value is the mean of the distribution. By the nature of Poisson distributions, the precision of such a measurement will be determined by the size of the population. Specifically, the precision of measurement will be equal to the standard deviation for the measured value, which can best be described as the square root of the mean value. As a result, precision of a measurement can be fixed by specifying a minimum count. To maintain a precision of ±20 percent, a count of at least 25 is necessary. The sample duration of 30 minutes used in all field measurements ensured that this minimum count was down to a concentration of less than 1 pCi/l for calibration factors that are greater than 1 cpm/pCi/l. Because the critical guidance level for action on radon-contaminated homes is 4 pCi/l, the precision goal was met at all times during sampling.

The QAPP called for a minimum of one pre-radon reduction sampling period consisting of three 48-hour sampling periods and a second post-radon reduction sampling period of the same duration. This minimum was met in the case of all but house C24E. Since completeness was 90 percent, the quality assurance goal for this measurement technique was achieved.

8.2 QUALITY ASSURANCE OBJECTIVES FOR CHARCOAL CANISTERS

Charcoal canister sampling and analysis were completed following procedures prescribed in the QAPP. Table 12 details quality control and assurance samples collected using this technique.

Overall precision and completeness goals were met. However, accuracy goals were not met in the case of one set of three simultaneously chamber-exposed canisters. In investigating the reason for the large negative bias in these canisters, it was found that the analytical laboratory determined the relative humidity based upon the charcoal weight gain to have been approximately half of the chamber recorder value, 68 percent. Some loose charcoal was reported when the canisters were returned from the exposure chamber, and charcoal loss would reduce the weight of the canister and mask the effect of adsorbed water vapor. Since quality assurance samples were handled in the same way, a similar bias might occur in some of the field samples due to loss of charcoal. However, when charcoal canister results are compared to continuous monitoring results, no clear bias is seen. When the concentrations determined by the analytical laboratory were recalculated using the actual chamber relative humidity, accuracy for the technique was well within the quality assurance goals for the project.

8.3 SYSTEMS AUDITS

An audit of project records was conducted by Keith Daum (RTI) during July 1986. Five sets of records were reviewed, namely: field notebooks (house sections), house files, instrument log, sample log, and pre-selection checklists. No major deficiencies were identified by the audit. Mr. Daum did identify some minor inconsistencies in the notebooks and files which were corrected following this audit. These corrections included:

- Floorplans drawn in the notebooks are now identified as soil contact floors.
- All pages of graphed data are now dated.
- All manual calculations were checked and the pages were initialed.
- A project decision was made to discontinue pre-radon reduction alpha-track monitoring so Mr. Daum's comments on these entries were not addressed.

As a follow-on to Mr. Daum's audit, a review was conducted onsite at the end of September by Ms. Judy Ford, Quality Assurance Officer for AEERL, RTP, and Mr. Michael Messner, the RTI project Quality Assurance Officer. The reviewers determined that approved quality assurance procedures were being followed and that minor recordkeeping inconsistencies had been corrected.

8.4 SEASONAL INDOOR RADON VARIATIONS

The factor having the greatest impact on the assessment of radon reduction technique effectiveness is the lack of information concerning the seasonal indoor radon variations in the Clinton area. Sampling results, discussed elsewhere in this report show that radon concentrations tend to increase significantly during the heating season, even if summer-collected samples are taken following the EPA-prescribed procedures with the house completely closed. Efforts to simulate winter conditions (as discussed in Section 4) showed variable success. In two cases, measurements matched the levels of radon recorded by the New Jersey DEP in their March and April screening study. Because pre-radon reduction sampling was done in early summer, when levels were expected to be at their lowest, and post-radon reduction sampling was completed in December, direct comparison of pre- and post-radon reduction monitoring results are misleading. Table 13 shows estimates of the maximum and minimum possible reductions. Minimum reductions were similarly calculated subtracting results of post-radon reduction canister monitoring from the pre-radon reduction closed house charcoal canister results. Maximum post-radon reduction calculations were made using the difference between the New Jersey DEP collected data and post-radon reduction monitoring results. In the worst case, radon reduction rates ranged from 0 to 97.6 percent (house C10B) and in the best case, from 99.7 to 99.8 percent (house C30A). Because minimum reductions are based on pre- and post-radon reduction canister results, the accuracy (bias) of the canister measurements is not a factor. Under these circumstances, the accuracy achieved in charcoal canister sampling was more than sufficient to meet the project goals.

8.5 CONTROL HOMES

Control homes were selected for simultaneous sampling from among the 10 homes involved in the demonstration work. Consequently, control homes for post-radon reduction sampling were often houses where radon had already been reduced. There is some evidence that installation of radon reduction techniques will affect not only the radon level but the daily pattern of radon buildup on a home (NYSERDA, 1986), making homes where radon has not been reduced the preferred controls. In this project it was necessary to use 10 demonstration homes also as control homes because of the time schedule and available equipment.

TABLE 13. APPROXIMATE REDUCTION IN RADON CONCENTRATION USING CHARCOAL CANISTER DATA FOLLOWING APPLICATION OF RADON REDUCTION TECHNIQUES (pCi/l)

House Code	Before Radon Reduction (Early Spring) (DEP)*	Before Radon Reduction (Summer) (Closed House)	After Radon Reduction** (Late Fall) (Closed House)	Minimum Percent Reduction	Maximum Percent Reduction
A30	2,254	1,450	4.1	99.7	99.8
A39	1,500	10.4 (1,250 w/Pylon)	4.3	58.7	99.7
A8	791	409	2.9	99.3	99.6
A46	635	772	9.0	98.8	99.2
B10	418	15.8 (70 w/Pylon)	16.0	0	97.6
B31	691	89.0	5.8	93.5	99.2
B48	936	771	11.1	98.6	98.8
C33	1,190	304	4.7	98.5	99.7
D32	1,357	29.0 (130 w/Pylon)	11.3	61.0	99.2
E24	426	91.0 (210 w/Pylon)	12.3	86.5	97.2

* DEP screening study charcoal canister measurements taken in March and April of 1986.

** Highest post-radon reduction charcoal canister measurements taken in August 1985 through January 1986.

9.0 RESULTS AND CONCLUSIONS

Figures 26 through 35 plot before and after radon reduction continuous monitoring results for each of the 10 homes. Results of the highest before radon reduction charcoal canister monitoring (including DEP screening results) and the last before radon reduction charcoal canister monitoring are also shown on these plots. Table 14 is a complete listing of charcoal canister monitoring results for the 10 homes.

9.1 HOUSE C8A

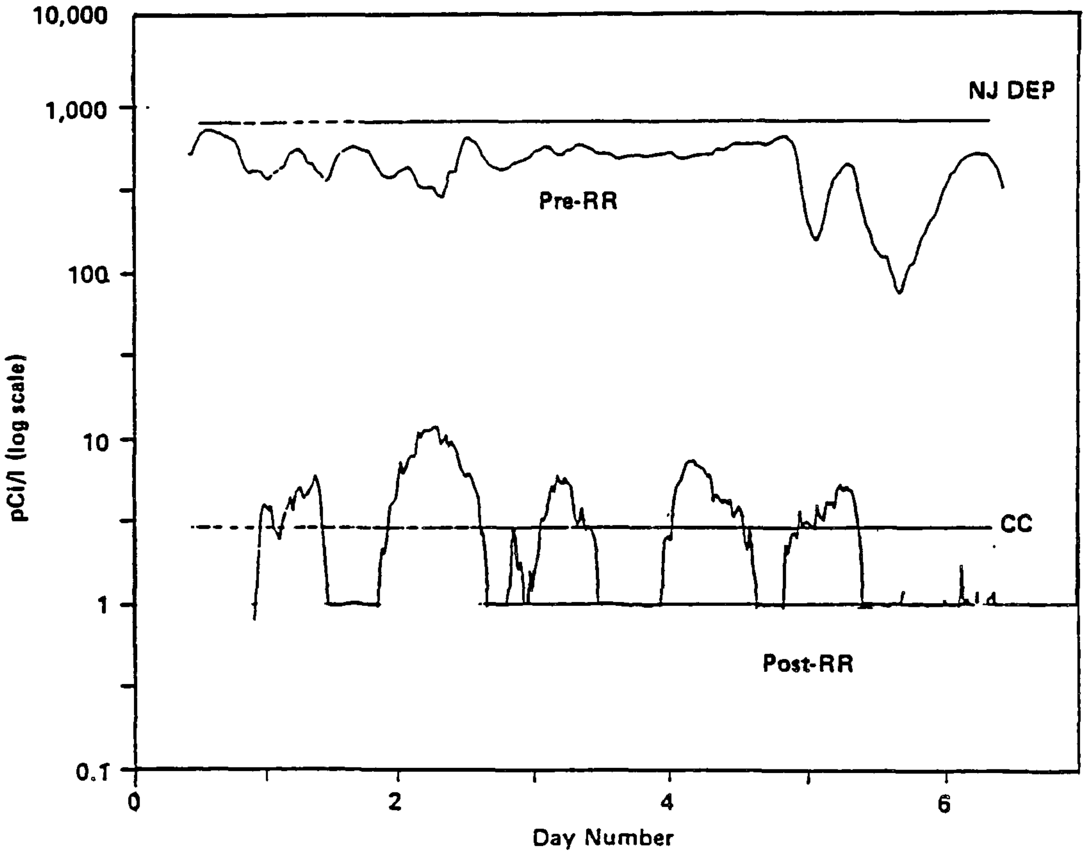
Monitoring results from house C8A are shown in Figure 26. This is a split-level house that had a finished basement with bedroom space in the basement. Radon reduction results were highly satisfactory and a reduction in average radon concentration by any measure was large. The cost associated with this house was slightly higher than average due to the need to route duct work through the finished portions of the house.

9.2 HOUSE C30A

Figure 27 shows the monitoring results for this split-level house. House C30A received radon reducing measures early in the project and the reduction plan was copied in the other A-floor plan homes, obtaining substantial reductions in all cases. The C30A homeowners preferred to keep their house very warm in the winter and extra attic insulation was noted during pre-radon reduction inspections. Consequently, to prevent an excessive stack effect a passive makeup air duct was connected from the outside of the house to the furnace return duct which provided dilution air without cooling the house excessively. The dilution air will be introduced only when the furnace is running.

9.3 HOUSE C39A

Figure 28 shows the results of monitoring in this split-level house. Estimation of real reductions in this house was complicated by the lack of success in simulating winter conditions during pre-radon reduction sampling.



Note: NJ DEP measurements were made using homeowner-located charcoal canister monitoring devices.

Pre-RR refers to Pre-Radon Reduction measurements

Post-RR refers to Post-Radon Reduction measurements

CC refers to RTI Charcoal Canister measurements.

Figure 26. House C8A: pre- and post-radon reductions results.

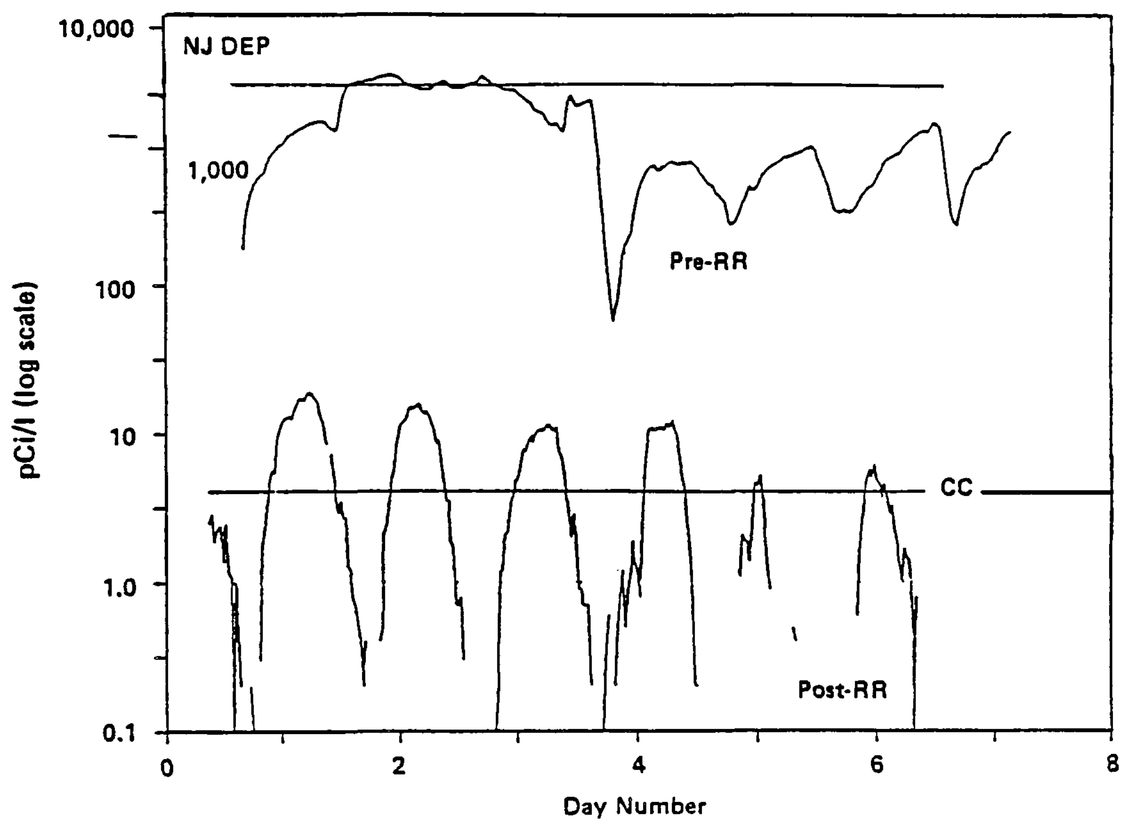


Figure 27. House C30A: pre- and post-mitigation results.

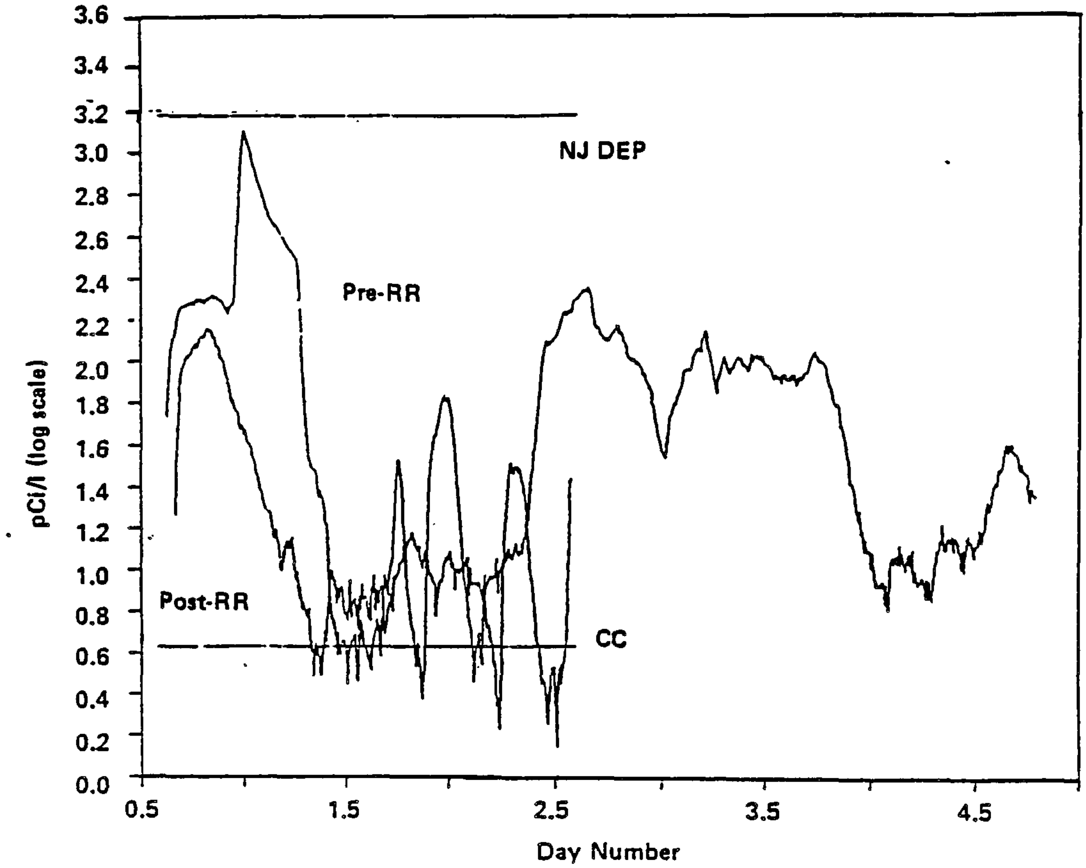


Figure 28. House C39A: pre- and post-radon reduction results.

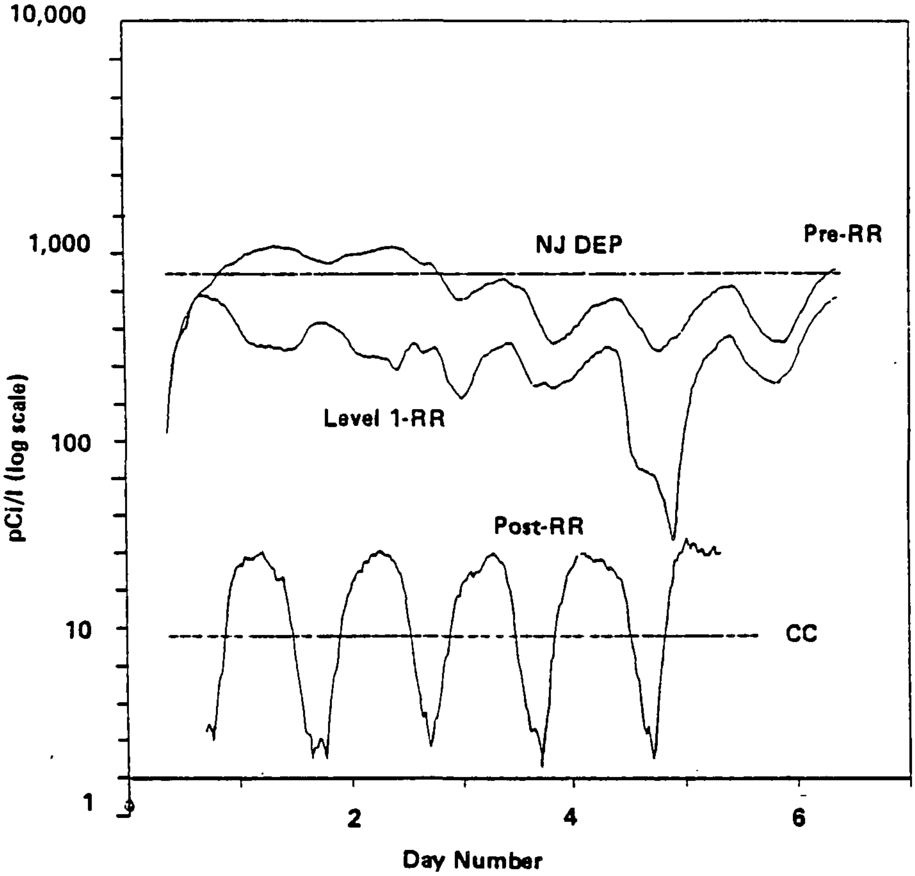


Figure 29. House C46A: pre- and post-radon reduction results.

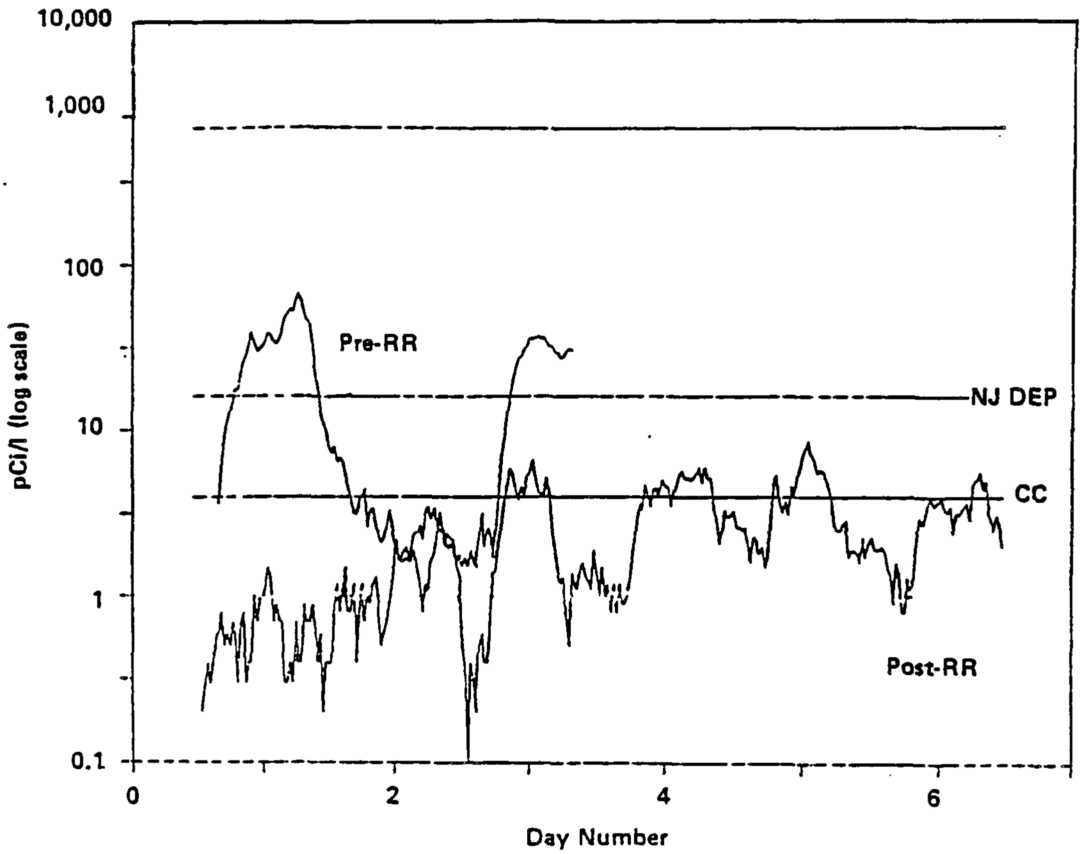


Figure 30. House C10B: pre- and post-radon reduction results.

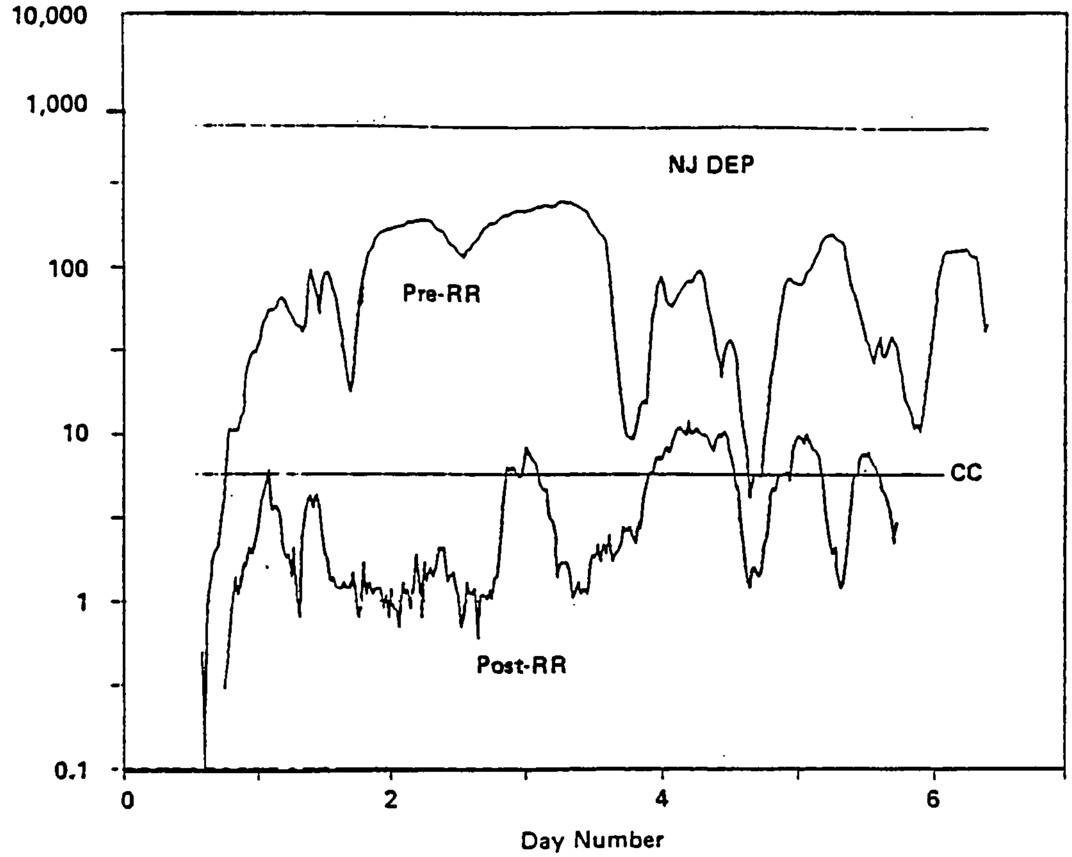


Figure 31. House C31B: pre- and post-radon reduction results.

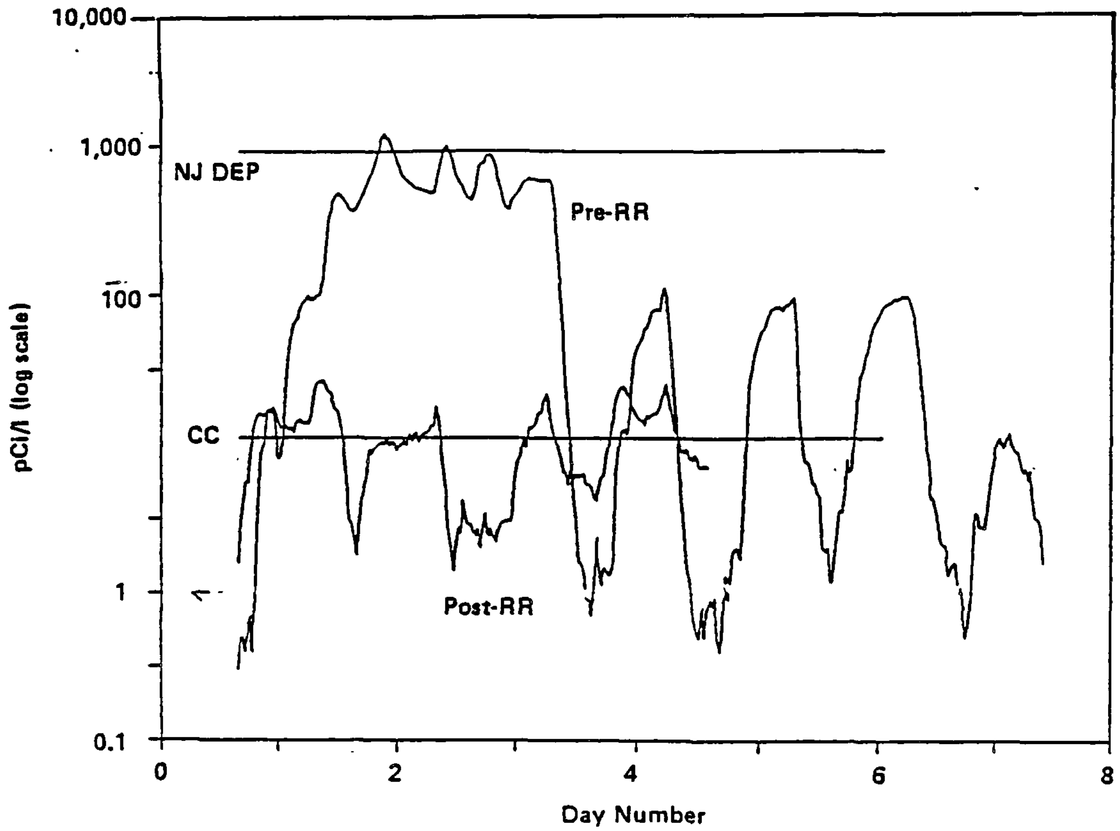


Figure 32. House C48B: pre- and post-mitigation results.

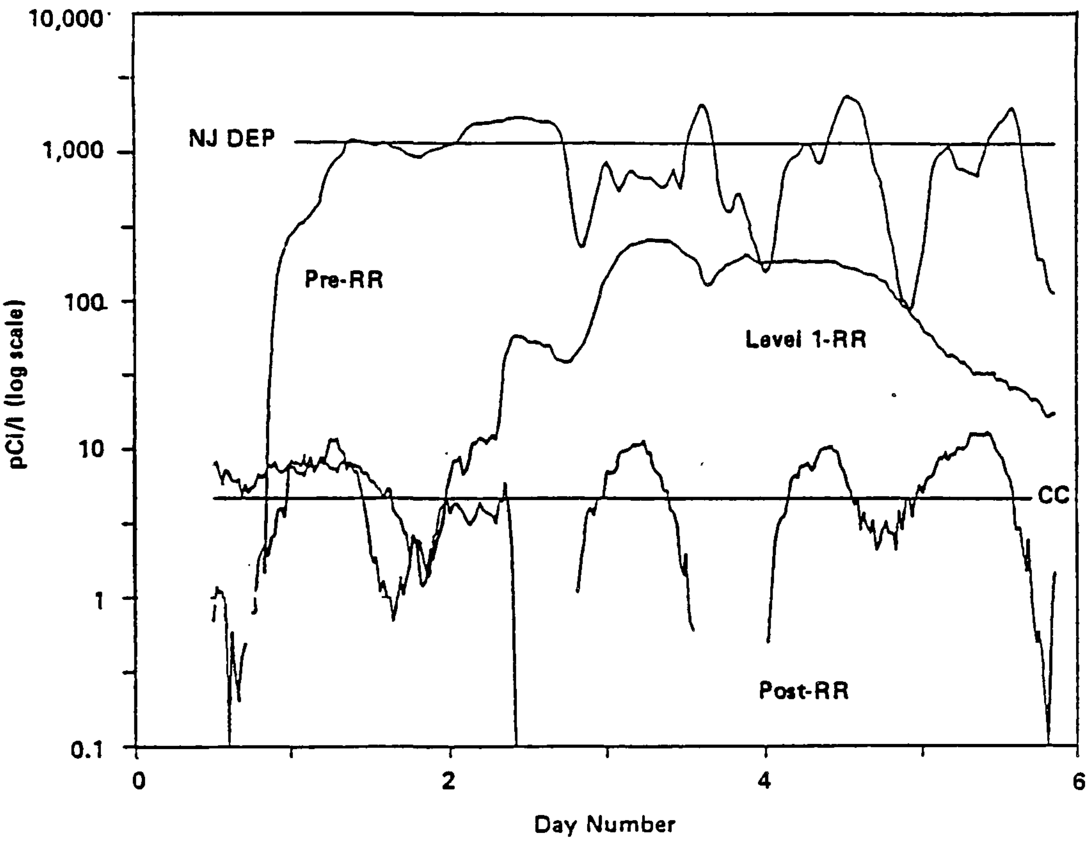


Figure 33. House C33C: pre- and post-radon reduction results.

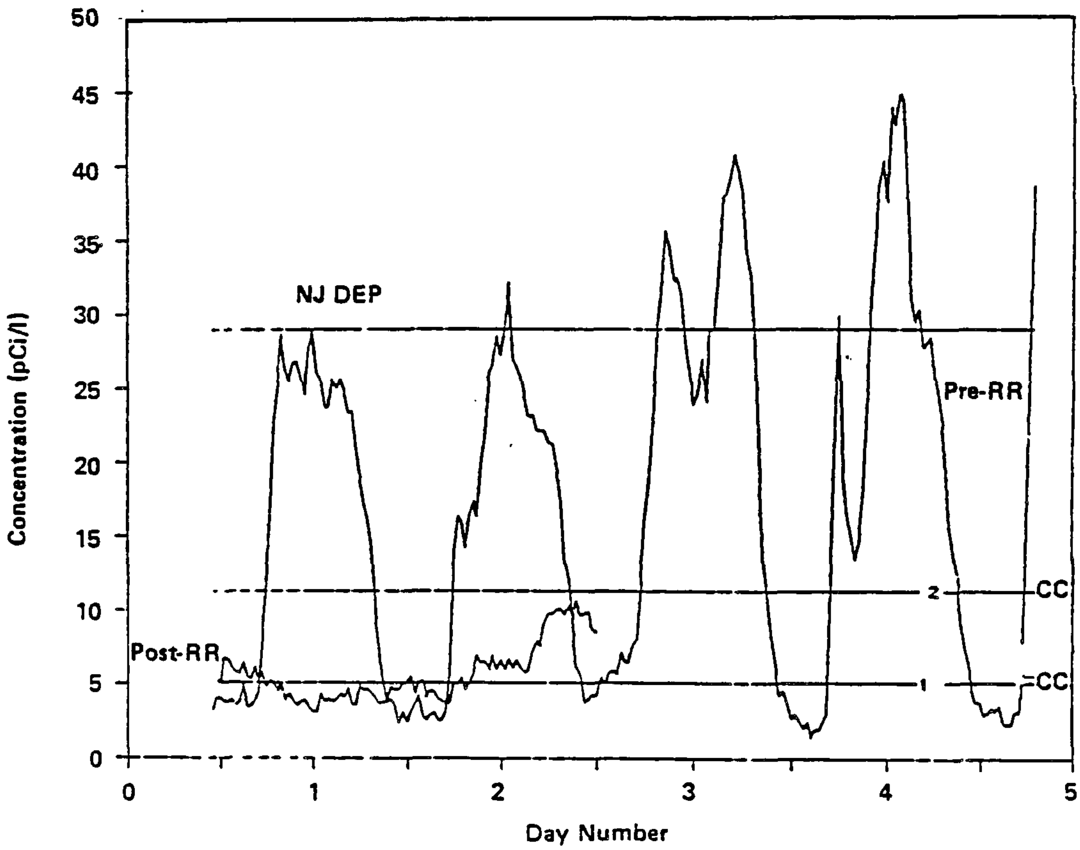


Figure 34. House C32D: pre- and post-radon reduction results.

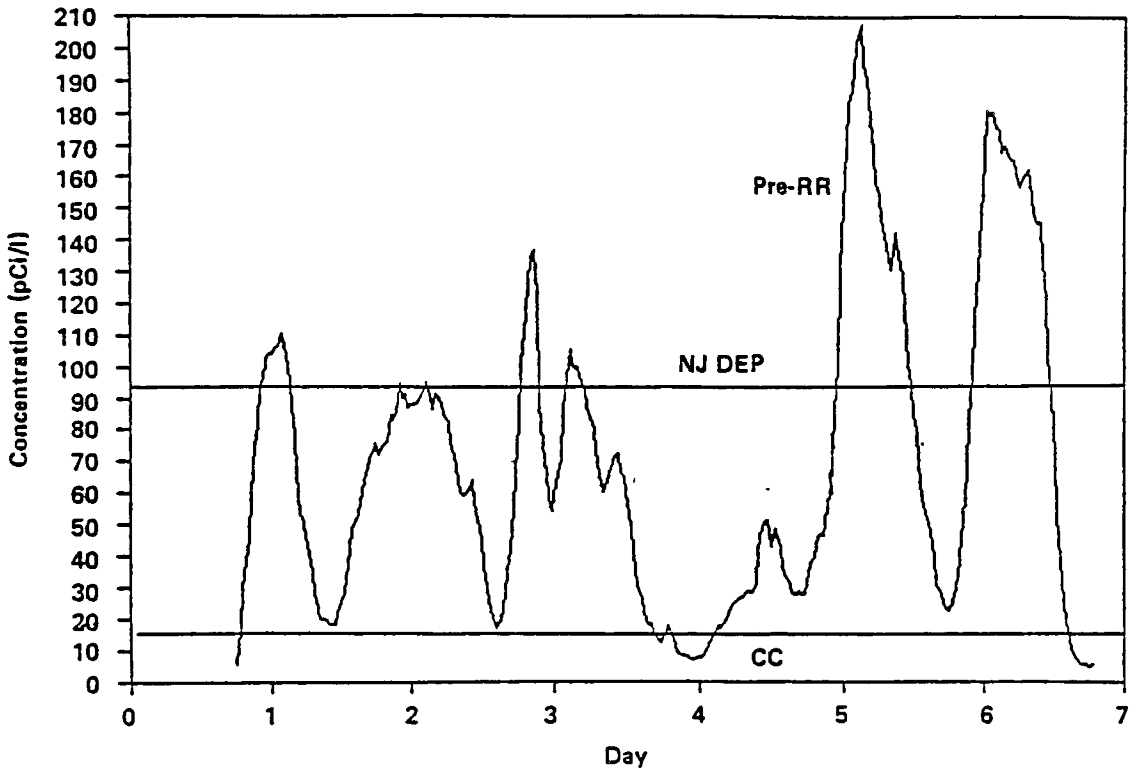


Figure 35. House C24E: pre- and post-radon reduction results.

TABLE 14. RADON CONCENTRATIONS AS DETERMINED WITH CHARCOAL CANISTERS

House code	Sample date	Concentration (pCi/l)	Comments
C30A	4/7	2,254	early spring
	6/7 to 6/9	1,450	closed house
Before	6/9 to 6/14	498	
After	6/27 to 7/2	2	dining room
	6/27 to 7/2	4	
	7/3 to 7/5	3.5	
	7/5 to 7/7	2.4	
	7/7 to 7/9	3.4	
	11/17 to 11/20	4.1	
C31B	3/22	691	early spring
	5/28 to 6/1	8.2	
	6/1 to 6/4	4.4	
	8/15 to 8/17	89	house closed
Before	8/15 to 8/21	76.6	
After	8/19 to 8/21	1.3	
	9/11 to	4.0	
	9/11 to	4.0	
	11/17 to 11/20	5.8	with heat on
C33C	3/15	1,190	late winter
	6/22 to 6/24	304.2	living room
	7/23 to 7/25	8	
Before	7/25 to 7/27	106	
After	7/27 to 8/1	8.7	
	10/4 to 10/10	8.5	small bedroom
	10/4 to 10/10	5.8	furnace room
	11/17 to 11/20	4.7	living room
	11/17 to 11/20	4.7	living room
C39A	4/7	1,523	early spring
	8/19 to	7.5	
	9/21 to	8.3	
Before	6/7 to 6/11	10.4	
After	11/17 to 11/20	4.3	basement

(continued)

TABLE 14. RADON CONCENTRATIONS AS DETERMINED WITH CHARCOAL CANISTERS (continued)

House code	Sample date	Concentration (pCi/l)	Comments
C46A	4/7	635	early spring
	6/25 to 6/27	771.9	basement
	6/27 to 6/29	433	
	7/31 to	157	
Before	8/7 to 8/9	238.5	
After	12/9 to 12/11	5.3	
	1/3/87 to 1/5/87	9.0	
C48B	4/7	936	early spring
	5/30 to 6/1	771.9	basement
	6/1 to 6/4	37.6	
Before	6/4 to 6/5	4	
After	11/17 to 11/20	12	heat on
	12/9 to 12/11	11.1	
C24E	4/16	426	early spring
	8/15 to 8/17	90.9	house closed
	8/17 to 8/19	2.5	
Before	8/19 to 8/21	1.3	
After	9/25 to 9/30	3.0	
	12/9 to 12/11	7.2	downstairs
	12/9 to 12/11	12.3	living room
C8A	3/22	791	early spring
	6/25 to 6/27	409.2	house closed
	6/27 to 7/1	241	
	7/31 to	3	
Before	8/15 to 8/17	5	
After	8/17 to 8/19	4.2	
	8/19 to 8/21	2.8	
	11/17 to 11/20	2.9	

(continued)

TABLE 14. RADON CONCENTRATIONS AS DETERMINED WITH CHARCOAL CANISTERS (continued)

House code	Sample date	Concentration (pCi/l)	Comments
C10B	4/18	418	early spring
	8/15 to 8/17	15.8	
	8/17 to 8/19	9.8	
	8/17 to 8/19	4.2	
Before	8/17 to 8/19	2.5	
After	9/11 to 9/16	4.0	
	11/17 to 11/19	16.12	heat on
C32D	3/22	1,357	early spring
	6/19 to 6/21	29.1	
	6/21 to 6/24	7.2	
Before	9/21 to 9/26	20.1	
After	11/17 to 11/20	8	
	12/9 to 12/11	5.1	family room
	12/9 to 12/11	11.3	basement

In addition, post-radon reduction monitoring only covered a 3-day period. However, both the before- and after-radon reduction changes shown by the charcoal canister results and the averages of the continuous monitoring results suggest substantial reductions were made. In this home, a passive dilution air system was attached to the furnace air handler similar to house C30A. The same techniques used in the other A-floor plan homes was used in this home.

9.4 HOUSE C46A

Monitoring results for this split-level house shown in Figure 29 indicate two levels of radon reduction. The first level shows the monitoring results with two smaller sized fans in place. The second shows the effect of upgrading the fans to the next largest fan size. Since this home was generally kept warm, dilution air was added to the furnace air handler. The post-radon reduction charcoal canister results shown on this plot were taken in January when demand on the passive system would be supplying dilution air to the house.

9.5 HOUSE C10B

Figure 30 shows the results of monitoring in this bi-level home. Interpretation of the results are difficult due to the low pre-radon reduction continuous monitor concentrations measured. In this home, because of active occupants and a continuously occupied house, full closed house conditions were not maintained. The radon reduction plan for this home took into account the very high usage of space and the active life of the family occupying the house. Consequently, the radon reduction plan called for an outside radon reduction system that would involve a minimum of disruption in the house. The fan and all the ductwork were outside of the house. An electrical code requirement included a cutoff switch on the outdoor system; therefore, a warning light was wired inside the house to show when the fan had been cut off allowing the homeowner to reactivate the system. The middle charcoal canister line on this plot shows the increased radon concentrations in this house due to winter conditions. This home may be a candidate for the addition of a passive fresh air vent to the furnace air handler to provide dilution air to the house in the winter.

9.6 HOUSE C31B

This bi-level house was continuously occupied with four small children. The same approach that was taken with house C10B was applied to this home. Figure 31 shows the monitoring results for this bi-level home. Again, winter monitoring may show that this house requires the addition of a passive fresh air vent to the furnace to provide dilution air during winter-time conditions.

9.7 HOUSE C48B

House C48B shown in Figure 32 was the first of the B-floor plans to receive radon reduction techniques. The techniques attempted in this bi-level home proved to be both more costly and less effective than the outdoor methods used in the other two B-floor plan homes. Subslab suction was installed using one hole drilled through the slab in the furnace room. A tunnel was dug out for approximately 1 meter (3.3 ft) out from the hole, under the slab. The subslab aggregate was insufficient to provide adequate subslab suction. Consequently, a labor intensive method of creating perimeter suction was attempted. This method was partially successful in further reducing the indoor radon levels. Finally, an unfinished portion of the foundation behind the earth filled front steps was repaired to prevent exposed earth contact with living space air.

9.8 HOUSE C33C

Results of monitoring in this slab-on-grade house are shown in Figure 33. This house was the most difficult of the 10 demonstration homes to achieve reduced radon levels. The subslab ducts had to be rerouted between the two floors of the house requiring considerable repair of finished space. No subslab aggregate was present and the earth had subsided under the slab leaving a substantial air space. Through perimeter suction, rerouting and sealing of subslab ducts, and a passive fresh air vent system to the furnace, significant radon reductions were achieved in this house.

9.9 HOUSE C32D

Radon reduction in this block-basement home involved sump hole suction, a secondary sub-slab suction at the opposite end from the basement of the sump hole, and extensive sealing. After application of radon reducing techniques difficulties were encountered due to the placement of fan exhausts at ground level where radon-rich air was permitted to leak back into the basement. Figure 34 shows the large radon reductions that were achieved in this house.

9.10 HOUSE C24E

House C24E was the only home selected that was not built by the subdivision developer and the only home with a crawlspace. In this split-level home, the crawlspace had earth exposure and a doorway which opened on to the lowest level of the house. Radon reduction in this home concentrated on isolating and ventilating the crawlspace. Figure 35 shows the results of this radon reduction effort. Due to the project time constraints continuous monitoring results were not collected for the period following radon reduction.

10.0 RECOMMENDATIONS

- A database of all homes receiving the application of radon reduction techniques in Clinton Knoll should be maintained and analyzed. The database should contain pre- and post-radon reduction radon levels. A summary of the radon reduction method used, the house floorplan and any unusual features of the house or the property on which it is built should be included.

- Long-term followup monitoring should be carried out in each of the mitigated homes to determine the average annual radon levels. This monitoring should be carried out for a period of at least two years and should include continuous monitoring for a period of 1 week in each season in an effort to identify seasonal effects on the radon concentrations in the homes and peak exposures.

- In future radon reduction projects at least 1 control home for each 10 demonstration homes should be monitored continuously during the entire period that radon reduction work and monitoring is being done. The control home should not be subjected to radon reduction methods during this time.

- Investigation into the mechanisms controlling the strong diurnal variation in radon concentration in indoor air should be pursued. If periods of high radon levels during the day can be reliably predicted, radon reduction techniques could be directed toward reducing or eliminating those peaks.

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APPENDIX A

RADON REDUCTION PLANS

House Code: C8A

REPORT ON MEASUREMENTS AND RADON REDUCTION PLAN

HOUSE CODE: C8A

DESCRIPTION: C8A is a classic split level with a finished half basement. The basement is divided into three rooms . the largest of which is a family room. One room is used as a child's bedroom. and the third room is used as a storage/workshop area and houses the furnace.

DIAGNOSTIC INVESTIGATION: A substantial leak of radon was found in a transite pipe in the bedroom showing a canister concentration of 1600 pCi/l. A scintillation cell grab sample was taken from electrical outlet in the block wall and showed a concentration of 1700 pCi/l. Pressure dry and blower door measurements were taken. The plumbing chase was considered a good option for suction fan ductwork to the attic. A hole was drilled in the slab and sub-slab pebbles were found to a depth of 3-4 inches.

BEFORE RADON REDUCTION

a) CHARCOAL CANISTERS

EARLY SPRING CONCENTRATION:(State of New Jersey): 791 pCi/l

DATE	LOCATION	CONCENTRATION (pCi/l)
6/25 to 6/27	On bar in basement (house closed)	409
6/27 to 7/1	On bar in basement (house open)	241

b) PYLON AB5 WITH PASSIVE RADON DETECTOR CONTINUOUS MONITOR:

DATE	LOCATION	CONCENTRATION (pCi/l)
6/25 to 7/1	On bar in basement (house closed)	~450 avg. ~720 max.
7/15 to 7/18	On bar in basement	~3.5 avg. ~13 max.

AFTER RADON REDUCTION

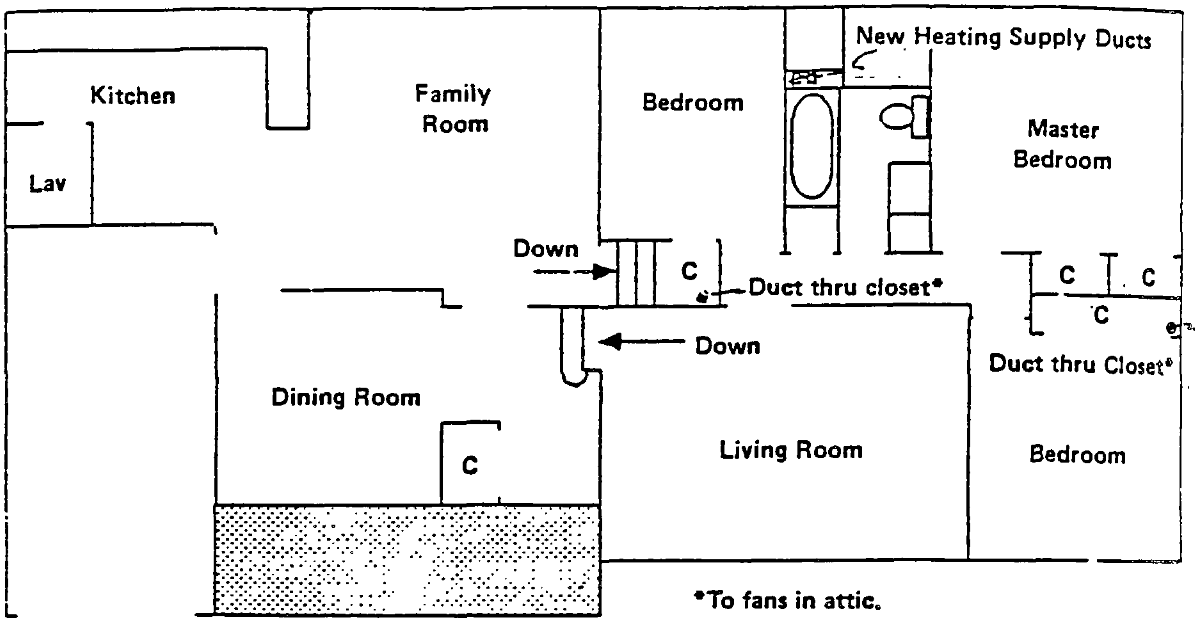
a) CHARCOAL CANISTERS

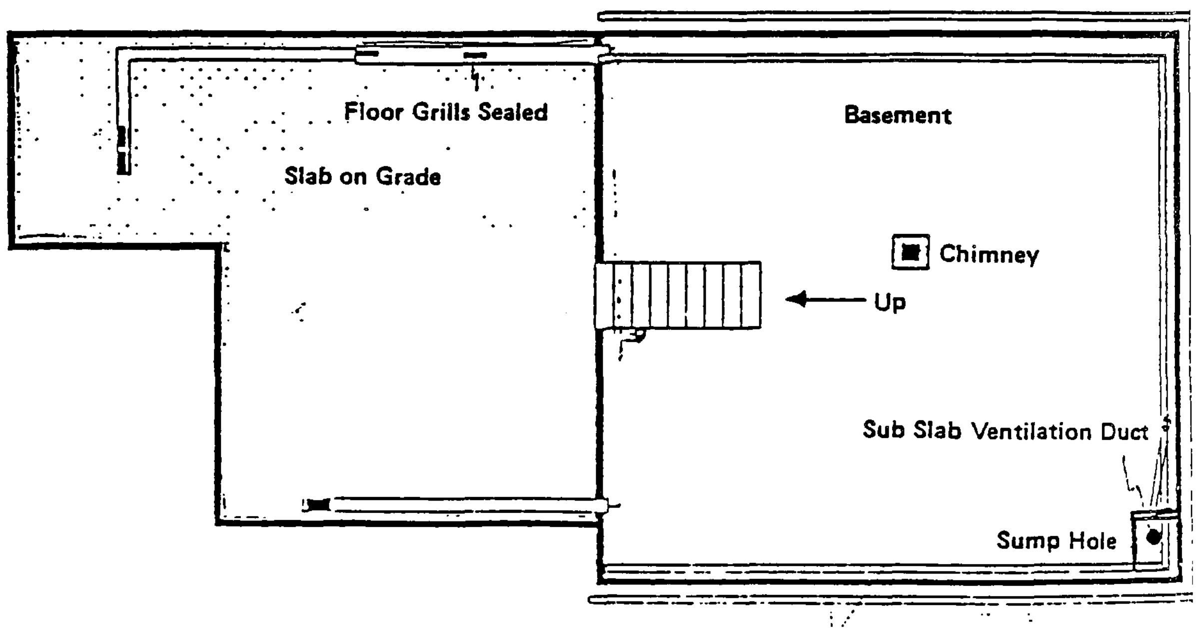
DATE	LOCATION	CONCENTRATION (pCi/l)
7/31 to 8/2	On bar in basement	3
8/15 to 8/17	same	5
8/17 to 8/19	same	4
8/18 to 8/21	same	2.8
11/17 to 11/20	same-heat on	2.9

b) PYLON AB5 WITH PASSIVE RADON DETECTOR CONTINUOUS MONITOR:

DATE	LOCATION	CONCENTRATION (pCi/l)
8/15 to 8/21	On bar in basement (house closed)	~0 min. 12 max. ~4 avg.

"A" Floorplan


New Heating Supply Ducts
Kitchen
Family Room
Bedroom
Master Bedroom
Lav
Down
C
Duct thru closet*
C
C
C
Down
Duct thru Closet*
Dining Room
C
Living Room
Bedroom
*To fans in attic.


Floor Grills Sealed
Basement
Slab on Grade
Chimney
Up
Sub Slab Ventilation Duct
Sump Hole
Footer Drains

RADON REDUCTION PLAN

House Code: CA8

Phase I

Basement Area

Since this house has a finished basement, special effort will be made to cover or enclose duct and pipe work.

1. Seal sub-slab heating ducts.

2. Seal wall and floor crack penetrations (several large openings around existing ducts).

3. Punch hole in floor of furnace room and evacuate.

   a. exhaust pipe to exit building via roof.

Slab-on-Grade Area

1. Seal and depressurize sub-slab ductwork.

   a. drill openings ~1.3 cm (~1/2") through transite duct where access allows. EPA Guidelines should be followed for this activity.

2. run new heating ducts to the kitchen and living room area.

Phase II

Basement Area

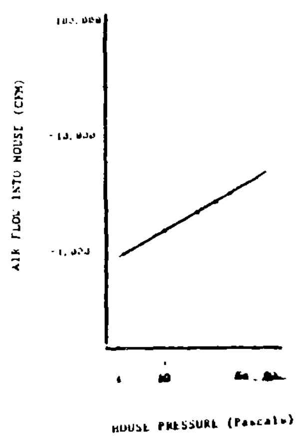
1. Ventilate block wall either actively or passively.

Slab on Grade Area

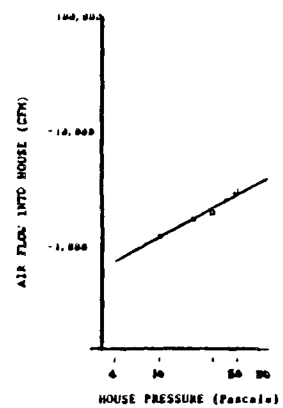
1. Seal perimeter crack at slab-block intersection being careful to allow for active or passive ventilation of the perimeter crack at a later date.

HOUSE TESTS
House C8A
(4/30/86)

Volume m^3 (ft^3)	Temperature in °C (°F)	Temperature out °C (°F)	Barometric pressure Pascals	Correlation coefficient	C	N	ACH at 50 Pascals	Effective Leakage Area (LBL Method) cm^2 (square inches)	Equivalent Leakage Area (Canadian Method) cm^2 (square inches)
Basement door open:(1)									
611.6 (21,600)	21 (70)	21 (70)	30.00	0.999	420	0.533	9.40	1,608.7 (249.35)	2,719.4 (421.51)
Basement door closed:(2)									
611.6 (21,600)	21 (70)	21 (70)	30.00	0.985	357.50	0.533	8.01	1,369.7 (212.30)	2,315.6 (358.92)
Redo door closed:(3)									
611.6 (21,600)	21 (70)	21 (70)	30.00	0.998	353.93	0.544	8.26	1,375.5 (213.21)	2,347.7 (363.89)



(1)



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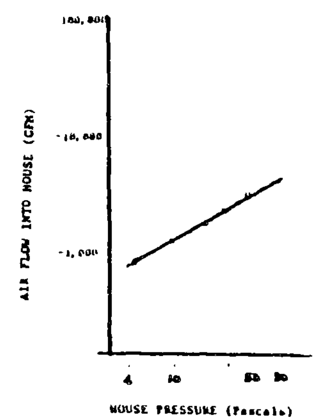


(3)

House Code: C30A

REPORT ON MEASUREMENTS AND RADON REDUCTION PLAN

HOUSE CODE: C30A

DESCRIPTION: This is a split-level house with an unfinished half-basement. An enclosed patio was added to the back of the house behind the family room. The residents prefer their home to be very warm (about 24°C, 75°F), and heavy insulation was found in the attic.

DIAGNOSTIC INVESTIGATION: Leakage was found at the uncapped block tops and in the space around the utility meter window. A major crack below grade was located on the front wall of the house and a baseball-sized hole was located between the internal basement wall and the back wall of the house. Upstairs, further leakage was found around the kitchen and bathroom. Access to the attic is through the garage. Chimney stack to the basement was located in the plumbing chase. The force air heating ducts ran under the slab. Grab sample measurement of air in these ducts showed concentrations as high as 53,000 pCi/l. Concentrations in the drain tile around the sump were 36,000 pCi/l and in the sump hole itself they were 2100 pCi/l.

BEFORE RADON REDUCTION

a) CHARCOAL CANISTERS

LATE SPRING CONCENTRATION:(State of New Jersey): 2254 pCi/l

DATE	LOCATION	CONCENTRATION (pCi/l)
6/7 to 6/9	basement-house closed	1450
6/9 to 6/14	basement	498

b) PYLON AB5 WITH PASSIVE RADON DETECTOR CONTINUOUS MONITOR:

DATE	LOCATION	CONCENTRATION (pCi/l)
6/6 to 6/13	Basement	max. ~ 2600 min. ~ 75

AFTER RADON REDUCTION

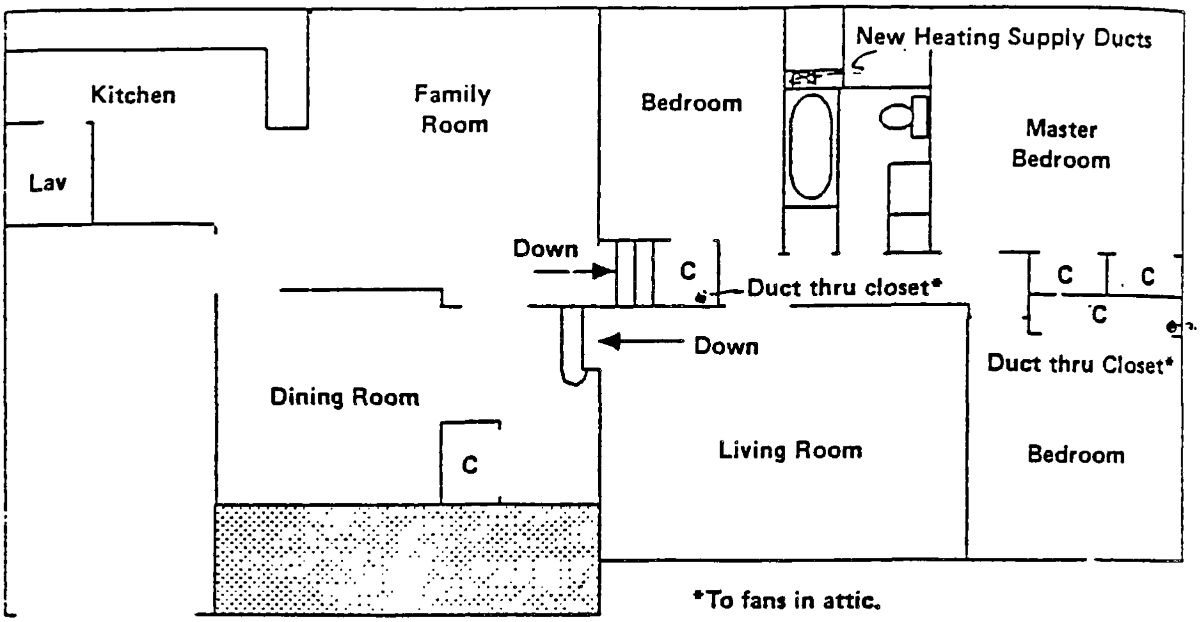
a) CHARCOAL CANISTERS

DATE	LOCATION	CONCENTRATION (pCi/l)
6/27 to 7/2	dining room	2
6/27 to 7/2		4
7/3 to 7/5		3.5
7/5 to 7/7		2.4
7/7 to 7/9		3.4
11/17 to 11/20		4.1

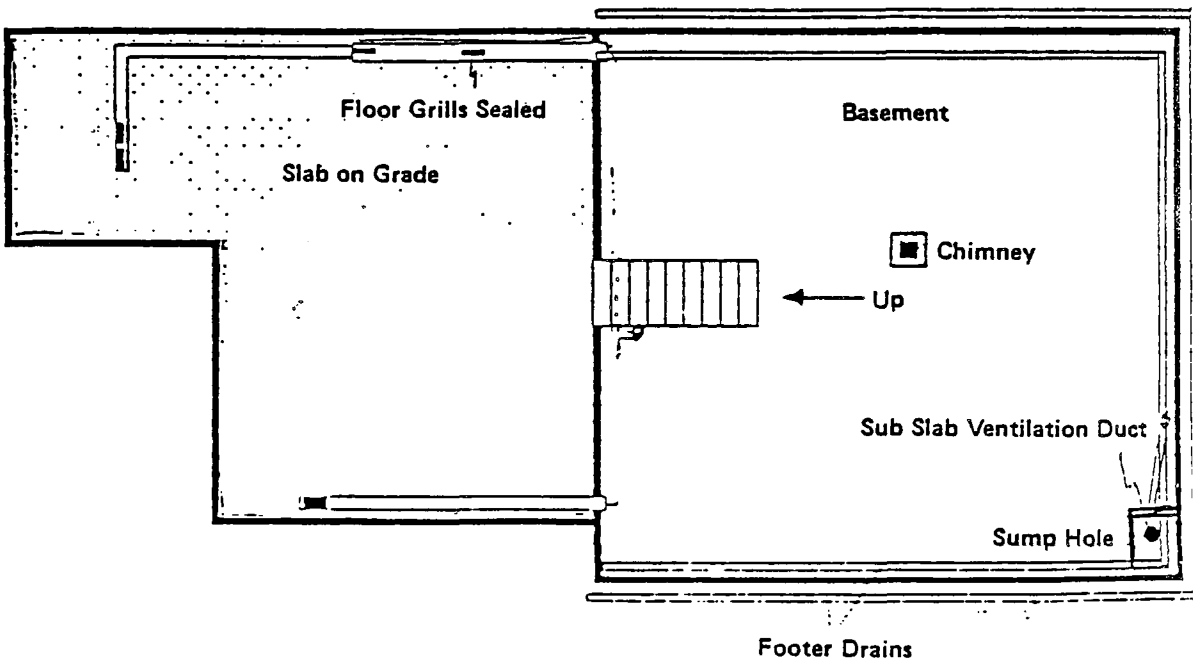
b) PYLON AB5 WITH PASSIVE RADON DETECTOR CONTINUOUS MONITOR:

DATE	LOCATION	CONCENTRATION (pCi/l)
6/26 to 6/27	basement level I radon reduction plan	max ~ 8 min ~ 0
7/3 to 7/10	basement level II radon reduction plan	max ~ 20 min ~ 2
8/7 to 8/3	basement	max ~ 20 min ~ 0

"A" Floorplan



New Heating Supply Ducts
Kitchen
Family Room
Bedroom
Master Bedroom
Lav
Down
C
Duct thru closet*
C
C
C
Down
Duct thru Closet*
Dining Room
Living Room
Bedroom
C
*To fans in attic.



Floor Grills Sealed
Basement
Slab on Grade
Chimney
Up
Sub Slab Ventilation Duct
Sump Hole
Footer Drains

RADON REDUCTION PLAN

House Code: C30A

Phase I

Basement Area

1. Seal and evacuate sump hole (see attached diagram).

    (a) exhaust pipe to exit building through roof with care taken to minimize visual impact on living areas

2. Seal wall and floor cracks and penetrations

    (specifically seal open block tops on each side of basement window, at corner where slab level attaches to basement wall and other locations where open blocks are found during site inspection.

3. Supply makeup combustion air to furnace area (passively)

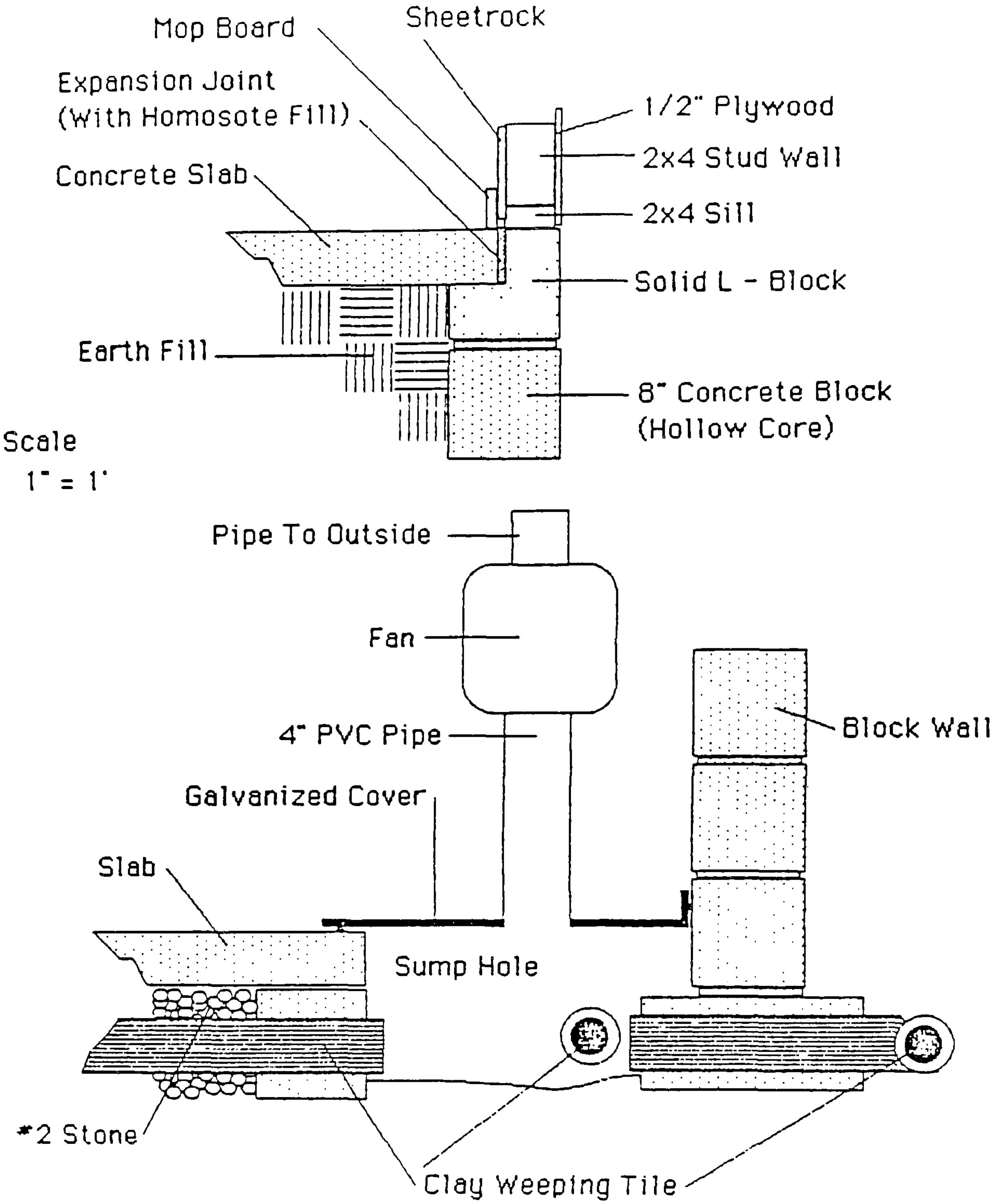
Slab-on-Grade Area

1. Seal and depressurize sub-slab duct work

    (a) drill openings (~1/2") through transit duct where access allows. EPA guidelines should be followed for this activity.

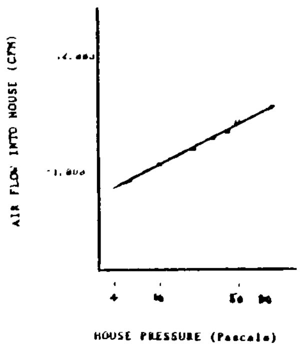
2. Run new heating ducts to the kitchen and living room area.

3. Seal perimeter crack at slab-block intersection being careful to do it in such a way as to allow future active or passive ventilation of the perimeter crack at a later date.


Mop Board
Sheetrock
Expansion Joint
(With Homosote Fill)
1/2" Plywood
2x4 Stud Wall
Concrete Slab
2x4 Sill
Solid L - Block
Earth Fill
8" Concrete Block
(Hollow Core)
Scale
1" = 1'
Pipe To Outside
Fan
Block Wall
4" PVC Pipe
Galvanized Cover
Slab
Sump Hole
*2 Stone
Clay Weeping Tile

HOUSE TESTS
House C30A
(4/30/86)

Volume m^3 (ft^3)	Temperature in °C (°F)	Temperature out °C (°F)	Barometric pressure Pascals	Correlation coefficient	C	N	ACH at 50 Pascals	Effective Leakage Area (LBL Method) cm^2 (square inches)	Equivalent Leakage Area (Canadian Method) cm^2 (square inches)
Basement door closed: (1)									
407.8 (14,400)	21 (70)	21 (70)	30.00	0.993	353.30	0.536	12.03	1,359.6 (210.74)	2,305.48 (357.35)
(refer to graph (2))									
611 6 (21,600)	21 (70)	21 (70)	30.00	0.999	335.86	0.568	8.63	1,351.0 (209.40)	2,358.6 (365.59)



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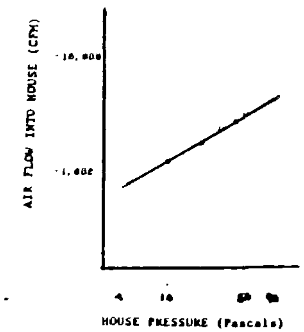


(2)

House Code: C39A

REPORT ON MEASUREMENTS AND MITIGATION

HOUSE CODE: C39A

DESCRIPTION: This is a split level house with half-basement. The basement is not finished. The house has a garage. The basement was built with sump hole. Forced air heating ducts pass under the slab.

DIAGNOSTIC INVESTIGATION: Potential areas of infiltration were found in open block, 2 large cracks along the front basement wall. Leaks around ventiliation ducts and sewer lines were sampled and showed a concentration of 2900 pCi/l. Grab samples ranged from 140-800 pCi/l. The air duct register in the family room read 7 pCi/l.

BEFORE RADON REDUCTION MEASUREMENTS

a) CHARCOAL CANISTERS

EARLY SPRING CONCENTRATION:(State of New Jersey): 1500 pCi.l

DATE	LOCATION	CONCENTRATION (pCi/l)
6/70 to 6/11		basement
10.4		
8/19 to 8/21		basement
7.5		
9/21 to 9/23		basement
8.3		

b) PYLON AB5 WITH PASSIVE RADON DETECTOR CONTINUOUS MONITOR:

DATE	LOCATION	CONCENTRATION (pCi/l)
6/6 to 6/13		basement
max ~ 230		
		min ~ 5
		avg ~ 40
8/7 to 8/13		basement
max ~ 1250		
		min ~ 10
		avg ~ 30

AFTER RADON REDUCTION MEASUREMENTS

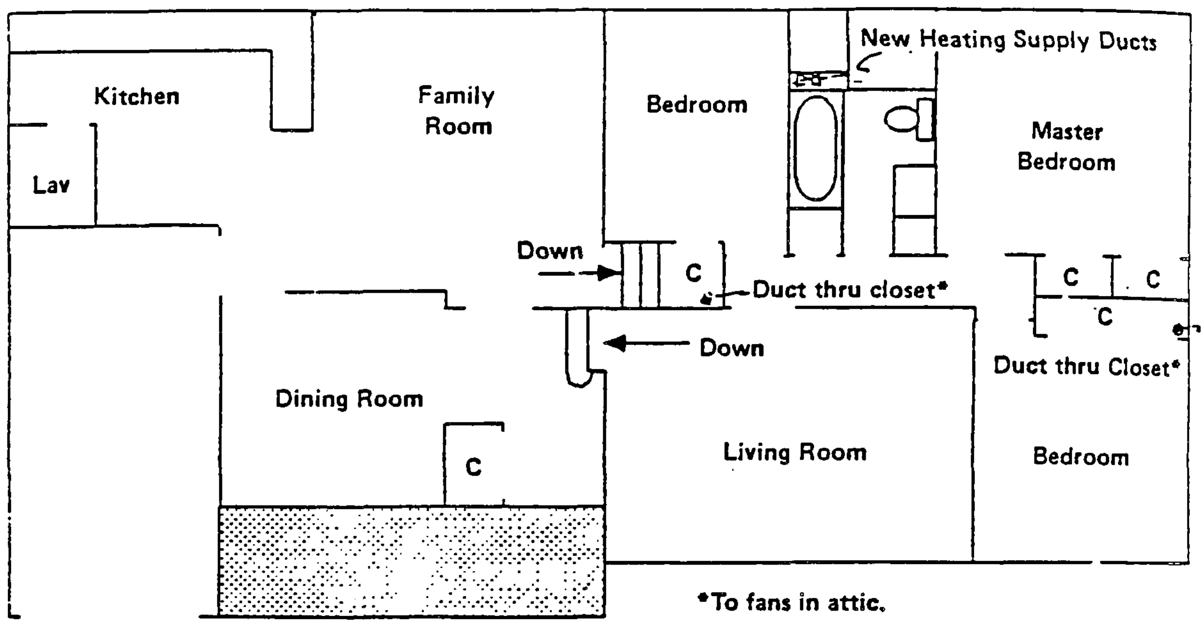
a) CHARCOAL CANISTERS

DATE	LOCATION	CONCENTRATION (pCi/l)
11/17 to 11/20	basement- (heating on)	4.3

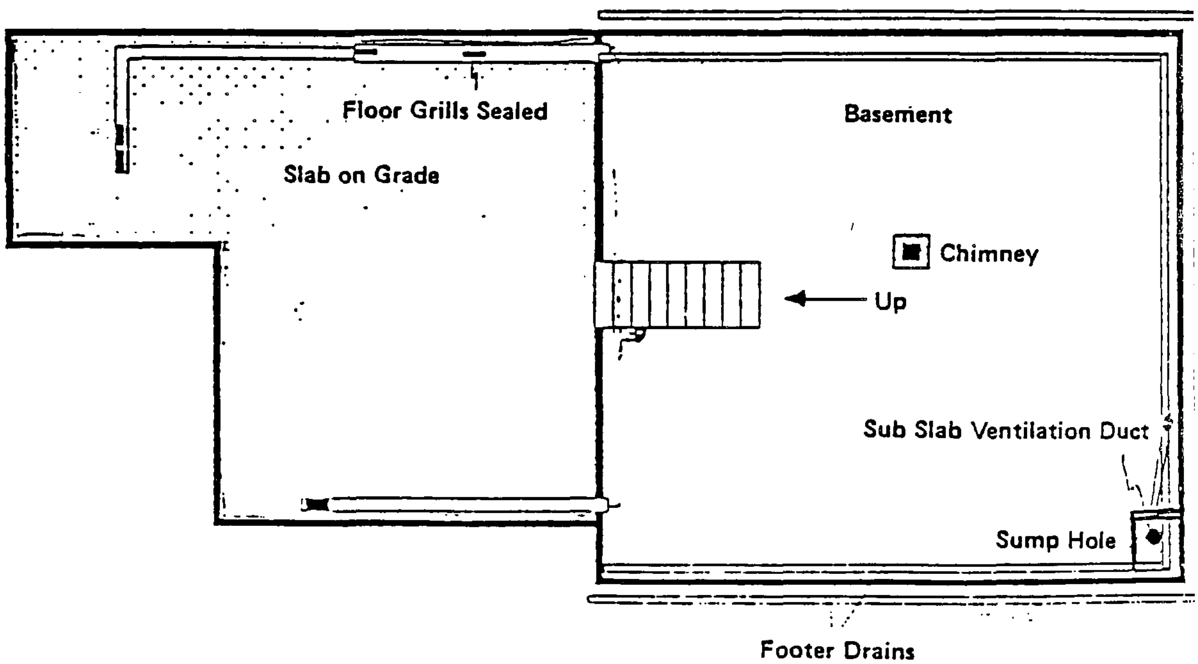
b) **PYLON AB5 WITH PASSIVE RADON DETECTOR CONTINUOUS MONITOR:**

DATE	LOCATION	CONCENTRATION (pCi/l)
8/29 to 9/3	basement - Level I radon reduction plan	 max ~ 14 min ~ 1 avg ~ 9
11/4 to 11/17	basement - Level II radon reduction plan	 max ~ 14 min ~ 0 avg ~ 7

"A" Floorplan



Kitchen
Family Room
Bedroom
New Heating Supply Ducts
Master Bedroom
Lav
Down
C
Duct thru closet*
C
C
C
Down
Duct thru Closet*
Dining Room
C
Living Room
Bedroom
*To fans in attic.



Floor Grills Sealed
Basement
Slab on Grade
Chimney
Up
Sub Slab Ventilation Duct
Sump Hole
Footer Drains

RADON REDUCTION PLAN

House Code: C39A

Phase I

Basement Area

1. Seal and evacuate sump hole (see attached diagram).
   (a) exhaust pipe to exit building through roof with care taken to minimize visual impact on living areas

2. Seal wall and floor cracks and penetrations

   (specifically seal open block tops on each side of basement window, at corner where slab level attaches to basement wall and other locations where open blocks are found during site inspection.

3. Supply makeup combustion air to furnace area (passively)

Slab on Grade Area

1. Seal and depressurize sub-slab duct work
   (a) drill openings ~1.3 cm (~1/2") through transit duct where access allows. EPA guidelines should be followed for this activity.

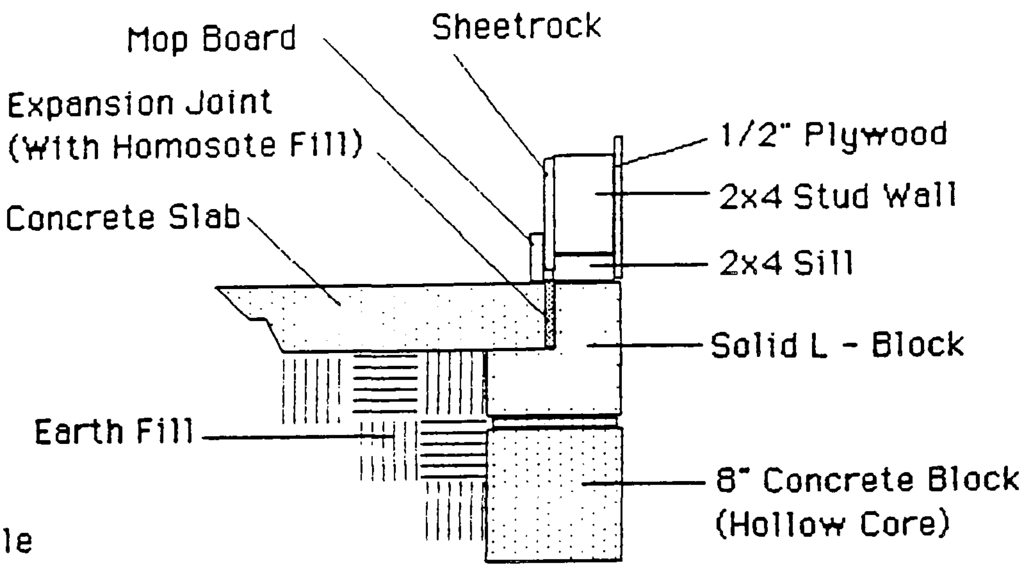
2. Run new heating ducts to the kitchen and living room area.

3. Seal perimeter crack at slab-block intersection being careful to do it in such a way as to allow future active or passive ventilation of the perimeter crack at a later date.

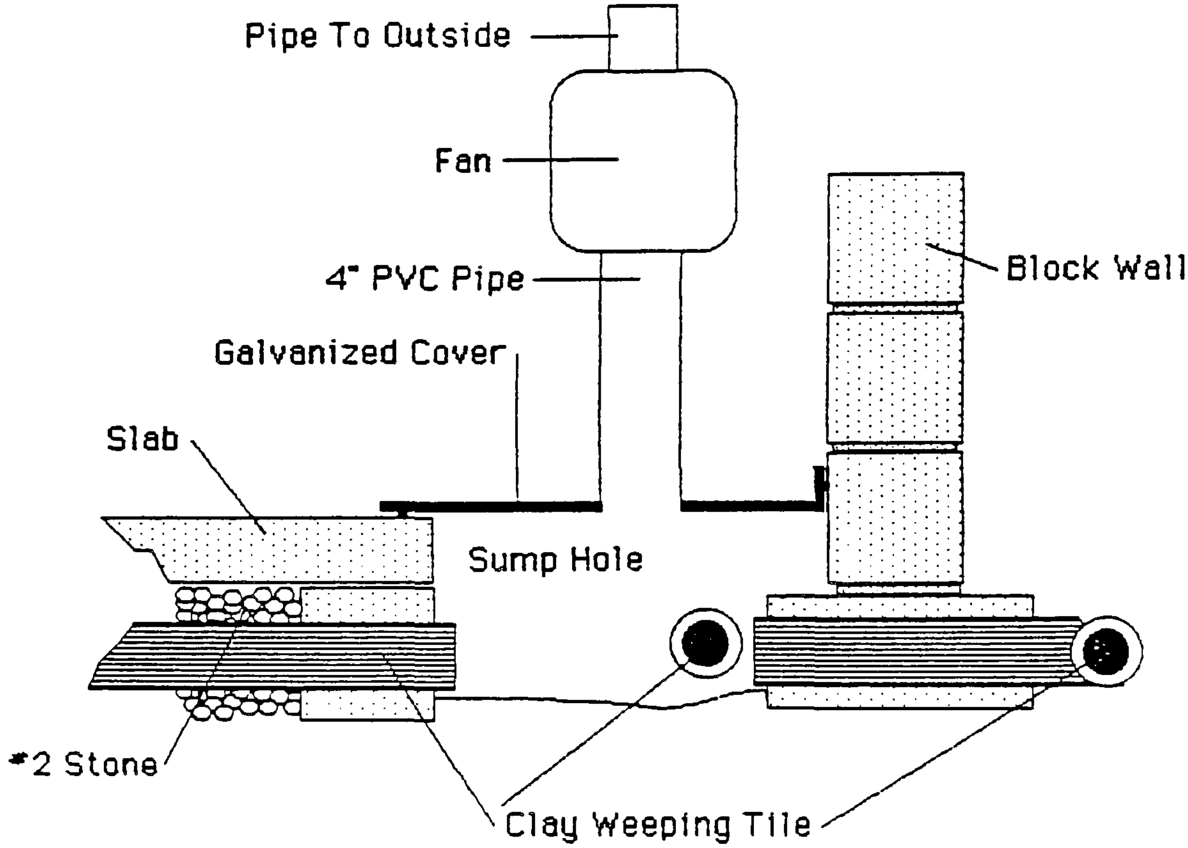
Phase II

1. Increase fan to ~15.2 cm (6") diameter

2. Inspect for holes and cracks previously missed and seal.

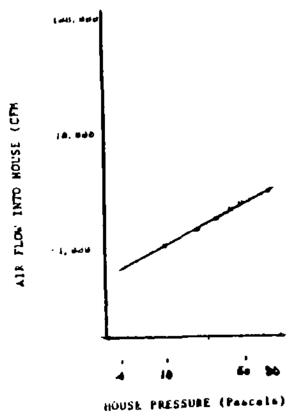

Mop Board
Sheetrock
Expansion Joint
(With Homosote Fill)
1/2" Plywood
2x4 Stud Wall
Concrete Slab
2x4 Sill
Solid L - Block
Earth Fill
8" Concrete Block
(Hollow Core)

Scale
1" = 1'

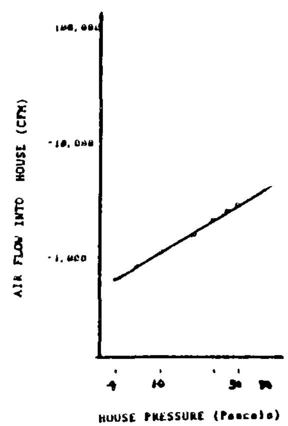

Pipe To Outside
Fan
4" PVC Pipe
Block Wall
Galvanized Cover
Slab
Sump Hole
#2 Stone
Clay Weeping Tile

HOUSE TESTS
House C39A
(4/30/86)

Volume m^3 (ft^3)	Temperature in °C (°F)	Temperature out °C (°F)	Barometric pressure Pascals	Correlation coefficient	C	N	ACH at 50 Pascals	Effective Leakage Area (LBL Method) cm^2 (square inches)	Equivalent Leakage Area (Canadian Method) cm^2 (square inches)
Basement door closed: (1)									
611.6 (21,600)	21 (70)	15.6 (60)	30.00	0.996	324.14	0.506	6.52	1,263.1 (185.29)	1,970.8 (305.47)
Basement door open: (2)									
611.6 (21,600)	21 (70)	15.6 (60)	30.00	0.997	283.35	0.589	7.89	1,172.4 (181.73)	2,085.6 (323.27)



(1)



(2)

House Code: C46A

REPORT ON MEASUREMENTS AND MITIGATION

HOUSE CODE: C46A

DESCRIPTION: This is a split-level with half slab and a, half, semi-finished basement. The basement has been divided into 2 rooms with the larger of the two with indoor/outdoor carpeting and wall panelling covering the cinder block. An attached garage is approximately 6" below the slab of the house.

DIAGNOSTIC INVESTIGATION: No major cracks or openings were found in the basement, although it was impossible to investigate walls and floor in the finished portion of the basement. A floor drain was concealed in a closet. Grab samples in the floor drain ranged from 13,000 to 19,000 pCi/l.

BEFORE RADON REDUCTION MEASUREMENTS

a) CHARCOAL CANISTERS

WINTER CONCENTRATION:(State of New Jersey):.635 pCi/l

DATE	LOCATION	CONCENTRATION (pCi/l)
6/25 to 6/27	basement (house closed)	771.9
6/27 to 6/29	basement	433
7/31 to 8/9	basement	157

b) PYLON AB5 WITH PASSIVE RADON DETECTOR CONTINUOUS MONITOR:

DATE	LOCATION	CONCENTRATION (pCi/l)
6/25 to 7/1	basement - closed	max. ~ 1100 min. ~ 900 avg. ~ 950
8/7 to 8/13	basement	max. ~ 600 min. ~ 30 avg. ~ 220

AFTER RADON REDUCTION MEASUREMENTS

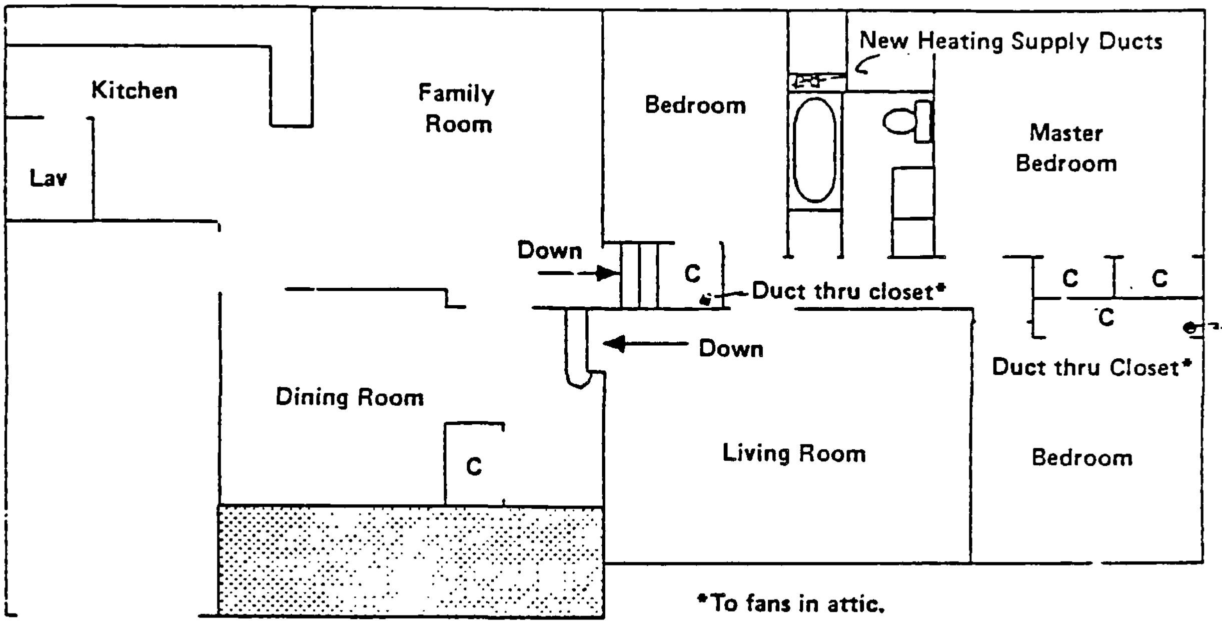
a) CHARCOAL CANISTERS

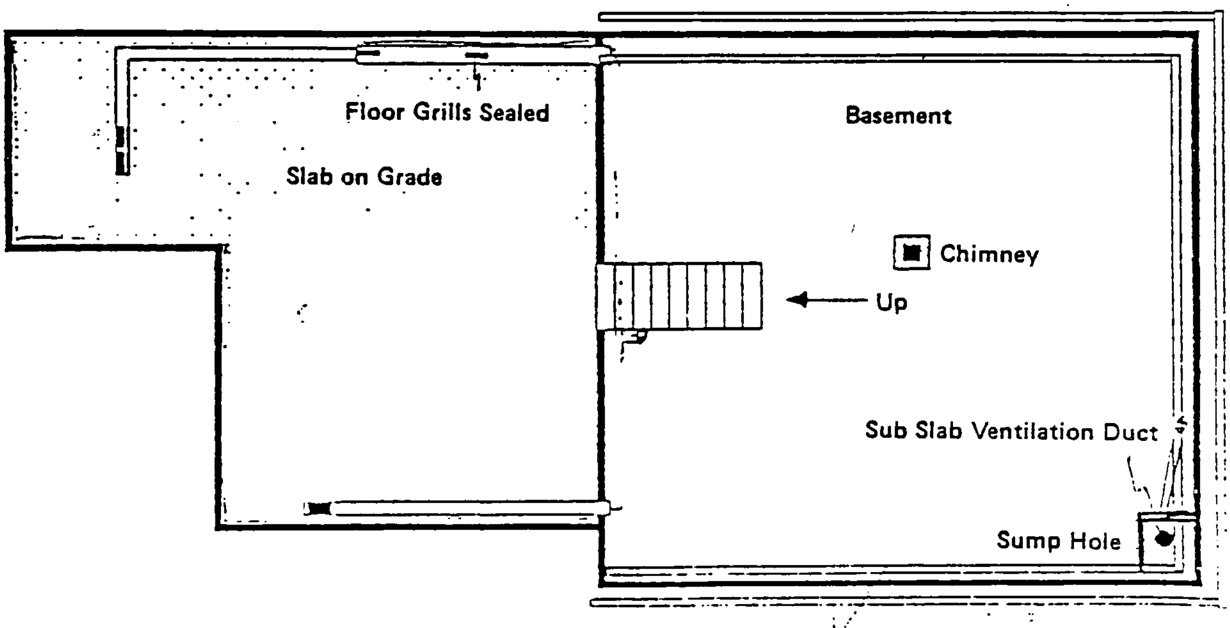
DATE	LOCATION	CONCENTRATION (pCi/l)
8/7 to 8/9	basement (After Level 1) radon reduction	238.5
12/9 to 12/11	family room	5.3
1/3/87 to 1/5/87	basement	

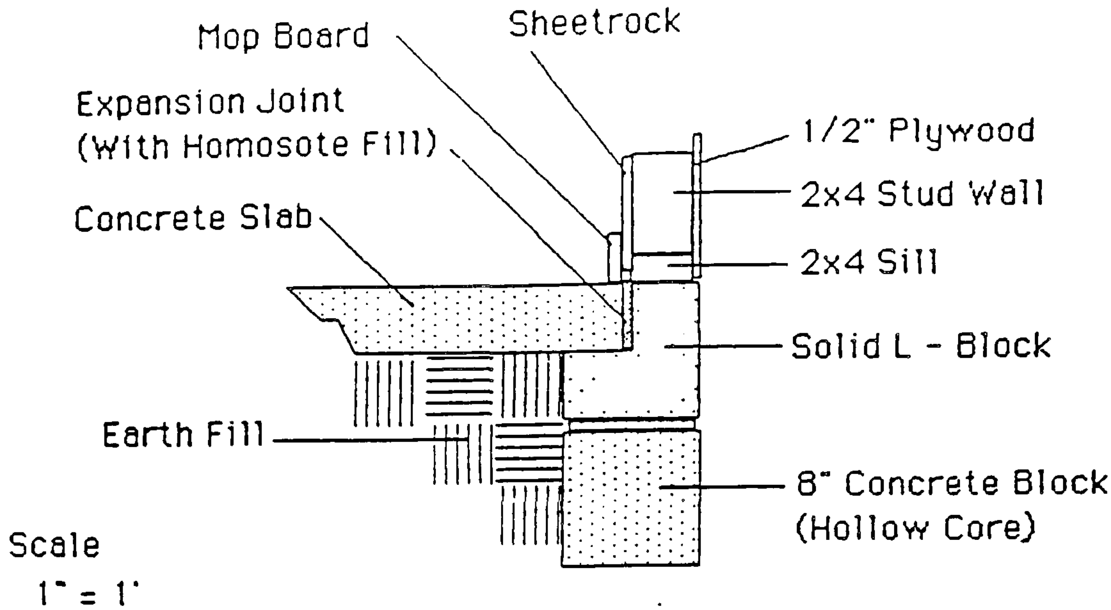
b) PYLON AB5 WITH PASSIVE RADON DETECTOR CONTINUOUS MONITOR:

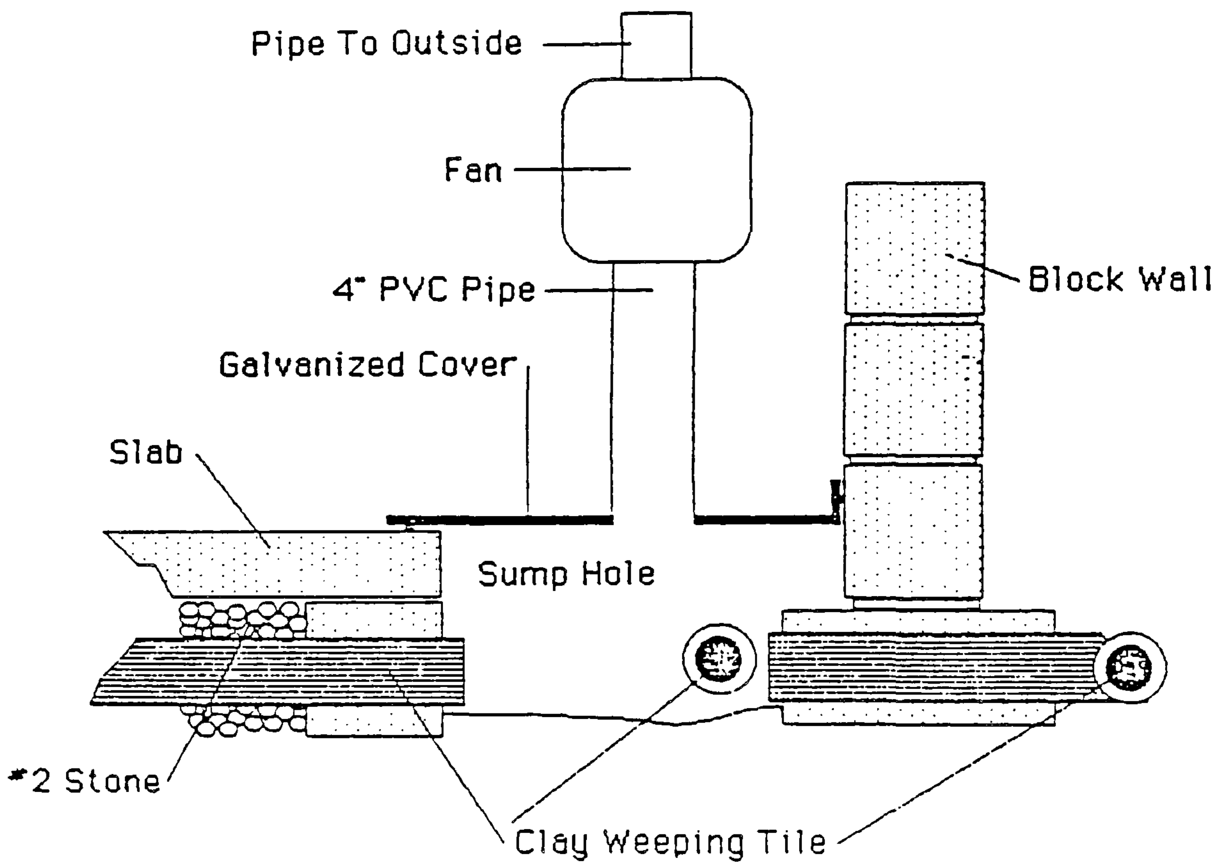
DATE	LOCATION	CONCENTRATION (pCi/l)
8/7 to 8/13	basement	max. ~ 30 min. ~ 3 avg. ~ 13
11/21 to 11/23	basement	max. ~ 17 min. ~ 4 avg. ~ 9

"A" Floorplan


Kitchen
Family Room
Bedroom
New Heating Supply Ducts
Master Bedroom
Lav
Down
C
Duct thru closet*
C
C
C
Down
Duct thru Closet*
Dining Room
C
Living Room
Bedroom
*To fans in attic.


Floor Grills Sealed
Basement
Slab on Grade
Chimney
Up
Sub Slab Ventilation Duct
Sump Hole
Footer Drains


Mop Board
Sheetrock
Expansion Joint
(With Homosote Fill)
1/2" Plywood
2x4 Stud Wall
Concrete Slab
2x4 Sill
Solid L - Block
Earth Fill
8" Concrete Block
(Hollow Core)
Scale
1" = 1'


Pipe To Outside
Fan
4" PVC Pipe
Block Wall
Galvanized Cover
Slab
Sump Hole
*2 Stone
Clay Weeping Tile

RADON REDUCTION PLAN

House Code: C46A

Phase I

Basement Area

1. Seal and evacuate sump hole (see attached diagram).
   (a) exhaust pipe to exit building through roof with care taken to minimize visual impact on living areas

2. Seal wall and floor cracks and penetrations

   (specifically seal open block tops on each side of basement window, at corner where slab level attaches to basement wall and other location that open blocks are found in during site inspection.

Slab on Grade Area

1. Seal and depressurize sub-slab duct work

   (a) drill openings ~1.3 cm (~1/2") through transit duct where access allows. EPA guidelines should be followed for this activity.

2. Run new heating ducts to the kitchen and living room area.

3. Seal perimeter crack at slab-block intersection being careful to do it in such a way as to allow future active or passive ventilation of the perimeter crack at a later date.

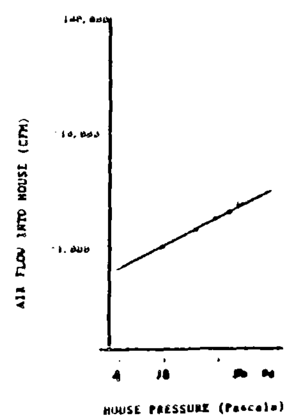
Phase II

1. Increase fan to 15.24 (6") diameter

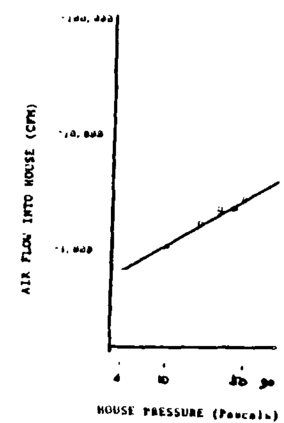
2. Inspect for holes and cracks previously missed and seal.

HOUSE TESTS
House C46A
(4/30/86)

Volume m^3 (ft^3)	Temperature in °C (°F)	Temperature out °C (°F)	Barometric pressure Pascals	Correlation coefficient	C	N	ACH at 50 Pascals	Effective Leakage Area (LBL Method) cm^2 (square inches)	Equivalent Leakage Area (Canadian Method) cm^2 (square inches)
Basement door closed: (1)									
407.8 (14,400)	21 (70)	21.1 (70)	30.00	0.998	339.76	0.524	11.0	1,284.7 (199.13)	2,153.3 (333.76)
Basement door open: (2)									
611.6 (21,600)	21 (70)	21.1 (70)	30.00	0.991	306.83	0.584	8.39	1,261.5 (195.54)	2,234.77 (346.39)



(1)



(2)

House Code: C10B

REPORT ON MEASUREMENTS AND READON REDUCTION PLAN

HOUSE CODE: C10B

DESCRIPTION: This is a split foyer house with a finished lower level divided into a family room, 2 bedrooms, a 2 piece bathroom and a utility room. The family room has a woodstove and poured concrete patio behind the family room.

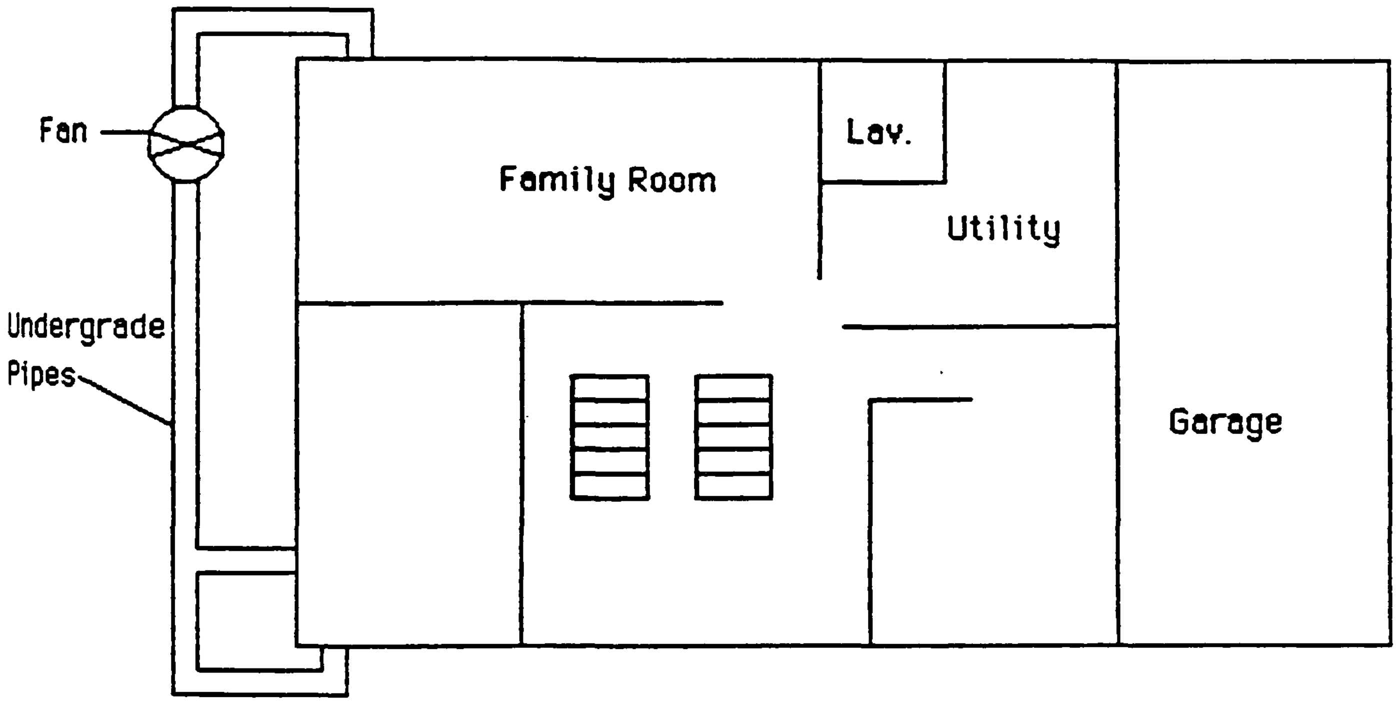
DIAGNOSTIC INVESTIGATION: Few entry routes were located due to the finish on the slab level floor. A grab sample in the plumbing access in upstairs bedroom tub showed a concentration of 0 pCi/l. The slab perimeter crack was exposed in places showing one likely source of infiltration.

BEFORE RADON REDUCTION MEASUREMENTS

a) CHARCOAL CANISTERS

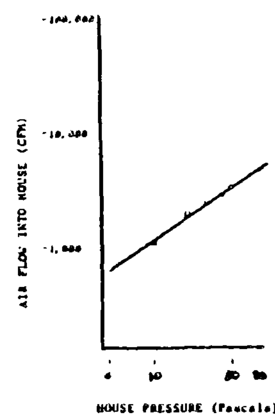
EARLY SPRING CONCENTRATION:(State of New Jersey):. 670 pCi/l

DATE	LOCATION	CONCENTRATION (pCi/l)
8/15 to 8/17	family room	15.8
8/17 to 8/19	family room	9.8
8/17 to 8/19	family room	4.2
8/17 to 8/19	family room	2.5


Fan
Family Room
Lav.
Utility
Undergrade
Pipes
Garage

HOUSE TESTS
House C10B
(4/30/86)

Volume m^3 (ft^3)	Temperature in °C (°F)	Temperature out °C (°F)	Barometric pressure Pascals	Correlation coefficient	C	N	ACH at 50 Pascals	Effective Leakage Area (LBL Method) cm^2 (square inches)	Equivalent Leakage Area (Canadian Method) cm^2 (square inches)
404.5 (14,288)	21 (70)	21.1 (70)	30.00	0.995	255.77	0.667	14.63	1,179.80 (182.87)	2,255.16 (349.55)



House Code: C31B

REPORT ON MEASUREMENTS AND RADON REDUCTION PLAN

HOUSE CODE: C31B

DESCRIPTION: This is a bi-level home. The downstairs portion is divided into general use rooms. The utility room and furnace is located here. The garage has been partially finished with a raised wooden floor. A storage room has been added on behind the utility room. All living areas are finished.

DIAGNOSTIC INVESTIGATION: Grab samples were taken under wood floor above garage slab: 3000 pCi/l; and in various walls, all less than 40 pCi/l. A grab sample in an open block was 5 pCi/l.

BEFORE RADON REDUCTION MEASUREMENTS

a) CHARCOAL CANISTERS

EARLY SPRING CONCENTRATION:(State of New Jersey):. 691 pCi/l

DATE	LOCATION	CONCENTRATION (pCi/l)
5/28 to 6/1	lower level	8.2
6/1 to 6/4	lower lèvel	4.4
8/15 to 8/17	lower level - house closed	89.
8/17 to 8/21	lower level	76.6

b) PYLON AB5 WITH PASSIVE RADON DETECTOR CONTINUOUS MONITOR:

DATE	LOCATION	CONCENTRATION (pCi/l)
8/15 to 8/21	Lower Level	max. ~ 260 min. ~ 5 avg. ~ 65

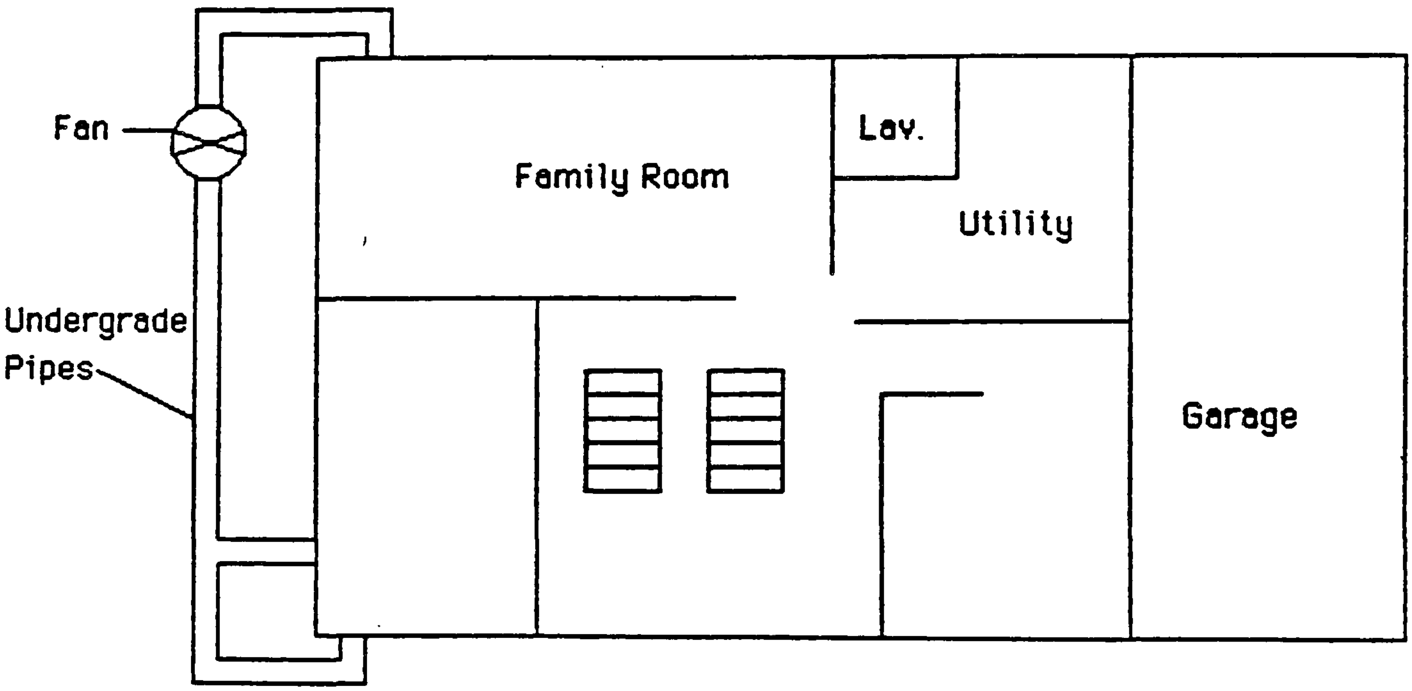
AFTER RADON REDUCTION MEASUREMENTS

a) CHARCOAL CANISTERS

DATE	LOCATION	CONCENTRATION (pCi/l)
11/9	Music Room	4.0
11/9 to 11/15	Music Room	4.0
11/17 to 11/20	Music Room (Heat on)	5.8

b) PYLON AB5 WITH PASSIVE RADON DETECTOR CONTINUOUS MONITOR:

DATE	LOCATION	CONCENTRATION (pCi/l)
11/9 to 11/15	Music Room	5.8


Fan
Undergrade
Pipes
Lav.
Family Room
Utility
Garage

RADON REDUCTION PLAN

House Code: C31B

Phase I

1. In a trench about 2.54 cm, (1') deep (below slab level), lay PVC pipe around the outside of three block walls of the house. One connection on each of the three walls to a fan will provide suction on the block walls. (See attached diagram).

2. Seal perimeter crack on the lower level with polyurethane caulk.

3. Seal all plumbing penetrations.

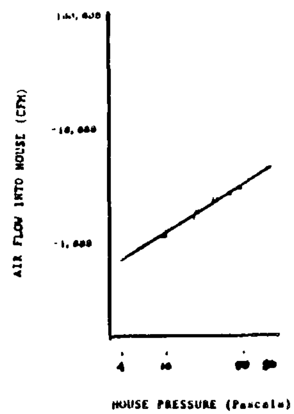
Phase II

1. Supply makeup air to the furnace.

2. Passively supply dilution air to the cold air return ducts. When the circulating system is on, it should draw in approximately 100 cfm of outside air to dilute radon levels.

HOUSE TESTS
House C31B
(4/30/86)

Volume m³ (ft³)	Temperature in °C (°F)	Temperature out °C (°F)	Barometric pressure Pascals	Correlation coefficient	C	N	ACH at 50 Pascals	Effective Leakage Area (LBL Method) cm² (square inches)	Equivalent Leakage Area (Canadian Method) cm² (square inches)
464.4 (16,400)	21 (70)	21.1 (70)	30.00	0.997	305.01	0.585	11.03	1,254.8 (194.50)	2,223.8 (344.69)



House Code: C48B

REPORT ON MEASUREMENTS AND RADON REDUCTION PLAN

HOUSE CODE: C48B

DESCRIPTION: This is a bi-level home. The lower level is slab-partially-below-grade with only a small utility room and attached garage in an unfinished state. An enclosure was added over a poured concrete patio behind the front-to-back family room. A low crawl space under the ground level entrance at the front of the house gives access to the front portion of the foundation.

DIAGNOSTIC INVESTIGATION: Few slab or wall penetrations were found. A hole was drilled in the floor of the front downstairs bedroom closet and a grab sample showed a concentration of 16,000 pCi/l. The foundation under the front stoop was found to be incomplete causing earth to be exposed to the interior structures of the house via the crawl space. A small amount of crushed stone was found under the slab. The perimeter crack was a potential source of infiltration.

PREMITIGATION MEASUREMENTS

a) CHARCOAL CANISTERS

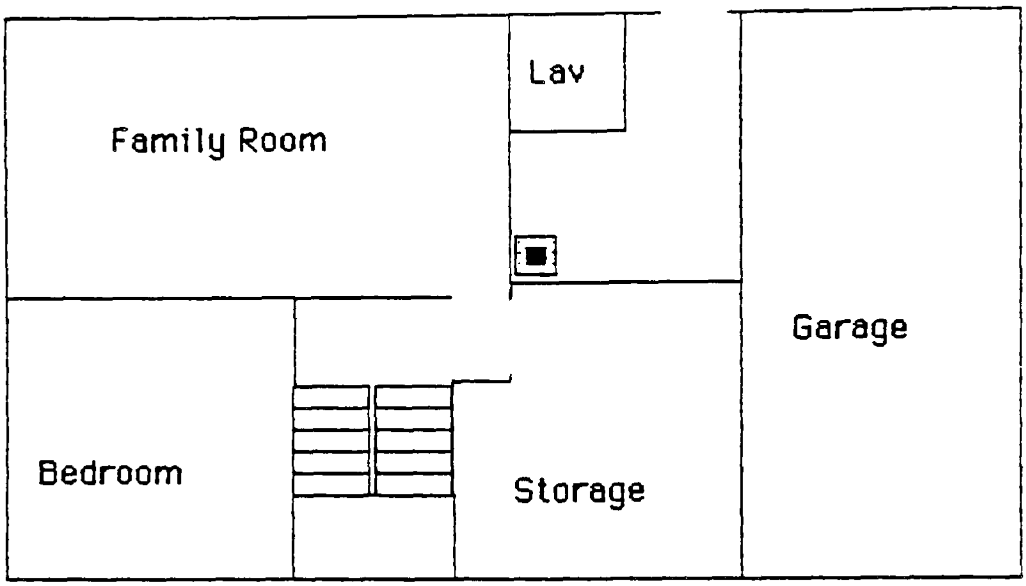
EARLY SPRING CONCENTRATION:(State of New Jersey): 936 pCi/l

DATE	LOCATION	CONCENTRATION (pCi/l)
5/30 to 6/1	downstairs- house closed	771.9
6/1 to 6/4	downstairs	37.6
6/4 to 6/5	downstairs	4

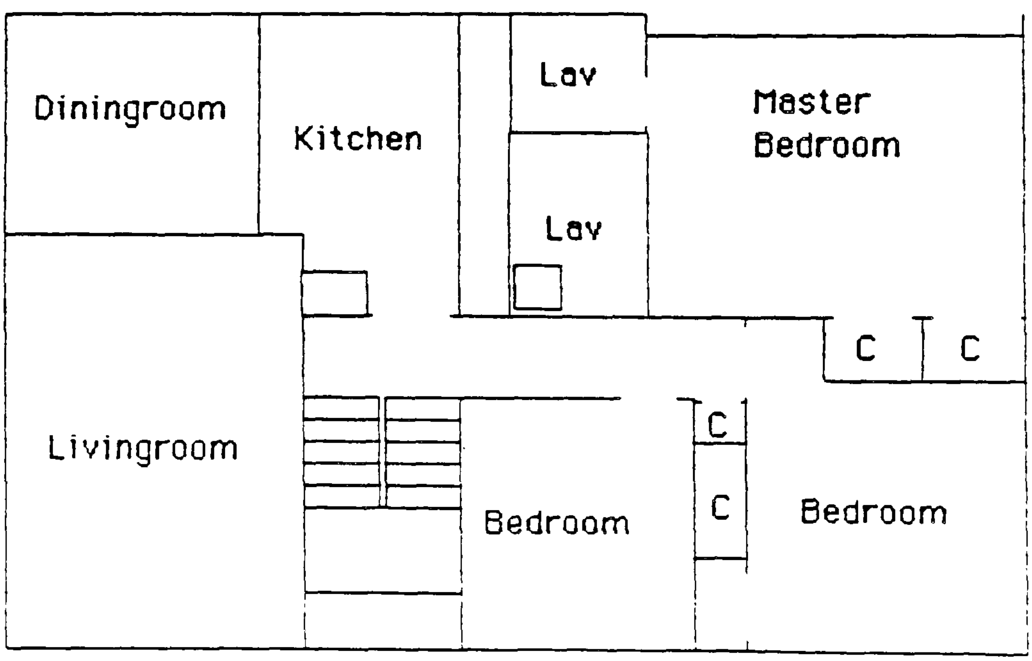
b) PYLON AB5 WITH PASSIVE RADON DETECTOR CONTINUOUS MONITOR:

DATE	LOCATION	CONCENTRATION (pCi/l)
11/4 to 11/9	downstairs	max ~ 30 ave. ~ 8

Bi-Level
1/8" = 1'



Lav
Family Room
Garage
Bedroom
Storage



Lav
Diningroom
Kitchen
Master
Bedroom
Lav
C
C
C
Livingroom
C
Bedroom
Bedroom

RADON REDUCTION PLAN

House Code: C48B

Bi-level with finished lower level. This is a slab-partially-below-grade house with few penetrations through the slab.

Phase I

1. Because there is some crushed stone under the slab the first attempt will be to use sub-slab ventilation. If at any point of installation this is not effective then Phase II shall be implemented with the remainder of Phase I.

2. The perimeter crack shall be sealed using backer rod or equivalent and pourable polyurethane in such a way that the crack can later be ventilated. See Figure 1 for details.

3. All other slab penetrations shall be revealed and sealed. These include plumbing stack, toilet soil pipe and water entry pipes.

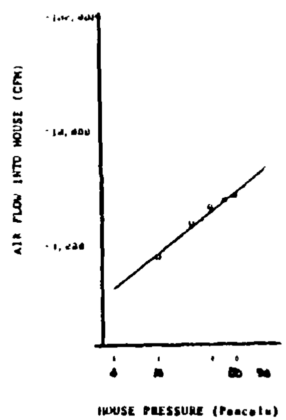
Phase II

1. In addition to Phase I, the perimeter crack shall be evacuated (Another alternative here is to go directly to air-to-air heat exchanger ventilation).

2. Fault in the original construction affecting the foundation under the steps will be repaired, replacing the present dirt and plywood portion with block, then sealing any cracks.

HOUSE TESTS
House C488
(5/2/87)

Volume m^3 (ft^3)	Temperature in °C (°F)	Temperature out °C (°F)	Barometric pressure Pascals	Correlation coefficient	C	N	ACH at 50 Pascals	Effective Leakage Area (LBL Method) cm^2 (square inches)	Equivalent Leakage Area (Canadian Method) cm^2 (square inches)
369.0 (13,032)	21 (70)	21.1 (70)	30.00	0.988	143.89	0.780	14.06	776.58 (120.37)	1,646.8 (255.25)



House Code: C33C

REPORT ON MEASUREMENTS AND RADON REDUCTION PLAN

HOUSE CODE: C33C

DESCRIPTION: This is a 2 story colonial house on slab with attached double garage and add-on room behind the garage. Heating ducts run under the slab. Soil was found to have substantially sub-sided under the slab.· A continuous perimeter crack was located around the slab.

DIAGNOSTIC INVESTIGATION: Cracks in the floor tested with the smoke tube showed air infiltration. Similarly, air entered from a hole drilled in the floor. Air flow was from the interior to the exterior at the baseboard. Grab samples taken of family room air show 0 pCi/l of radon. Thermal by-passes were found around the chimney, the attic scuttle and the plumbing chase.

BEFORE RADON REDUCTION MEASUREMENTS

a) CHARCOAL CANISTERS

EARLY SPRING CONCENTRATION:(State of New Jersey): 1190 pCi/l

DATE	LOCATION	CONCENTRATION (pCi/l)
6/22 to 6/24	livingroom house closed	304.2
7/23 to 7/25	livingroom house closed	106
7/25 to 7/27	livingroom house closed	8.7
7.27 to 8/1	livingroom house closed	8.5

b) PYLON AB5 WITH PASSIVE RADON DETECTOR CONTINUOUS MONITOR:

DATE	LOCATION	CONCENTRATION (pCi/l)
6/16 to 6/24	livingroom	max ~ 7500 min ~ 0 avg ~ 2000
7/23 to 8/1	livingroom	max ~ 280 min ~ 0 avg ~ 30

AFTER RADON REDUCTION MEASUREMENTS

a) CHARCOAL CANISTERS

DATE	LOCATION	CONCENTRATION (pCi/l)
10/4 to 10/10	small bedroom- R. R. Plan Level I	8.5
10/4 to 10/10	furnace room- R. R. Plan Level I	5.8
11/17 to 11/20	livingroom- R. R. Plan Level II	4.7 calculated samples
11/17 to 11/20	livingroom- R. R. Plan Level II	4.7

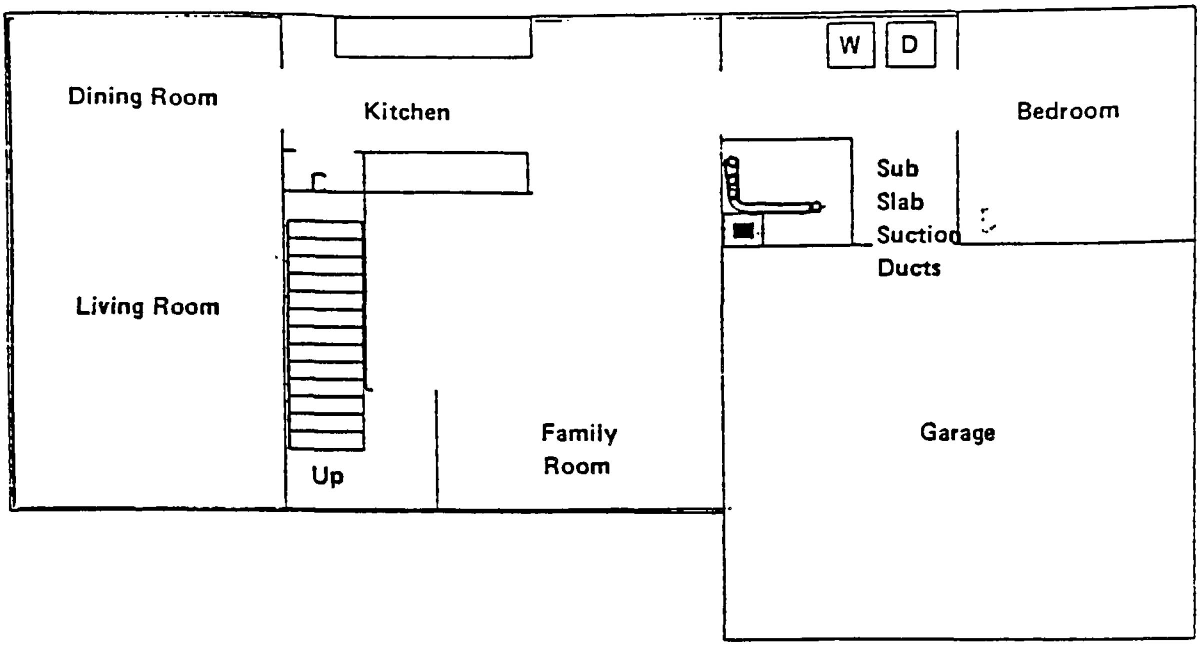
R. R. = Radon Reduction

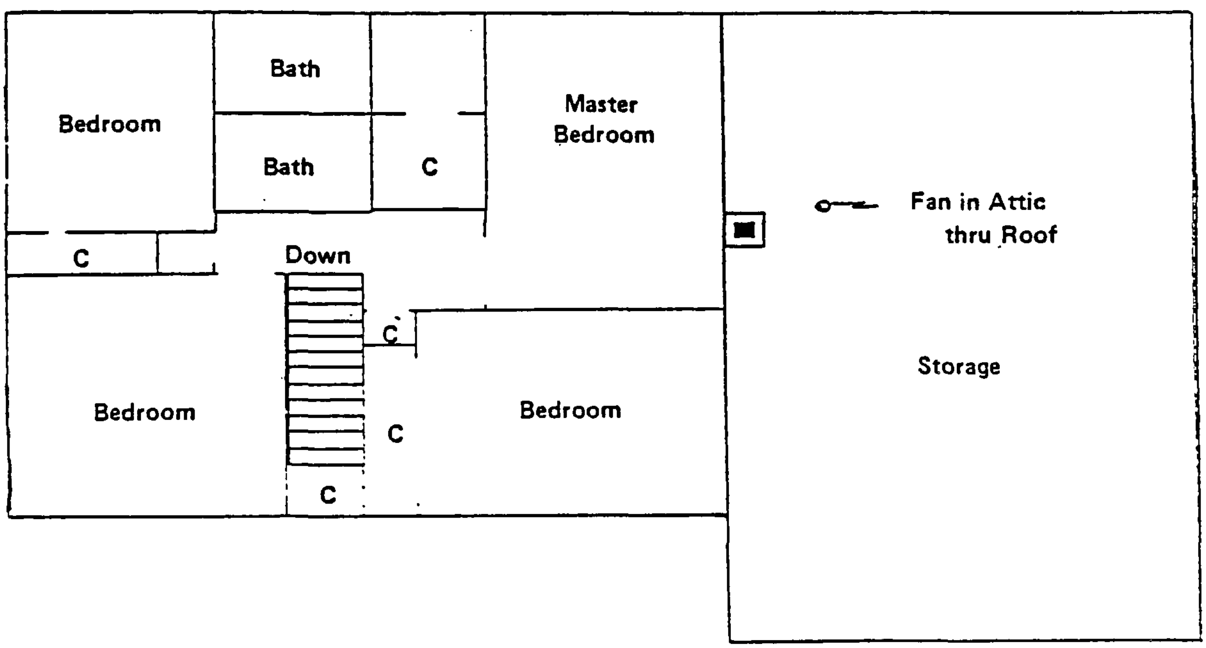
b) PYLON AB5 WITH PASSIVE RADON DETECTOR CONTINUOUS MONITOR:

DATE	LOCATION	CONCENTRATION (pCi/l)
9/11 to 9/16	R. R. Plan Level I	max ~ 33 min ~ 1 avg ~ 14
10/3 to 10/16	R. R. Plan Level II	max ~ 14 min ~ 0 avg ~ 5

R.R. = Radon Reduction

"C" and "D" Floorplan





RADON REDUCTION PLAN

House Code: C33C

Phase I

Slab-on-Grade-Area

1. Seal heating grills from the sub-slab ductwork with plasticized concrete.

2. Vent sub-slab ductwork through storage area over garage to roof turbine. Use 15.3 cm (6") duct and K-6 fan mounted in attic.

3. Seal floor cracks and penetrations (specifically seal perimeter crack at wall slab joint, leaving a small cavity beneath the seal that could later be ventilated, and plumbing penetrations through slab)

4. Supply makeup combustion air to furnace area.

5. Run new heating ducts to the kitchen and livingroom areas.

Phase II

Slab on grade area

1. Ventilate perimeter crack with small fan.

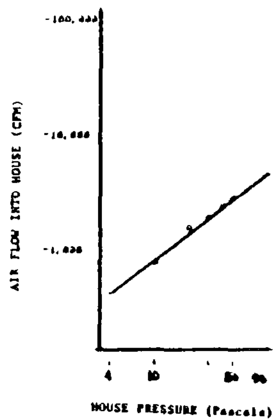
2. Add heat recovery ventilation.

Phase 111

3. Increase fan on perimeter crack to 6" diameter size.

HOUSE TESTS
House C33C
(5/2/86)

Volume m³ (ft³)	Temperature in °C (°F)	Temperature out °C (°F)	Barometric pressure Pascals	Correlation coefficient	C	N	ACH at 50 Pascals	*Effective* Leakage Area (LBL Method) cm² (square inches)	*Equivalent* Leakage Area (Canadian Method) cm² (square inches)
489.9 (17,300)	21 (70)	21.1 (70)	30.00	0.992	142.74	0.776	10.34	776.06 (118.74)	1,618.38 (250.85)



House Code: C32D

REPORT ON MEASUREMENTS AND RADON REDUCTION PLAN

HOUSE CODE: C32D

DESCRIPTION: This is a 2 story colonial with basement and garage. An enclosed deck with crawlspace attaching to the basement through a former exterior window was added on. A sump hole was located in the basement.

DIAGNOSTIC INVESTIGATION: The block wall was extremely porous with several large cracks. Pressure under the slab was found to be different on opposite sides of the basement implying some sub-slab blockage. Several major floor cracks were found. Grab sampling in the air above the sump hole showed a 1200 pCi/l level. Interior basement air that was grab sampled was found to range from 3 - 360 pCi/l. Post-level I diagnostics revealed in leakage around basement windows and at the block to wood juncture of the building.

BEFORE RADON REDUCTION MEASUREMENTS

a) CHARCOAL CANISTERS

EARLY SPRING CONCENTRATION:(State of New Jersey):. 1357 pCi/l

DATE	LOCATION	CONCENTRATION (pCi/l)
6/19 to 6/21	basement	29.1
6/21 to 6/24	living room	7.2

b) PYLON AB5 WITH PASSIVE RADON DETECTOR CONTINUOUS MONITOR:

DATE	LOCATION	CONCENTRATION (pCi/l)
6/16 to 6/25	living room	max. ~ 120 min. ~ 0 avg. ~ 30
8/29 to 9/3	living room	max. ~ 44 min. ~ 3 avg ----
7/23 to 8/11	basement	min. ~ 0 max. ~ 130 avg. ~ 43

AFTER RADON REDUCITON MEASUREMENTS

a) CHARCOAL CANISTERS

DATE	LOCATION	CONCENTRATION (pCi/l)
9/21 to 9/26	basement level I R.R.	20.1
11/17 to 11/20	basement fans sealed	8
12/9 to 12/11	family room level II R.R. heat on	5.1
12/9 to 12/11	basement	11.3

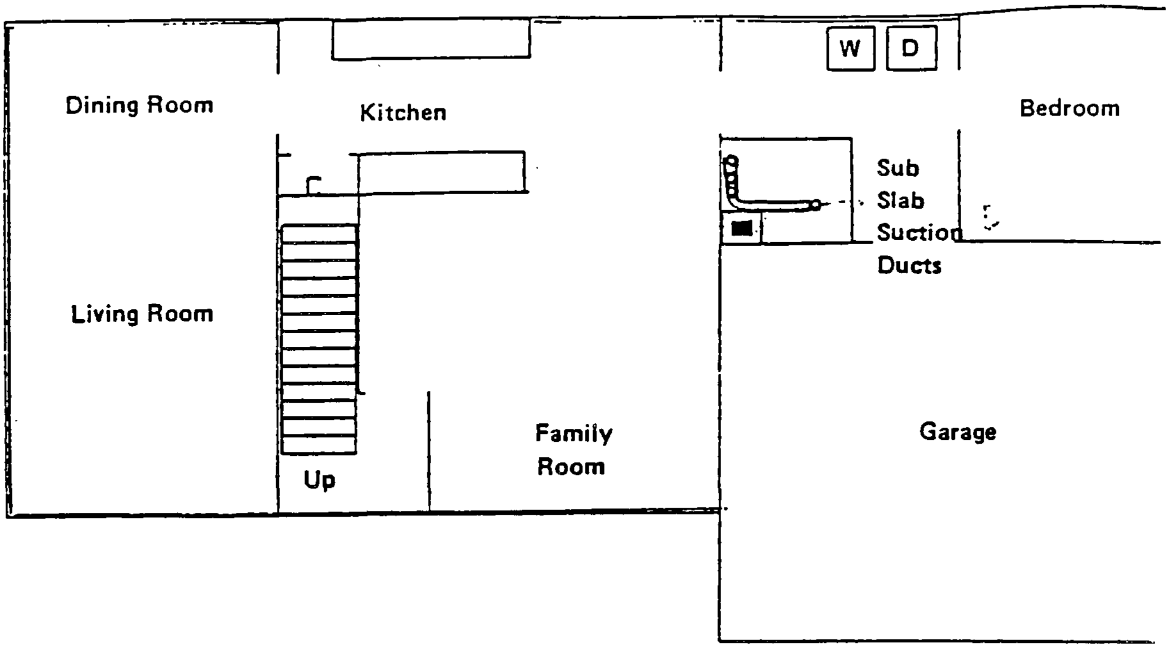
R.R. = Radon Reduction

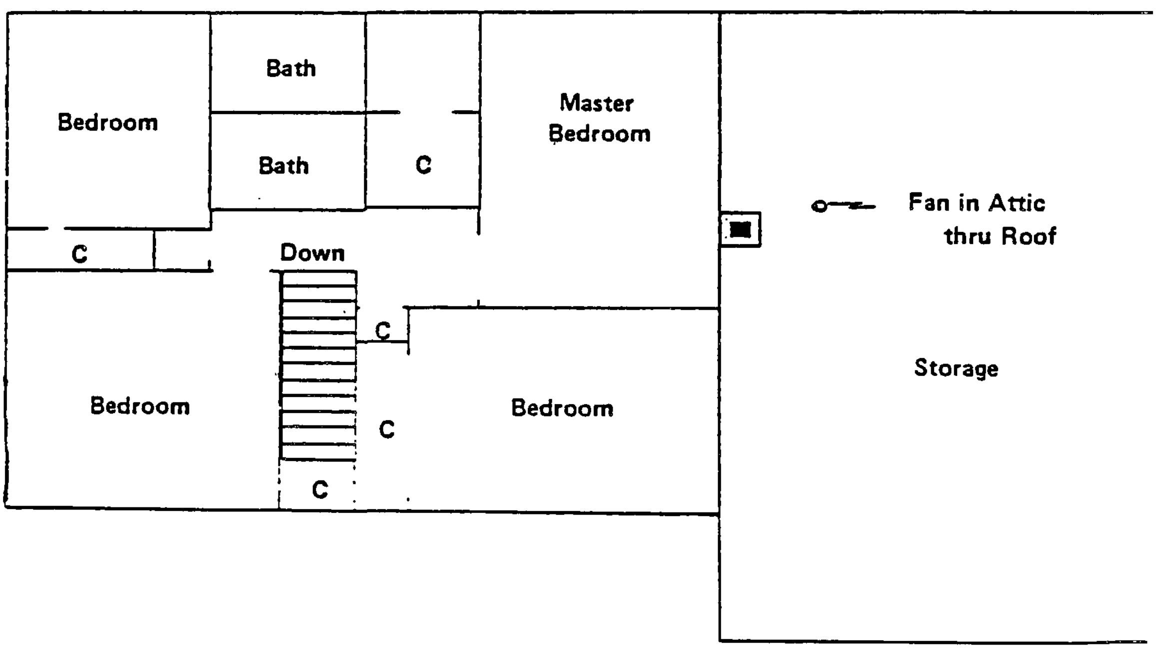
b) PYLON AB5 WITH PASSIVE RADON DETECTOR CONTINUOUS MONITOR:

DATE	LOCATION	CONCENTRATION (pCi/l)
8/29 to 9/3	Level II - 1 fan R.R.	min. ~ 3 max. ~ 55 avg. ~ 20
9/3 to 9/20	Level II - 2 fans R.R.	min. ~ 5 max. ~ 180 avg. ~ 73
11/17 to 11/21	Level II - R.R. exhaust raised	min. ~ 3 max. ~ 10 avg. ~ 5.7

R.R. = Radon Reduction

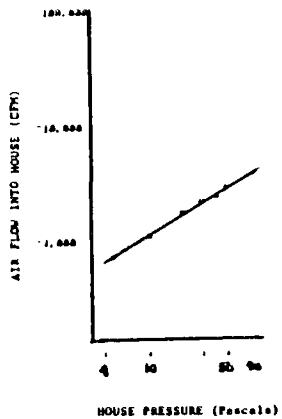
"C" and "D" Floorplan





HOUSE TESTS
House C34D
(5/2/86)

Volume m^3 (ft^3)	Temperature in °C (°F)	Temperature out °C (°F)	Barometric pressure Pascals	Correlation coefficient	C	N	ACH at 50 Pascals	Effective Leakage Area (LBL Method) cm^2 (square inches)	Equivalent Leakage Area (Canadian Method) cm^2 (square inches)
636.8 (22,488)	21 (70)	17.8 (64)	30.00	0.997	295.65	0.591	7.98	1,227.6 (190.28)	2,188.9 (339.28)



House Code: C24E

REPORT ON MEASUREMENTS AND MITIGATION

HOUSE CODE: C24E

DESCRIPTION: This is a split level with open earth crawlspace under the living room and kitchen. The lower slab on grade level is 1/2 finished. The interior of this house has been recently renovated. The finished slab on grade portion has a fireplace and woodstove.

DIAGNOSTIC INVESTIGATION: The crawlspace area is open earth and extremely damp. It is the principle location of soil gas entry to the house. Foundation was blasted out of bedrock.

BEFORE RADON REDUCTION MEASUREMENTS

a) CHARCOAL CANISTERS

WINTER CONCENTRATION:(State of New Jersey): 426 pCi/l

DATE	LOCATION	CONCENTRATION (pCi/l)
8/15 to 8/17	lower level near crawlspace (house closed)	90.9
8/17 to 8/19	lower level	2.5
8/19 to 8/21	lower level	1.3

b) PYLON AB5 WITH PASSIVE RADON DETECTOR CONTINUOUS MONITOR:

DATE	LOCATION	CONCENTRATION (pCi/l)
9/3 to 9/9	lower level	min. ~ 7 max ~ 210 avg. ~ 73

AFTER RADON REDUCTION MEASUREMENTS

a) CHARCOAL CANISTERS

DATE	LOCATION	CONCENTRATION (pCi/l)
9/25 to 9/30	lower level near crawlspace	3.0
12/9 to 12/1	lower level near crawl space heat on	7.2
12/9 to 12/11	living room above crawlspace heat on	12.3

RADON REDUCTION PLAN

House Code: C24E

Level I

1. Work will concentrate on sealing and isolating the crawlspace.

2. Two layers of six mil plastic will be supported by a ankadrain fiber mat and roofing paper. This entire assembly will be sealed to the block walls of the crawlspace using first a caulking compound and then fir wood trim nailed through the three layers to the block.

3. The block wall will be punctured at the back of the house and pipe will be set in puncture and fitted with a fan. The fan will vent to the outside of the house and be covered with a shield.

4. The interior opening to the crawlspace will be fitted with rubber sealing so as to allow access but prevent in-leakage of air to room.

Level II

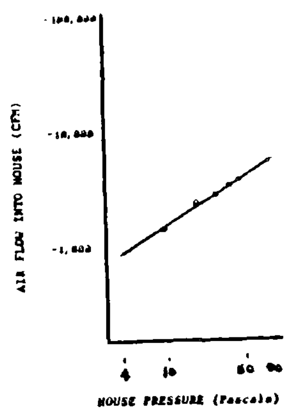
1. Increase fan to 15.24 cm (6") diameter.

2. Three wall suction from the exterior of the slab-on-grade level of the house on three walls.

3. Sealing around the interior perimeter.

HOUSE TESTS
House C24E

Volume m³ (ft³)	Temperature in °C (°F)	Temperature out °C (°F)	Barometric pressure Pascals	Correlation coefficient	C	N	ACH at 50 Pascals	Effective Leakage Area (LBL Method) cm² (square inches)	Equivalent Leakage Area (Canadian Method) cm² (square inches)
358.8 (12,672)	21 (70)	21.1 (70)	30.00	0.996	364.53	0.596	17.76	1,522.45 (235.98)	2,724.96 (422.37)



APPENDIX B

HOMEOWNER PERMISSION FORM

AGREEMENT NO. ______

BETWEEN

RESEARCH TRIANGLE INSTITUTE (RTI)

AND

OWNER(S) AND/OR TENANT(S) OF OCCUPIED HOME

NAME(S) - OWNERS

____

NAME(S) - TENANTS

I/We, as owners of the house and lands located at:

Clinton, NJ

or I/We, as tenants of the house and lands located at:

____

Clinton, NJ

agree to participate in a study sponsored by the U.S. Environmental Protection Agency (EPA) and the New Jersey Department for Environmental Protection and conducted by Research Triangle Institute (RTI), to develop experimental low-cost radon mitigation methods for these premises; and I/we hereby authorize Research Triangle Institute's authorized representatives to install mitigation devices or otherwise take any necessary steps to attempt to mitigate the radon presence, if any, within the house and/or on the premises of the address given above.

I/we understand that this authorization will allow Research Triangle Institute's representatives to have access to this house and its surroundings during reasonable working hours during a period beginning ________________ and continuing through ________________, at no cost to RTI, to the EPA, the U.S. Government, and the State of New Jersey.

I/we realize that for effective mitigation RTI may be required to modify the house design and/or structure for a reasonable period of time agreed upon between the parties to this agreement, in writing, and that with its "Best Efforts" RTI will attempt to return the house to an "as found" condition, at no charge to the Homeowner(s) and/or Tenant(s). In consideration for my/our being selected to participate in this study and other considerations, I/we agree to indemnify and hold harmless RTI, the U.S. Government, and the State of New Jersey for any injury to person or damage to property that may occur as a result of the work done or omitted by or for RTI and/or the U.S. Government and/or the State of New Jersey in connection with this study, including without limitation, modifications to the house design and structure and the installation of mitigation devices. I/we have been advised that the process of installing mitigation equipment may result in a temporary increase in radon concentrations on the premises and that I/we may temporarily vacate the premises during the mitigation process at no cost to RTI, the U.S. Government or the State of New Jersey, or I/we may accept the inconvenience of the process and remain on the premises, understanding that all steps reasonably necessary will be taken to minimize these inconveniences.

RTI will treat the data and resident locations as confidential. All reports to parties other than the EPA will be coded to prevent recognition of the premises participating in the study.

I/we understand that any mitigation devices or installations will remain attached to the premises and become the property of the owner, and RTI, the U.S. Government, and the State of New Jersey shall have no responsibility for the maintenance of such devices or the subsequent use or removal of such devices; and we further understand that these procedures are experimental in nature and that RTI, the U.S. Government, and the State of New Jersey make no promises, nor accept any liability nor have responsibility for the success or failure of the mitigation process, and I/we hereby agree to hold RTI and the Government harmless for any of the possible detrimental effects of radon exposure directly resulting from the performance of the process outlined herein.

Subscribed to the _____ day of   , 1986.

____

Research Triangle Institute
Authorized Agent

Homeowner(s)

____

Tenant(s)

Witness

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/8-87-027	2.	3. RECIPIENT'S ACCESSION NO.
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		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Linda D. Michaels, Terry Brennan, Andrew Viner, Arthur Mattes, and William Turner		8. PERFORMING ORGANIZATION REPORT NO. 471U-3065-52
9. PERFORMING ORGANIZATION NAME AND ADDRESS Research Triangle Institute P.O. Box 12194 Research Triangle Park, North Carolina 27709		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. 68-02-3992, Task 5
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Air and Energy Engineering Research Laboratory Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Task Final; 4/86 - 1/87
		14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES AEERL project officer is Michael C. Osborne, Mail Drop 54, 919/541-4113.

16. ABSTRACT The report discusses the development and demonstration of indoor radon reduction methods for 10 houses in Clinton, New Jersey, where (in the spring of 1986) the New Jersey Department of Environmental Protection (DEP) located a cluster of houses with extremely high radon levels. The work was to be completed before the 1986-87 winter heating season began. The demonstration houses were selected from 56 in the Clinton Knolls subdivision. All of these houses had shown radon concentrations in excess of 64 pCi/l when monitored in the spring of 1986. Each house was inspected, and 10 representative houses were selected for the radon reduction demonstration project. Following intensive diagnostic work and monitoring in each house, house-specific radon reduction plans were developed. With the agreement of the homeowners, radon reduction systems were installed during the summer of 1986. All 10 of the houses had radon concentrations reduced significantly by the fall of 1986. The average cost of radon reduction was $3,127.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution; Ventilation	Pollution Control	13B 13A
Radon	Stationary Sources	07B
Atmosphere Contamination Control	Indoor Air	
	Soil Gas	06K
Residential Buildings		13M
Monitors		14G

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