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Installation and Testing of Indoor Radon Reduction Techniques in 40 Eastern Pennsylvania Houses

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INSTALLATION AND TESTING OF INDOOR RADON REDUCTION TECHNIQUES IN 40 EASTERN PENNSYLVANIA HOUSES

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16. ABSTRACT The report discusses the installation and testing of indoor radon reduction techniques in 40 houses in eastern Pennsylvania. Early in 1985, the Pennsylvania Department of Environmental Resources (PDER) started a large radon survey in communities in the Reading Prong (a granite formation) in eastern Pennsylvania, following the discovery of a house with extremely high radon concentrations, greater than 1.2 MBq/cu m. Candidate houses for this program, with radon concentrations in excess of 750 Bq/cu m, were selected from this survey. A total of 40 houses with representative substructure types were chosen from this group, and mitigation methods were selected and installed from June 1985 to June 1987. Initial soil ventilation installations achieved large reductions in radon concentrations at low cost, but these reductions were not always sustained in colder weather, and several systems were modified during the project to improve their performance. Major reductions in radon concentration were realized in all the houses worked on, with most houses with active soil ventilation systems achieving less than 150 Bq/cu m (4 pCi/L) on an annual average basis in the living areas. Labor and material cost was as low as $500 in a few houses, generally ranging from $1200 to $2400. Costs were as high as $6000 to $10,000 in a few houses with unique features and extensive experimentation.

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Radon	Stationary Sources	07B
Residential Buildings	Indoor Air	13M
Monitors	Soil Gas	14G
Ventilation		13A
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ABSTRACT

In 1984 the EPA started the first of several projects to demonstrate that soil-generated radon concentrations in most housing types could be reduced by moderate cost methods. A literature survey of previous work in Canada, Sweden, and the United States identified active soil ventilation as the most promising method.

In early 1985 the Pennsylvania Department of Environmental Resources (DER) started a large radon survey in communities on the Reading Prong (a granite formation) in eastern Pennsylvania, following the discovery of a house with extremely high radon concentrations greater than 1.2 MBq/m³. Candidate houses for this program with elevated radon concentrations in excess of 750 Bq/m³ were selected from this survey. A total of 40 demonstration homes with representative substructure types (basements with concrete block or solid concrete walls) were chosen from this group, and mitigation methods selected and installed from June 1985 to June 1987.

The initial soil ventilation installations achieved large reductions in the radon concentrations at low cost, but these reductions were not always sustained in colder weather and a number of the systems were modified over the course of the project to improve their performance. Air-to-air heat exchangers were installed in three of the houses. In one house the elevated radon concentration was caused by high concentrations of dissolved radon in the well water, and a radon adsorption unit was installed.

Major reductions in radon concentration were realized in all the houses worked on, with most houses with active soil ventilation systems achieving less than 150 Bq/m³ (4 pCi/l) on an annual average basis in the living areas.

The labour and material cost for this work was as low as $500 in a few houses, and generally ranged from $1 200 to $2 400. Costs were high as $6 000 to $10 000 in a few houses with unique features, where extensive experimental work was done.

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SECTION 1.
INTRODUCTION

The U.S. Environmental Protection Agency (EPA) is conducting a program to develop and demonstrate cost effective methods to reduce the concentration of naturally occurring radon gas inside houses. This program is intended to investigate a wide range of radon reduction methods in an effort to demonstrate suitable mitigation approaches for the full range of U.S housing designs, substructure types, construction methods, geological conditions and initial radon concentrations.

This report describes one project in the overall EPA radon mitigation program. Specifically, it describes the installation of developmental radon reduction measures in 40 existing houses with elevated radon concentrations located in the Reading Prong region of eastern Pennsylvania.

The 40 houses were selected to be representative of the substructure types common in that region. All of the houses have basements with concrete floor slabs, sometimes with an adjoining slab-on-grade or crawl-space wing. In 30 of the houses the basement foundation walls are constructed of hollow concrete blocks, and in the remaining 10 houses of poured concrete. The houses had initial indoor radon concentrations of at least 750 Becquerel per cubic meter (Bq/m^3) equivalent to 20 picoCuries per litre (pCi/L) or 0.1 Working Level of radon progeny, as determined by prior measurements conducted by the Pennsylvania Department of Environmental Resources. Most concentrations were considerably higher, with an initial level of 44,000 Bq/m^3 (1,200 pCi/L) in one house. In all but one house, soil gas was the predominant radon source for the house. Well water with up to 11.5 MBq/m^3 (310,000 pCi/L) was the predominant source in the remaining house and is an important secondary contributor in a number of other houses. Extensive gamma measurements in and around the houses gave no indication that elevated radium concentrations in the building materials were a significant radon source in any of the houses.

The active soil ventilation technique for radon reduction was selected for testing in most of the houses. Where soil gas is the predominant radon source, active soil ventilation offers a moderate cost method of achieving the very high levels of reduction (more than 99% in some of these houses) needed to reach the EPA guideline of 150 Bq/m³. Air-to-air heat exchangers (heat recovery ventilators) for increased house ventilation were tested in three of the houses, where the initial radon level was less severely elevated (close to the 750 Bq/m³ level), and reductions of 75% would be satisfactory. Greater reductions with ventilators were not considered practical in view of the natural infiltration rates in these houses. Carbon adsorption systems for radon removal from well water were tested in two houses.

The work described in this report was conducted by AMERICAN ATCON INC. of Wilmington, Delaware, with the assistance of ACRES INTERNATIONAL CORP. of Buffalo, New York. The work was carried out for EPA under Contract No 68-02-4203.

SECTION 2.
SUMMARY AND CONCLUSIONS

Table 1 summarizes the results from the 40 houses worked on in this project. For simplicity, only the result achieved by the final reduction system is shown. Most of the houses had more than one installation during the course of the project, and some installations were modified several times as testing proceeded. These different installations and modifications are described generally in the report, and in detail for each house in Appendix C.

The radon measurements reported in Table 1 below are the arithmetic averages of at least 48 hours of hourly radon measurements both before and after the mitigation systems was activated.

The following conclusions can be drawn from the work carried out in this project:-

1. Where perimeter drain tiles are present at the foot of a buried concrete block foundation wall, suction on this drain should be one of the first reduction approaches considered because: a) high reductions are often achieved, as the drain applies suction near the footing where it is most effective; b) it is generally the least expensive of the active soil ventilation approaches, and the most practicable for do-it-yourself installation, and c) where the tiles drain to a point outside the house, the entire installation can be carried out from outside, offering advantages in convenience and aesthetics. Unfortunately, perimeter drain tiles are not always present.
2. Sub-slab suction, using individual exhaust pipes penetrating into the sub-slab fill, can be very effective in houses with either hollow-block or poured concrete foundation walls. Accordingly, it should be considered as a candidate control approach whenever major reductions are needed. If the sub-slab permeability is good, only one or two suction points can be sufficient. Even if the sub-slab permeability is low, good performance can be obtained if more suction points are installed, located near the known soil gas entry routes. For example, best results were

achieved when one or more suction points are placed near each load-bearing block wall (including interior as well as perimeter walls). The actual number and location of suction points required in a given house will depend upon the nature and uniformity of the sub-slab permeability, the location of the major soil gas entry routes relative to the exhaust points, and system design parameters (such as whether a hole is excavated under the slab where the pipe penetrates, in order to reduce system pressure loss). It appears, that through proper system design, sub-slab suction systems can give high reductions even in houses with limited or poor sub-slab permeability. Testing the sub-slab permeability before installation could aid in assessing the extent of the sub-slab system that will be required in a given house.

3. In houses with block foundation walls, ventilation of the interconnected network of block voids inside the walls alone can give high radon reductions if there are no major slab-related soil gas entry routes. However, current results suggest that a well-designed sub-slab suction system by itself might be expected to treat both slab-and wall-related entry routes more effectively and less expensively than a wall ventilation system alone. Accordingly, even in block basement houses with high radon concentrations, it might be wise to consider sub-slab suction rather than wall ventilation. Wall ventilation might sometimes be required in combination with sub-slab suction to reduce radon concentrations in concrete block basement houses with high initial concentrations to below 150 Bq/m³ (4 pCi/L).

4. With any active soil ventilation technique, it is important to close major openings in the floor slab and wall so that the suction is distributed effectively over the basement surfaces. In houses where the french drain around the slab edge is required to handle water draining from the wall, the closure must allow water drainage to continue. Closure of openings in the block wall appears to be less important, but all major accessible openings in the floor and walls should be closed as a matter of course. Floor drains connecting to the soil should be trapped or plugged to prevent soil gas entry. Sumps should be capped even if suction on the sump is not planned.

5. The fans in the satisfactory drain tile and sub-slab ventilation systems provided about 100 Pa at the suction points at the soil gas flow

encountered (typically 20 to 70 L/s). Higher suction fans did not produce a performance improvement proportional to the increase in suction.

6. Dilution appears to be the major mechanism in determining the performance of heat recovery ventilators. However, other mechanisms, such as changes in internal air circulation also play a role, so that radon reduction on different floors of a given house cannot be predicted from dilution considerations alone. In houses without forced air circulation, such as those with hot water or electric resistance heat, reductions in the average radon concentration of up to 80% in the living area can be achieved if it is ventilated directly with a reasonably sized HRV. Lesser reductions may be found in other parts of the house. One unresolved issue in selecting a HRV is whether it is cost-effective relative to a simple fan providing a comparable increase in natural ventilation without heat recovery.

TABLE 1 SUMMARY OF RESULTS FROM RADON MITIGATION INSTALLATIONS IN 40 EASTERN PENNSYLVANIA HOUSES

HOUSE NO	TYPE*	FINAL MITIGATION SYSTEM	MEAN RADON LEVEL (Bq/m^3) BEFORE	AFTER	% REDUCTION
1	1	Wall + sub-slab pressurization (baseboard duct)	5 957	185	97
2	1	Wall + sub-slab pressurization (baseboard duct) + carbon adsorption on well water	8 806	111	99
3	1	Wall + sub-slab suction	44 585	185	99
4	1	Sub-slab suction	740	111	86
5	1	Wall pressurization	4 070	185	95
6	1	Sub-slab suction	2 220	185	92
7	1	Sub-slab suction + wall suction	35 376	148	99
8	1	Wall suction	3 256	222	93
9	1	Wall + sub-slab pressurization (baseboard duct over French drain)	13 320	259	98
10	1	Drain tile suction (exterior)	7 733	259	97
11	1	Wall + sub-slab suction (baseboard duct over French drain)	2 220	777	65
12	1	Drain tile suction (exterior)	407	111	75
13	1	Sub-slab suction + drain tile suction (exterior)	3 478	74	98
14	1	Wall suction	2 257	37	98
15	1	Drain tile suction (exterior)	666	37	94
16	2	Wall suction	8 880	148	98
17	1	HRV	2 220	1 406	37
18	1	HRV	74	37	50
19	1	Wall suction	1 295	407	68
20	2	Sub-slab + wall suction, + suction on sub-slab in crawl space	10 434	148	99
21	1	Sub-slab suction	4 107	111	97
22	3	Sub-slab suction (basement + slab)	1 258	333	74
23	3	Sub-slab suction (basement + slab)	3 515	333	97
24	4	Sub-slab suction	1628	333	93
25	4	Sub-slab suction	5 476	296	93
26	1	Drain tile suction (exterior)	3 293	37	99
27	1	Drain tile suction (exterior)	1 554	111	93
28	1	HRV	592	370	38
29	5	Drain tile suction (interior sump) + crawl space liner/vent	1 739	74	96
30	1	Carbon adsorption on well water	1 073	185	83
31	1	Sub-slab suction	17 945	148	99

TABLE 1 (CONTINUED)

HOUSE NO	TYPE	FINAL MITIGATION SYSTEM	MEAN RADON LEVEL (Bq/m³) BEFORE	AFTER	% REDUCTION
32	1	Sub-slab suction	222	36	80
33	4	Sub-slab suction	3 108	185	94
34	4	Sub-slab suction	25 752	185	99
35	4	Sub-slab suction	6 068	37	99
36	3	Sub-slab suction (basement + slab)	5 254	74	99
37	3	Sub-slab suction (basement only)	703	37	97
38	1	Sub-slab suction	13 875	185	99
39	1	Sub-slab suction	888	74	93
40	4	Sub-slab suction	4 181	111	97

* Type 1 Block basement walls
Type 2 Block basement walls + paved crawl space
Type 3 Poured concrete basement walls + slab on grade
Type 4 Poured concrete basement walls
Type 5 Block basement walls + unpaved crawl space

SECTION 3.
OBJECTIVES AND APPROACH

The installation of mitigation measures in the 40 houses was conducted in three separate test phases. The objectives for each phase were determined in part by the information gained in the prior phases.

3.1. OBJECTIVES

3.1.1. Overall Objectives

This was the initial field project in EPA's current radon mitigation program. The primary objective was to develop and demonstrate cost-effective methods to reduce the radon concentrations in existing housing with radon levels greater than 750 Bq/m³ down to the EPA guideline of 150 Bq/m³ (4 pCi/L) annual average or lower. The methods were to focus on soil gas as the predominant source of the indoor radon, although testing also addressed well water as a source. The radon reduction methods were tested in houses with substructure type, design and construction details representative of eastern Pennsylvania (and many other parts of the country).

Existing houses (rather than new houses in the construction stage) were selected as the focus of this study because homeowners in existing houses needed to know that the technology was available to address existing radon problems. New construction will be addressed in other parts of the EPA program. The Reading Prong region of eastern Pennsylvania was selected as the test site for because of the large number of homes with high radon concentrations that had been found there. In fact, it was only three months after this contract had been awarded in September 1984 that dramatically elevated radon concentrations of 122 kBq/m³ (3,300 pCi/L) were discovered in one house near Boyertown, PA. It was this house that first alerted the world to the extremely high and hitherto unsuspected indoor levels that could result from naturally occurring radium in the underlying soil and rock. Houses with radon levels above 750 Bq/m³ were emphasized in the program because a significant number of houses with concentrations above that level were identified shortly after this project got underway. The house substructures representative of the region were basements with hollow concrete block or poured concrete foundation walls, sometimes with an adjoining slab-on-grade or crawl-space wing.

Most of the testing in this project focussed on active soil ventilation techniques i.e. techniques which utilize a fan to draw or force radon-bearing soil gas away from the house foundation to prevent entry. Based on an initial literature review phase that examined possible low cost radon mitigation methods, it appeared that active soil ventilation techniques had the greatest potential of providing high reductions in soil gas entry rate with practical systems at reasonable cost, in accordance with the project objective. House ventilation is another mitigative option; high house ventilation rates can be very effective at reducing radon levels, but this approach is not practical during cold weather. One variant of house ventilation, heat recovery ventilators (HRV's), was tested in three houses with less elevated initial radon concentrations. Sealing of soil gas entry routes into the house is another possible mitigative approach, but it was not tested here. Prior experience indicated that is rarely practical or low cost to achieve the high reductions needed here by sealing, due to the extensive and concealed nature of the entry routes in hollow concrete block foundations.

The testing attempted to determine how the necessary radon reductions could be achieved at minimum cost. The object was to ascertain whether "rules of thumb" might be defined which would enable effective mitigation systems to be designed and installed in houses of this type with a minimum of pre-mitigation testing and installation labour. Ideally, the system would be simple enough that the homeowners could install it themselves using standard materials, in which case the system could be truly low-cost - perhaps only a few hundred dollars. Even if a contractor were required, to carry out the radon mitigation work, minimizing the pre-installation testing and installation labour requirements would still minimize costs.

In view of this objective, the initial installations in the first phase of this project were made with a deliberate effort to minimize costs - only minimal efforts were made to close slab and wall openings in conjunction with active soil ventilation systems. In addition, installation methods were used that a homeowner could conveniently employ, rather than methods which would require the skills and equipment of a general contractor. Where the initial system installed using this least-cost approach did not achieve the needed radon reductions, more detailed investigations were carried out to find reasons for the failure. The system was then modified and retested - sometimes more than once - in an effort to determine how the system would have to be designed to be successful under the conditions of the particular house. In some cases, the lessons learned from this modification/retesting indicated that the system could not be installed as simply and inexpensively as had been hoped prior to the initial installation. In other cases it appeared that, with new knowledge obtained from the retesting, this type of system could now be designed to be effective in future houses without an increase in complexity or cost. Modification and retesting normally continued in a given house either until the house had been reduced below 150 Bq/m³ (4 pCi/L), or until it became apparent that no further significant radon reduction could be achieved at reasonable cost by further modifications to the existing system.

It should be noted that there was no prior experience in radon mitigation at these radon levels, or in this type of terrain, when the first phase of the project began. Many of the active soil ventilation design techniques which are now accepted as "conventional wisdom" were not developed when this work began, and, in fact, evolved in part through the experience gained in this project among others.

The scope of this project was not the development of a fundamental understanding of why radon enters a house, nor to discover exactly how a given mitigative system worked. The resources and time available did not permit detailed and extensive testing. Rather, this project utilized practical scientific judgement, together with simple tests, in an effort to quickly and efficiently demonstrate and develop effective moderate cost mitigation technology.

3.1.2. Objectives of Phase 1 Testing

Phase 1 testing focussed on determining the effectiveness of minimum-cost active soil ventilation systems. Steps which would increase the cost of the installation - such as extensive closure of slab and wall openings, or use of equipment which would require a general contractor, were reduced or avoided.

Radon mitigation installations were carried out in 18 houses, with the installation in two of these houses being substantially modified during this phase. Table 2 summarises the installations. All 18 houses had basements with hollow-block foundation walls; one had an adjoining paved crawl-space. In 17 houses, the system tested was an active soil ventilation system; in the eighteenth (House #18), the system was a variation of house ventilation. Of the 17 soil ventilation systems: 4 (Houses #1 to #4) involved suction on vertical pipes penetrating the concrete slab (sub-slab suction): 4 (Houses #5 to #8) involved suction on the void networks inside the hollow-block foundation wall; 2 (Houses #9 and #11) involved suction on a baseboard duct covering a perimeter (french) drain and holes drilled into the block wall cavities; 6 (Houses #10, and #12 to #16) involved suction on exterior drain tiles around the house footings; and 1 (House #17) involved suction on the sub-slab region via a sump in the basement. The initial sub-slab suction systems in Houses #2 and #3 were modified to include block wall ventilation as well as sub-slab suction. In all of the active soil ventilation systems, the fans were operated in suction.

TABLE 2 SUMMARY OF MITIGATION SYSTEMS INSTALLED IN PHASE 1

HOUSE	TYPE*	SYSTEM
1	1	Two point sub-slab suction.
2	1	Two point sub-slab suction.
2A	1	Two point sub-slab; one wall ventilated.
3	1	One point sub-slab suction.
3A	1	One point sub-slab + block wall suction.
4	1	Two point sub-slab suction.
5	1	Block wall suction.
6	1	Block wall suction.
7	1	Block wall suction.
8	1	Block wall suction.
9	1	Sub-slab + wall suction (baseboard over french drain).
10	1	Drain tile suction (exterior).
11	1	Sub-slab + wall suction (baseboard over french drain).
12	1	Drain tile suction (exterior).
13	1	Drain tile suction (exterior).
14	1	Drain tile suction (exterior).
15	1	Drain tile suction (exterior).
16	2	Drain tile suction (exterior).
17	1	Drain tile suction (interior sump).
18	1	Forced air house ventilation.

* Type 1 = Block basement walls 2 = Type 1 + paved crawl space

The results of Phase 1 testing carried out in the summer indicated that:

a) drain tile suction was generally effective even if there was not a complete loop of drain tile surrounding the house,

b) block wall ventilation could be very effective, but not in all houses,

c) sub-slab suction was not an effective mitigation method, presumably due both to the common local practice of pouring the basement floor slab directly on the subsoil without a layer of crushed stone, and low soil permeability preventing the sub-slab suction from extending beneath the footings to prevent soil gas entry through the block walls.

3.1.3. Objectives of Phase 2 Testing

As a consequence of these early results, the Phase 2 primary objectives were:

- to determine what modifications would be required to the original least-cost wall ventilation systems to improve performance by decreasing the wall leakage area. Particular attention was to be given to those houses where the block voids at the top of basement walls could not be closed readily due to openings concealed by exterior brick veneer walls, or fireplace structures.
- to demonstrate successful wall ventilation systems in additional "textbook" houses where all major wall openings were accessible, and could be closed effectively.
- to demonstrate wall ventilation systems in houses where some major wall openings were inaccessible.
- to demonstrate drain tile suction (interior and exterior) in additional houses with a drain adjacent to each buried wall.
- to determine whether sub-slab suction could be effective in houses having poured concrete basement walls, despite the poor performance in houses with hollow concrete block basement walls. The poured concrete wall could not be a radon entry route in these houses.
- to determine whether HRV's would provide sufficient reduction in radon concentrations to be a useful mitigation strategy in houses with moderately elevated radon levels.

Table 3 summarises the installations carried out in Phase 2.

TABLE 3 SUMMARY OF MITIGATION SYSTEMS INSTALLED IN PHASE 2

HOUSE	TYPE	SYSTEM
1A	1	Wall + sub-slab suction (baseboard duct over conventional wall/floor joint)- replaces original sub-slab system.
1B	1	Additional sealing; fans in pressure.
2B	1	Wall + sub-slab suction (baseboard over conventional wall/floor joint -replaces original sub-slab system.
2C	1	House 2B plus carbon adsorption on well water.
5A	1	Wall suction, pressurization (improved system in House 5).
6A	1	Sub-slab + wall suction (sub-slab ventilation added to House 6).
7A	1	Wall suction, pressurization (improved system in House 7).
7B	1	Sub-slab system (separate system in House 7).
7C	1	Sub-slab + wall suction (systems 7A and 7B combined).
9A	1	House 9 with improved sub-slab + wall baseboard system.
14A	1	Block wall suction (replaces original system in House 14).
16A	2	Block wall suction (replaces original system in House 16).
17A	1	Heat recovery ventilator (HRV) (replaces original system in House 17).
18A	1	HRV (replaces original system in House 18).
19	1	Block wall suction.
20	1	Two point sub-slab suction.
20A	1	Five point sub-slab suction (replaces original system in House 20).
21	1	One point sub-slab suction.
22	3	Four point sub-slab suction in basement only.
23	3	Four point sub-slab suction in basement only.
24	4	Three point sub-slab suction.
25	4	Four point sub-slab suction.
26	1	Drain tile suction (exterior).
27	1	Drain tile suction (exterior).
28	1	Drain tile suction (interior sump).
29	5	Drain tile suction (interior sump).
29A	5	House 29 with plastic liner over soil in crawl space venting under liner.
30	1	Carbon adsorption on well water.

* Type 1 Block basement walls.
Type 2 Block basement walls + paved crawl space.
Type 3 Poured concrete basement walls + slab on grade.
Type 4 Poured concrete basement walls.
Type 5 Block basement walls + unpaved crawl space.

As Phase 2 proceeded, it became apparent that some of the conclusions reached at the end of Phase 1 were misleading. In particular, while wall ventilation could prevent entry of soil gas and radon through the hollow block wall, the connection from the walls to the sub-slab space was generally not good enough to deal with major slab entry routes. Moreover, sub-slab suction now appeared to offer much greater potential than seemed to be the case in Phase 1. Sub-slab permeability in many houses was reasonably good, improved installation methods had been developed, and a suitable low cost, quiet, higher-suction fan suitable for soil ventilation work had been identified.

In addition, as testing proceeded during Phase 2, it also became apparent that the radon concentration in some houses had been reduced by the soil ventilation systems to the point where radon in the well water could be responsible for a significant portion of the residual airborne radon concentration.

Accordingly, additional objectives were added to Phase 2:

- to reassess sub-slab suction as a mitigation method for basement houses with block foundation walls.
- to demonstrate that combined sub-slab plus wall ventilation ("5 surface treatment") could provide sufficient reductions in complex concrete block basement houses with high radon concentrations.
- to demonstrate the effectiveness of carbon adsorption for radon removal from well water in :

  a) a house where soil gas had been the predominant radon source, but where soil ventilation had now reduced levels to the point where water could be the major residual source;

  b) a house where well water was the predominant radon source.

With these objectives, the Phase 2 program included major modifications to 10 of the Phase 1 houses. In addition, new installations were made in 12 additional houses beyond the original 18, bringing the total number of houses tested to 30.

Of the 10 Phase 1 houses which were modified, several were houses which originally had wall ventilation systems. The modifications were intended to determine what improvements would be required in the original "least-cost" installations in order to make wall ventilation function effectively in houses having major inaccessible wall openings. The improvements tested included : additional closure of wall openings; additional ventilation pipes in the walls, adjustment of the piping configuration to reduce pressure losses; additional and/or higher suction fans; and testing of the fans in pressure as well as suction. In other houses among the 10, the original Phase 1 sub-slab or drain tile system was replaced with an upgraded wall ventilation system. In Houses #1 and #2A, the sub-slab system was replaced by a "baseboard duct" wall ventilation system around the perimeter. In houses #14 and #16, where ventilation of the partial drain tile loops had been found to be ineffective, the drain tile ventilation system was replaced by a wall ventilation system.

Other modifications to the Phase 1 installations included: addition of sub-slab suction to an original wall ventilation system in order to test 5-surface treatment; replacement of the initial system with an HRV in Houses #17 and #18; and installation of a carbon adsorption unit for radon removal or the well water line in House #2.

In the 12 houses added to the program: a nominally "textbook" wall suction system was tested in 1 house; interior or exterior drain tile suction was installed in 4; sub-slab suction was installed in 2 with block basements, and in 2 with poured concrete basements having adjoining slabs; and radon removal by carbon adsorption from the well water was tested in 1 house.

3.1.4. Objectives for Phase 3 Testing

The objectives for the Phase 3 testing were extensions of those for Phase 2:

- to demonstrate the conditions under which sub-slab suction alone was a sufficient treatment for block basement houses. To determine the conditions under which 5-surface treatment was necessary and to try to optimize 5-surface treatment.
- to demonstrate sub-slab ventilation for basement houses with poured concrete foundation walls.
- to demonstrate sub-slab ventilation for poured concrete basement houses with adjoining slabs on grade.
- to test the effectiveness of an HRV in a house with moderately elevated radon concentrations.

To address these objectives, Phase 3 included modifications to (or replacement of) the mitigation systems in 7 of the Phase 1/Phase 2 houses, plus new installations in 10 additional houses, bringing the total number of houses treated to 40.

Table 4 summarises the installations carried out Phase 3.

TABLE 4 SUMMARY OF MITIGATION SYSTEMS INSTALLED IN PHASE 3

HOUSE	TYPE	SYSTEM
4A	1	Six point sub-slab suction (replaces original in House 4).
6B	1	Three point sub-slab suction (modification of system in House 6A).
7D	1	Seven point sub-slab suction (improved system, sub-slab component of House 7C).
13A	1	Four point sub-slab suction (second system supplementing the drain tile system in House 13).
20B	2	Sub-slab in basement + wall suction + suction on installed sub-slab pipe in crawl space (modification of system in House 20A).
20C	2	Sub-slab suction in basement + crawl space alone (increased sub-slab suction for system in House 20B).
22A	3	Two point sub-slab suction under adjoining slab as well as basement.
23A	3	Two point sub-slab suction under adjoining slab as well as basement.
28A	1	HRV (replaces original system in House 28).
31	1	Six point sub-slab suction.
32	1	Six point sub-slab suction.
33	4	One point sub-slab suction.
34	4	Six point sub-slab suction.
35	4	Six point sub-slab suction.
36	3	Four point sub-slab suction in basement and two point beneath adjoining slab.
37	3	Six point sub-slab suction on basement only.
38	1	Two point sub-slab suction.
39	1	Three point sub-slab suction.
40	4	Twenty point sub-slab suction.

* Type 1 Block basement walls
Type 2 Block basement walls + paved crawl space.
Type 3 Poured concrete basement walls + slab on grade.
Type 4 Poured concrete basement walls.
Type 5 Block basement walls + unpaved crawl space.

In 8 houses the prior installations were modified: 3 block basement houses had improved sub-slab systems (Houses #4A, #6B, and #13A); 2 block basement houses involved optimization of sub-slab plus wall ventilation (Houses #7C/7D and #20C); 2 poured concrete basements involved an improved sub-slab system with adjoining slab treatment (Houses #22A and #23A); and 1 involved replacement of an unsatisfactory interior drain tile (sump) suction system with an HRV (House #28A).

The installations in the 10 new houses included: 4 block basement houses receiving a sub-slab suction system; and 6 poured concrete basements (including 2 with an adjoining slab) receiving a sub-slab suction system.

3.2. APPROACH

3.2.1. Overall Approach

To identify candidate houses for inclusion in this testing program, the Pennsylvania Department of Environmental Resources (DER) contacted prospective homeowners prior to each test phase. For the first two phases, DER contacted all the homeowners regardless of house type, whose houses had been found to have radon concentrations of 750 Bq/m^3 (20 pCi/L) or above based upon DER measurements. By the time house selection was required for Phase 3, extensive data on the house characteristics were available in DER's computerized data base, and so contacts were directed only to homeowners whose houses were above 750 Bq/m^3, and appeared to have both the desired substructure type and an unfinished basement.

Visits were made to the houses of those homeowners who indicated an interest in becoming involved in the program. During the visit a visual inspection of the house was carried out, and the program discussed with the homeowners. In some cases, limited diagnostic testing was done, such as grab samples to check radon levels in the house, near soil gas entry routes, and gamma radiation measurements. The houses were then selected on the basis of the information gained on these visits, utilizing the selection criteria described later.

An agreement between AMERICAN ATCON and the selected homeowners was signed prior to the start of the work. In this agreement, the homeowners agreed to make their house available for installation and testing of the mitigation system. AMERICAN ATCON agreed to install the system at no cost to the homeowner, and to turn the system over to the homeowner (or, at the homeowner's option, to remove the system) at the end of a year of testing. The effectiveness of the system to be installed was not guaranteed.

All the homeowners were promised that their identity, and all data collected in their houses, would be kept confidential. Accordingly, each house has been assigned a code number, and the houses are identified by that number in this report.

As discussed in Section 3.1, the approach involved initially installing mitigation systems in Phase 1 on a least-cost basis, and then modifying the systems as necessary if the initial installation did not provide sufficient radon reductions. The program included a variety of commercially practicable test or diagnostic procedures, but could not include extensive fundamental diagnostic testing.

3.2.2. House Selection Procedure

The contract was awarded in 1984, and at that time there was a limited number of areas where radon measurements had been made on any scale. Radon measurements had been made in Pennsylvania by groups from Princeton University and Argonne National Laboratory, both of whom had found levels as high as 3.7 kBq/m³ (100 pCi/L) in some houses. These concentrations were among the highest measured in the USA at that time, and therefore Pennsylvania looked an attractive site for the study. These groups were contacted in late 1984. As they had agreed to keep their measurements confidential, they could not supply the names of those people with the highest radon concentrations directly to AMERICAN ATCON, but they did agree to send letters to inform these people of the proposed EPA program to demonstrate low-cost radon mitigation measures, and ask them if they would be interested in participating in the program. Neither group received replies to their letters.

In early 1985, the DER started a large radon survey in the Boyertown area as the result of the accidental discovery in December 1984 of a house with average radon levels in excess of 122 kBq/m³ (3 300 pCi/L). By April 1985, approximately 150 houses with at least one survey measurement greater than 0.1 WL or 750 Bq/m³ (20 pCi/L) radon had been identified in the Boyertown area. Subsequently the survey area was extended to cover the whole of the Reading Prong which extends from Reading to Easton in Pennsylvania. By mid 1986 over 25 000 houses had been surveyed by the DER, providing an unparalleled data base of measurements and house descriptions. A summary of the results of all the DER measurements in the houses selected for the program is given in Table A-1 in Appendix A.

3.2.2.1. Phase 1 House Selection

The DER was contacted in early 1985, and were willing to assist in finding persons interested in participating in the first phase of this program. As they had promised the homeowners the measurements would remain confidential they could not release the names, but they did agree to send a letter to each of the homeowners with concentrations in excess of 750 Bq/m^3 (20 pCi/L) to inform them of the EPA program, and provided them with a form letter to return to AMERICAN ATCON if they wished to be considered for participation in the program. This letter also gave permission for DER to release the survey information.

Replies were received from 71 homeowners by early April 1985, a number far in excess of the 18 needed for the first stage of this program. As only a fraction of the houses could be selected, it was felt that the fairest selection procedure would be to visit and inspect all the houses, and only then make decisions on their suitability for the program. In the last two weeks of May, 69 of these houses were visited. Each house was photographed, received a brief visual inspection, and notes were taken on the construction and any other details that might affect the mitigation work.

The criteria used to select 18 houses from the 69 were:

- The homeowners must be willing to participate in a development program such as this.
- The house must be accessible during the work day.
- The house should have a basement with a hollow concrete block walls, because this was most common substructure type among the houses visited.
- The houses should have the features needed for the testing of the intended mitigation systems (e.g., some must have drain tiles).
- The house should not be unnecessarily expensive to mitigate. In particular, houses with moderate sized unfinished basements were preferred.
- The house location should be reasonably convenient to a central location, and in an area where more than one house with elevated radon concentrations had been identified.
- The radon level should be above 750 Bq/m^3.

All of the houses chosen in Phase 1 were within an 10 km radius of Boyertown. Six of the houses were in the country, eight were in rural subdivisions noted for high radon levels in their houses, and four were in town or suburban subdivisions. The houses were typical of the type of houses built in the area over the past 40 years.

Table A-2 shows the locations and initial radon concentration of the houses selected for Phase 1, Table A-3 shows the work planned and carried out in these houses, and Table A-4 shows the sum of contractor charges for labour and materials to carry out the work.

3.2.2.2. Phase 2 House Selection

As discussed in Section 3.1.3 above, 10 of the Phase 1 houses were carried over into Phase 2, either to modify the initial systems or to install different ones. In addition, it was desired to select some additional houses.

The criteria used to select the additional houses were basically the same as those for the Phase 1 houses. The differences were that, for Phase 2:

- Basement houses with poured concrete foundation walls were also considered.
- Houses where the tops of the concrete block basement walls were readily accessible so that they could be closed for wall ventilation, in addition to the other criteria listed above.

By the end of 1985, the DER survey had extended well beyond the original Boyertown area, and had now identified more than 250 houses over 750 Bq/m³ (20 pCi/L). To achieve a greater geographic coverage, and hopefully to reach a number of different housing types, the DER was requested to send a letter to the newly identified houses to inform them of the EPA program, and provide them with a form to indicate if they would be interested in participating in the program.

Replies were received from about 90 of the 250 homeowners, but there was a considerable overlap with the initial group that had responded to the Phase 1 mailing. The DER had collected details of house construction and layout of all these houses, so an initial selection of 27 new candidate houses was made from their records. Some preference was given to houses outside the immediate Boyertown area with concrete basement walls. All houses with exposed earth in the basement or field-stone basement walls were rejected.

In January and February 1986, candidate sites were visited by the Field Construction Supervisor who photographed the house and basement, and noted the construction features that might affect mitigation work. The final selection of 12 additional houses was made on the basis of the selection criteria described above. Four of the 12 additional houses were in a rural subdivision 20 km from Boyertown noted for the high radon levels in the houses, and the remainder were in the country. Three of the houses were on the same hills as houses selected in Phase 1. All of the houses were within a 25 km radius of Boyertown.

Table A-5 shows the locations and initial radon concentration in the houses selected for Phase 2. Table A-6 shows the work planned and carried out in houses during Phase 2, and Table A-7 shows the sum of contractor charges for labour and materials to carry out the work.

3.2.2.3. Phase 3 House Selection

Some of the Phase 1/Phase 2 houses were carried over into Phase 3 for additional work. In addition, it was desired to select additional houses, using the same selection criteria as for Phase 1 and 2.

By the fall of 1986, the DER survey results had been greatly expanded as the result of a large alpha-track detector survey focussed on the Reading Prong region. The measurement results, along with data on the characteristics of the houses, were in the process of being entered into a computerized data base. Using a version of the data base that did not allow names or addresses of the homeowners to be identified, EPA selected 47 previously uncontacted candidate houses that met the screening criteria of radon level above 750 Bq/m^3, unfinished concrete block or poured concrete basement walls, with or without an adjoining slab on grade. As before, the DER sent letters to these 47 homeowners, most of whom lived on the northern end of the Reading Prong in the Allentown - Bethlehem - Easton area.

Of the 47, 23 homeowners responded. These 23 houses were visited in September 1986 with an EPA group including the Project Manager. Each house and basement was photographed and sketched, and extensive notes made on construction details using a standard evaluation form developed by another EPA project. Notes were also made of details that would affect the choice of mitigation method. The final selection of 10 additional homes was made on the basis of the selection criteria.

Table A-8 shows the location and initial radon concentration in the houses selected for Phase 3. Table A-9 shows the work planned and carried out in houses during Phase 3, and Table A-10 shows the sum of contractor charges for labour and materials to carry out the work.

Table A-11 shows the cost of small modifications and fan changes that did not amount to a change of installation.

SECTION 4.
PROGRAM SCHEDULE

4.1. PHASE 1

The first phase of this work was carried out in July and August 1985. The summer months are convenient for outside work, but as the forces that urge soil gas containing radon into the houses are at their lowest at this time, it is difficult to tell if the measures installed will be effective in the winter. All but one of the installations produced major reductions in summer radon concentrations, so further work was suspended until the winter, when the system performance could be measured under more challenging conditions.

Short term measurements were made during November and December 1985 in the Phase 1 houses to confirm that the reductions found in the summer were still valid. Some of the temporary fan installations were modified to cure problems with condensed soil gas moisture blocking the ducts in cold weather, and to increase the suction. Where concentrations were low, "Track-Etch" detectors were placed in the house to provide a long term estimate of the radon concentration. In those places where concentrations had not been reduced, the system was examined to find the cause of the reduced performance, and then modified. Short term measurements were used to judge the value of system changes. When radon concentrations had been reduced to low values, "Track-Etch" detectors were placed in the homes for confirmation.

4.2. PHASE 2

New Phase 2 houses were selected in January and February 1986, and mitigation systems were installed and evaluated in all of these houses by the end of May 1986.

During November and December 1986, most of the exhaust fans on Phase 1 and 2 houses were changed from 50 or 100 L/s fans to 150 l/s plastic body exhaust fans, and system and performance measurements made to see if the higher suction or flow made any performance improvement. Where radon concentrations were low, "Track-Etch" detectors were placed in the house to provide a long term estimate of the radon concentration.

In those places where concentrations had not been reduced, the system was examined to find the cause of the reduced performance, and then modified. Short term measurements were used to judge the value of system changes. When concentrations were reduced to low values, "Track-Etch" detectors were placed in the homes for confirmation.

4.3. PHASE 3

New Phase 3 houses were selected in November 1986, and work on these was conducted between December 1986 and June 1987. Only 150 L/s exhaust fans were used in these installations. Some installations were completed after the end of the heating season, so "Track-Etch" detectors could not be used to give long-term estimates of the cold weather performance.

SECTION 5.
DESCRIPTION OF ACTIVE SOIL VENTILATION SYSTEMS

Most of the radon reduction installations tested during this project involved some form of active soil ventilation. Active soil ventilation was emphasized because it appeared to be the approach most likely to provide the very high reductions usually needed in these houses at a reasonable cost.

The general principle of soil ventilation is to change the pressure in the soil adjacent to the building foundations to divert the radon-bearing soil gas away from the house before it can enter. When fans are employed to produce the pressure change, the approach is referred to as <u>active</u> soil ventilation. The systems can be used to either a) draw suction on the soil around the foundation to collect the soil gas from the soil and to vent it away from the house; or b) to blow outdoor air into the soil, creating a "pressure bubble" underneath the house which forces the radon bearing soil gas away.

If an active soil ventilation system is operated with the fan in suction, as was the case with most of the installations here, it will be effective only if it is able to maintain soil gas pressure lower than the air pressure inside the house near all of the major soil gas entry routes. Under this condition, if there is any gas movement through those potential entry routes, it should be house air flowing out rather than soil gas flowing in. If the fan is operated in pressure, blowing outdoor air into the soil, it will be effective only if it can maintain a sufficiently high air pressure near the entry routes that soil gas will be forced away from them. Soil ventilation systems in pressure also work in part by diluting the soil gas in the general area of the foundations with outdoor air before it can enter the house.

In this project, active soil ventilation was accomplished in several different ways.

- Suction on the perimeter drain tiles located beside the footings for water drainage purposes. The drain tiles can be on the outside of the footings (in which case they are referred to as an exterior drain), or inside the footing, under the slab (interior drain tiles). There were no internal drain tiles in these houses. If the tiles drain to a sump inside the house, drain tile suction is most conveniently carried out by suction on the sump.

- Suction on the region underneath the concrete floor slab, by inserting suction pipes vertically downward through the slab from inside the house.
- Suction on (or pressurization of) the network of voids inside hollow-block foundation walls. This was accomplished by inserting individual ventilation pipes into the void network.
- Suction on both the void space of hollow concrete block walls, and on the sub-slab material, by installing a baseboard duct which covers holes drilled into the wall block cavities and the joint between the floor slab and the walls.

Figures 1 through 5 present generic illustrations of these types of active soil ventilation systems. These figures are taken from the second edition of EPA's "Radon Reduction Techniques for Detached Houses: Technical Guidance". Most of the installations made under this project differ in some details from these generic figures. In fact, the testing under this project helped lead to some of the design refinements which are incorporated into these figures from EPA's guidance document.

SECTION 6.
MEASUREMENT PROCEDURES

6.1. RADON MEASUREMENT PROCEDURES

The performance of the radon reduction systems was determined through two types of radon measurements in the indoor air. The first was short-term monitoring for 2 to 4 days with Pylon AB-5 radon monitors both before and after the system was activated. These measurements provided an immediate indication of the approximate reduction in radon concentration, and whether the post-mitigation concentrations had been reduced below 150 Bq/m³ (4 pCi/L). The second was a long term measurement over a period of up to three months with alpha track detectors during the heating season to indicate whether the house was being reduced below 150 Bq/m³ under worst-case conditions. By comparison with any alpha-track measurements that the DER might have made the previous winter, these long-term measurements could also indicate the long-term winter-time reduction in radon concentrations.

"Control houses" were not used in this project. First, there was no expectation that the variation of radon concentrations in one house chosen essentially at random would be identical to the variations in another house. Second, an effective mitigation system reduces radon concentrations to a low level and keeps them low. This can be shown readily with real-time radon concentration measurements, so "controls" are unnecessary to determine if a mitigation system is effective.

6.2. MEASUREMENT GOALS

The goals of the post-mitigation measurement program were to estimate:

a) the long term average radon concentration with a total measurement uncertainty of less than 80 Bq/m³ (2 pCi/L)

b) the short term average radon concentration with a total measurement uncertainty of less than 10%

c) individual radon concentrations with a total measurement uncertainty of less than 20%

6.3. LONG TERM MEASUREMENTS

The long term average concentration in a house was measured with Track Etch detectors, exposed for a minimum of 1 month, and normally for 3 months. The forces that urge soil gas and radon into a house are at a maximum in cold weather, so detectors were exposed in the winter months when the effect of the mitigation work might be lowest. The original survey measurements by the DER were largely taken in the winter, so their measurements provided a realistic estimate of pre-mitigation radon concentrations for comparison of the long term concentrations before and after the mitigative work. A summary of all the post mitigation alpha track results is given in Table A-12.

6.3.1. Sampling Procedure

The procedure used at the start of the program was to expose detectors in groups of three in both the basement and the living area of the house. The initial criterion for placement was that the basement detectors should be hung centrally, and the upstairs detectors should be placed in locations where they would receive an exposure representative of the occupants.

In the second year of this program the EPA produced a Protocol for Indoor Measurements, and the sampling location criteria were formalised to agree with the Protocol.

6.4. SHORT TERM MEASUREMENTS

The short term variation of radon concentration with time was measured by a Pylon AB-5 operated as a quasi-continuous radon monitor. An internal pump draws an air sample for 10 minutes each hour into a 285 cm³ scintillation cell, and six consecutive 10 minute counts are made. In this mode the machine can make consecutive 99 hourly cycles, and the counts are stored internally. The data is subsequently transferred via the printer interface and a specially designed parallel to serial converter to the RS-232 port of a portable computer. A BASIC program sums the counts, and calculates the radon concentration in the sample, and produces a report. The counts observed in each time period are corrected for the counts resulting from activity deposited in the cell by previous samples, so that the actual radon concentration in the sample is calculated.

To prevent small children from tampering with the machine and altering the settings, each AB-5 is stored and used inside a lockable foam lined aluminum travel case. Two holes are drilled in the case, one for a sample hose to bring in the air, the other for the power cord, so that the machine can operate with the case closed and locked.

6.4.1. Sampling Procedure

The standard procedure was to place the AB-5 in the basement, close the windows and the stair door to standardise the ventilation rate to some extent, and measure the radon concentration over the next 48 hours. A state of quasi-equilibrium between radon supply and removal was usually reached in less than 24 hours. The soil ventilation fan was then turned on or off, depending on the test being made, and measurements continued for another 48 hours. The systems normally develop most of their effect within 24 hours.

The initial criterion for monitor placement was simply that the unit should not be placed close to known or suspected radon entry routes. The basement walls are always colder than the basement air, and there are large convection flows mixing the basement air, so the concentration is relatively uniform throughout each room in the basement, except near radon entry points. In the second year of this program (1986) the EPA produced a Protocol for Indoor Measurements, and the sampling location criterion was formalised to agree with the protocol. The sampling location was now selected to be at least 50 cm from the floor or wall, 1.5 m from fireplaces, windows or HVAC vents, 2.5 m from exterior doors, and away from radon entry routes.

The protocol required that measurements be made at least 50 cm from the floor, and so the aluminum travel cases were modified. A bulkhead connector was placed on one end of the handle face of the case, and the AB-5 inlet hose attached to this on the inside of the case through an in-line filter. A rigid plastic tube screwed into the connector. When the case stood with the handle uppermost, the top of the tube was 50 cm from the ground. If the case stood at right angles to the wall, the sample tube was 50 cm from the wall.

The AB-5 measurements were not intended to be definitive, but to indicate only whether the mitigative actions taken had significantly reduced the radon supply rate. The effectiveness would not be determined on the basis of short term measurements over a few days with an AB-5, but would be based on the average concentration over a month or more obtained with multiple "Track Etch" detectors.

6.5. DIAGNOSTIC TEST PROCEDURES

6.5.1. <u>Pre-Mitigation Diagnostics</u>

The primary types of pre-mitigation diagnostics conducted during this project were the following.

- Visual survey. This includes inspection of the house to identify potential soil gas entry routes other than hollow concrete block walls and joints in the basement floor slab, and for features that would increase the installation difficulty of particular mitigation systems.
- Gamma measurements. These are intended to confirm that building materials are not a major contributor to indoor radon.
- Well water measurements. These are intended to identify the degree to which well water is a contributor. These measurements were usually conducted by DER as part of their survey program.
- Sub-slab permeability measurements. In a few of the later houses where sub-slab suction was planned, the permeability of the material under the

slab was determined qualitatively. A high suction industrial vacuum cleaner was used to draw suction on a 3/8 inch hole drilled through the slab, while a pressure gauge or a smoke stick was used to determine whether this suction extended beneath the slab to other test holes through the slab some distance away.

6.5.2. Post Mitigation Diagnostics

The primary types of post-mitigation diagnostics conducted during this project were the following.

- Radon in Air Measurements. The prime indicator that a mitigation system was operating effectively was the radon concentration in the basement air. Measurements were made with Pylon semi-continuous radon monitors for two at least days before and following activation of any installation or change in a system.
- Visual inspection. This included inspection of the installation to ensure that seals were intact and the fan was properly mounted. As part of this inspection, a smoke stick was used to check the seals in active soil ventilation systems, and that air flows through potential entry routes had in fact been reversed by the suction systems. The smoke stick was also used to visualize the direction of house air flows during the operation of HRV's.
- Pressure difference and airflow measurements. The pressure differentials to atmosphere and the air flow rate in each pipe or duct of the active soil ventilation systems were measured using a hot film anemometer. A probe adaptor enables the same instrument to read both flow and pressure.
- Spot radon concentrations. Grab samples were taken from each pipe in the active soil ventilation system with a scintillation cell for radon analysis. Similarly, where soil ventilation systems did not provide sufficient reductions, grab samples were made from enclosed potential entry routes to assess which routes were not being adequately treated. These grab samples were taken through holes drilled through the face of block foundation walls, or from inside temporary plastic enclosures.

SECTION 7.
EXPERIENCE WITH SUB-SLAB VENTILATION

7.1. PHASE 1 - GENERAL

It had been speculated that the radon source in these houses might be the highly fractured granite bedrock that lay just beneath the basement floors. The radon concentration would be very high in the thin film of air between rock surfaces, so a small flow of this "rock gas" could produce high radon levels in the house. If this was the case, then sub-slab ventilation could be very effective in reducing the radon inflow by intercepting the flows of "rock gas" before it could enter the house through openings in the floor.

Sub-slab ventilation had been used at other mitigative projects where the radon source was local soil. The success rate of sub-slab ventilation there had been high in houses with solid concrete basement walls, but it was less effective in houses with hollow concrete block basement walls. The voids in the blocks, and the inevitable small openings in the walls at the footing level provided a horizontal entry path for soil gas containing radon. If the entry route was almost completely through openings in the floor and the wall/floor joint, as was the case in basements with solid walls, then sub-slab ventilation could effectively prevent soil gas entry. But if there was a significant horizontal flow of soil gas through the block basement walls that could not be diverted and intercepted by the sub-slab system, the reductions obtained would be much smaller. Although sub-slab ventilation was not an assured mitigative procedure, the prospects for success were good, and it would be by far the simplest procedure to install. The decision was made to start the program by installing sub-slab ventilation.

An illustration of a typical sub-slab ventilation system is shown in Figure 1.

7.1.1. <u>Installation Procedure (Phase 1)</u>

To minimize installation costs, active soil ventilation systems with sub-slab collection were chosen. These systems use the coarse stone fill beneath the floor slab as the collector, and compensate for the flow resistance by using a small electric fan to produce the suction.

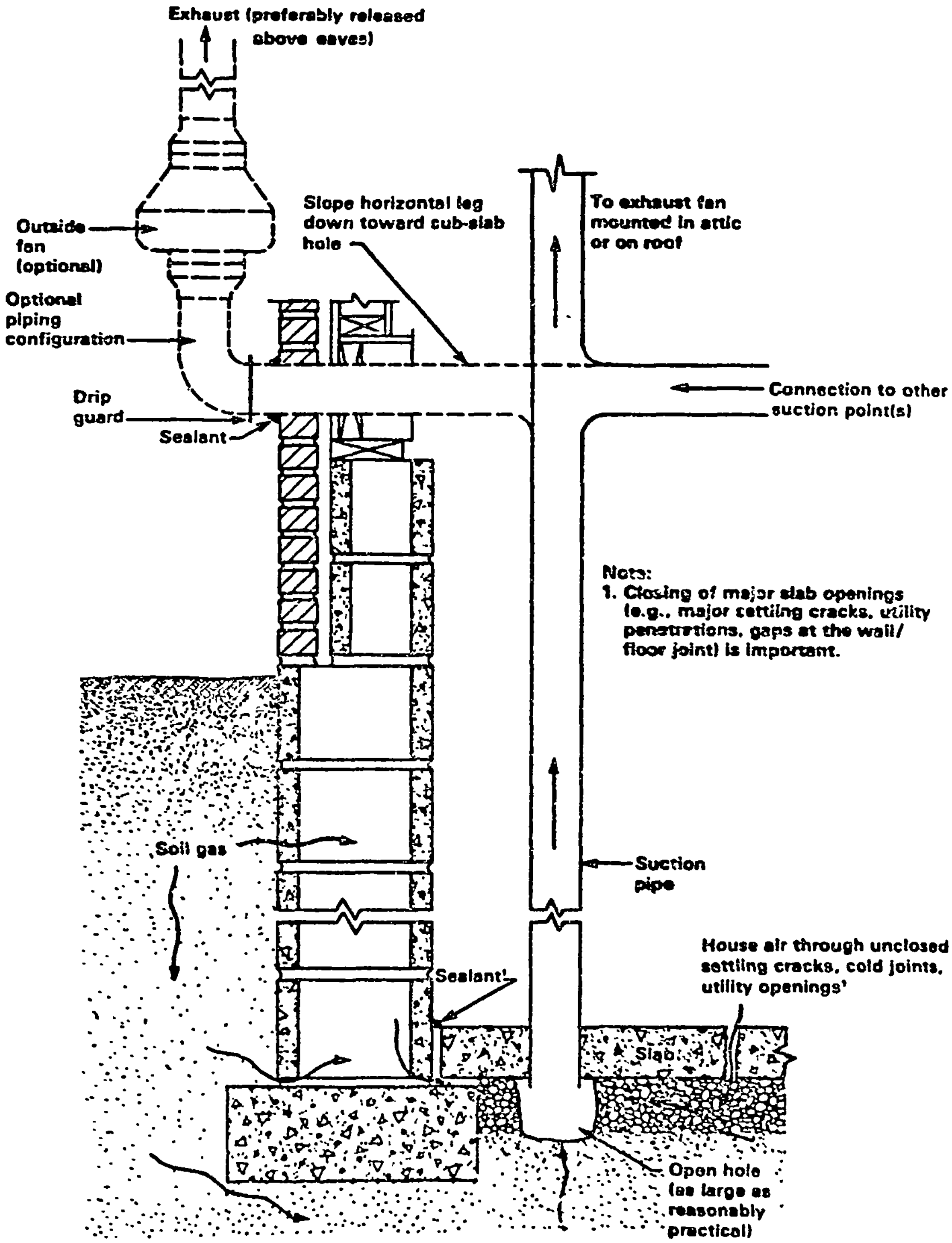


FIGURE 1 TYPICAL SUB-SLAB VENTILATION INSTALLATION

In passive systems, where the suction produced by wind and weather forces is only a few pascal more than the pressure differential between the house and the soil, a network of pipes would have to be placed under the floor to effectively utilise this low suction. This was considered too disruptive and expensive, and so passive systems were not considered for this program.

Vertical exhaust pipes were placed through the floor into the fill layer, and were located by the rule of thumb that the collection point should be equidistant from, and not more than 5 m from the external walls. Three of the Phase 1 houses were rectangular, and required two collection points. To further reduce costs, in houses #2 and #4, the exhaust pipes were Tee'd to an indoor collection pipe which lead to a single fan outside the house. The basement of house #1 was extensively finished, so there was no place to run a central collection pipe. In this case, each exhaust pipe had its own fan.

The basement at house #3 was almost square, and only one central exhaust location was installed there. In all four houses the exhaust fans were placed outside in the basement window wells. The windows were removed, the openings blocked off with plywood, and a flexible exhaust pipe passed through to the fan on the outside. This was a temporary mounting, and was used to reduce the amount of work needed to remove the installation if it were unsuccessful.

7.1.2. Piping

The piping used was "4 inch" plastic drain pipe. It was light weight, readily available, and airtight joints could be produced by gluing. The tradesmen who performed the work were plumbers and used to working with pipe. Although the pipe itself was always in stock, the number of fittings (Tee's and elbows) needed caused temporary local shortages, and supplies had to be obtained from every builder's supply store within a ten mile radius.

It was found that air flows in the systems were small enough that the low resistance to air flow of large pipe was not needed, and much smaller piping ("2 inch" drain pipe) would have been sufficient. Smaller piping would be easier to conceal. In these systems the exhaust pipe ran vertically from the centre of the floor to the joist space, and then between the floor joists to the wall.

7.1.3. Floor Patching

Only house #4 had a 50 mm layer of clean crushed stone beneath the floor slab. At the other houses, the thickness ranged from zero, with the slab poured on top of bedrock at houses #1, #4, to 25 mm of loose bedrock at house #3. The bedrock surface was exposed in the bottom of each hole cut through the slab, and was broken up with the jack-hammer to a depth of 100 to 150 mm to loosen the fill in the area around the pipe, and reduce the air flow resistance in the area. The gap between the pipe and the concrete was filled with a commercial prepackaged mix with pea gravel as aggregate. This could be brought to a good finish to match the floor.

To keep the wet concrete out of the fill, a cover is placed over the fill before the hole was patched. A variety of materials were tried, including foam board, sheet steel, and an asphalt impregnated roofing felt. The felt was the most convenient, as it could be cut to shape easily, and sealed to both the floor edge and the pipe with an asphaltic sealant. This ensured that the opening was airtight, and the only function of the concrete was to fill the opening.

7.1.4. Fans

Four different fans were used to power the soil ventilation systems. The first was a small 80 mm diameter plastic and aluminum axial fan that gave 50 L/s flow in free air and 50 Pa suction at zero flow. These fans were used for wall ventilation at one house, and were then used in drain tile ventilation systems. Their corrosion-resistant design made them especially suitable for this, but the suction was lower than that generated by other fans.

The second was a low speed centrifugal ventilation fan in a weather protective aluminum housing, which gave 100 L/s free air flow and 110 Pa suction at zero flow. These were immediately available from a local supplier. Their large flow capacity but relatively low suction made them most suitable for wall ventilation systems.

This fan was too large to mount unobtrusively, and a higher suction was felt desirable, so smaller high speed centrifugal fans without a weather protective housing also used. These were small enough to fit inside a window well with a weather shield above them, or to mount directly onto the end of an exhaust pipe. Two models were investigated. Both used the same fan body, but one ran at 3500 rpm with a motor outside the body, the other ran at 1700 rpm with the motor placed inside the body within the fan wheel. The latter was quieter, but did not develop as high a suction or handle as much air.

The higher speed fan gave 50 L/s free air flow and 200 Pa at zero flow, and was adopted as the standard unit. Several fans were fitted with flanges to accept flexible wire-reinforced plastic hose, and were mounted in weather protective wooden boxes with "child-proof" discharge protectors for use as temporary fans, and were used for all three types of system.

All of these fans were used at the start of the project in 1985. In 1986 a supplier was located for a centrifugal fan in a plastic axial mounting, complete with an integral conduit connector. The "150 mm" model (inlet and outlet connectors 150 mm in diameter) of this fan gave 150 L/s free air flow and 450 Pa at zero flow, and was suitable for use on all three mitigation systems. A metal screen was available to fit the inlet to prevent children from putting fingers into the rapidly revolving fan wheel. This model was adopted in late 1986 as the standard fan for all systems.

A version of this fan was also available in a half mounting, which could be screwed to the outside of a wall for use as a pressure fan. The casing was of galvanised sheet metal, and there was no conduit connector. This fan was used only on the wall ventilation systems at houses #1, #2, #9 with an external weather protection cover.

The capacities listed for these fans are not the manufacturer's specifications, but the measured performance of these fans as determined from pressure/flow tests using the actual field mountings.

7.1.5. Problems

Installation of the systems was surprisingly difficult. The floor slabs were all a full 90 mm (3.5 inches) thick, and the aggregate used in the concrete was either a granite or a hard metamorphosed sedimentary rock. This made the floors very difficult to break, and compressed air equipment had to be used to complete the job in a reasonable time.

An experiment was carried out in house #4 to confirm that the electric demolition equipment that a homeowner could hire was not adequate to break the floors. An electric demolition hammer (Hilti) was used exclusively to drill a 450 mm diameter ring of holes where the concrete was to be removed to install a 200 mm diameter exhaust pipe. Not only was progress very slow, each hole taking five minutes to drill, but the rotating bit frequently jammed on aggregate, rotating the drill body. When this happened, only a 100 kg (220 lb) workman was able to control the drill. The chisel bit was unable to break the aggregate, so it was not possible to break between the holes to remove the concrete as a disc. The conclusion was that professional air-powered equipment was definitely required to break the local concrete, and homeowners could not be expected to do this work.

7.1.6. Evaluation

Short term measurements were carried out during the summer. The performance of the first three systems was disappointing. At house #1 no reduction at all was produced in the radon concentration. Reductions were produced in the other two houses (#2, #3), but the resulting radon concentrations were still to high to be regarded as acceptable.

This generally poor performance, plus the installation difficulties, led to the early conclusion that sub-slab ventilation was not likely to be a low-cost or effective mitigation method in this area of the Reading Prong.

In light of this, and the major installation difficulties, it was decided that only one more house (house #4) would be fitted with a sub-slab system, and alternate methods would be sought for the other project houses where sub-slab ventilation had been planned. House #4 was thought to be more suitable than the other houses to test a sub-slab system for it was on a sloping site with only two basement walls in contact with the soil, the basement was undecorated, there were no internal block walls, and the floor had been poured in two sections with a large open construction joint. The results from these houses are summarised below in Table 5.

The performance was better in house #4, with radon concentrations reduced to near the EPA criterion of 150 Bq/m^3, despite the floor slab resting directly on the bedrock, and flow resistance of the sub-slab fill being so high that the exhaust fan ran stalled with almost no airflow. The centrifugal fan surged, creating more noise than normal, so the installation was not regarded as a complete success.

TABLE 5 SUMMARY OF PHASE 1 RESULTS WITH SUB-SLAB SUCTION

HOUSE NO.	RADON LEVELS WITH SYSTEM OFF (Bq/m³)		RADON LEVELS WITH SYSTEM ON (Bq/m³)		PERCENT REDUCTION IN MEAN
	RANGE	ARITH.MEAN	RANGE	ARITH.MEAN	
1	4 660– 7 360	5 950	4 000– 6 960	5 000	16
2	3 260–18 610	8 810	1 110– 2 150	1 760	80
3	31 380–54 580	44 590	18 650–21 050	19 460	56
4	*	~1 480*	670– 1 040	820	~45

* Insufficient data to determine range.

These results are based upon 1 to 2 days of hourly Pylon measurements both before and after the system was activated.

The only feasible additional mitigation measure for these houses was wall ventilation, which had not been tried previously. Work at the three houses (house #1, #2, #4) in which sub-slab ventilation had failed to reduce concentrations sufficiently was therefore suspended until experience had been gained with wall ventilation at other sites.

7.1.7. Comments

A properly operating sub-slab system draws air down through every opening in the floor and thus prevents the entry of radon-laden soil gas. An extensive check with smoke tubes was made of the floor at houses #2 and #1. In both places the air was found to flow down through each accessible major crack or opening into the sub-slab space, showing that the poor performance was not the result of poor installation, for the sub-slab system was depressurizing the sub-slab space as intended. This led to the conclusion that there was a major radon supply route into these houses via the walls that was not being intercepted by the sub-slab depressurization.

7.2. PHASE 2 - GENERAL

Short term measurements were carried out during the winter in houses #1, #4 both of which had their sub-slab systems operating without modification since the summer. Radon concentrations in both houses were comparable to the summer pre-mitigation measurements, and to those measured in the previous winter by the DER, indicating that the systems were not effective during the heating season. House #2 had the sub-slab system modified, but radon concentrations there were even higher than those measured previously. This was taken as further confirmation of the conclusion reached in the summer, that sub-slab ventilation was not a viable mitigation method for concrete block houses in the Reading Prong.

Despite this discouraging experience, it was decided to try sub-slab ventilation again in a number of Phase 2 houses. Two houses (#24, #25) had poured concrete basement walls, so there could be no question of radon entry through the walls, and two (#21, #20) had concrete block walls. The owners of the first three houses (#21, #24, #25) had seen them built, and said that there was a good layer of crushed stone beneath the basement floor, and a new installation procedure using a diamond core drill had been developed to avoid the use of a pneumatic drill and compressor to cut open the floor.

A sub-slab system was installed in house #22, after a small local exhaust system failed to change the radon concentrations in the house.

7.2.1. New Installation Procedure (Phase 2)

The strong concrete floors met with in this area required the use of specialist machinery to cut them open. Once this was accepted, there were a number of alternatives to the use a jack hammer. The contractor had a concrete coring drill, which could cut discs of concrete out of wall or floors up to 200 mm in diameter, and as it was water cooled and non impact, would do it with much less dust and noise than the jack hammer.

The largest core that could be removed was much smaller than the openings that were made with the hammer, and so the volume of high permeability material that could be placed round the end of the pipe was limited. The core drill technique was best suited to those places where the sub-slab permeability was high.

The drill was able to cut a 200 mm diameter hole in about 30 minutes, depending on setup time, and could work adjacent to walls. This was rapid enough that it was feasible to consider drilling multiple holes. The original sub-slab system design used only one or two central exhaust points to reduce the labour needed for installation, and relied on the permeability of the sub-slab material to transmit the suction from those points to the major routes of radon entry at the perimeter wall/floor joint. When the permeability was low, the suction was transmitted poorly. If the suction were applied near the walls instead, it would be highest in the region of the routes of entry, and even in areas of low permeability sub-slab fill, would be transmitted along the footing by the disturbed material in that area. This might also lower the pressure in the soil beneath and outside the footing, and reduce the flow of soil gas into concrete block walls at the footing level.

7.2.2. Piping

The "4 inch" lightweight plastic piping was used for these systems. The core drill made it easy to set pipes close to the walls, where they were less obtrusive than in the middle of the floor, so there was less need to go to smaller diameter pipe to aid concealment.

The sub-slab ventilation systems planned for Phase 2 work were more elaborate than the Phase 1 systems. In addition, instead of relying completely on the system to produce sufficient soil depressurization to deal with all floor openings, all accessible floor openings were closed to ensure that the sub-slab suction was as high as readily achievable.

7.2.3. Problems

The core drill was water cooled, and used two or three gallons of water while drilling a hole. This water could be collected by continually running a wet vacuum cleaner, but it was found easier to build a small dam round the machine with sand. The water wetted the sand and then pooled inside the dam. When the core was removed, the water ran away down the hole, verifying that the opening was connected to the sub-slab space. The sand was shovelled up, and the area was dry in 30 minutes.

The water cooling made this drill suitable for use only in uncarpeted areas. Diamond bits are available for dry drilling, but the large amount of dust produced requires a higher standard of dust control than usual in the contracting world.

7.2.4. Evaluation

The results from the Phase 1 houses that had their systems modified and the new Phase 2 houses are summarised below in Table 6.

The first house where the new procedure was tried was house #21. This house had a concrete block basement, and a carpeted floor and finished ceiling in most of the basement restricted the location of the exhaust pipe to a single pipe in the utility room at one end of the house, which was connected to a 100 L/s exhaust fan. There was at least 50 mm of crushed stone beneath the floor slab. Openings in the floor slab around the drains were closed with silicone caulk, and an untrapped floor drain closed with a rubber plug. A major reduction in the radon concentration was achieved in the winter, showing that high radon supplies through the walls were not inevitable if the sub-slab fill had good permeability.

TABLE 6 SUMMARY OF PHASE 2 RESULTS WITH SUB-SLAB SUCTION

HOUSE NO.	RADON LEVELS WITH SYSTEM OFF (Bq/m^3)		RADON LEVELS WITH SYSTEM ON (Bq/m^3)		PERCENT REDUCTION IN MEAN
	RANGE	ARITH.MEAN	RANGE	ARITH.MEAN	
Basements with block foundation walls					
7B	5 750-23 150	14 890	30- 240	120	99
20	5 460-25 750	10 440	740-2 920	1 600	85
20A	5 460-25 750	10 440	140- 770	450	95
21	1 410- 7 440	4 100	40- 150	100	98
Basements with poured concrete foundation walls					
24	888- 2 405	1 628	74- 185	111	93
25	444-11 470	5 476	185- 592	333	94
Basements with poured concrete foundation walls and adjoining slab on grade					
22	814- 1 998	1 258	111- 555	259	77
23	3 219- 3 811	3 515	148- 444	296	92

These results are based upon 2 to 4 days of hourly Pylon measurements in the basement both before and after the system was activated.

The second house where this new procedure was tried was house #25. This house had solid poured concrete basement walls, and a floorslab that had shrunk away from the walls 2 to 3 mm in places. The owner said that insects entered the basement via this crack, and that there was a layer of crushed stone beneath the slab. Four holes were cored through the slab close to each exterior wall, connected to a 50 L/s centrifugal fan. The top of the footing was exposed in all the holes, and was generally covered with a layer of small stones. The sub-slab stone exposed in the holes ranged from 30 to 100 mm in depth beneath the slab. A major reduction in radon concentration was achieved when the fan was turned on.

The airflows up the exhaust pipes were lowest where the stone layer was thinnest, and smoke tests found that parts of the wall/floor joint were not under negative pressure. This indicated that there could be large variations in the sub-slab permeability, and that more than one exhaust pipe per wall might be needed to guarantee that almost all of the floor area was under suction. Closing the open portion of the wall/floor joint with caulking did not improve the system performance significantly.

A direct comparison of the effect of pipe location was carried out at house #20. A central two point system was installed connected to a 100 L/s fan, using the core drill to cut 200 mm diameter holes. Smoke tests showed that the suction extended to the edge of the floor slab. This system produced major reduction in radon concentrations, but there was indication of a small radon supply via the concrete block walls. The central system was then removed, and a five point system connected to the 100 L/s fan, with two points on each of the front and rear walls and a single point on the buried end wall. The other end wall contained a garage door and was almost completely out of the ground. The new arrangement gave a slightly better performance, but there was still a small radon supply from the walls.

The block walls at this house were painted, and the sill plate covered the blocks tops. To test if the suction in the footing area would reduce the radon supply if the airtightness of the walls was increased, the sill plate was caulked to the top of the blocks, and open blocks in the pilaster were closed with expanding urethane foam. This made no significant change in the radon concentrations, and did not change visibly the effects of wind on the airflow in or out of the wall, or the radon concentration in the wall. This indicated that the although the multipoint sub-slab system could work effectively in concrete block houses, but if there was still a small radon supply via the walls, just increasing the wall airtightness would not allow the random connections from the sub-slab space to depressurize the walls. If the radon supply from the walls was to be reduced, a separate system would be required.

House #24 had solid concrete basement walls, but a large concrete block basement chimney structure in the wall at one end. The owner intended to finish the basement, and the choice of locations for the exhaust pipes was very limited. The owner had seen the house built, and said that there was a good layer of stone beneath the basement floor, so the final system only had three exhaust points, two at the fireplace end of the basement, and one at the opposite end. Good performance was achieved here with a 50 L/s fan, with suction extending beneath all parts of the floor.

House #22 was a split level with solid concrete basement walls, and half the house was over a grade level concrete slab. Operation of a four point sub-slab system with a low suction 50 L/s axial fan reduced radon concentrations to a low level.

7.2.5. Comment

The new installation procedure using a core drill effectively overcame all the installation difficulties caused by use of an air powered jack-hammer in occupied houses identified in Phase 1. The good system performance in these houses, without excavating the sub-slab fill around the pipe entry, plus knowledge gained in installing mitigative systems in other houses, suggested that the houses selected in Phase 1 had features which decreased sub-slab ventilation performance. It was likely that if they had been fitted with multi-point systems with high suction fans, good results would have been obtained there.

7.3. PHASE 3 - GENERAL

The experience in Phase 2 houses with sub-slab ventilation, and with wall ventilation combined with sub-slab ventilation, suggested that sub-slab ventilation could be effective in a wide range of housing types. As a result, all the Phase 3 houses were to receive sub-slab ventilation as the primary mitigation measure. Six of them (#36, #33, #40, #34, #37, #35) had solid concrete basement walls so there was no concern for radon entry via the walls, and three (#32, #39, #31) had concrete block walls.

In addition, as a specific test of the improved design, house #4, where an unsuccessful two point sub-slab system had been installed, was to receive a new design six point system. Two Phase 1 houses (#13, #6) with concrete block basement walls where other systems had been unsuccessful were to be converted to sub-slab ventilation. One Phase 1 house (#38) which had not had any system installed was to receive a sub-slab system.

Two Phase 2 houses (#22, #23) which had a sub-slab system exhaust system in the basement section alone, were to have the system extended to the grade level slab.

7.3.1. Installation Procedure (Phase 3)

The installation procedures were generally the same as used in Phase 2. The "standard system" had six exhaust points, two on each long wall of the house, and one on each end wall. If the basement was rectangular, only one pipe was used at the centre of each wall. More points were added in large houses. All accessible floor openings, such as construction joints and openings beneath well pressure tanks were closed. The 150 L/s fan was used in all new installations.

A four point exhaust system was installed in house #13, where a weeping tile exhaust system installed in Phase 1 produced only moderate reductions.

As a test of the ability of the multiple point system to deal with conditions of poor sub-slab permeability, a six point system was installed at house #4, where a two point system was ineffective in Phase 1.

House (#38) had concrete block walls and a french drain. Half of the basement was finished as a laundry room, bathroom and family room. The accessible part of the french drain was in the garage, and was closed by placing 40 to 50 mm of sand in the bottom of the drain, and then filling the remainder with mortar. If water entered the wall, it would leak out at the bottom of the wall, and drain to the sub-slab space via the sand. The parts of the drain that were concealed behind paneling were closed by injecting expanding foam through small holes drilled through at the foot of the wall. These were concealed by an added baseboard molding.

The system at house #6 was converted from a wall plus floor ventilation system by removing the exhaust pipes and the garage fan from the walls, and using the three holes in the floor of the unfinished part of the basement as the exhaust points for the sub-slab system.

House #32 had concrete block walls, and a large sump pit that contained the well pump and pressure tanks. This pit was normally covered with a plywood sheet. In addition to installing six peripheral sub-slab ventilation pipes, a fitted plywood door was placed over the pit, and it was ventilated with a separate line.

Houses #36, #22, #23 had half of the house on a grade level slab. A sub-slab system was initially installed in the basement alone at #22, and #23, and then the slab was treated by placing an exhaust pipe into the sub-slab fill. An extended system was installed at #36 from the beginning.

House #37 had a family room on a grade level slab. A system was installed in the basement only.

House #34 had concrete walls and a french drain. The drain was filled with mortar over a layer of sand, and a standard six point system installed.

Most of the basement at house #35 was taken up with a garage, leaving only a small work room. A four point system was installed in this room.

A non-standard system was installed at house #33, where there was a dry sump with no connection to a drainage tile. A cover was placed over the sump and it was ventilated with a high suction fan.

7.3.2. Fans

A supplier of a series of in-line centrifugal exhaust fans was identified late in Phase 2. A suitable unit was available with a weather protective plastic housing that would give 150 L/s free air flow, and more importantly, produce 450 Pa suction at zero flow, and more than 200 Pa suction at any flow less than 80 L/s. The inlet and outlet connectors would just fit inside "six inch" lightweight plastic pipe which was convenient for mounting. This fan was adopted as the standard unit for new installations, and was retrofitted to most of the previous ones.

7.3.3. Comment

A test procedure had been developed by another contractor to measure the airflow resistance of the sub-slab fill, to provide guidance as to the size of system required. The basic idea was to drill a small hole through the slab at the proposed site of the exhaust pipe and intervals over the slab, suck on one hole with a high suction vacuum cleaner, and measure the decrease of pressure with distance from the hole. The flow out of the test hole was also measured, so that a fan with sufficient flow capacity could be specified.

A modified version of this procedure was tried at houses #39 and #40. A professional 1/2 inch rotary/hammer drill was barely adequate to drill through the floors. It took several minutes to drill through the pieces of hard aggregate that were encountered in almost every hole. At house #40 the sub-slab permeability was so low that there was no measurable pressure difference (4 Pa), or even airflow down holes only 450 mm from the test hole with 15 000 Pa suction applied. At house #39, only one pair of holes had a measurable connection, and a suction of 25 Pa was measured at a distance of 1.3 m from the test hole.

This was a valuable test in that it suggested the system flows would be low enough that one exhaust fan would be sufficient at #40, which was a very large house. The overall conclusion was that the sub-slab permeability in these houses was too low for the modified test procedure to be very useful as a design guide.

7.3.4. Evaluation

The results from the Phase 1 and Phase 2 houses that had their systems modified and the new Phase 3 houses are summarised below in Table 7.

As a test of the ability of the multiple point system to deal with conditions of poor sub-slab permeability, a six point system with a high suction fan was installed at house #4, where a two point system was ineffective in Phase 1. This was successful, and gave reassurance that increased and widely distributed suction could overcome low permeability.

House #7 originally had a wall ventilation system installed in Phase 1, and considerable effort was spent in Phase 2 to improve the performance. The system converted to a sub-slab system, and good results were obtained. The systems at houses #6, #38, #39, #31 were also successful, confirming that sub-slab ventilation alone could reduce the entry rate of soil gas and radon, even in houses with concrete block basement walls.

The system at house #32 reduced the radon concentrations, but the premitigation concentrations were low. It was subsequently discovered that the DER alpha-track detector which indicated high long term average radon concentrations was exposed in the sump pit, and did not represent a valid estimate of the average radon concentration in the basement. The house would not have qualified for the program if a realistic measurement had been made.

The sump ventilation system at house #33 initially produced only a small reduction in radon concentration, and the sub-slab suction was limited to the region round the sump. Holes were drilled in the side of the concrete pipe sump liner, and in the bottom of the sump. It was found that the pipe was set in concrete, covered by a layer of stones and dirt, rather than being open to the sub-slab fill as it appeared. Satisfactory performance was achieved after the communication was improved.

TABLE 7 SUMMARY OF PHASE 3 RESULTS WITH SUB-SLAB SUCTION

HOUSE NO.	RADON LEVELS WITH SYSTEM OFF (Bq/m^3)		RADON LEVELS WITH SYSTEM ON (Bq/m^3)		PERCENT REDUCTION IN MEAN
	RANGE	ARITH.MEAN	RANGE	ARITH.MEAN	
Basements with block foundation walls					
4A	550- 900	740	40- 160	100	86
6B	1 300- 3 610	2 210	100- 220	180	92
7D	5 740-23 150	14 890	40- 330	150	99
13A	2 780 4 330	3 500	20- 150	80	98
20C	5 460-25 750	10 440	110- 260	160	98
31	15 510-19 490	17 945	80- 240	130	99
32	110- 410	210	20- 100	45	79
39	40- 2 330	890	20- 110	60	93
Basements with poured concrete foundation walls					
33	2 553- 3 589	3 108	111- 259	185	94
34	20 313-29 970	25 752	111- 259	185	99
35	3 219-11 026	6 068	18- 74	37	99
Basements with poured concrete foundation walls and an adjoining slab on grade					
22A	814- 1 998	1 258	185- 592	333	74
23A	3 200- 6 000	4 700	40- 950	450	90
36	2 442- 6 327	5 254	37- 148	74	99
37	370- 1 221	703	18- 74	37	97

These results are based upon 2 to 4 days of hourly Pylon measurements in the basement before and after the system was activated.

In houses #40, #34, #37, and #35, where the basement walls were all of solid concrete, the systems were successful and achieved low radon concentrations. House #37 had a family room on a slab adjacent to the basement, but reduction in basement radon concentrations still led to low radon concentrations upstairs.

At house #13, operation of the sub-slab system at the same time as the weeping tile system produced low radon concentrations, but the system by itself was not much more effective than the weeping tile system. An explanation for this is that the systems produce asymmetrical but different pressure fields. This house is unusual in that the bed of crushed stone beneath the floor slab is much thicker than normal at the rear of the house, as it was used to level a sloping excavation. The flows in the sub-slab exhaust pipe from this location were high and the radon concentrations very low, indicating that this section was drawing mainly atmospheric air, not soil gas. The weeping tile in this section is nearest the fan, and has the highest suction.

At house #22, radon concentrations upstairs were higher than in the basement, so the fill beneath the grade level slab was ventilated with two exhaust points inserted through the stub wall. This reduced radon concentrations upstairs to low levels, but basement radon concentrations remained slightly elevated.

At house #23, with just a sub-slab system in the basement, radon concentrations upstairs were higher than in the basement. Therefore the fill beneath the grade level slab was ventilated with a single exhaust point through the slab, placed in a closet beneath the stairs. This reduced radon concentrations to low levels both upstairs and in the basement.

7.4. OVERALL EVALUATION OF SUB-SLAB VENTILATION

The initial Phase 1 sub-slab installations performed poorly, and led to a premature dismissal of sub-slab ventilation as an effective mitigation method for the Reading Prong area. In retrospect, the reasons for the poor performance were largely that the design was based on experience in areas where the sub-slab permeability was much higher than in this area. When the design was modified to compensate for the lower permeability, by use of multiple exhaust points, closure of all accessible floor openings, and high suction exhaust fans, then large reductions in radon concentration were obtained. The step of most value seemed to be use of multiple exhaust points, for improvements in system performance were minor when higher suction fans were installed.

These steps also reduced the entry of soil gas through concrete block walls. The good performance of the later sub-slab systems suggested that in the majority of houses the depressurization was not limited only to the sub-slab region, but extended beneath the footing to the outside of the basement walls. In these cases there was no need for a separate system to depressurize the soil outside of the walls, or collect the soil gas from inside the walls.

Split level houses and basement houses with extensions could be dealt with successfully by ventilating beneath both floor slabs.

However, despite the excellent performance of the modified system in most houses, there were some places where the performance was poorer. These include both houses with concrete block walls (where the walls could be an untreated source) such as house #13, and #20; but also places with solid walls, such as house #25 where the reasons for poor performance must be related only to low and variable sub-slab permeability. Tests of the effective sub-slab permeability may enable us to identify these places in advance, but it is not clear how much the tests will assist in designing the systems to overcome this, other than by pointing out that there is a problem.

SECTION 8.
EXPERIENCE WITH PERIMETER DRAIN VENTILATION

8.1. PHASE 1 - GENERAL

In previous projects, active soil ventilation using the perimeter drain tile (weeping tile) as the soil gas collector had been a generally effective mitigative measure for concrete block structures. However, only about 30% of houses in the Boyertown area have perimeter drain tiles. Houses that had them were commonly built into the side of a hill, and the tile drain was intended to intercept water moving downhill through the soil after rain and during the spring melt. These drains are often omitted on the downhill and garage walls of the basement, so the fraction of houses where there was a complete loop of tile round the basement was smaller still. The collected water was normally discharged by gravity down the hill, rather than brought to a sump inside the house.

Some basements without perimeter drainage tiles have a "French Drain". This is an opening about 50 mm (2 inches) wide between the edge of the floor slab and the basement wall, exposing the upper surface of the footing and the sub-slab fill. Water that enters the concrete block wall weeps down the wall surface, and is collected and drained to the sub-slab fill without flowing onto the floor surface. These houses present a major challenge, for not only are there the usual routes of soil gas entry through the floor and walls, but also a direct route from the soil via the french drain.

The soil in the area is believed to be free draining, and this is probably the reason why perimeter drain tiles are not installed routinely. However, on top of the hills the soil is a mixture of rock, clay and sand. Most of the houses inspected had some signs of water entry through the block walls, so the drainage capacity is not always good enough to deal with high water loadings, such as are found during the spring thaw.

The drain tile installations tested during this study were of two types. Where the tiles drained to an above-ground discharge, the system resembled that shown in Figure 2. Where they drained to an internal sump, the system resembled that shown in Figure 3.

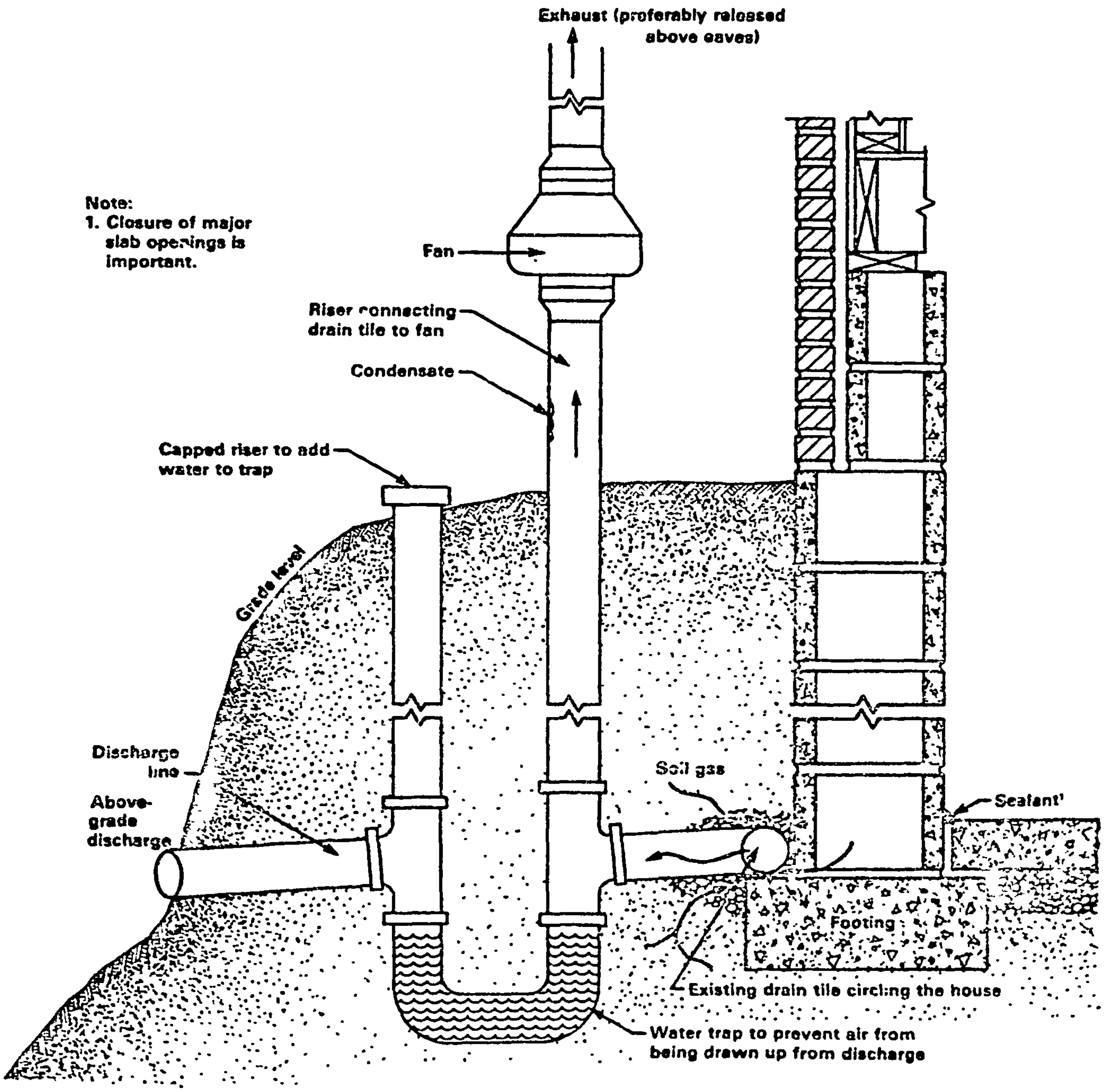


FIGURE 2 TYPICAL DRAIN TILE VENTILATION SYSTEM
(ABOVE-GROUND DISCHARGE)

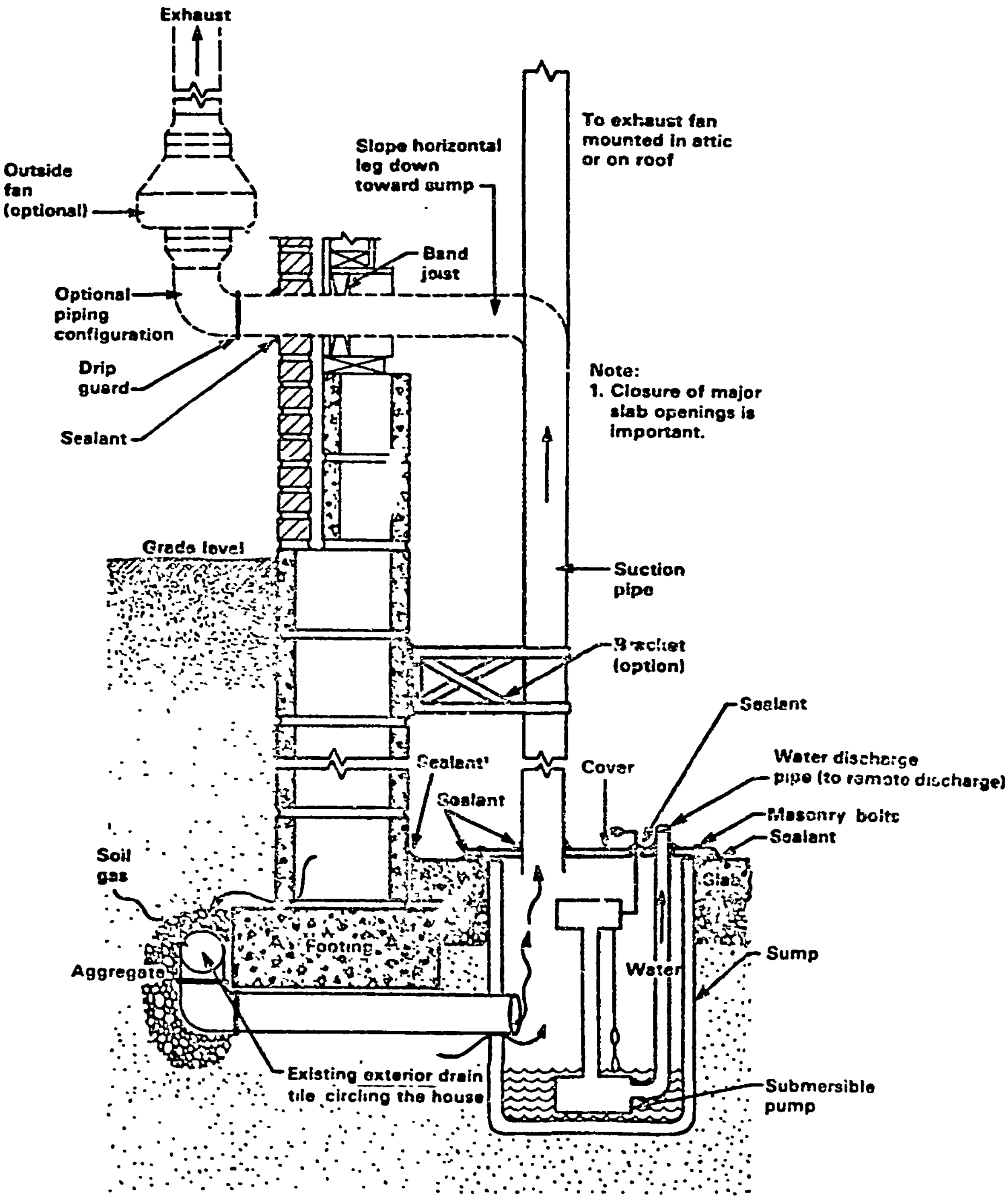


FIGURE 3 TYPICAL DRAIN TILE VENTILATION SYSTEM
(INTERNAL SUMP DISCHARGE)

8.1.1. Installation Procedure (Phase 1)

The drain line from the perimeter drain tile is open to the air at the discharge end, so the tile cannot be used as a soil gas collector until that opening is closed. Otherwise the fan will just draw air from the atmosphere, instead of depressurizing the soil around the basement. A pit was dug to the junction of the perimeter drain tile and the drain line, a water trap placed in the drain line to close it against the passage of air, and a vertical riser for the fan attached to the perimeter drain tile.

The "U" water trap was fabricated from "4 inch" plastic drain pipe elbows. To prevent the water from freezing during the winter and perhaps blocking the trap during a sudden thaw, each trap was covered with at least 600 mm (2 feet) of earth. In these initial installations, a vertical riser topped by a cap was attached to the atmosphere side of the trap so it could be filled with water after it was buried, and the water level checked from the surface. Although there was a drought in Pennsylvania, the water levels in the traps did not fall visibly over a month, showing that evaporation should not be a problem.

A perimeter drain tile ventilation system with a sub-slab component was installed at house #17. This house was unusual for the area in that it had an internal sump and pump to dispose of the water collected by the perimeter drain tile, and there was also a tile network beneath the basement floor. This had been installed in a bed of crushed stone over the top of the original basement floor, and a new floor slab poured over all. The house was at the foot of a small hill, and the owners stated that large amounts of water were handled by the system when rainfall was normal. Most of the basement was finished. The sump and pump were concealed in a corner by panelling.

An airtight wooden cover was constructed to fit in the available space, and a "4 inch" plastic sewer pipe was installed behind the panelling to ventilate the sump. It ran through the wall into the garage where a free standing fan was placed, discharging to the outside. There was a considerable gap visible between the floor slab and the wall in the sump area. This was filled with expanding foam to decrease the leakage area into the system. The gap extended behind the panelling, and no attempt was made to remove the panelling to close the gap for that would not have been low cost.

More details on the installations are given in Appendix C.

8.1.2. Fans

Two different fan installations were used. At the first three houses #12, #13, #14) a small axial fan of 50 L/s (100 cfm) capacity and 50 Pa suction at zero flow was installed on the end of a 900 mm (3 feet) vertical riser. When the corners of the 130 mm (4.25 inch) metal frame around the fan were cut off, it fitted inside the large end of a 6x4 plastic drain pipe reducer. The gap between the edge of the frame was filled with an single component expanding urethane foam. A protective wire grill was bolted in front of the fan to prevent children putting their fingers into the rapidly revolving plastic fan blades. Two of these fans had to be replaced, for unreacted foam seeped between the rear of the fan frame and the adaptor, expanded into the fan blades, and jammed them. The solution was to use a "reverse mounted" fan with the mounting spider on the suction side of the fan. This enabled the fan to be screwed down against a soft rubber gasket without fouling the blades, and all further axial fans used were of that type.

The 6x4 reducer was attached to the vertical riser from the perimeter drain tile water-trap by an inverted "U" made of two elbows, so that the fan discharged downward, and was protected from the weather. The riser was able to support the fan without additional bracing. Although the performance of these fans was satisfactory, a higher suction was felt to be desireable for the larger houses with higher radon levels.

A different fan and mounting procedure was used for the next three houses (#10, #15, #16). A small centrifugal fan of 50 L/s capacity and 200 Pa suction at zero flow was mounted in a free standing wooden box, and connected to the riser with 100 mm diameter wire reinforced plastic hose (dryer hose). The fan was hung inside the box from its discharge port flange, a plastic toilet flange was screwed to the metal fan body as an intake adaptor, and a 300 mm length of "4 inch" plastic pipe with an elbow was placed over the discharge opening to prevent children from putting their fingers into the rapidly revolving metal fan wheel. This was a temporary arrangement, for the air leaving the soil is saturated with water vapour, and in cool weather this will condense in the discharge piping, blocking the flexible hose if it has a low spot.

8.1.3. Problems

There were no unexpected installation difficulties. The ground was stony, and so the effort involved in digging to the tile was high. In some areas it was impossible to insert a spade point into the ground, for it would always strike a small stone. It was necessary to break up the soil with a pickaxe or a crowbar before it could be moved with a spade. An electric hammer with a chisel blade was found to be a considerable assistance. We were fortunate in that many of the homeowners had seen their house built, and were able to tell us where the tile ran, and where the drain connection was. This greatly reduced the amount of digging needed to find the junction of the drain line and the tile.

The perimeter drain tile was buried only 300 to 900 mm (1 to 3 feet) deep at the rear of most houses on sloping sites. This minimised the labour required. At one house (house #16) there was a full depth basement, and the excavation was over 2.1 m (7 feet) deep. This pit was dug on two days of record breaking temperatures, and one of the labour crew resigned during the task. When the fan was turned on in house #16, the untrapped floor drain was found to be connected to the perimeter drain tile. A commercial watertrap adaptor to close this drain is not available, so an expanding rubber plug was placed in the drain.

8.1.4. Evaluation

Short term measurements in the summer gave good results from all these systems. Soil ventilation with the perimeter drain tile as the collector seemed to be an effective way to deal with soil gas entry routes. As the greatest suction is near the footing, the good success of this method, together with the relative failure of sub-slab collection, indicated that the major entry route in these Reading Prong houses was via the walls. This in turn suggested that wall ventilation might be an effective mitigation strategy for those basements without perimeter drain tile.

Inspection of the systems in the late fall of 1985 found that the flexible hose to the freestanding fans was filling with water during the cool nights, and blocking the airflow to the fan. To keep the systems operating through the winter, the fans were mounted directly on top of the exhaust risers. This increased the suction in the systems. The low suction 50 L/s axial fans were also replaced with direct mounted 50 L/s centrifugal fans with higher suction.

To direct mount the centrifugal fans, they were removed from the boxes, and were placed directly on top of the exhaust riser pipes with a 4x3 reducer attached to a plastic flange screwed to the metal fan body. These fans were not weather protected, so a length of flexible plastic hose was slipped over the top of the fan to keep the motor and terminals dry.

Short term measurements after fan remounting found the system was effective at houses #12, #10, #15, where the perimeter drain tile completely surrounded the basement, but was ineffective at house #16, where the tile ran only partly round the basement. At house #13, where the tile ran only part way round the basement the low suction axial fan was replaced with a 50 L/s centrifugal before any measurements were made, but measurements showed that even with the higher suction fan the system was not very effective. The system at house #17 was found to be ineffective even with the fan operating properly, and was removed.

The system was effective at house #12, except when the internal pressure was lowered by running an open fire. Replacement of the axial fan by a directly mounted 50 L/s centrifugal fan increased system suction from 50 to 100 Pa, and improved the performance.

The system was ineffective at house #14, where the tile ran only along three sides of the basement, and there was a low suction axial fan. The system was removed from this house, as the poor performance of systems at houses where the perimeter drain tile did not make a complete loop suggested that other mitigation methods were needed.

8.2. PHASE 2 - GENERAL

Four new Phase 2 houses had block basement walls, and were said by the owners to have perimeter drain tiles which ran completely round the basement, and were therefore selected for perimeter drain tile ventilation. Two houses were selected to test the effect of internal openings on system performance.

House #26 had a garage in the basement, and tile was adjacent to the 3 buried walls. There was a cold room with a soil floor underneath the front porch, with a door into the basement, and the floor was poured in several sections. House #27 had a large concrete block structure in the centre of the basement that supported a upstairs fireplace and flue.

The 50 L/s axial fans were used at each of these houses, with good results. A concrete slab was poured over the exposed soil of the cold room floor at house #26, with only a small reduction in radon concentration. This, and the generally good performance in both houses indicated that the perimeter drain tile system was able to divert soil gas away from the floor openings as well as from the walls.

Detailed inspection of the site at house #28 led to the conclusion that the owner might have been mistaken about the presence of a perimeter drain tile drain. There was not enough slope on the site for an external discharge from the tile, and although there was an internal sump with a sump pump, only one small diameter pipe led into it. The main use of the sump was as a discharge point for the basement washing machine. The basement walls in the sump area were heavily water stained, and the owner complained of surface water entering the basement despite regrading the site. Taking all these things into consideration, it was felt that it would be undesirable to do any external excavation on this site. The sump would be ventilated, and if that was unsuccessful, a HRV would be installed.

A fifth Phase 2 house, #21, had been considered for drain tile ventilation. However, detailed inspection of the site, and discussions with the owner found that the attached garage had been added to the house a few years after it was built, and the perimeter drain tile along the garage wall might have been rerouted or damaged during the addition. The original perimeter drain tile drainage discharge pipe was probably underneath the garage floor slab, and no other discharge pipe could be found. Rather than undertake the extensive excavation that would be needed to expose the tile, it was decided to install sub-slab ventilation in this house, as discussed in Section 7.

A supplier of large plastic body in-line 150 L/s centrifugal exhaust fans was located at the start of Phase 2. These fans were weather protected, had built-in conduit boxes, and were suitable for a permanent electrical connection. These fans would develop 150 Pa suction at zero flow. All the perimeter drain tile exhaust fans were replaced with these fans during Phase 2, except for houses #16, #17, which had been converted to other mitigation systems. None of the new houses selected for Phase 3 had perimeter drain tile.

8.2.1. New Fan Installation Procedure (Phase 2)

The inlet and outlet connectors of the new fan would just fit inside a "6 inch" light weight plastic drain pipe. The fan was secured to the pipe with three sheet metal screws, and the pipe attached to the "4 inch" vertical riser by a 4x6 coupling.

8.2.2. Evaluation

Results from both the Phase 1 and Phase 2 installations (except for houses #15 and #17 where the systems were replaced) with the new high suction fans in operation are shown below in Table 8.

TABLE 8 SUMMARY OF PHASE 1 AND 2 RESULTS WITH DRAIN TILE SUCTION

HOUSE NO.	RADON LEVELS WITH SYSTEM OFF (Bq/m^3)		RADON LEVELS WITH SYSTEM ON (Bq/m^3)		PERCENT REDUCTION IN MEAN
	RANGE	ARITH.MEAN	RANGE	ARITH.MEAN	
Tiles drain to low point on site					
10	3 400-11 400	7 400	70- 550	250	97
12	220- 740*	440*	70- 130	100	77
13	2 220- 3 260*	2 660*	150- 630	120	84
14	1 960- 2 480*	2 220*	300- 850	580	74
15	180- 1 810*	670*	15- 110	40	94
16	5 030-12 100*	8 880*	3 030-8 140	5 580	37
26	1 180- 7 070	3 310	15- 70	10	99
27	670- 2 370	1 550	10- 330	110	93
Tiles drain to interior sump					
17	920- 1 630*	1 180*	480- 850	670	43
28	**	~800	380-2 500	800	~0
29	150- 3 330	1 710	40- 130	70	96

* All measurements marked with an asterisk were made in warm weather- July to August. Radon levels are expected to be highest during cold weather due to increased thermal stack effect, and to the house windows being closed.

** Insufficient data to determine range.

These results are based upon 2 to 4 days of hourly Pylon measurements in the basement before and after the system was activated.

Installation of the new fans increased system suction to around 200 Pa, generally with only a slight improvement in performance. Good results were obtained at all the houses, with the exception of house #13, which was the only one where the tile did not completely surround the basement. Concentrations remained high despite the increase in suction, indicating that the distribution of suction in the soil around the basement was as important as the size of the suction developed in the system.

8.3. OVERALL EVALUATION OF PERIMETER DRAIN TILE VENTILATION

The performance of perimeter drain tile ventilation in those houses where the tile formed a complete loop around the basement was uniformly good. The affect was not confined just to houses with entry routes in the walls, for good reductions were obtained in houses where there were internal block walls and other openings in the floor slab. On the sloping sites common in this area, the work required to install the systems was minor, for the drain tile was often only 500 to 800 mm below the surface on the down slope side of the house.

SECTION 9.
EXPERIENCE WITH WALL VENTILATION

9.1. PHASE 1 - GENERAL

There are many small openings on the outer face of concrete block basement walls in the footing area where soil gas can enter. If sub-slab suction does not reduce the soil pressure in this area, and there is no weeping tile, there is no simple way to lower the pressure in the soil in the footing area. Ventilation of the block cavities to intercept the soil gas and radon that leaked into the wall before it entered the house had been suggested as a possible mitigative measure, but had not been tried previously.

In all but one of the Phase 1 houses, the voids in the top course of blocks were open to the house atmosphere, or at best, closed only by the sillplate on which the floor joists rested. There was a course of solid cap-blocks on top of the wall in only one house. Wall ventilation could only be expected to be a practical mitigation measure if these voids could be closed well enough that a small fan would be able to produce a pressure drop large enough to ensure that air flowed from house to wall, even when the exterior pressure was raised by wind blowing against the wall. The perceived major problem was that of closing the top block voids. Installation of the fans was anticipated to be a minor problem in comparison.

A typical wall ventilation system is shown in Figure 1.

Wall ventilation was tested in four house during Phase 1. The first house selected for a wall ventilation installation was #15, for this was the one with solid cap blocks at the top of the wall. Discussions with the owner revealed that the house had been built by an industrial builder to keep his labour force busy between two large jobs. The walls had been constructed to industrial standards, and were not only capped at the top, but were internally reinforced by filling a vertical set of block voids at each corner and at 2.4 m (8 feet) intervals along each wall with concrete. As this cut each wall up into several airtight compartments, a multiple point collection network would be needed to draw air from every wall compartment.

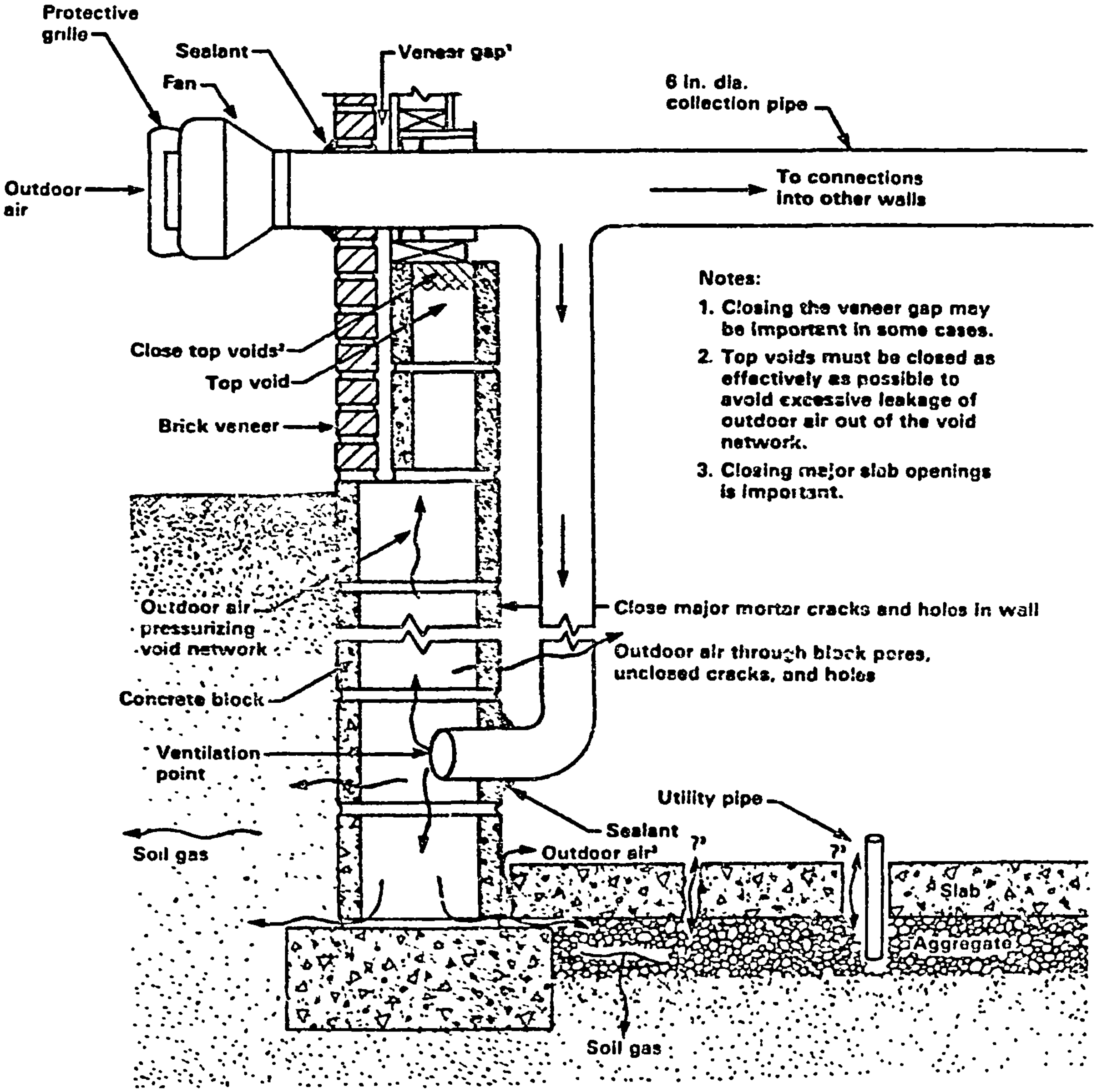


FIGURE 4 TYPICAL WALL VENTILATION SYSTEM

As the house also had weeping tile, it was decided to see what effect weeping tile ventilation had on radon concentrations, before proceeding with such a large piece of work. In any case, although success at this site would have been proof of principle, it would still have left unanswered the question as to how well the system would work when the wall top had to be closed as part of the work.

9.1.1. Installation Procedure (Phase 1)

Wall ventilation was first tried at house #5. This house was unusual in that the floor joists rested directly on top of the basement walls, without a sillplate beneath them. The block voids were completely open, but were only accessible in 35 cm (14 inch) segments between the joists. This was also the only house where more than the top block course of the basement wall was exposed above grade level.

The tops of the walls were closed with sheets of roofing felt cut to fit between the irregularly spaced joists, and were stapled to the joist and header, while the junction between the felt and the top of the block was closed with an asphaltic sealant. The area around the electrical panel where the wires prevented placement of a strip of felt was closed by injecting a single component urethane foam. A small 50 L/s axial exhaust fan was installed in each wall.

At the other houses there was insufficient clearance to grade to install a fan in each wall. At those houses, a collection system of "4 inch" lightweight drain pipe with an entry point into the top course of each basement wall was used, connected to either a 50 L/s or 100 L/s centrifugal fan outside the house. The larger fan was used in the larger houses.

At house #6, half the basement was finished, and only three walls were easily accessible. The sill-plate closed the block voids along the front and back basement walls, and partially closed the top of the garage-end wall, which was finished, and virtually inaccessible. The voids in the top of the other end wall were closed with a strip of roofing felt stapled and caulked to the header board in the same manner as at house #5. A pipe network was installed to ventilate the three accessible walls with a single pipe into the centre of each wall with a 100 L/s centrifugal fan installed outside. A separate 50 L/s axial fan was installed in the garage to ventilate the fourth (finished) basement wall.

Visual inspection and smoke flow tests at #5 and #6 found that the felt did not close the openings as effectively as hoped. Although it was impregnated with asphalt, it still took up moisture from the humid air in the wall cavities, and warped and pulled away from the wood. Alternatives to the use of felt were considered, and the most practical included the use of a wooden strip ("2x4") coated with asphaltic sealant to close the gap between the sillplate and block edge (this was dubbed the "sticky strip" by the labour crew), or filling the top block cavities directly, either with cement or an expanding foam. Both these methods were tried in the next two houses (house #7, #8).

The wall tops at house #8 were closed with asphalt coated wood strips, with mortar used on the side walls, and foam used to fill a few inaccessible areas. To ensure that radon gas did not leak out of the wall into the house, the fans were set to blow into the wall. As the air flow would be from wall to soil, the radon concentration in the wall would be very low. Two 50 L/s centrifugal fans in parallel were used, to ensure sufficient airflow capacity even if there were large unclosed areas.

The last installation was made at house #7, which was about three times the size of house #8. End walls were closed with mortar and expanding foam in inaccessible places, and the sill plate was caulked to the top of the block wall along the front and rear walls. Two 50 L/s centrifugal fans were used to compensate for the larger wall areas, and good results were also achieved here.

9.1.2. Fans (Phase 1)

Three different fan installations were used. At the first house (#5) small axial fans of 50 L/s (100 cfm) capacity and 50 Pa suction at zero flow were installed. A protective wire grill was bolted in front of the fan to prevent children putting their fingers into the rapidly revolving plastic fan blades.

Two other fans were used at the other houses. The first was a small centrifugal fan of 50 L/s capacity and 200 Pa suction at zero flow mounted in a free standing wooden box, and connected to the central collection duct with 100 mm diameter wire reinforced plastic hose (dryer hose) generally passed through a sheet of plywood replacing a basement window pane. The fan was hung inside the box from its discharge port flange, a plastic toilet flange was screwed to the metal fan body as an intake adaptor, and a 300 mm length of "4 inch" plastic pipe with an elbow was placed over the discharge opening to prevent children from putting their fingers into the rapidly revolving metal fan wheel. The second was a larger centrifugal fan with a weather-protective aluminum housing, mounted on a wooden stand, and connected to the system by 100 mm diameter plastic hose.

9.1.3. Problems

Closing the blocks with mortar was slow, and physically demanding. Stuffing the blocks with paper took a long time. A 22 kg bag of cement will only fill the tops of eight blocks, so considerable time and effort was spent in just mixing mortar. The mortar was heavy to handle. The task was judged only just within the capability of the average homeowner.

The use of an expanding foam was investigated as an easier and more rapid way to fill the block voids. Two kinds of single component foam and a two component foam, available from local stores, were tried as block fillers. The major use foreseen for foam was in areas of limited access, particularly where it was not even possible to reach into the cavity to insert paper. None of these foams was entirely satisfactory, and a more systematic search and test program was carried out in the fall.

9.1.4. Evaluation

The results from the Phase 1 installations are shown in Table 9 below. Both wall closure methods were effective in areas where there was good access to the top of the block walls. Each method had its own advantages. The "sticky strip" was quick to apply on unobstructed lengths of wall, where long lengths could be used. On the walls at right angles to the floor joists, wedges could be inserted between the strip and the joists to hold the strip in place. On the walls parallel to the joists this could not be done, and the strips had to be nailed into position. This did not locate them as well as wedges, and was slower, but the closure was still effective.

Where the block cavities were readily accessible, they were filled with mortar by first stuffing newspaper into the cavity to provide a support layer about 5 cm (2 inches) below the top of the block, and then placing a moist mortar on top of the paper. The mortar had to be vibrated slightly to fill to the edges of the cavity. The small cavities between blocks are irregular in shape, and it was hard to fill them with mortar even with vibration. In general, if there was enough space to insert the paper, the cavities could be filled readily.

TABLE 9 SUMMARY OF PHASE 1 RESULTS WITH BLOCK WALL SUCTION

HOUSE NO.	RADON LEVELS WITH SYSTEM OFF (Bq/m³)		RADON LEVELS WITH SYSTEM ON (Bq/m³)		PERCENT REDUCTION IN MEAN
	RANGE	ARITH.MEAN	RANGE	ARITH.MEAN	
5	0- 74*	40*	999-1 850	1 580	---
6	1 221-2 516*	1 850*	777-1 221*	999*	46
7	3 115-5 180*	4 144*	111- 444*	259*	93
8	1 961-5 880*	3 700*	74- 148	111	97

* All measurements marked with an asterisk were obtained in warm weather - June to August.

Levels in House 7 rose to 4 033 Bq/m³ - 18 537 Bq/m³ during cold weather.

These results are based upon 1 to 2 days of hourly Pylon measurements in the basement before and after the system was activated.

In less accessible areas, the cavities were stuffed with paper and an expanding foam was injected over the top. This worked well, and the small cavities between the blocks could be closed either by injecting foam directly into them, or by placing a bead of foam on top.

The performance in the first house (#5) was disappointing, for the radon concentrations in the house rose when the fans were turned on. This was attributed at the time to the fans drawing radon-laden soil gas into the wall, which then leaked into the house through the many openings at the top of the house walls. (Later work found that sufficient air was drawn into the walls by the fans to depressurize the basement sufficiently that airflow was reversed in an untrapped floor drain, which brought in radon and soil gas). Work was suspended at this house while better methods of wall closure were tested.

The results at house #8 were very satisfactory. When the fans were turned on the radon concentration fell almost to background. A smoke tube survey of the basement walls showed that the unclosed areas were quite small. The remaining openings were closed by caulking, and the fans reversed to suck on the walls. The performance remained good, and did not deteriorate when only one fan was used. This confirmed that a satisfactory level of wall closure could be obtained by the methods available. The success at this house gave confidence that wall ventilation systems cold be an effective mitigative measure.

The initial summertime success of three of these installations was encouraging, suggesting that wall ventilation might have wide applicability in the area. However, when short-term measurements were made in cold weather, only house #8 continued to show low radon concentrations.

9.1.5. Comment

The reason for running the fans to suck on the wall is one of convenience. If the fans blow into the wall, in cold weather the cold air will blow onto the inner leaf of the block wall and may cause condensation there of the warmer house air. If the fans suck, warm house air will be drawn into the wall, but condensation will take place on the cold outer leaf of the wall. This will not be noticed, and is therefore preferred. For similar fans, the air leakages in or out of the wall will be similar, so there is no difference in the impact of the systems on ventilation rate or energy consumption.

9.1.6. Expanding Foams Tested

The first expanding foam tried was sold in an 150 g (1 lb) household aerosol can. It had a moderate expansion on leaving the nozzle, and a small expansion over the next hour. Unfortunately, the foam had to be dispensed with the can upside down (nozzle at bottom), and there was rarely enough space between the top of the wall and the underside of the floor above to do this. The foam was effective for caulking joints and openings in vertical wall surfaces and floors but could not be used for the purpose required.

The second single component foam came in a 4.5 kg (10 lb) commercial pack, together with a dispensing hose and an on/off control nozzle. The foam was intended for caulking, and was delivered from the nozzle in a sticky bead. The initial expansion was small, but the foam continued to expand to more than double its initial volume over the next few hours. If this foam was dispensed into a cavity that had been stuffed with paper to provide a support, the individual foam beads joined to form a solid mass as they expanded. This mass continued to expand and effectively filled the block void. It could be used as a caulk in all places where the bead was supported, but could not be used to form a layer over a large opening like the two other foams. None of the foams used were fully satisfactory for block filling, but this foam was found useful in several houses.

The two component foam came in two small aerosol cans, with a dispensing hose and mixing nozzle assembly. The foam expanded moderately on leaving the nozzle, with a small expansion over the next hour or so. The hose allowed access to all places that could be reached by hand, but the nozzle allowed only on/off control. If the flow was off for more than 20 seconds, the reaction chamber in the nozzle clogged, and had to be replaced before the unit could be used again. This was very inconvenient and time consuming, and made the use of this foam impractical in this work.

The variety of foam properties and packages met with in local stores was large enough to hope that a systematic search might find a fully suitable foam. This was carried out in the fall, and a single component urethane foam in a large commercial package was identified as the most satisfactory to use for closing openings and voids in concrete block walls.

9.2. PHASE 2 - GENERAL

The systems were modified at houses #5, #6, #7 where the systems were ineffective in cold weather. Two houses (#14, #16) in which weeping tile ventilation had been unsuccessful, and one new Phase 2 house (#19) in the same area and of similar design to house #14, had new wall ventilation systems installed. The voids at the top of the block basement walls of these two houses were readily accessible, and they seemed to be "textbook" cases for wall ventilation systems.

9.2.1. Additional Work On Phase 1 Houses During Phase 2

Extensive work was carried out at the houses where the Phase 1 wall ventilation systems were no longer effective, to ensure that leakage from the walls was not the reason for the failure.

At house #5, where the tops of the walls had been closed with felt sheets, the felt was removed and the top voids of the wall were filled with mortar or expanding foam. The five axial fans were removed, the openings closed, and a six point wall exhaust system installed. This had two exhaust points in each long wall and one exhaust point in each short wall, connected to a single 100 L/s exhaust fan.

At house #6 the felt sheets closing the end wall were removed and the block voids were filled with mortar. The 100 L/s centrifugal exhaust fan on the pipe network was removed and replaced by a 50 L/s centrifugal blowing into the walls, and the 50 L/s axial in the garage was reversed to blow into that basement wall.

At house #7, the walls were put under pressure by reversing the 50 L/s centrifugal fans, and a smoke stick survey carried out to check the caulking. Any openings detected were caulked. System performance was tested with the fans both in suction and in pressure.

The wall exhaust pipes at house #7 and #C entered the walls near the top, so soil gas would be drawn up the entire inner surface of the wall on its way to the pipes. The exhaust points at these houses were moved to the bottom course of the walls to improve the wall ventilation efficiency. No improvement in performance was noted.

9.2.2. Installation Procedure on Additional Phase 2 Houses

A six-point wall ventilation system was installed at house #14, with one exhaust point in each end wall and two points in the front and rear walls. Each pipe dealt with a similar wall area, and was connected to a central collection duct. At house #16 a four point system was installed in the basement, connected to a three point system in the crawl space walls. This was later enlarged to a six point system in the basement, with a larger central collection duct to increase air flow from the crawlspace walls. Both these systems had 100 L/s centrifugal exhaust fans mounted on the exterior basement wall, and the wall exhaust points placed near the floor for better ventilation efficiency. A four point system with the exhaust points in the top of the wall was installed at house #19. The system was a duplicate of that installed at house #8, which was a house of identical basement design. The tops of all walls were closed with mortar where access permitted, or else by caulking the sill plate to the top of the wall.

9.2.3. Problems

Several of these houses had brick veneer walls. In this case the basement wall is of 300 mm (12 inch) block, and the brick rests on the outer 75 mm (3") of the wall. The wooden interior framing stands on the sole plate which covers the inner 200 mm (8") of the wall, with a nominal 25 mm (1") gap between the sheathing and the brick. If this gap were unobstructed, this would be a very large unclosed opening into the wall. At house #6, the gap was even larger, for the frame walls stood on top of a course of 300 mm (8 inch) blocks, which ran inside the brick veneer to increase the basement headroom. In practice the gap is partially filled with mortar droppings, but three methods were examined to close this gap with expanding foam.

The first method was only applicable in those houses where the sillplate did not cover the block voids completely. Fiberglass batting was stuffed into the block voids to act as a temporary support, and then expanding foam was injected into the void with a long nozzle so that the void would be filled even at the back. The foam filled the entire block cavity as it expanded, and so closed both the brick/sheathing gap, and the gap between the block and the sole plate. This method was used at house #5, where the absence of a sole plate made it the method of choice.

The second was to drill 6 mm holes in the header board at 150 mm intervals, and inject foam until it appeared at the adjacent hole. The third was to use a hole saw to remove a 100 mm diameter plug from the header board, insert a flexible tube through the hole up to 400 mm between the back of the brick wall and the sheathing, and then slowly withdraw the tube while injecting foam into the space. These methods were tested, and the large hole method found to be the most convenient. These methods were not used in these houses.

9.2.4. Evaluation

The results from the Phase 2 installations in the houses are summarised in Table 10 below.

Wall ventilation systems were expected to be an effective and complete mitigation measure because the suction in the walls would not only prevent soil gas from entering the house directly from the walls, but also because the numerous small openings in the wall at the footing would allow the wall suction to depressurize the both the wall/floor joint area, and the sub-slab fill as well. The systems would therefore act as combined sub-slab and wall ventilation systems, provided that the walls could be closed well enough for a small fan to produce suctions and airflows significantly larger than those that would be induced by wind and temperature forces.

The generally low sub-slab permeability found in the region prevented the walls from depressurizing the sub-slab space in most of the houses. Only at house #14 was there direct evidence from smoke tests of the wall suction extending into the sub-slab space, and the system performance was good there. At house #16, a flow of soil gas was measured out of the sub-slab space in the crawl space despite the walls being under suction at the time, and good performance was not achieved until that opening was closed.

The open block voids at the top of the walls could be closed at reasonable expense if the sill plate covered the top of the wall so that the gap between the wood and the block was small and could be closed by caulking, or by a caulked wood strip. The gap at the outer edge of the sole plate was inaccessible, and so this closure was not as airtight as filling the top block voids. The labour involved in mixing and placement made mortar filling expensive. Expanding foam was also effective and required less labour, but the high material cost made it more costly than mortar.

The methods used to close the tops of the walls greatly reduced the open area. However, inaccessible joints in the sill plate and header board, and the multiple joints and pores in the concrete blocks themselves provided relatively large leakage areas into the walls. As a result, it was difficult to depressurize the walls without drawing a significant amount of air from the basement. This severely limited the pressure drop that could be produced in the walls, and so the sub-slab suction produced by this method was low. In addition to increased heating or cooling costs caused by this increase in ventilation rate, depressurization produced by operating the fans in exhaust could backdraft combustion appliances, and draw combustion products into the house.

At house #19, while the walls were completely under negative pressure, an airflow was detected out of a large floor crack into the house. At house #7 the fans were reversed to fill the walls with fresh air, which made no difference to the radon concentration even though the concentration in the walls was a fraction of that in the house. The fans were returned to suction, openings in the floor were closed, and radon concentrations in the house were reduced. This indicated conclusively that the walls were not the only radon source for these houses, and that the floors would have to be treated as well if radon concentrations were to be reduced.

Houses #7 and #6 were converted to wall plus floor ventilation systems with a major reduction in radon concentrations. A conversion of house #19 to wall plus floor was proposed, but refused by the owners who were concerned that openings in the basement floor might let in water.

TABLE 10 SUMMARY OF PHASE 2 RESULTS WITH BLOCK WALL VENTILATION

HOUSE NO.	RADON LEVELS WITH SYSTEM OFF (Bq/m^3)		RADON LEVELS WITH SYSTEM ON (Bq/m^3)		PERCENT REDUCTION IN MEAN
	RANGE	ARITH. MEAN	RANGE	ARITH. MEAN	
Individual suction points in walls					
5A	2 479- 7 400	4 255	111- 296	185	96
7A	5 772-23 162	14 874	518-2 479	1 184	92
14A	1 961- 2 479*	2 257*	18.5- 74	37	98
16A	5 032-12 099	8 880*	74- 259	148	98
19	777- 1 887*	1 295*	111- 710	407	68

* All measurements marked with an asterisk were obtained in warm weather - July to August.

These results are based upon 2 to 4 days of hourly Pylon measurements in the basement before and after the system was activated.

The untrapped floor drain at house #5 was found to be a major radon entry route, despite discharging to daylight in front of the house. When the soil temperature was higher than the air temperature, there was a steady convectional flow of air up the drain line into the house, picking up radon on the way. In the summer, when the soil was cooler than the air, the drain was not a radon entry route, for the airflow was out of the house into the drain. The small driving force could be overcome if the basement was depressurized by exhaust fans, as occurred in Phase 1. Closing this entry route, fully closing the open blocks at the top of the walls, and installing a six point exhaust system produced a major reduction in radon concentrations. The system was finally operated with the fan blowing air into the walls, to avoid depressurizing the basement and backdrafting a coal stove.

9.3. PHASE 3 - GENERAL

No houses were selected for wall ventilation in Phase 3.

9.4. OVERALL EVALUATION OF WALL VENTILATION

Despite initially encouraging results, wall ventilation was not as complete a mitigative method as had been hoped. The generally low sub-slab permeability prevented the lowered pressure in the walls from effectively ventilating the sub-slab space, and the relatively large residual leakage areas left in the walls after closure limited the wall suction to a few Pascal even with large fans. This was sufficient to ensure that the airflow was from house into the wall under most weather conditions, eliminating the walls as a route of radon entry, but not enough to consistently reverse the flows through floor openings. Experience with sub-slab ventilation suggests that much higher suction in the sub-slab fill was needed for satisfactory performance.

Some houses were operated with the walls pressurised, which effectively prevented radon from entering the walls, but also encouraged soil gas to enter the house through openings in the floor. In general, slightly lower radon concentrations were obtained with pressurization, but concentrations could increase for a few days after turning the system on until the airflows from the walls into the soil diluted and displaced the radon-rich soil gas adjacent to the basement floor.

Although wall ventilation could be an effective treatment, as shown by the results in houses #5, #8, #14, and #16, it did not seem to be a good initial mitigation strategy to pursue. There was a real possibility that even after installing a system that was more expensive than a sub-slab ventilation system, even more money would be required to install a sub-slab system to treat the floor. This is illustrated particularly by house #19, where the walls were effectively closed and ventilated, but radon entry through openings in the basement floor-slab kept radon concentrations elevated. By the end of the project, experience with sub-slab ventilation systems was that a better order of events would be to treat the floor first, which would generally be effective in most houses, and only if that failed, to proceed to wall ventilation.

SECTION 10.
EXPERIENCE WITH WALL PLUS SUB-SLAB VENTILATION

10.1. INTRODUCTION

Two methods of combined wall plus sub-slab ventilation were tested in this project. The first involved drilling holes into the lowest course of the block wall, and placement of a "baseboard duct" to cover the holes and the wall/floor junction. This duct then ventilated both the wall and the sub/slab space. A typical baseboard duct installation is shown in Figure 5. The second method involved placement of individual suction pipes into both the wall and the sub-slab space - a simple combination of the wall and sub-slab ventilation methods described in Sections 7 and 9.

10.2. PHASE 1 - GENERAL

Some houses without weeping tiles have a 'french drain' to deal with water entry. This is an opening about 50 mm (2 inches) wide between the edge of the floor slab and the basement wall, exposing the upper surface of the footing and the sub-slab fill. Water that enters the concrete block wall weeps down the wall surface, and is collected and drained to the sub-slab fill without flowing onto the floor surface. These houses present a major challenge, for not only are there the usual routes of soil gas entry through the floor and walls, but also a direct route from the soil via the french drain.

A suggested mitigation method for houses which had french drains and concrete block walls was to place an airtight cover over the drain, and drill holes through the lowest blocks at intervals, so that suction on the cover would also ventilate the wall via the holes. Radon laden soil gas would be collected from the wall, and from the soil connections to the french drain. The function of the drain would not be impaired, for water that entered the wall would still be able to flow out to the drain through the holes.

The major problems with this concept were what was the best way to place a cover over the french drain, and how to achieve small enough open areas in the wall and the cover for it to be a practical solution.

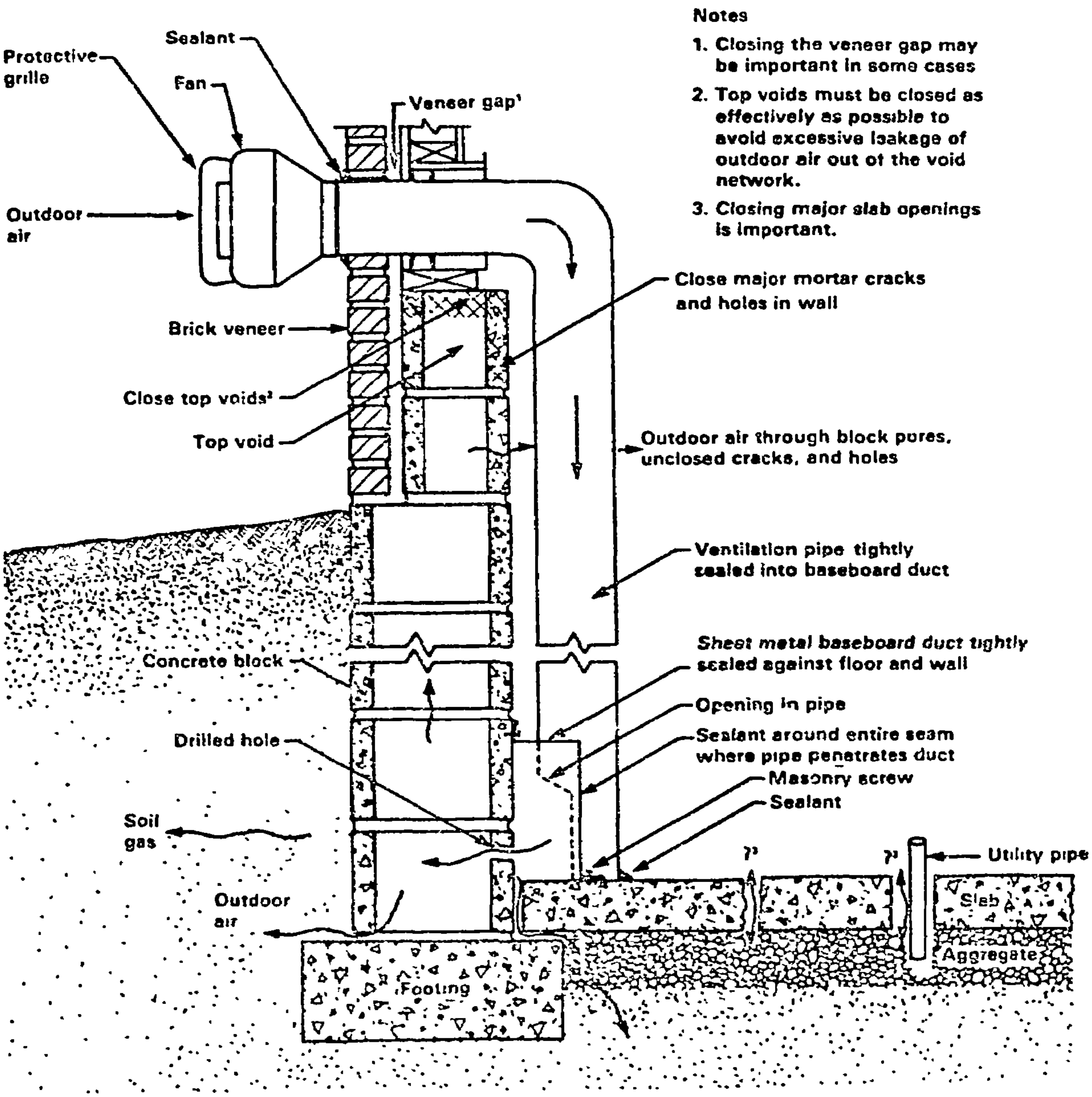


FIGURE 5 TYPICAL "BASEBOARD DUCT" INSTALLATION

10.2.1. Baseboard Duct Installation Procedure

Two different types of baseboard duct were used at two different sites. The first site (house #11) was a small end row-house basement with a french drain around the three external walls. The drain was connected to a sub-slab drainage pipe, and the top of each block wall was covered with a caulked soleplate. A brick veneer external wall stood on top of the basement wall, so the walls were not well closed at the top. In this case, the drain and cover was used to carry the suction from the fan, and the walls were ventilated via the holes drilled in the blocks.

The cover was a commercial "Z" channel made out of plastic and available in 1.2 m (4 feet) lengths. This is sold as an internal drain channel to place at the foot of concrete block walls to trap water leaking out of the blocks at floor level, and to lead it off to a drain. Inside and outside corners, joiners, and plumbing connectors were available, but they would only glue the sections together if the pieces were perfectly square. The workmen found it easier to form overlapping corners and caulk the gaps than to glue the sections.

Holes were drilled with an electric rotary impact drill and 12 mm (1/2") bit at 40 mm from the floor in the mortar joint between each block. The channel was placed over the french drain at an angle of 60° to the floor, forming a baseboard duct of triangular cross section, and secured to the floor and wall by screw anchors placed in previously drilled holes. A bead of asphaltic sealant was placed on each surface beneath the cover edge to take up surface irregularities. A "four inch" plastic drain pipe was connected to the channel at one end, and ran out through a window to a 30 L/s centrifugal fan.

The second site (house #9) was a much larger house and needed long lengths of material to cover the drain. Joining the short lengths of plastic channel was time-consuming, and the joined lengths were very flexible and difficult to work with, so for this house flat sheet metal covers were fabricated locally in 3.3 m (10 feet) lengths. Each cover was 250 mm (10") wide, and the edges were folded, punched at intervals of 600 mm, and set at angles of 30° and 60° to the plane of the cover.

Holes were drilled into each cavity of the lowest course of blocks at 60 mm from the floor with an electric rotary impact hammer and 12 mm (1/2 inch) drill bit. The covers were placed over the drain at an angle of 60 degrees to the floor, so their edges were parallel to the wall and floor, and were attached to the wall and floor with screw anchors inserted into previously drilled holes. A bead of asphalt sealant was placed on each surface beneath the cover edge to take up the surface irregularities.

About 2.5 m (9 feet) of the french drain was concealed behind an ornamental brick fireplace. The drain in this area was filled with concrete. A wet concrete mix was flowed down a plastic tube slipped between the fireplace brick facing and the basement wall. A further 11 m (36 feet) of drain was inaccessible because a frame wall covered with wallboard had been built over it to finish one end of the basement as a laundry room and a bathroom. A shower stall unit also covered 1 m of the drain in the bathroom. As the wall sole plate covered the drain reasonably tightly, it was decided not to cut off bottom of the wall and install a cover, but to simply connect this part of the drain to the ventilation duct, and increase the fan capacity to compensate for the additional leakage expected in this area. If it proved necessary, this section would be dealt with in Phase 2 of this program.

The block voids at the top of the front and back basement walls were partially closed by a large sillplate, which did not give enough room to insert paper into the cavities so that they could be filled with cement or foam. The sillplate was therefore sealed to the top of the wall with wood strips coated with caulking. The wood strips had to be cut specially, for a standard "2x1" was slightly thicker than the sillplate and could not be inserted between the top of the wall and the underside of the joists. In areas where a wood strip could not be inserted because of construction details, wiring or piping, a layer of expanding foam was placed on top of the wall to close the voids.

The cover could not run round the basement in one continuous ring, for there were internal walls, a fireplace and an exterior door. It was installed as four physically separate sections, each exhausted by a "1 inch" lightweight plastic drain pipe. These were connected to a header pipe with a 50 L/s centrifugal fan on each end. When the fans were turned on, radon concentrations were greatly reduced in the house.

10.2.2. Modifications to Existing Systems (Individual Pipes)

House #3 was adjacent to house #8, and was of similar design and construction, except that a secondary concrete block wall had been constructed on the floor to reinforce the uphill and rear walls which had cracked. Two vertical steel beams tied to the floor joists provided additional support. A sub-slab ventilation had been installed in house #3, but it had not made a large enough reduction in radon concentrations to be considered effective.

A wall ventilation system was added to this house, similar to that used in the adjacent house #8. An exhaust pipe was inserted in each basement wall, with an additional pipe into the reinforcing wall at the rear of the house. The original single-pipe sub-slab system was left in place, and tee'd into the wall exhaust system. A single 100 L/s centrifugal fan exhausted the entire network. The reinforced wall was two blocks thick on two sides of the basement, and access to the top of this thick wall was severely limited by the floor joists. Enclosure of the top of this wall was all that could be managed, and this required much more carpentry than usual. Joints were closed with caulking and expanding foam, and the final result had very little leakage area. Good results were achieved.

House #2 had a sub-slab system installed, which had made a considerable reduction in radon concentrations, but the results were not fully satisfactory. This house had been inspected by a contractor for the DER who had made radon "flux" measurements on the walls. The highest reading was obtained on the basement wall adjacent to the garage, and it had been suggested that this was an indication that the wall was a major route of radon entry. As a test of this, the garage wall was ventilated by connecting the existing sub-slab fan into the wall (#2A). No significant change in radon concentration was produced, even though a smoke test showed that air flowed from the house into the garage wall through every opening, eliminating the wall as a source.

Further smoke testing in this house found air flowing into all the external walls and into all accessible floor cracks. The only remaining route of radon entry was an internal concrete block wall and fireplace structure, which did not have a positive airflow into it. Closing and ventilating this structure would be a major task, and so it was left for Phase 2.

10.2.3. Evaluation

The success of wall plus sub-slab ventilation (five surface treatment) in Phase 1 was ambiguous. The results are summarised in Table 11 below. The summer-time results indicated good performance at houses #9, #3, #11, but only a marginal effect at house #2. This could have been because only one wall was ventilated. Short-term measurements in the winter found that the cold weather performance of all systems except house #3 had deteriorated markedly.

TABLE 11 SUMMARY OF PHASE 1 RESULTS ON SUB-SLAB + WALL SUCTION

HOUSE NO.	RADON LEVELS WITH SYSTEM OFF (Bq/m³)		RADON LEVELS WITH SYSTEM ON (Bq/m³)		PERCENT REDUCTION IN MEAN
	RANGE	ARITH. MEAN	RANGE	ARITH. MEAN	
Baseboard duct over French drain					
9	8 954 -17 575*	13 320*	74 - 259*	185	99
11	**	~ 2 220*	555 - 1 036	777	~65
Individual pipes in slab and walls					
2A	3 256 -18 611* (Only one wall ventilated)	8 806*	444 - 1 702*	1 036	88
3A	31 376 -54 575*	44 585*	37 - 74	37	99

* All measurements marked with an asterisk were obtained during warm weather months - July to August

** Insufficient data to determine range.

Note: Post-mitigation levels rose during cold weather:

House 2A rose to 13 505 - 54 575 Bq/m³

House 9 rose to 296 -1 480 Bq/m³

These results are based upon 1 to 2 days of hourly Pylon measurements in the basement before and after the system was activated.

10.3. PHASE 2 - GENERAL

Based the Phase 1 experience with separate wall ventilation and sub-slab ventilation systems, it was felt that combined wall/floor systems would be needed to effectively deal with the higher level houses (>1 kBq/m³). Further testing of combined systems was planned for Phase 2 to determine the important parameters, and to optimise the design. Improvements were planned for the systems at house #9 and #11, and a new system was planned for house #2. Houses #7 and #6, which had unsuccessful wall ventilation systems, and #1 which had an unsuccessful sub-slab ventilation system would all be converted to wall plus sub-slab systems.

The owner at house #11 did not wish further work to be done, and this house was therefore dropped from the program.

No new Phase 2 houses were selected for wall plus sub-slab ventilation as a primary mitigation measure. As it was clearly the highest cost option, it would be installed in houses only if less costly mitigation systems were ineffective.

10.3.1. Installation Procedure

The new systems installed at house #2 and #1 were baseboard duct systems, similar to those installed at houses #9, #11. However, there was no french drain in houses #1, #2, only a shrinkage crack at the wall/floor joint. The baseboard duct therefore primarily provided wall ventilation with a smaller sub-slab ventilation component. The floor at house #1 had been poured in several sections, and the peripheral crack was smaller than at house #2. The overall system design was similar at each place, the walls would be closed at the top and multiple openings would be drilled at the bottom, and a cover would be placed over the wall/floor joint and the openings in the walls. The cover would be exhausted, ventilating the walls and the sub-slab space via the wall/floor joint and the wall/footing openings.

A few test holes were drilled through the floor slab at each house in areas that would be beneath the cover to see if the communication to the sub-slab fill could be improved. In each case the drill struck the footing without passing through a significant layer of fill, so this idea was given up.

The baseboard cover design used at house #2 was the same as that used at house #9. The houses were similar in size, but at house #2 the basement walls were painted, and the sill plate was caulked to the top of the basement wall. The airflows out of the walls were expected to be lower than at house #9, so the same size of duct was expected to be satisfactory. The cover could not be installed in one continuous loop, for the basement walls were interrupted by two doors to outside and an internal wall which included a fireplace. The cover was therefore installed in two separate sections each with its own 100 L/s centrifugal fan. One section was extended to ventilate the internal wall.

The cover design at house #1 was a large rectangular duct 300 mm high and 80 mm wide fabricated locally from sheet metal. The walls at this house were of porous cinder block and had many openings, so it was expected that large airflows would be drawn from the walls. The duct had about four times the cross-section of the ducts used at houses #2 and #9 to decrease the flow velocity and the pressure losses in the duct. The basement walls were painted with waterproofing paint to increase their airtightness. The duct was originally installed as a "C" ring with only one interruption at the exterior basement door and with one 100 L/s fan at one end of the house. This did not produce any airflow into the wall at the far end of the duct, and so the duct was made into a continuous loop by running a duct around the door frame, and a second 100 L/s fan was added at the opposite end of the house.

The system at house #9 was extended to cover all of the french drain, except for a short 2.3 m section behind a basement bathroom wall and shower stall. The 50 L/s fans were replaced by 100 L/s units.

Initial testing was done at these three houses with fans exhausting the ducting. This led to significant depressurization of the house, as shown by smoking fireplaces and stoves. The exhaust fans at these houses were all replaced with wall mounted 150 L/s pressure fans.

At houses #7 and #6, wall ventilation system was extended to act as a combined wall and floor system. The procedure used in these houses was to core drill a hole in the floor beneath the wall exhaust pipe and extend the pipe into the hole. The same fan then exhausted both the walls and the sub-slab space.

10.3.2. <u>Evaluation</u>

The results from these Phase 2 and Phase 3 installations are summarised in Table 12 below.

One end of the basement at house #2 was used as a store room and there was a workshop with a finished walls and floor. In preparation for the duct installation, the stored materials were removed and the walls cut away to expose the wall/floor joint. The sub-slab exhaust system was running at the time, and a smoke test showed although the airflow was down into the sub-slab space in the easily accessible parts of the basement, the airflow from the wall/floor joint along the formerly concealed end wall of the house was into the house. This indicated that there must be a low permeability zone in the sub-slab layer of crushed stone that was preventing suction from reaching to this end of the house. A multiple point floor exhaust system would have overcome this.

TABLE 12 SUMMARY OF PHASE 2 AND 3 RESULTS FOR SUB-SLAB + WALL SUCTION

HOUSE NO.	RADON LEVELS WITH SYSTEM OFF (Bq/m^3)		RADON LEVELS WITH SYSTEM ON (Bq/m^3)		PERCENT REDUCTION IN MEAN
	RANGE	ARITH.MEAN	RANGE	ARITH.MEAN	
Baseboard duct					
1A	4 662 - 7 363*	5 957*	1 665 - 5 883	2 812	53
1B	4 662 - 7 363*	5 957*	111 - 259	185	97
2B	3 256 - 18 611*	8 806*	74 - 222	148	98
9A	8 954 - 19 575*	13 320*	111 - 370	259	98
Individual pipes in slab and walls					
6A	851 - 3 626*	2 294*	555 - 1 924	1 221	47
7C	5 772 -23 162	11 874	592 - 1 739	962	93
20B	5 476 -25 752 *	10 134*	74 - 222	148	99

* All measurements marked with an asterisk were obtained during warm weather - July to August.

These results are based upon 2 to 4 days of hourly Pylon measurements in the basement before and after the system was activated.

The triangular duct was installed without problems. One 3 m section of wall was isolated between two doorways, and the duct there was connected to the fan by a square duct that ran round one of the doors. There was a disproportionate air leakage into this duct at the transition fittings, and the gain in performance (if any) from the short duct was probably not worth the cost.

The top course of blocks were removed from the internal wall and fireplace to gain access to the voids, which were then filled with mortar to increase the airtightness of the interior wall. The blocks were then replaced. The fireplace flue structure interior could not be accessed, so there was an untreated air leakage path there.

Operation of the system placed all the walls and the sub-slab fill under suction relative to the house as shown by smoke stick testing, and gave low radon concentrations. Air leakage into the system was large enough to cause the basement fireplace to backdraft. The 100 L/s exhaust fans were replaced with 150 L/s pressure fans, which cured this problem, and equally good performance was achieved.

At house #9, the triangular duct was extended beneath the stairs, and walls were cut away at the base to instal a duct in the laundry room. In preparation for permanent wall mounted exhaust fans, the air collection system was modified. Much of the plastic pipe collection header was replaced with two wall mounted square sheet metal ducts connected to the triangular duct in two places. The wall closures carried out in Phase 1 were checked, and improved by additional caulking or expanding foam.

Operation of the system placed all the walls and the sub-slab space generally under suction relative to the house, as shown by smoke stick tests, and reduced radon concentrations. However, air leakage into the system was large enough to cause the basement wood stove to backdraft and smoke. The fans were replaced with 150 L/s pressure fans, which cured this problem, and satisfactory performance was obtained.

At house #1, the 2 initial 100 L/s fans were too small to produce a significant depressurization in the walls, for leakage areas were much larger than anticipated. A major inaccessible opening was around the basement stove flue, which passed out through a hole in the block wall to an external block chimney. The hole in the outer leaf of the wall was much larger than the flue pipe, and could not be reached to close it without dismantling the chimney. Much of the capacity of the fan at this end of the house was taken up in drawing air through this opening. Part of the front wall of his house was of brick veneer, and there was a gap between the brick and the header board. This was filled with expanding foam injected through 100 mm diameter holes cut in the header board, which reduced the airflow from this section of the wall. Airflows in the system were high even after considerable effort was spent trying to find internal leakages, and the radon concentrations in the ducts were elevated, suggesting large exterior subsurface openings.

Routes of radon entry were discovered by radon measurements in temporary enclosures placed over the wall/floor joint adjacent to walls under suction, so it was clear that the sub-slab fill was not being ventilated. The air drawn from the basement caused the stove to backdraft, so before the fans were reversed to pressurise the basement, additional plastic 'Z' ducting was placed over all the wall/floor joints to prevent soil gas from being forced out of these openings. A test using two 50 L/s in pressure increased radon concentrations, and soil gas was forced out of floor joints and small floor openings. These were closed, and the small fans replaced with 150 L/s wall mounted pressure fans, which gave higher system pressures and flows, and low radon concentrations (house #2B).

Shortly after this work was completed the owner sold the site, and removed the house superstructure to a new basement constructed on a new site several km distant. The old basement was demolished in the moving process, so no long-term winter-time measurements could be made.

The performance of the wall ventilation system at house #7 had been improved by work to increase the air tightness of the floor, which indicated that the size of the random connections between the walls and the soil were too small (and the wall suction too low) to effectively depressurize the sub-slab space. Extending the wall exhaust pipes into the sub-slab fill produced a major reduction in radon concentrations.

The 3 wall exhaust pipes in the unfinished half of the basement at house #6 were extended into the sub-slab fill. The second isolated exhaust fan treating the finished basement wall adjacent to the garage was turned off. A major reduction in radon concentrations was obtained, even though there had been no work to close the construction joint between the two halves of the basement slab, and the wall ventilation had been reduced.

The success with relatively little extra effort of these two multipoint wall plus sub-slab ventilation systems, compared to the major efforts required to achieve comparable success with the baseboard duct systems, suggested that the multipoint system was the more practical of the two. Performance was better for the suction was applied directly to the sub-slab fill rather than indirectly via random openings in the wall footing, resulting in better control of floor entry routes, which was more necessary than had it had seemed in Phase 1.

10.1. PHASE 3 - GENERAL

No new houses were selected for wall plus sub-slab ventilation as the initial mitigation method in Phase 3. If any of the Phase 3 concrete block basement houses where sub-slab systems were to be installed did not give good results, then they would be converted to wall plus sub-slab systems. Modifications were made to the system at house #7 to see what ratio of wall to sub-slab ventilation gave the best results. House #20, where a sub-slab system had been installed in Phase 2, was converted to a wall plus sub-slab system, for there was a known radon supply via the walls. House #6 was converted to a sub-slab only system.

10.4.1. Evaluation

Dampers were installed in the wall exhaust pipes at house #7, and the ratio of air drawn from the walls to air drawn from the sub-slab fill varied. Closing the dampers increased the suction in the floor pipes, and low radon concentrations were obtained with the wall dampers fully closed. The system was now operating essentially as pure sub-slab system, with a very small wall ventilation flow.

The wall exhaust pipes were removed at house #6, and the system re-installed as a sub-slab system with closure of floor openings. An exhaust pipe was not installed in the finished half of the basement, so only three exhaust pipes were used. Low radon concentrations were obtained.

The owners of house #20 added an extension to the house over the summer, with a sub-slab ventilation system consisting of a loop of perforated drain tile beneath the paved crawlspace slab. The system tested in this house consisted not only of a wall ventilation plus sub-slab system in the original basement, but also the extension sub-slab system (#20B). These were ultimately connected to the same 150 L/s exhaust fan. It was found that it was necessary to operate both systems to achieve low radon concentrations in the basement, but that the performance did not vary as the crawl space system exhaust flow was varied. Disconnecting the suction pipes from the walls and running as a pure sub-slab system (#20C) appeared to give a small increase in basement radon concentrations. All measurements in this house were complicated by the presence of high dissolved radon concentrations in the well water, which caused large increases in the airborne radon concentrations whenever water was used.

10.5. OVERALL EVALUATION OF WALL PLUS SUB-SLAB VENTILATION

Although the wall plus sub-slab ventilation systems effectively reduced the radon concentrations, the general conclusion was that the elaborate wall/floor baseboard duct systems used in the first houses were probably unnecessary. The use of a perimeter multiple point sub-slab exhaust system with high suction fan was able to reduce radon entry through the walls without a separate wall ventilation system. Presumably, although the soil permeability beneath the foundations was low, it was still high enough for suction to pass underneath the footings and depressurize the soil in the vicinity of the exterior wall/footing joint.

The preferred solution for a french drain was not to place a cover over it, but to fill it with mortar over a layer of gravel. This would decrease the air leakage area, and still allow water to drain from the walls. A sub-slab ventilation system could then be installed.

SECTION 11.
EXPERIENCE WITH HOUSE VENTILATION

11.1. PHASE 1 - GENERAL

House #18 had block walls open at the top, and an open "french drain" round the basement. Despite these large soil connections, premitigation measurements found only moderately elevated and highly variable radon concentrations averaging 600 Bq/m³ (15 pCi/L). This suggested that the radon supply rate was relatively low, and that increasing the basement ventilation rate might be an effective mitigation measure in this case.

11.1.1. Installation Procedure

The house was heated by an oil-fired hot water system, and a recuperator was installed on the boiler chimney. When the oil-burner operated, a small fan blew basement air through the recuperator to extract heat from the hot chimney gasses. As with any combustion appliance, the flow of combustion gasses and draft air up the furnace flue would tend to lower the pressure in the basement, and draw in soil gas.

To reduce the depressurization a fresh-air supply duct was attached to the inlet side of the recuperator. When the oil furnace operated, the recuperator fan would draw in exterior air from outside, heat it, and then supply it to the basement to replace some of the combustion and draft air that was leaving. Even when the fan was not operating, the duct wold still provide some ventilation to the basement. This would reduce the pressure differential between the basement and the ground, decrease the radon supply rate, and the fresh air would also dilute the radon that did enter.

11.1.2. Evaluation

As the system would be most effective in winter months when the burner would run frequently, measurements were delayed until then.

11.2. PHASE 2 - GENERAL

Short term wintertime measurements in house #18 found that the radon concentrations in the basement were similar to those measured by the DER the previous winter. Thus the increased airflow of 15 L/s into the basement when the furnace burner was running had not significantly reduced the radon concentration. The additional airflow was clearly insufficient. It was decided to install a Heat Recovery Ventilator (HRV) in this house, to provide a higher and continuous ventilation rate. In addition, HRV vendors had recently reported substantial reductions in houses similar to house #18, large enough to reduce concentrations to the 150 Bq/m³ level. These reductions were larger than might be expected from dilution alone, and it was therefore desired to test HRV's as a potential solution for houses with radon concentrations in the <800 Bq/m³ range.

The sump ventilation system installed at house #17 had not made any significant reduction in radon concentration, and had been removed. This house was extensively finished in the basement, had a number of unique construction features, and relatively low radon concentrations. It was decided to install a HRV there, as it would be the lowest cost mitigation measure.

11.2.1. Installation Procedure for HRV's

A local contractor who had installed a number of HRV's for radon control was asked to design and install a HRV mitigation system at each house. His recommendation was a split system, with tempered fresh air discharged upstairs through floor ducts, and the exhaust air taken directly from the basement. This system was installed at house #18 and house #17.

11.2.2. Heat Recovery Ventilators

The same model of HRV was used at each house. This unit uses a rotating wheel made of a coiled flat plastic strip as the heat exchange medium, and has a nominal air delivery rate of 100 L/s, and an actual delivery between 45 to 70 L/s depending on the fan speed setting and the ducting. There is a fiberglass filter in the inlet airstream, and a foam filter on the exhaust airstream to protect the narrow air passages through the wheel from airborne dust.

11.2.3. Evaluation

The results of both the Phase 2 and the Phase 3 measurements are shown in Table 13 below.

The performance of the two systems was similar. The radon concentration in the upstairs portion of the house was reduced to a satisfactory level, but the concentrations in the basement were virtually unaffected by system operation with this duct configuration. This suggested that the mode of action in these hot-water heated houses was that the upstairs air supply slightly decreased the pressure differential relative to the basement, which decreased the amount of basement air that found its way upstairs, and so decreased the upstairs radon concentration. The large differences in radon concentration that were seen in these houses can be attributed directly to the hot-water heating. Forced air heating ducts provide good connections from floor to floor. On the other hand, either the exhaust from the basement was insufficient to change the radon concentration, or else it induced a compensatory increase in radon supply, so the basement concentrations were unaffected.

The HRV installer and the manufacturer suggested that basement concentrations might be reduced by changing to a balanced basement ventilation system, where outside air was discharged into one end of the basement and the exhaust removed from the other end. This was tested at house #17, and it was found that although the basement concentrations were lower with this system, the concentrations upstairs were not as low as when the split system was in use.

The system at house #17 was modified to allow easy adjustment of the air delivery and exhaust. Dampered ducts were added to allow a variable air discharge into the basement, and the amount of air exhausted from the basement.

11.3. PHASE 3 - GENERAL

The modifications to the system at house #17 were not tested in Phase 2 as they were completed after the weather was warm and windows were open. The system at house #18 was also modified to a balanced basement ventilation system, and both houses were tested in cold weather in Phase 3. A third HRV was installed at house #28, for the sump ventilation system installed there in Phase 2 was not effective. This house was a good candidate for a HRV installation, for the radon concentrations were only moderately elevated, and the basement was extensively finished.

11.3.1. <u>Installation Procedure</u>

The same local contractor who had installed the previous HRV's was asked to design and install a HRV mitigation system at house #28. Most of the basement at this house was finished as a family room, and his recommendation was to install the same type of rotary wheel HRV as previously used, but in a balanced basement ventilation configuration. The HRV was placed in and exhausted from the unfinished laundry room, and delivered tempered fresh air into the recreation room through a grille placed in the dividing wall. The recreation room was a major living area, so the focus of the installation was to reduce radon concentrations there.

11.3.2. <u>Evaluation</u>

The results of the Phase 2 and the Phase 3 tests on the HRV's are shown in Table 13 below.

The HRV at house #18 was modified to operate as a balanced basement ventilation system for a test, and the radon concentrations in the basement remained essentially the same as when it was operated in the split mode with all fresh air discharged upstairs, and basement exhaust. Upstairs concentrations were always lower than in the basement, but the lowest concentrations were achieved with upstairs fresh air discharge. The ventilation rate and inter-floor transfer rates were measured by passive PFT detectors during this test. The accuracy of the measurements was low, due to the short exposure duration, but they did indicate that both the basement and main floor ventilation rates were high, and greater than the HRV flows. The net transfer rate of basement air to the main floor was only a fraction of the upstairs ventilation rate, and the transfer rate decreased when fresh air was discharged on the main floor, rather than in the basement. This confirmed the general picture deduced from the radon measurements.

TABLE 13 SUMMARY OF PHASE 2 AND 3 RESULTS WITH HRV's

HRV CONFIGURATION	BASEMENT RESULTS MEAN Rn (Bq/m^3) HRV ON	OFF	% REDUCTION	UPSTAIRS RESULTS MEAN Rn (Bq/m^3) HRV ON	OFF	% REDUCTION
		HOUSE 17A				
70 L/s from basement 90 L/s fresh air to upstairs	1 776	2 146	-19	444	74	81
75 L/s from basement; 75 L/s fresh air to upstairs	1 776	1 406	21	444	74	82
70 L/s from basement; 70 L/s fresh air to basement	2 701	1 702	37	703	185	75
55 L/s from basement; 33 L/s fresh air to basement	2 701	1 702	37	703	259	62
60 L/s from basement; 20 L/s fresh air to upstairs; 60 L/s fresh air into basement	1 480	444	70	--	--	--
		HOUSE 18A				
95 L/s from basement; 62 L/s fresh air upstairs	518	481	6	296	74	74
75 L/s from basement 65 L/s fresh air to upstairs	518	333	31	296	56	81
75 L/s from basement; 65 L/s fresh air to upstairs	851	518	38	333	92	72
95 L/s from basement; 85 L/s fresh air to basement	851	481	45	333	148	60
		HOUSE 28A				
20 L/s from basement; 80 L/s fresh air to basement	592	333	44	333	259	15

The HRV at house #17 was tested as a simple ventilation supply fan by closing the stale air exhaust damper and diverting the airflow back into the basement. Equal amounts of fresh air were delivered to the upstairs and to the basement. The dampers were then returned to the normal position to operate with exhaust from the basement. The fresh air supply was slightly higher under these conditions. Concentrations upstairs were always lower than in the basement, and both upstairs and basement radon concentrations were slightly lower when the system was run as a HRV. The ventilation rate and inter-floor transfer rates were measured by passive PFT detectors during this test. The accuracy of the measurements was low, due to the short exposure duration, but they did indicate that the ventilation rate upstairs was much higher than the forced air supply, but the basement ventilation rate was comparable. The inter-floor transfer rate was low, and decreased when the HRV exhausted from the basement. This confirmed the general picture deduced from the radon measurements.

The dampers were adjusted to decrease the fraction of air sent to upstairs to 25%, and this lead to lower radon concentrations in the basement and higher radon concentrations upstairs.

At house #28, short term measurements found that operation of the HRV reduced radon concentrations in the basement from about 600 to 370 Bq/m^3. The concentration upstairs remained at about 300 Bq/m^3, regardless of whether the HRV was running or not. This suggested that there was a separate radon supply to the upstairs, for if all the radon that reached the upstairs came from the basement, the concentration upstairs should have decreased as well. Large transfers between upstairs and downstairs were expected in this house, for it had a forced air heating system, and operation of the fan would transfer air from the basement to upstairs.

11.1. OVERALL EVALUATION OF INCREASED VENTILATION

The results obtained with HRV's suggest that two separate factors were at work in determining the reduction in radon concentration obtained in a house zone. The first was that fresh air forced into the upstairs zone could decrease the flow of radon bearing air from the basement, and by reducing the radon supply could reduce the radon concentrations by much more than the increase in the zone ventilation rate. The second factor was the increase in ventilation rate caused by the fresh air forced into the zone. This was dependent on the natural ventilation rate in the zone, which could be higher than the HRV flow.

Although these units were installed by an experienced contractor, only the inlet air duct was insulated to prevent the cold outside air from picking up heat on its way to the HRV. The stale air exhaust duct was not insulated, and so this cooled air was able to recover a large portion of the heat it had given up to warm the incoming fresh air. The heat recovery efficiency of the installation was therefore much lower than the HRV efficiency. Economic justifications based on significant heat recovery efficiencies are likely to be in error unless contractors pay attention to the thermal performance as well as the ventilation performance of the system.

Measurements of ventilation and inter-floor transfer flows are needed to predict the performance of HRV's. Although increasing the ventilation rate is simple in principle, the air circulations in a house are more complex than it appears at first. If better performance is to be achieved than just that given by simple dilution, the changes produced in the flow dynamics throughout the house, and the possible effect on the entry rate of soil gas must be understood.

SECTION 12.
EXPERIENCE WITH RADON REMOVAL FROM WELL WATER

12.1. PHASE 2 - GENERAL

By the end of Phase 2, average radon concentrations in house #2 had been reduced to a level where it was apparent that the radon supply via the well water (thought to have a concentration of about 2.5 MBq/m³ - 67 000 pCi/L) was comparable to the supply via soil gas entry. The DER had also identified a house, house #30, where the radon concentration in water (11.5 MBq/m³- 310 000 pCi/L) was the highest that they had measured, and was probably responsible for the elevated radon concentrations in that house. It was decided to place radon removal units on the water supplies of these houses to evaluate their efficiency and determine what problems they might cause in practice.

12.1.1. Installation Procedure

Activated carbon was selected as the removal method for it had been used successfully in other high radon in water areas such as Maine. The unit consists of a pressure tank containing activated carbon installed between the well pump and the pressure control tank. All the water that enters the house passes through the tank, and the radon in the water is adsorbed to the carbon surface.

Two different suppliers were used. The first came from a specialist firm in Maine, and contained 60 L of coconut charcoal selected for radon removal. This was installed at house #30, where the radon concentrations were the highest.

The second unit came from a local water purification supplier, and contained 60 L of charcoal of unknown origin, which had probably been selected for organic removal. This was installed at House #2.

12.1.2. Evaluation

Both units initially had very high radon removal efficiencies (ca. 99%), reduced the radon concentrations in the water, and eliminated the peaks in the house radon concentrations associated with water use. However, large amounts of radon and its progeny were stored on the carbon, and the gamma radiation field in the house was increased considerably in the region of the unit.

12.2. PHASE 3 - GENERAL

The increased radiation fields concerned the householders, and so shielding was installed around the tanks in Phase 3.

12.2.1. Installation Procedure

Theoretical calculations showed that at least 10 mm of lead would be needed around the most active tank (house #30), and a test by wrapping the tank in two layers of 1.5 mm thick lead sheeting confirmed this. A lead shield would have to be specially fabricated, and would be expensive, so a concrete block shielding structure was built around the tank in each of houses #2, #30.

The walls of the structure were of four inch block, and a concrete patio stone was used to cover the top. These structures produced a satisfactory reduction in radiation field at both locations.

After the shielding had been installed, there was a new baby at house #30, and the water consumption increased. The radiation field increased correspondingly, and additional shielding was required. The space between the inside wall of the block structure and the tank was filled with sand, approximately doubling the mass of shielding material. This reduced the radiation field to a level lower than that given by the original shielding.

12.2.2. Evaluation

The radon removal efficiency of the carbon was initially high, in the region of 99% for the specialist charcoal, and 95% for the standard charcoal. Over a period of eight months, it decreased, and stabilised at around 95% for the high efficiency charcoal (house #30), and 75% for the other charcoal at house (#2). These reductions were sufficient to reduce the airborne radon concentration resulting from water use to a low level.

The concrete block shield was not sufficient to deal with the combination of high radon concentration and high water use, and sand had to be placed in the enclosure to increase the shielding mass. Given this, an alternative and cheaper shielding method would have been to use a large 60 cm diameter lightweight impregnated paper tube (Sonnotube) around the tank, and fill this with sand.

12.3. OVERALL EVALUATION OF RADON REMOVAL FROM WATER

There was a significant difference in the radon removal efficiency of different carbons, but both units performed well, reducing the contribution from waterborne radon to a low level.

The major problem with these radon removal units is the radiation field from the radon collected on the carbon. The greater the need for a radon-in-water removal unit, ie high radon concentrations in water and use of large volumes of water, the higher this radiation field will be. A lightweight paper tube filled with sand would provide relatively cheap shielding. In addition, after the carbon has been in use for several years, it may have accumulated enough long-lived radon progeny (^{210}Pb) for the carbon to qualify as a legally radioactive. Current regulations would require this to be disposed of in a licenced radioactive waste storage facility, at high cost.

In view of these difficulties, a better long term solution might be to use a stripping unit for radon removal. This would remove the radon from the water as it was used, and discharge it outside the house. There would be no large radiation source in the basement requiring shielding, and no radioactive waste disposal problem. However, there are still problems with the stripper, for domestic sized radon stripping units are not as commercially developed as carbon adsorption units, and comparable performance at a comparable price may not be available.

SECTION 13.
TERRESTRIAL RADIATION MEASUREMENTS

13.1. EQUIPMENT

Gamma radiation measurements were made at mitigation houses and in the area generally with a 5-channel NaI scintillation meter which had been calibrated at the Department of Energy, Mines and Resources radioactive test pads in Ottawa. The exposure rate from cosmic rays indicated on this instrument is approximately 2 uR/h. When the threshold is set so that the instrument responds only to gamma-rays above 400 keV, the count rate in a terrestrial radiation field is approximately proportional to the total exposure rate.

13.2. GENERAL

Radiation fields were significantly higher in the vicinity of these houses than in the general area. The radiation field in the house and on the site is noted in the description of each house. Table A-13 summarises the measured gamma radiation levels at each house.

In the Boyertown area, the terrestrial exposure rates along the main roads - which run in valleys - ranged from 4 to 6 uR/h. In contrast, all the mitigation houses are located on high ground, where the exposure rates ranged from 7 to 12 uR/h, with significant changes in exposure rate in short distances. For example, near Boyertown, the exposure rate along Indian Road, which runs along the top of a ridge, varied from 5 to 6 uR/h at Applewood Road, rose to 7 to 8 uR/h at the junction with Funk Road, and reached a high of 10 uR/h on Knoll Circle. On Hillcrest Road, which is on a second ridge just two hundred metres away from Knoll Circle, the exposure rate was only about 6 uR/h.

13.3. VARIATION WITH DEPTH

The soil gamma activity increased with depth. Part of the variability of the radiation field at a house site was evidently due to higher activity excavated material having been dumped on the lower portion of the site. At one house (#9) a swimming pool was under construction, which enabled measurements to be made of the distribution of activity with depth. Fill from the house excavation covered the site to a depth of 30 cm, and gave 24 uR/h on contact. The original surface soil beneath this layer gave about 11 to 16 uR/h, but a layer of rocks near the bottom of the excavation had fields of 30 uR/h, with one rock reaching 40 uR/h on contact.

Granite bedrock was exposed on a road cut near house #9. The general activity was about 6 uR/h on contact, but a localized 2 m wide band of more highly fractured granite with 24 uR/h on contact was visible. The activity of the hot spot was estimated at 2.7 pCi/g ^{232}Th, 6 pCi/g ^{235}U, and 10 pCi/g ^{40}K from the ratio of the counts in the channels of the meter. The granite beneath house #9 must have an even higher activity zone to produce the more active rocks found in the swimming pool excavation.

13.4. RADON PRODUCTION RATE

Rock fragments were collected from both the host granite and the higher activity zone, and the radon production rate was measured at 0.13 pCi/g and 0.48 pCi/g of emanating radium (emRa) for host rock and active zone respectively. The radon production rates were also measured for a soil sample from the swimming pool excavation at house #9, and for a sample collected from a hilltop building site of lower gamma activity. The values were 1.1 pCi/g emRa for the house #9 sample, and 0.24 pCi/g emRa for the building site. The emanating radium content of the house #9 soil is high, and is comparable to that found in reclaimed Florida phosphate lands, which are themselves among the highest activity soils in the USA.

13.5. COMMENT

The area was not glaciated in the recent geological past, so the local soil is derived entirely by weathering of the underlying rocks. The soil in the valleys is derived mainly from the lower activity sandstones that form their floor, whereas the soil on the hilltops is derived mainly from granites. Given the large variations observed in the gamma activity of the parent sandstones and granites, the variations in soil activity from site to site are not surprising. The surface materials may be lower in activity than the base rocks from which they are derived as the result of aeons of weathering. If this is generally the case, then surface radiation measurements will be a poor indicator of the radon potential of a given site, although they may be useful as a general indicator of locally increased radon potential.

SECTION 14.
QUALITY CONTROL AND QUALITY ASSURANCE

14.1. QUALITY ASSURANCE PLAN

The Quality Assurance Project Plan (QAPP) was issued on 25 October 1984, and modified in January 1985, and December 1986 to reflect changes in emphasis in the program. The QAPP covered Quality Assurance Objectives, instrument calibration, sampling, and control checks. A brief review of these topics is included in this section.

14.2. TRACK ETCH DETECTORS

Calibration and quality control of Track Etch detectors is performed by the manufacturer, Terradex. As an independent check on calibration, ten detectors from each of the two batches used were exposed in the EML radon chamber at the same time as detectors were deployed in the field, and a similar number of detectors were retained to act as unexposed controls. They were returned 'blind' to the processing laboratory.

14.2.1. Calibration Checks

Detectors were exposed in the EML radon chamber in December 1985 and in December 1986. The first batch was exposed to 1590 pCi.d/L, and the average exposure reported was 1428 pCi.d/L (10% low). The analytical uncertainty on each measurement was reported at 160 pCi.d/L. The standard deviation of all the measurements about the mean was 228 pCi.d/L (16%).

The second batch was exposed to 423 pCi.d/L, and the average exposure reported was 364 pCi.d/L (11.5% low). One outlier with a reported value of 1190 pCi.d/l ± 200 pCi.d/L was rejected from our analysis. The analytical uncertainty on each measurement was reported at 58 pCi.d/L, and the standard deviation of all the measurements about the mean was 53 pCi.d/L (12%).

As the difference between the reported and actual exposures was less than twice the standard deviation of the measurements, the reported exposures in the houses were not corrected.

14.2.2. Zero Checks

The average exposure reported for the unexposed detectors for the first batch was 15 pCi.d/L, with an analytical uncertainty of 16 pCi.d/L. The average exposure reported for the second batch was 2 pCi.d/L, with an analytical uncertainty of 4 pCi.d/L.

These exposures were not large enough for the reported exposures in the houses to require correction.

14.2.3. Field Quality Control

The EPA Protocol for Indoor Measurements suggested that 10% of the measurements should be made in duplicate. This was not felt adequate for this program, and 100% of the measurements were made in triplicate.

Detectors were exposed taped together in groups of three to detect outliers. The average radon concentration at a location was calculated as the average of the detector readings. At the low radon concentrations found in these houses after mitigation, the standard deviation of the group was usually about 30%, or 1.5 pCi/L. Outliers were rejected if this would reduce the standard deviation of the group to less than 2 pCi/L or to less than 20%. Three outliers were detected in 224 detectors exposed in the field, and in 1 of the 20 calibration detectors exposed at the EML.

14.2.4. Completeness

Results were received for all of the 264 detectors sent to Terradex for processing. Six detectors could not be found at one house. It is believed that they were collected in error by another group making measurements with Terradex detectors in the area. Six detectors were issued to one homeowner who had dropped out of the program, but he did not return them.

14.2.5. Quality Assurance Objectives and Performance

The Accuracy objective for Track Etch measurements may not have been achieved, for the manufacturer's calibration is apparently 10% to 15% lower than that derived from the EML exposures. The difference is not significant for the low post-mitigation exposures of a few hundred pCi.d/L, for the major source of uncertainty in those measurements is the analytical variability between detectors.

	PRECISION	ACCURACY	COMPLETENESS
QAPP Goals	2 pCi/L (30%)	10%	100%
Actual Performance	2 pCi/L (30%)	<15%	100%

14.3. AB-5 RADON MONITORS

The AB-5 monitors used in this program were calibrated at 12 month intervals at the DOE Environmental Measurements Laboratory in New York. A specially modified cell containing a small emanating radium source (Check Cell) with a nominal count rate of 2000 cpm, was used to set the optimum high voltage and discriminator setting for radon measurements. To minimise the background count rate, the high voltage was set just above the knee, approximately 60 volts onto the plateau.

Simultaneous measurements over 16 to 24 hours were made with the AB-5 and the laboratory standard continuous radon monitor from the large radon chamber. The radon concentration in the chamber was not changed, and varied only slightly. The cell counting efficiency was determined by setting the average radon concentration as measured by the AB-5 equal to the average radon concentration in the chamber as measured by the standard monitor.

Typical count rates at equilibrium were 1.90 counts ~~per~~ hour per Bq/m^3 (70 counts/h per pCi/L), with backgrounds of 60 counts per hour. The precision of a single measurement at a radon concentration of 150 Bq/m^3 (4 pCi/L) is 20 Bq/m^3 (12%). An average of 6 or more readings will have a precision of at least 5%.

The relative contribution to the counts recorded in each period from the radon in the sample, and from the activity deposited in the cell by the radon in previous samples, was derived directly by switching the monitor input from the radon chamber to low radon air, and following the change in count rate with time. A two term polynomial correction was sufficient to correct for activity deposited in the cell by previous samples. The equation used was:-

$$R_n = (C_n - 0.3C_{n-1})/(0.7K)$$

where R_n is the radon concentration in the n'th sample, C_n is the net count over the 50 minutes following the sample, C_{n-1} is the net count for the 50 minutes following the preceding n-1'th sample, and K is the number of counts in 50 minutes for a radon concentration of 1 Bq/m^3 (1 pCi/L).

The calibration factors (0.7K) to give radon concentrations in pCi/L as determined at each calibration for each monitor were:-

MONITOR	JUNE 1985	JULY 1986	JULY 1987
203	40.5	43.5	43.2
206	42.9	40.5	---
213	44.3	42.6	---
228	43.0*	41.8	42.0
238	46.0*	42.0	42.5
255	---	43.1	40.1
256	---	42.3	40.8
257	---	45.7	43.0

*cell calibrated alone, not complete machine

The sum of the systematic and counting uncertainties in the calibration factor amounted to about 1%, or 0.5.

Monitor 206 was not calibrated in July 1987 as it had been returned to the manufacturer for repair of the charging circuit, and monitor 213 was not with the project at that time. The calibration factor and background for each monitor is included in the BASIC program used to convert raw data to radon concentrations and is called automatically by the program.

14.3.1. Field Quality Control

Field quality control was maintained by two 285 cm^3 scintillation cells. One was an ordinary cell which was kept closed and therefore contained very little radon (Blank Cell). The other was a specially modified cell containing a small emanating radium source (Check Cell). These cells were counted in the units on a monthly basis to check that the machines were operating properly. A higher check frequency was used in the early part of the program, but found unnecessary.

14.3.2. Completeness

The AB-5 has an internal gel-cell battery which will operate the machine in the quasi-continuous mode for 24 to 48 hours, depending on the initial state of charge, and will maintain the memory for 1 to 4 days. The machines are normally run on AC power, and are unaffected by temporary power interruptions. However, 7 runs were not completed, for the electrical supply was interrupted for more than 24 hours. The causes included defective receptacles with poor contacts, and switched receptacles where the power was inadvertently turned off. The later models have an indicator to show that the power is connected, so problems with these machines were due only to power being turned off after the machine was connected. All the data was lost from one completed run when the on/off switch was accidentally pushed twice. The first time stops the machine, the second time starts the machine on a new run, and erases the data stored in the memory. Only time was lost with these failures, for the run was repeated to obtain the information.

The AB-5 memory is dumped to a portable computer, which calculates the radon concentration, produces a hard copy report, and outputs the basic information for the report on magnetic media. Cassette tape was used as the initial storage media, and results were later transferred to $5^1/_4$ inch disks. Of the 244 completed measurement runs, the data from 4 runs were lost entirely due to a recorder malfunction, and some data was lost from a further 4 runs due to tape faults. In 1986 a $3^1/_2$ inch disc recorder replaced the cassette recorder, and no data has since been lost in the transfer to storage.

14.3.3. Quality Assurance Objectives and Performance

The Quality Assurance Objectives for the AB-5 monitors were met. The average radon concentration was calculated on the basis of more than six measurements, and so the precision was greater than 5%, and the change in calibration factor from one calibration to the next was less than 5%. Fewer data sets were lost than expected.

	PRECISION	ACCURACY	COMPLETENESS
QAPP Goals	5%	5%	95%
Actual Performance	5%	5%	97%

14.3.4. Problems

The source cell had been modified from a standard cell, and still had the self-sealing connectors. On two occasions during testing, the cell was connected to the inlet tubing by mistake, with a short term loss of radon. The connectors were blocked to prevent this happening again. There was a slight leak in the cell, probably at the connectors, and the count rate of the cell was affected by changes in atmospheric pressure. Count rates varied from 2 200 to 2 600 cpm. To allow precise comparisons of the machines, a scintillation cell simulator was constructed with an ^{241}Am source and a scintillation disk mounted at the end of a tube. The pulse height spectrum from this was similar to that from a cell, and the count rate was unaffected by atmospheric pressure changes. The count rate of this simulator varied by less than 2% from machine to machine.

Three machines had defective high voltage feedback resistors, which gave increased tube noise as they slowly failed. These machines were identified, and the resistor replaced with modification kits sent by the manufacturer.

The memory contents of the AB-5 are transferred to the portable computer via a parallel to serial converter that plugs into the AB-5 printer port. Three converters were damaged in the winter by static electricity sparks while they were being connected to the AB-5. One spark damaged the converter and also reset the portable computer memory, and the programs had to be reloaded. An anti-static spray on the nylon office carpet reduced the sparking, but did not eliminate it. Care had to be taken to ground both the equipment and the operator when reading out the units.

14.4. SCINTILLATION CELL MEASUREMENTS

Scintillation cells are used to make grab sample measurements of the radon concentration in ducts and in soil gas. The cells used are plastic bodied cells with nominal volumes of 0.1, 0.5, and 1.5 litres, with nominal sensitivities of 0.5, 2.2, 4.5 cpm per pCi/L. They are counted on a 120 mm diameter photomultiplier tube, with a background count rate of less than 1 cpm at the operating voltage. The cells have a background of less than 2 cpm.

Selected cells were calibrated by sampling from the EML radon chamber, and those cells were subsequently compared with the other cells by sampling from a sample of soil gas collected in a 100 litre plastic bag. The sensitivities of all the cells did not vary by more than 10% from the nominal value.

14.4.1. Scintillation Cell Field Quality Control

Scintillation cells were inspected at each use for damage, such as broken or loose valves, cracks, or loss of scintillation covering. The photomultiplier and scaler combination used to count the cells was checked monthly with the 285 ml radon source cell.

14.4.2. Completeness

The equipment was reliable. Results were obtained for all of the radon samples taken in the houses.

14.4.3. Quality Assurance Objectives And Performance

The Quality Assurance Objectives for the scintillation cells were exceeded. The concentrations measured were all high enough that the precision of individual measurements was greater than 50%, the calibration factors were not more than 10% in error, and all samples taken were measured.

	PRECISION	ACCURACY	COMPLETENESS
QAPP Goals	50%	20%	75%
Actual Performance	<50%	10%	100%

14.5. AUDITS

14.5.1. EPA Audits

Field Audits were conducted by the EPA Quality Assurance Group in July 1985, April and November 1986. They made suggestions regarding measurement protocols, which were addressed by modifying the project protocols to be in accordance with the then newly issued EPA Protocol for Indoor Measurements; external Quality Assurance on the radon monitor measurements, which were addressed by participation in the EPA Proficiency Program; and on record keeping for the photographs taken of each house. This was addressed by standardising photograph size (by using only one processor) so that all photos would fit into a standard photopage, and using a camera that automatically dated the photographs as they were taken.

14.5.2. Internal Audits

An internal audit was carried out in September 1986 to ensure that all data collected had been transferred to the house files from the field notebooks and other data sources. Missing data included official copies of DER measurements in 16 houses, and incomplete house plans for eight houses. The missing data was obtained over the next two months.

The Project Manager visited all the sites to conduct a final systems audit, where the mitigation system was inspected to ensure that it had been installed and was working as intended. A final internal records audits was carried out in July 1987 to check that the house files contained a complete set of records.

14.6. RADON MEASUREMENT PROFICIENCY PROGRAM

In 1986 the EPA introduced a Radon/Radon Progeny Measurement Proficiency Evaluation Program to evaluate the performance of the many firms that were entering the field of radon measurements. Measuring devices were exposed 'blind', and the reported concentrations were compared with the known concentrations by the organizers, and the performance evaluated by them.

Four of the AB-5 monitors used in this program were submitted for the November 1986 comparison round. They gave results within 5% of the measured average concentration.

APPENDIX A

SUMMARY TABLES

TABLE A-1 PENNSYLVANIA DER MEASUREMENT SUMMARY

HOUSE ID	KUSNETZ TEST SAMPLING DATE	KUSNETZ TEST RESULT (WL)	RPISU TEST START DATE	RPISU TEST FINISH DATE	RPISU TEST RESULT (WL)	TERRADEX TEST START DATE	TERRADEX TEST FINISH DATE	TERRADEX TEST RESULT (pCi/L)	WATER TEST SAMPLING DATE	WATER TEST RESULT (pCi/L)
1	85-02-05	2.207	85-02-15	85-02-20	0.411	85-02-05	85-03-14	146	*	26 700
2	85-01-05 85-01-15	0.342 0.360	--	--	--	85-01-05	85-02-08	413	85-08-28	66 500
3	85-01-31	3.002	--	--	--	85-01-31	85-03-05	350	*	LOW
4	85-03-20	0.252	85-04-22	85-04-25	0.033	85-03-30	85-06-07	25	*	8 000
5	85-03-25	0.354	85-03-25	85-03-28	0.257	85-03-25	85-05-29	29	*	4 300
6	85-01-18	0.461	85-01-29	85-02-01	0.372	85-01-18	85-02-22	60	*	14 500
7	85-02-27	1.712	85-03-05	85-03-08	0.138	85-02-27	85-03-28	25	85-02-27	5 400
8	85-02-22	1.704	85-02-25	85-02-28	0.128	85-02-22	85-03-26	183	*	LOW
9	85-01-15	0.340	85-01-23	85-02-01	0.473	85-01-15	85-02-15	533	85-01-30	29 400
10	85-01-25	1.260	85-01-29	85-01-31	1.088	85-01-25	85-02-25	626	85-02-05	35 200
11	85-02-20	0.749	--	--	--	85-02-20	85-04-29	49	*	LOW
12	85-03-27	0.220	85-04-01	85-04-04	[illegible]	85-03-27	85-06-10	6	85-04-04	4 300
13	85-01-24	0.060	--	--	--	85-01-24	*	64	*	12 900
14	85-02-05	0.416	85-02-12	85-02-15	0.124	85-02-05	85-03-13	36	85-02-12	2 500
15	85-03-29	[illegible]	85-04-29	85-05-03	0.019	85-03-29	*	*	85-03-29	4 900
16	85-01-25	0.630	85-01-29	85-02-01	[illegible]	85-01-25	85-02-25	398	85-02-25	27 700
17	85-04-11	0.130	85-04-22	85-04-25	[illegible]	85-04-11	85-10-17	9	85-04-22	4 600
18	85-01-18	0.394	85-02-07	85-02-11	0.014	85-01-18	85-02-21	12	85-02-21	1 800
19	85-07-03	0.327	85-07-08	85-07-10	[illegible]	85-07-03	86-01-03	22	85-07-03	80
20	85-08-05	1.024	85-08-12	85-08-15	0.463	85-08-05	85-10-30	210	85-08-05	68 300
21	85-02-22	0.553	85-02-25	85-02-28	0.465	85-02-22	85-03-27	172	85-02-22	1 100

TABLE A-1 (CONTINUED)

	KUSNETZ TEST		RPISU TEST			TERRADEX TEST			WATER TEST	
HOUSE ID	SAMPLING DATE	RESULT (WL)	START DATE	FINISH DATE	RESULT (WL)	START DATE	FINISH DATE	RESULT (pCi/L)	SAMPLING DATE	RESULT (pCi/L)
22	85-07-30	0.170	85-08-05	85-08-08	0.029	85-07-30	86-01-07	24	*	8 000
23	85-11-14	0.836	85-11-14	85-11-18	0.102	85-11-14	86-02-05	98	85-11-18	17 900
24	85-07-29	0.178	85-07-30	85-08-02	0.092	85-07-29	86-01-10	56	*	14 700
25	85-05-10	0.986	85-05-14	85-05-17	0.243	85-05-10	85-11-27	122	*	3 700
26	85-05-06	0.134	85-05-13	85-05-16	0.013	85-05-06	85-11-12	11	85-05-06	5 100
27	85-07-10	0.412	85-07-15	85-07-18	0.008	85-07-10	86-01-02	21	85-07-10	14 200
28	85-07-29	0.155	85-07-30	85-08-02	0.119	85-07-29	86-01-14	24	*	*
29	85-07-26	0.584	85-08-05	85-08-08	0.032	85-07-26	86-01-08	61	*	23 000
30	85-08-02 85-10-22 85-12-24	0.051 0.167 0.098	--	--	--	85-08-02	86-01-09	17	85-08-02 86-03-10	235 70[illegible] 265 900
31	85-02-27 85-11-01	1.339 1.920	85-03-11	85-03-14	0.509	85-02-27	85-03-28	65	*	*
32	86-03-28	0.060	--	--	--	86-03-28	*	200	86-04-01	22 400
33	86-04-03	0.313	--	--	--	86-04-03	*	82	86-04-03	660
34	86-04-07	2.496	--	--	--	86-04-07	*	470	86-04-07	46 300
35	86-04-07	0.934	--	--	--	86-04-07	*	144	*	527
36	86-03-31	0.405	--	--	--	86-03-31	*	237	86-03-31	970
37	86-04-17	0.256	--	--	--	86-04-17	*	87	86-04-17	2 20[illegible]
38	86-03-28	0.3[illegible]5	86-04-01	86-04-04	0.370	86-03-29	86-05-[illegible]4	303	86-04-04	14 800
39	86-04-22	0.345	--	--	--	86-04-22	*	111	*	LOW
40	86-04-08	1.459	--	--	--	86-04-08	*	143	*	LOW

* = Not Reported LOW = Municipal Water Supply

TABLE A-2 HOUSES SELECTED FOR PHASE 1 WORK

HOUSE NUMBER	LOCATION	APPROXIMATE PREMITIGATION RADON CONCENTRATION (pCi/L)
1	Country	116
2	Subdivision 1	413
3	Subdivision 2	350
4	Town	25
5	Country	29
6	Subdivision 1	60
7	Country	25
8	Town	183
9	Subdivision 1	533
10	Subdivision 1	626
11	Town	49
12	Country	6 (0.22 WL)
13	Subdivision 1	64
14	Subdivision 2	36
15	Country	- (0.17 WL)
16	Subdivision 1	389
17	Country	9 (0.13 WL)
18	Subdivision 1	12 (0.38 WL)
38	Town	309

TABLE A-3 PROPOSED AND ACTUAL PHASE 1 TREATMENTS

HOUSE	PROPOSED TREATMENT	ACTUAL TREATMENT
1	Sub-slab	Sub-slab
2	Sub-slab	Sub-slab + wall
3	Sub-slab	Sub-slab + wall
4	Sub-slab	Sub-slab
5	Wall	Wall
6	Wall	Wall
7	Sub-slab	Wall
8	Wall	Wall
9	Wall and drain	Wall and drain
10	Sub-slab	Weeping tile
11	Weeping tile	Wall and drain
12	Weeping tile	Weeping tile
13	Weeping tile	Weeping tile
14	Weeping tile	Weeping tile
15	Wall	Weeping tile
16	Weeping tile	Weeping tile
17	Weeping tile	Weeping tile
18	Wall and drain	Ventilation
38	Weeping tile	None

TABLE A-4 COSTS OF PHASE I MITIGATIVE WORK

TREATMENT	
Weeping Tile Ventilation	
HOUSE NUMBER	COST $
10	547
12	673
13	755
14	427
15	675
16	701
17	651
Sub-slab Ventilation	
1	1 458
2	1 531
3	1 242
4	899
Wall Ventilation	
2	408*
3	1 549*
5	1 700
6	1 361
7	1 652
8	1 700

*Cost to add to sub-slab ventilation system

Baseboard Ventilation	
9	3 254
11	1 804
House Ventilation	
18	150

TABLE A-5 NEW HOUSES SELECTED FOR PHASE 2 WORK

HOUSE NUMBER	LOCATION	APPROXIMATE PREMITIGATION RADON CONCENTRATION (pCi/L)
19	Subdivision 2	32
20	Country	210
21	Country	170
22	Subdivision 3	24
23	Country	98
24	Subdivision 3	66
25	Country	121
26	Country	11 (0.13 WL)
27	Country	21
28	Subdivision 3	21
29	Subdivision	61
30	Country	17 (water source)

TABLE A-6 PROPOSED AND ACTUAL PHASE 2 TREATMENTS

PHASE 1 HOUSES	PREVIOUS TREATMENT	NEW TREATMENT
1	Sub-slab	Wall plus floor (x2)
2	Wall plus floor	Wall plus floor
5	Wall	Improved wall
6	Wall	Wall plus floor
7	Wall	Wall plus floor
9	Wall plus floor	Improved wall plus floor
11	Wall plus drain	None (refused by owner)
14	Weeping tile	Wall
16	Weeping tile	Wall
17	Weeping tile	HRV
18	Ventilation	HRV
PHASE 2 HOUSES	**PROPOSED TREATMENT**	**ACTUAL TREATMENT**
2	Water treatment	Water treatment
19	Wall	Wall
20	Sub-slab	Sub-slab (x2)
21	Weeping tile	Sub-slab
22	Slab joint	Slab joint
23	Slab joint	Slab joint
24	Sub-slab	Sub-slab
25	Sub-slab	Sub-slab
26	Weeping tile	Weeping tile
27	Weeping tile	Weeping tile
28	Weeping tile	Weeping tile HRV
29	Sump, crawl space	Sump. crawl space
30	Water treatment	Water treatment

TABLE A-7 COSTS OF PHASE 2 MITIGATIVE WORK

TREATMENT	
Weeping Tile Ventilation	
HOUSE NUMBER	COST $
26	851
27	594
28	271 (sump)
29	1 598 (sump +)
Sub-slab Ventilation	
2	1 246
20	970 (system 1)
	587 (system 2)
21	852
22	860 (joint)
	552 (conversion)
23	1 360 (joint)
24	1 205
25	679
Wall Ventilation	
5	2 657
7	2 897
14	1 851
16	1 865 (system 1)
	1 242 (system 2)
19	1 804
Wall plus Floor Ventilation	
1	1 200 (improvement)
2	4 171
6	277 (conversion)
7	1 347 (conversion)
9	3 241 (improvement)
Improved Ventilation	
17	1 100
	500 (modification)
18	1 100
Radon Removal from Water	
2	816
30	1 796

TABLE A-8 HOUSES SELECTED FOR PHASE 3 WORK

HOUSE NUMBER	LOCATION	APPROXIMATE PREMITIGATION RADON CONCENTRATION (pCi/L)
31	Country	85
32	Country	201
33	Bethlehem	82
34	Country	470
35	Country	144
36	Allentown	297
37	Macungie	87
39	Allentown	- (0.345 WL)
40	Easton	- (1.15 WL)

TABLE A-9 PROPOSED AND ACTUAL PHASE 3 TREATMENTS

PHASE 1 HOUSES	PREVIOUS TREATMENT	NEW TREATMENT
2	None	Shielding
4	Sub-slab	Sub-slab
6	Wall plus floor	Sub-slab
13	Weeping tile	Sub-slab/Weeping tile
38	None	Sub-slab
PHASE 2 HOUSES	**PREVIOUS TREATMENT**	**NEW TREATMENT**
19	Wall	None (refused by owner)
20	Sub-slab	Wall/floor plus crawl space
22	Slab joint	Sub-slab, slab
23	Slab joint	Sub-slab, slab
30	None	Shielding
PHASE 3 HOUSES	**PLANNED TREATMENT**	**ACTUAL TREATMENT**
31	Sub-slab	Sub-slab
32	Sub-slab	Sump/Sub-slab
33	Sump	Sump/Sub-slab
34	Sub-slab	Sub-slab
35	Sub-slab	Sub-slab
36	Sub-slab plus slab	Sub-slab plus slab
37	Sub-slab	Sub-slab
39	Sub-slab	Sub-slab
10	Sub-slab	Sub-slab

TABLE A-10 COSTS OF PHASE 3 MITIGATIVE WORK

TREATMENT	
Sub-slab Ventilation	
HOUSE NUMBER	COST $
4	2 026
6	758 (conversion)
13	1 129
22	1 398 (extension)
23	1 825
	881 (extension)
31	1 700
32	1 686
33	897 (sump)
34	2 878
35	1 183
36	2 478
37	1 556
38	1 760
39	1 100
40	4 255
Wall Ventilation	
20	514 (extension)
	257 (addition)
House Ventilation	
28	1 240
Radon Removal from Water	
2	487 (shielding)
30	981 (shielding)

TABLE A-11 COST OF SMALL SYSTEM MODIFICATIONS AND FAN CHANGES

HOUSE NUMBER	COST $
PHASE 2	
1	551 (fan change)
3	275(fan change)
6	295 (modifications)
8	269 (fan change)
9	491 (fan change)
10	351 (fan change)
13	222 (fan change)
15	313 (fan change)
PHASE 3	
3	438 (fan change)
5	267 (fan change)
7	379 (fan change)
8	331 (fan change)
12	192 (fan change)
21	589 (fan change)
24	613 (fan change)
25	579 (fan change)
26	412 (fan change)
27	362 (fan change)
29	432 (fan change)

TABLE A-12 SUMMARY OF POST MITIGATION ALPHA TRACK RESULTS

HOUSE ID #	DATE OF INSTALLATION	DATE OF REMOVAL	BASEMENT AVERAGE(pCi/L)	LIVING SPACE AVERAGE(pCi/L)
1	House Moved	---	---	---
2	86-12-17	87-03-16	2.6	5.2
3A	85-12-05	86-03-20	4.4	1.7
3A	86-12-14	87-03-19	3.5	2.1
4	87-01-16	87-03-19	0.7	0.8
5	87-01-16	87-03-19	4.3	4.3
6	87-01-16	87-03-19	3.3	4.9
7	87-01-16	87-03-17	4.1	2.8
8	85-12-06	86-03-20	3.1	1.3
8	86-12-18	87-03-25	3.9	1.8
9	86-12-17	87-03-16	11.6	14.5
10	85-12-05	86-03-11	3.3	3.0
10	86-12-17	87-03-16	9.0	6.5
12	86-12-15	87-03-19	3.7	2.5
13	85-12-13	86-03-31	17.0	11.4
13A	87-02-21	87-04-11	2.3	2.0
14	86-02-18	86-04-26	0.7	0.6
14	86-12-18	87-03-17	0.5	0.7
15	85-12-08	86-03-12	3.8	2.5
15	86-12-17	87-03-18	1.1	1.0
16	86-01-04	86-01-21	78	22
16A	86-03-14	86-05-20	2.9	2.4
16A	86-12-16	87-03-16	5.4	1.7
17	87-02-21	87-04-11	7.6	4.1
18	87-02-21	87-04-11	8.8	2.1
19	86-12-18	87-03-16	32.0	0.6
20	87-03-10	87-03-29	5.8	9.9
21	86-12-14	87-03-16	3.1	2.6
22	87-02-21	87-04-15	7.6	2.7
23	87-01-26	87-03-19	7.6	11.6
24	87-03-06	87-04-15	4.3	4.6
25	87-03-10	87-04-15	5.1	3.0
26	86-12-16	87-03-16	2.1	1.5
27	86-12-16	87-03-16	3.8	2.2
28	87-02-21	87-04-21	2.4	5.3
29	87-02-21	87-04-15	1.9	1.4
30	86-12-17	87-03-19	3.0	1.3
31	87-01-19	87-03-19	1.8	5.7
32	87-01-21	87-03-19	1.0	3.2
33	87-03-07	87-04-11	2.2	1.1
34	87-02-19	87-04-15	5.5	3.7
35	87-02-21	87-04-14	0.7	0.8
36	87-03-06	87-04-15	1.6	1.7
37	87-02-19	87-04-17	0.6	0.6
38	87-03-10	87-04-11	14.4	11.2
39	87-06-20	Not yet	removed	
40	87-06-19	"	"	

TABLE A-13 SUMMARY OF GAMMA SURVEY RESULTS

HOUSE	INTERNAL FIELD (uR/h) RANGE	AVERAGE	EXTERNAL FIELD (uR/h) RANGE	AVERAGE	ADDITIONAL COMMENTS
1	8-11	10	11-12	11	exposed subsurface cut 17-20 uR/h
2	11-15	13	8-12	10	surface cover from basement excavation 20 to 35 uR/h
3	5-11	5	5-12	9	
4	7-12	10	12-15	14	6 uR/h at asphalt driveway 18 uR/h at exposed road bank
5	4-7	5	6-10	8	
6	6-12	10	6-12	10	
7	7-10	8	8-13	11	6 uR/h on asphalt driveway
8	6-12	9	6-10	9	
9	7-10	9	10-14	12	pool excavation dirt 14 uR/h; in excavation range 14-42 uR/h
10	9-14	10	10-35	20	
11	6-9	8	7-10	9	exposed soil at road cut 13-16 uR/h
12	3-6	5	5-9	7	
13	5-12	9	8-25	16	driveway 4-10 uR/h
14	6-10	8	5-12	10	
15	4-10	6	8-12	10	
16	4-10	7	5-19	13	
17	7-9	8	9-12	11	interior high spots of 10-12 uR/h by sump and in cedar closet
18	4-6	5	6-7	6	
19	5-9	7	5-8	6	
20	5-15	9	11-27	16	hot water tank 39 uR/h on contact
21	4-7	5	7-12	9	

TABLE A-13 (CONTINUED)

HOUSE	INTERNAL FIELD (uR/h) RANGE	AVERAGE	EXTERNAL FIELD (uR/h) RANGE	AVERAGE	ADDITIONAL COMMENTS
22	3-6	5	5-10	8	
23	4-16	7	6-16	12	13 uR/h on contact with well pressure tank; 6 uR/h at driveway
24	2-6	4	6-10	9	
25	10-16	13	8-14	11	
26	4-8	6	5-10	7	
27	4-9	6	12-25	16	2 radium dial compasses in closet gave up to 150 uR/h
28	4-8	6	4-10	7	
29	5-7	6	8-14	12	8-9 uR/h in crawl space 12-14 uR/h near sump, 10-13 uR/h near well pressure tank
30	6-12	8	7-13	10	12 uR/h in vicinity of well pressure tank
31	5-13	8	5-14	11	
32	2-18	5	2-12	5	hot spots of 12 and 18 uR/h
33	6-8	7	7-9	7	
34	5-1	7	5-10	7	
35	4-5	5	3-4	4	
36	6-9	7	3-10	7	
37	4-9	6	5-8	7	
38	3-12	10	8-12	10	
39	7-11	9	9-18	13	
40	6-10	8	9-11	10	3 m diameter hot spot of 16 uR/h in basement

APPENDIX B

PUBLICATIONS

Publications arising from the work carried out in this project.

1. Henschel, D. B. and Scott, A. G., "The EPA Program to Demonstrate Mitigation Measures for Indoor Radon: Initial Results", Indoor Radon: Proceedings of an APCA International Specialty Conference, pp. 110 - 121, Philadelphia, PA, February 1986.

2. Henschel, D. B. and Scott, A. G., "Testing of Indoor Radon Reduction Techniques in Eastern Pennsylvania: An Update", in Indoor Radon II: Proceedings of the Second APCA International Specialty Conference on Indoor Radon, pp. 146 - 159, Cherry Hill, NJ, April 1987.

3. Henschel, D. B. and Scott, A. G., "Some Results from the Demonstration of Indoor Radon Reduction Measures in Block Basement Houses", in Indoor Air '87: Proceedings of the 4th International Conference on Indoor Air Quality and Climate, Vol 2, pp. 340 - 346, Berlin, West Germany, August 1987.

APPENDIX C

INDIVIDUAL HOUSE DESCRIPTIONS

HOUSE 1

PENNSYLVANIA DER MEASUREMENTS

Working Level grab samples (Kusnetz)	2.207 WL
Heating season average (RPISU)	0.411 WL
Heating season radon average (Terradex)	146 pCi/L
Radon in water	27 000 pCi/L

1. DESCRIPTION

This single story house was built by the owner in the late 1950's on a fairly level site near the top of a ridge several miles west of Boyertown. One half of the front house wall is brick veneer, the other walls are siding. Heating is by oil fired hot water baseboard convectors upstairs, supplemented by a wood stove in the basement.

The basement walls, and two central support walls are of hollow cinder block. Two internal buttress walls are of concrete block. The internal walls penetrate the floor. There is an external entrance into the basement.

The concrete floor slab was poured in sections and there are several construction joints. The well pressure tank is supported on concrete blocks whose voids penetrate the floor. There is a trapped basement floor drain. The basement is approximately one third finished, with wood panelled walls, a bar, and a suspended ceiling.

2. ACTION

2.1. PHASE 1

As the basement was partially finished, the mitigation measure selected for demonstration at this house was subslab ventilation. Two exhaust points were necessary due to the length of the house, and the subdivision of the subfloor space by the footing beneath the buttress walls.

A Hilti electric percussion drill was used to drill 12 holes around the perimeter of a 60 cm circle, and an air hammer was used to break out the concrete. When the holes were cleaned out it was found that lab at the workshop end was poured directly on solid bedrock. The air hammer was used to break up the rock to a depth of 10 to 15 cm. At the laundry end of the basement, there was about 8 cm of broken bedrock over solid bedrock.

The holes were cleaned out, and 10 to 15 cm of "1/2 inch" clear crushed stone was placed in the holes and a "4 inch" lightweight plastic drain pipe was placed vertically into the stone. As an experiment, galvanized metal sheet was used to cover the stone in the workshop hole, and styrofoam was used in the laundry hole. The edges of the cover material were caulked to the slab and the pipe with asphaltic cement, and the hole filled to floor level with 5 cm of concrete made from a bag mix.

The basement layout and degree of internal finish made it impracticable to join the risers together with concealed piping, and the lack of subslab material suggested that one fan might not be sufficient. The pipes were extended vertically to the joists, and then run to the closest basement window. In the laundry a small centrifugal fan was mounted directly on the outside face of a plywood sheet placed in the window opening. The fan was small enough to fit into the window well with a weather cover over it. The other fan was a large centrifugal exhaust unit fitted on a wooden box, with a flexible connection through a plywood sheet replacing a window in the work room.

In June 1985 the radon concentration in the basement prior to any work varied from 140 to 220 pCi/L, averaging 180 pCi/L. In July 1985, with the fans turned on the concentration ranged from 141 pCi/L to 188 pCi/L, averaging 166 pCi/L.

A smoke tracer survey of the floor was carried out, and the smoke was observed to be drawn down through the few visible cracks and openings in the floor near the exhaust pipes. The fans drew very little air. The laundry room fan drew only 5 L/s at 105 Pa suction, and the workroom end fan drew only 3 L/s at 90 Pa.

2.2. PHASE 2

As the subfloor system was so ineffective, the options for additional mitigative work were limited. The subfloor performance could only be improved by removing the entire basement floor, placing a layer of crushed stone over the bedrock, and pouring a new floor. This would be disruptive, expensive, reduce the basement headroom to 2.0 m, and still could not prevent soil gas and radon entering through the walls. As excellent performance had been obtained at other sites by ventilating the walls, wall ventilation seemed the most cost-effective solution at this site.

This house was considerably larger than the other houses where wall ventilation had been used, and the installation would also have to include the interior walls. Rather than just inserting a ventilation pipe at one or two places per wall, it was decided to treat both the walls and the floor by using a perimeter duct that would cover the wall floor joint.

The basement walls were made of cinder block, and were very porous. The owner said that he had not parged the exterior walls below grade. The ductwork was therefore designed to have double the cross sectional area of the previous installations. The initial design was for only one fan, (a large wall mounted centrifugal) but there was provision for a similar fan to be installed at the opposite end of the basement if needed.

In November 1985, the owner removed the basement panelling, and disconnected the electrical wiring. The subfloor system was removed and the holes filled with mortar. The well pressure tank was removed, and the openings through the floor were filled with mortar and sealed with asphaltic sealant.

The block voids were exposed on the internal stub walls, beneath the windows, and on end walls. These were filled with mortar. The block voids on the front and rear walls, where the access was too poor to use mortar, were closed by nailing wood strips to the sill plate, and caulking the gap between the wood and wall top. Holes were drilled into each void of the lowest block course of the walls, and an 8x30 cm rectangular baseboard duct was installed. This ran round the basement in a 'C' loop, with a gap of about 3 m total at the exterior door.

As work progressed, many small openings in the walls and mortar were noticed, and it became clear the walls would not be made airtight by local patching alone. One option considered was to cover the walls with polyethylene sheets, but the final choice was to paint the walls with a cement based waterproofing paint. This formed a continuous airtight film over the surface of the blocks, and bridged cracks and openings if applied thickly. The paint vehicle was 30% vinyl toluene, 70% aliphatic hydrocarbons, and had a strong unpleasant odour. The residents were sent to a motel for two days to allow the solvent to evaporate from the walls.

The system was essentially complete in December 1985. Over the period 13 December to 6 January the radon concentration in the basement with the fan running varied from 12 to 159 pCi/L, averaging 80 pCi/L.

Investigation in January 1986, found that one fan was not sufficient, for only the front wall of the house was lower in pressure than the basement. Air flowed out of the rear and end walls into the house. Radon concentrations in the ducting were 60 pCi/L at the rear wall, 160 and 270 pCi/L at two points on the front wall, and 210 pCi/L at the end wall. The basement radon concentration was 45 pCi/L at that time

Additional ducting was added over the rear basement door to make a continuous loop of ducting round the basement, and the second fan was added. All the walls were then under suction.

A relatively high airflow came from the small section of the front basement wall that was topped with brick veneer. To increase the airtightness, 10 cm diameter holes were drilled through the header board, exposing the junction between the brick facing and the block wall. The gap was generally filled with mortar droppings, but expanding urethane foam was injected into the space to increase the airtightness. The airflow out of this portion of the wall decreased only slightly, suggesting that there were subsurface routes of entry as well.

In late January 1986, the radon concentration in the basement with both fans on varied from 4 to 25 pCi/L, averaging 10 pCi/L.

The owner complained that his basement wood stove was now difficult to light, and would smoke on a low fire. Despite the extensive efforts to close the leakage areas from the house into the walls, the two fans were still drawing large amounts of air from the house, and hence backdrafting the stove. It was decided to reverse the fans so that they would pressurize the walls, and prevent backdrafting.

Before the fans were reversed, an extensive investigation was carried out in February 1986, to see if the entry route of the remaining radon could be identified. Temporary enclosures were placed over joints in the basement structure at 20 locations, and the radon concentration in the enclosure measured 18 hours later. High radon concentrations indicating soil gas entry were found only at 2 locations, 900 pCi/L over a sewer cleanout set into the floor, and 550 pCi/L at the wall/floor joint on a buttress wall despite the well being under negative pressure. An additional 9 wall/floor joint locations were tested in the same way. Five of the enclosures had concentrations in excess of 200 pCi/L, indicating that suction in the walls was not transmitted effectively to the subfloor space.

In March 1986, the fans were replaced by temporary small centrifugal blowers. The radon concentration in the basement initially rose from 6 to 70 pCi/L in four hours, then fell slowly over the next 24 hours, finally ranging from 13 to 18 pCi/L, and averaging 15 pCi/L.

Even though the connection was poor between the walls and the subslab space, pressurizing the walls would still tend to force soil gas up from beneath the floor. Accordingly, the ducting was extended to cover the wall/floor joint both sides of each internal support and buttress wall to prevent soil gas entry in these areas. The radon concentration in the basement following this varied from 16 to 37 pCi/L, averaging 25 pCi/L. This decrease in performance suggested that the increased pressure at the perimeter of the floor slab was now forcing soil gas out of hitherto less important openings in the centre of the floor.

Investigation in March found that the radon concentration in the walls was 5 to 9 pCi/L when the basement concentration was 9 pCi/L. A smoke stick survey found small airflows from the subfloor space into the house via hollow oil tank legs, floor joints, and where the stair stringers passed through the concrete floor. The radon concentration in the tank leg with the highest flow was 1 100 pCi/L.

After these openings were closed, the radon concentration in the basement ranged from 13 to 17 pCi/L, averaging 15 pCi/L. When the fans were turned off, the radon concentration started to rise after a delay of 12 hours, and reached a maximum of 98 pCi/L after 36 hours.

This was interpreted as showing that pressurization was effective in displacing radon rich soil gas away from the house, and that larger pressurization fans might give better performance.

In May 1986, the temporary blowers were replaced by large wall mounted centrifugal blowers which produced a pressure of 11 Pa in the ducts. With these fans in operation, the radon level in the basement ranged from 1 to 3 pCi/L, except for a peak to 14 pC/l when the washing machine was used. When the fans were turned off, it again took nearly 12 hours before concentrations started to increase, and the maximum concentration of 17 pCi/L was not reached until the following day.

2.3. PHASE 3

In November 1986 the radon concentration in the basement with the fans in operation ranged from 3 to 16 pCi/L, averaging 5 pCi/L. The high concentrations were associated with use of the washing machine, and were attributed to release of water-borne radon.

Further measurements were not made in this house as the owner sold the site. The house was moved in December 1986 to a new foundation several miles away.

3. OTHER MEASUREMENTS

Radiation fields on the site ranged from 11 to 12 uR/h near the house but where subsurface soil was exposed on a cut on the uphill side of the site, the field was 17 to 20 uR/h. The field in the basement ranged from 8 to 11 uR/h, averaging 10 uR/h.

MEASUREMENTS SUMMARY FOR HOUSE 1

PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON RANGE	(pCi/l) MEAN	COMMENTS
1	Central sub-slab ventilation 50 L/s and 100 L/s centrifugal fans	06/87	Premitigation	140-220	180	over 53 hrs
		07/85	Fans off	126-143	135	over 15 hrs
			Fans on	141-188	166	over 21 hrs
2	As above	08/85	Fan on	17-116	79	over 24 hrs
2	Baseboard ventilation of wall 100 L/s centrifugal	12/85	Fan on	12-159	80	over 22 days
	As above	01/86	Fan on	50-118	84	over 53 hrs
	Two 100 L/s centrifugal fans	01/86	Fans on	4- 25	10	over 4 days
		03/86	Fans on	6-70	42	Initial 4 hr rise
			Fans on	15-70	33	33 hr fall to equilibrium
			Fans on	13-18	15	36 hrs at equilibrium
	Baseboard ventilation of walls two 50 L/s centrifugal fans on blow extended to all interior walls	03/86	Fans on	15- 37	22	over 4 days
	Baseboard ventilation of walls two 50 L/s centrifugal on blow openings at oil tank leg and stair stringers closed	04/86	Fans on	13 -17	15	over 38 hrs
			Fans off	14- 98	44	over 14 hrs still climbing

MEASUREMENTS SUMMARY FOR HOUSE 1

PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	MEAN	COMMENTS
2	Baseboard ventilation of walls two 150 L/s centrifugal fans on blow	05/86	Fans on	11-14	3	over 48 hrs
			Fans off	2-47	26	over 51 hr slow rise to equilibrium of 32 pCi/L
3	Baseboard ventilation of walls two 150 L/s centrifugal fans on blow	11/86	Fans on	3-16	5	over 90 hrs

SYSTEM MEASUREMENTS FOR HOUSE 1

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
1	Central sub-slab ventilation 50 L/s and 100 L/s centrifugal fans	11/85	105	5		Laundry rm fan
			90	3		Workroom fan
2	Baseboard ventilation 100 L/s centrifugal fan	01/86			270	Front w duct
					160	Front w duct
					210	End w riser
					60	Rear w riser
					45	room air
				0.1	2 800	Floor drain
2		02/86			4	Indoor air
					0	Outdoor air
					9	Indoor air
					1	Bsmnt. door
					280	Rec. Rm Fan discharge

SYSTEM MEASUREMENTS FOR HOUSE 1

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
2	Baseboard ventilation	03/86			30	oil tank leg
	two 50 L/s				30	oil tank leg
	centrifugal fans on				20	oil tank leg
	blow				1 100	oil tank leg
	baseboards extended				5	front wall
	to all interior block				9	rear wall
	walls				9	basement air

BASEBOARD DUCT MEASUREMENTS

DUCT POSITION

1	2	3	4	5	6	7	8	9	10	11	12	13	14
FLOW IN DUCT AT POSITION (L/s)													
System - Baseboard ventilation 100 L/s fan 01/86													
4	4	8	8	9	10	11	17	18	28	59	7	7	-
System - Baseboard ventilation with two 100 L/s fans 01/86													
2	31	-	9	15	22	-	2	11	21	78	11	8	76
System - Baseboard ventilation with two 150 L/s fans 05/86													
-	28	-	11	15	8	1	2	11	11	43	8	2	55
PRESSURE IN DUCT AT POSITION (Pa)													
System - Baseboard ventilation with two 100 L/s fans (Suction) 01/86													
3	18	-	20	15	13	-	15	15	15	25	15	4	-
System - Baseboard ventilation with two 150 L/s fans (Pressure) 05/86													
-	11	-	11	11	11	11	11	11	11	13	11	5	11
RADON MEASUREMENTS AT POSITION (pCi/l)													
System - Baseboard ventilation with two 150 L/s fans 05/86													
-	0	-	0	0.4	0.4	0.6	0.5	0	1.7	1.4	0	0	0.8

ROUTE OF RADON ENTRY SURVEY

RADON CONCENTRATION (pCi/L) IN FLOOR ENCLOSURES

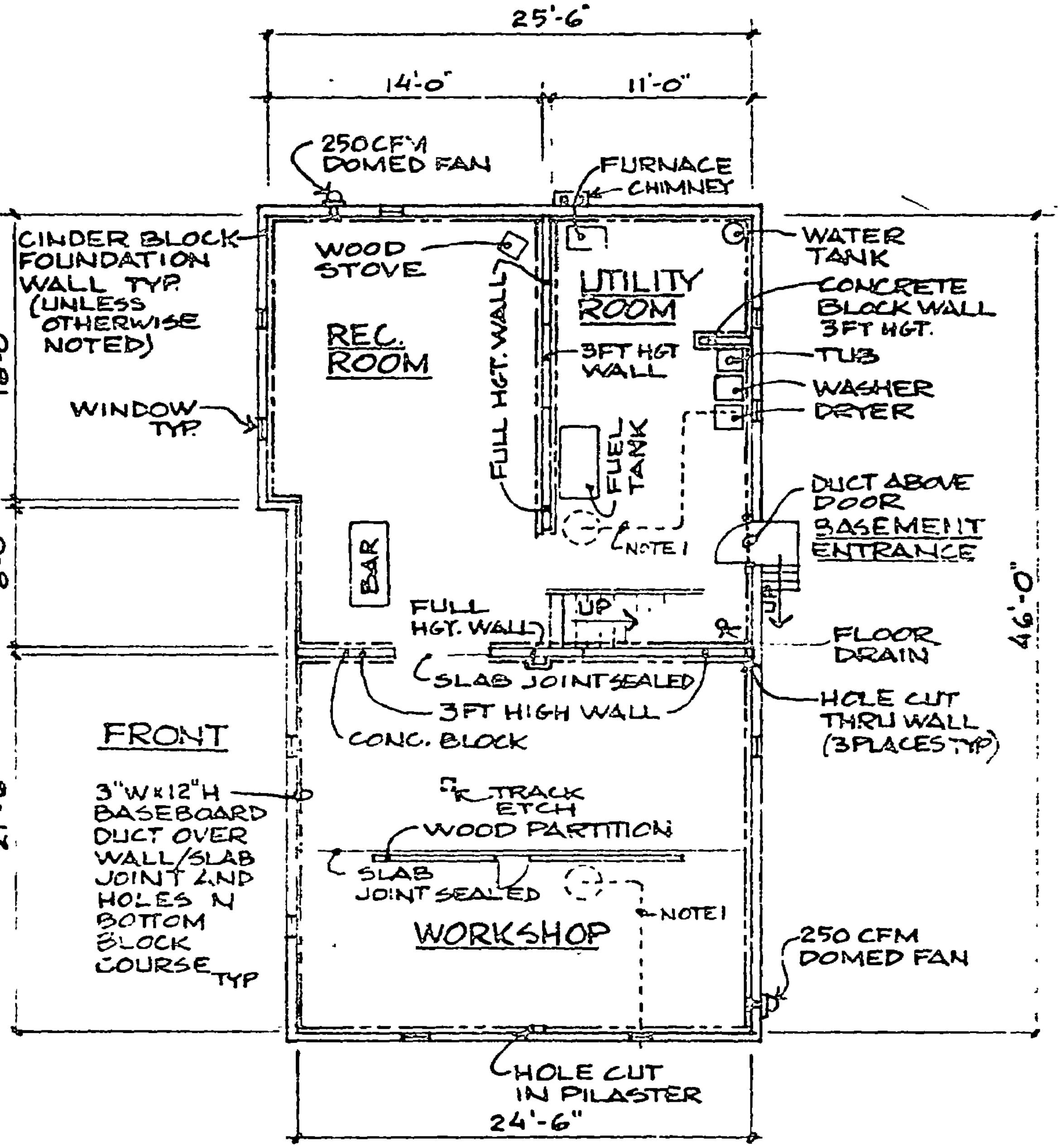
A	B	C	D	E	F	G	H	I	J	K	L	M	N
System - Baseboard ventilation of wall with two 100 L/s fans 02/86													
870	7	10	3	540	20	9	33	2	8	11	3	3	5

RADON CONCENTRATION (pCi/L) IN WALL/SLAB JUNCTION ENCLOSURES

#1	#2	#3	#4	#5	#6	#7	#8
19	520	290	65	13	220	490	750

LIST OF MEASUREMENT LOCATIONS

POSITION		FLOOR ENCLOSURES		WALL/SLAB ENCLOSURES	
1-	rear wall duct near laundry	A:	cleanout	#1	stair wall
2	rear wall duct central	B:	cold joint	#2	wing wall
3	driveway wall at rear	C:	cold joint	#3	wing wall
4	driveway wall before pilaster	D:	cold joint	#4	stair wall
5	driveway wall after pilaster	E:	wall/slab	#5	stair riser
6	driveway wall at front	F:	cold joint	#6	stair wall
7	front wall before wing wall	G:	crack	#7	wing wall
8	front wall after wing wall	H:	concreted area	#8	central wall
9	front wall at jog	I:	cold joint		
10	front wall at end	J:	drain		
11	end wall at fan	K:	block in slab		
12	end wall at centre	L:	cold joint		
13	end wall at laundry area	M:	pipe penetration		
14	riser to fan 2	N:	furnace slab		



NOTES: 1. SUB-SLAB SUCTION SYSTEM (PHASE I) REMOVED.
2. PHASE 3 (FINAL) FANS: METAL KANALFLÄKT WITH RAIN HOOD.
3. INTERIOR WALLS PENETRATE SLAB

ACRES	LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
	FOUNDATION PLAN	Date: 4/20/86	1
	Mitigation system: BASEBOARD TYPE WALL/SLAB PRESSURIZATION	PHASE: 1 THRU FINAL	

HOUSE 2

PENNSYLVANIA DER MEASUREMENTS

Working Level samples in basement (Kusnetz)	0.350WL
Heating season basement radon average (Terradex)	413pCi/L
Radon concentration in water	67 000 pCi/L

1. DESCRIPTION

This single story dwelling with adjacent two car garage was built in the mid 1970's on a sloping site at the top of a ridge in a rural subdivision to the west of Boyertown. The front house wall is brick veneer, the other walls are siding. Heating is by hot water circulating through radiators from an oil-fired boiler. The partially finished walk-out basement has concrete block walls.

The poured concrete slab has a small wall/floor joint. There is an open construction joint across the centre of the slab, a large diagonal crack at the garage end, and the well pressure tank is supported on concrete blocks laid with the voids penetrating the slab.

There are no serious cracks visible in the concrete block walls, which are all painted. The top course of the exterior walls is completely covered by a sillplate caulked into place. There is a central concrete block structure that encloses a brick faced basement fire place and the boiler flue. These blocks are open at the top.

2. ACTIONS

2.1. PHASE 1

The mitigative action selected for initial demonstration at this house was sub-slab ventilation. If this were unsuccessful, then wall ventilation was the next choice, for it could be carried out easily since the tops of the walls were closed with the caulked sillplate.

Since the basement was much longer than wide, two exhaust points were needed on the centre line, each one quarter of the way from either end. The final locations were adjusted slightly to place the pipes as much out of the way as possible.

In June 1985, two 50 cm diameter holes were opened in the concrete slab by means of an air hammer and compressor following guide holes made by a Hilti drill. The sub-slab material was crusher run stone which was removed and replaced by 1/2 inch clear crushed stone. This was covered with a sheet of roofing felt cut to fit the hole and caulked to the concrete with an asphalt caulk. A vertical exhaust pipe of 4 inch schedule 40 PVC sewer pipe was placed in the crushed stone through a hole in the felt cover, and caulked. The holes were then concreted over.

The two vertical pipes were connected into a horizontal run of 4 inch schedule 40 pipe which led to a front basement window, which was temporarily replaced by a sheet of plywood. A flexible hose ran from the pipe, through the plywood sheet to a large centrifugal exhaust fan installed on a plywood sheet placed on top of the window well.

In July 1985, with the fan turned off, radon concentrations in the basement varied between 80 to 503 pCi/L, averaging 243 pCi/L. When the fan was turned on, concentrations varied between 30 to 53 pCi/L, avereging 41 pCi/L. This was an encouraging reduction, but the high residual concentrations indicated that the system was not treating all the routes of radon entry.

Previous measurements by another contractor had indicated that the garage end wall of the basement was a major radon source, so a further reduction in radon concentration was sought by extending the ventilation into that wall. In August 1985, a T-connector was added to the top of the sub-slab ventilation pipe nearest to the garage wall, and a 4 inch schedule 40 plastic pipe was run from there into the garage end wall.

At the same time, to reduce the area of floor leakage paths, the major construction joint and the floor cracks were cleaned and filled with vinyl concrete filler to reduce the floor leakage area. Openings around water lines through the floor were caulked with asphaltic sealer.

No attempt was made to treat the other walls or the large concrete block central structure. These were left for Phase II of the program.

In August 1985, with the fan running continually radon concentrations in the basement ranged from 12 to 56 pCi/L, averaging 28 pCi/L.

Examination found that air flowed from the house into the entire garage wall, and also into all the other external walls. Air flowed down through all cracks and openings in the garage end of the basement floor, including the openings beneath the well pressure tank. The floor was inaccessible at the other end of the basement where there was a storage room and a work room with a built up wood floor. The fan produced a suction of 60 Pa in each pipe at floor level.

The minor reduction in radon concentration produced by ventilating one wall indicated that there were still other routes of entry. The internal block wall structure was regarded as the probable route, for it penetrated the slab, was not keyed into the exterior walls, and was open at the top. Further work was delayed until the fall, to enable evaluation of the system under cold weather conditions.

2.2. PHASE 2

In October 1985 a spot WL measurement found levels equivalent to 3 000 pCi/L in the basement. The owners were concerned over these high levels, and started to install an air-to-air heat exchanger (heat recovery ventilator or HRV). This entailed disconnecting part of the sub-slab system piping to allow installation of the air distribution duct work, so a test of the full system was not possible until late December, when it was reconnected.

Investigation in December 1985 found that air was still drawn down all floor openings. The radon concentration was 4 100 pCi/L in the exhaust air, despite withdrawing 4 L/s of air from the sub-slab space for 3 months.

From December 13, 1985 to December 19, with the HRV in operation and the sub-slab system operating with just one extraction point, radon concentrations in the basement ranged from 90 pCi/L to 522 pCi/L, averaging 250 pCi/L. The sub-slab system was reassembled on December 19, and both it and the HRV continued in operation until December 28. Radon concentrations in the basement ranged from 26 pCi/L to 692 pCi/L, averaging 400 pCi/L.

The HRV was turned off from December 28 to January 5, 1986. Radon concentrations in the basement with just the subfloor system operating ranged from 13 pCi/L to 1 476 pCi/L, averaging 1 000 pCi/L. The HRV was turned on again on January 5, 1986, and measurements were made till January 7. Radon concentrations ranged from 203 pCi/L to 682 pCi/L, averaging 439 pCi/L.

The radon concentrations with just the sub-slab system on were comparable to those measured the previous winter, and so it was clear that the existing system was not reducing the radon supply significantly. The factor of two reduction produced by HRV operation was encouraging, but far from the reduction factors of 20+ needed to approach tolerable radon levels.

The only improvement to the sub-slab system that could be made rapidly was to ventilate the central block fireplace structure, which was suspected of being a soil gas entry route as it penetrated the slab. This could be done and the result tested while an improved mitigative system was being designed.

The top course of blocks was removed from the structure without disturbing the brick facing on the fireplace side. This gave a working space 25 cm high. The voids of the second course of blocks were stuffed with fiberglass as a temporary support and filled with mortar. This greatly reduced leakage area, but did not close the structure entirely, for the space between the chimney flue and the surrounding blocks could not be filled without major structural work.

A 2 inch plastic drain pipe was inserted into the void of a second course block, and Teed into the exhaust line of the sub-slab system. The first course of blocks was replaced and repainted to match.

The effect of this change was minor. In January, with the system fan running continually and the HRV in operation, radon concentrations in the basement ranged from 287 pCi/L to 498 pCi/L, averaging 397 pCi/L. With the HRV turned off, the concentrations ranged from 87 pCi/L to 950 pCi/L, averaging 300 pCi/L. No measurements were made with the fan turned off, for the occupants were concerned that even higher radon concentrations might result.

Radon concentrations in the individual exhaust pipes were 10 700 pCi/L in the laundry room pipe, 2 350 pCi/L in the other floor exhaust pipe, 4 300 pCi/L in the garage wall, and 165 pCi/L from the central block wall - approximately the room air concentration.

The conclusion was that there were much more important routes of radon entry than the central block structure.

2.3. PHASE 2A

By this time, results from other experimental houses had indicated that wall ventilation alone was not always an effective solution. Accordingly, it was decided to install a combined wall and wall/floor joint ventilation system to treat all five surfaces of the basement.

The system consisted of an 8 inch wide flat sheet metal cover, locally fabricated in 10 foot lengths, placed over the wall/floor joint at a 60 degree angle. The system dimensions were chosen so that a "2 by 4" could be installed as a spacer above the cover if the walls were framed and finished. Holes were drilled into every cavity of the lowest course of blocks so that air could be drawn out of the wall into the duct formed by the cover. The duct would also collect any soil gas that entered through the wall/floor joint.

The basement was divided into two halves by the internal concrete block wall at the front of the house, and the rear wall was divided into three sections by a single door and a double door. To deal with this two separate sets of ducting were provided, each with its own wall mounted large centrifugal fan. One set treated one half of the front wall, the garage wall, and the rear wall as far as the single door. The other set treated the other half of the front wall, the central block structure, the end wall, and the remaining part of the rear wall. A closed duct ran round the double door to carry the suction to the portion of the rear wall between the two doors.

A workroom at the front of the basement had a built-up wood floor and frame walls covered with wallboard. The upper plate of the wall was spiked to the joists, so it was possible to cut off the bottom 20 cm (8") of the studs and take out the sole plate without removing the floor. This exposed the wall/floor joint. When this was done, and piled lumber and other stored material was removed from the adjacent storage end of the basement, a significant wall/floor joint was exposed all along the end wall. Smoke tests showed that there was a visible air inflow there, even with the sub-slab system in operation. The suction did not extend to that end of the basement, even though it was close to an exhaust pipe.

The duct installation was completed on 23 January 1986. Each fan drew about 50 L/s (100 cfm), and air flowed into all walls. Radon concentrations in the air drawn from the walls ranged from 300 pCi/L at the rear wall, which was completely out of the ground, to 4 000 pCi/L from the front garage wall corner.

The radon concentration in the basement with the HRV running and the sub-slab system turned off, fell from 200 pCi/L to 15 pCi/L within a day. With the sub-slab system turned on as well, concentrations ranged from 7 to 25 pCi/L, averaging 15 pCi/L. This indicated that the sub-slab system did not provide much additional effect.

The system was inspected to find if there was an obvious cause for the concentrations to still be in the region of 15 pCi/L. Smoke tests showed that air flowed into all walls and the central block structure, and into the floor, suggesting that the route of entry was concealed.

The smoke tests also found a number of joints in the ductwork that had not been effectively caulked. Closing these increased the wall suction, and decreased the amount of air drawn from the house. This was important, because with the HRV extracting air from the basement, and all the radon control fans running, air was drawn down the basement chimney.

Following this, concentrations in early February with the HRV and the sub-slab system on, ranged from 2 pCi/L to 10 pCi/L, averaging 5 pCi/L.

The concentration peaks seemed to be associated with water usage, so a set of measurements were made in early March 1986 in a bathroom and in the basement close to the washing machine. Bathroom concentrations rose from 2 pCi/L to 220 pCi/L when the shower was run, and short term peak concentrations as high as 40 pCi/L were measured in the basement. Clearly some of the radon measured in the basement was due to water use, and not to soil gas entry.

Following this work, the large centrifugal exhaust fans on the wall ventilation system were temporarily replaced by smaller centrifugal blowers, and the sub-slab system fan was turned off. The HRV was left turned on. This was to check if the same standard of performance could be achieved with the system under pressure to avoid the chimney back-drafting problem. A check in March 1986 found that radon concentrations in the basement during times of no water use were in the region of 3 pCi/L, even though the radon concentration in the air forced up through floor joints and in the sub-slab system pipes was 500 pCi/L. In April 1986, the HRV was turned off, and the concentration in the basement during times of no water use was in the region of 2 pCi/L. The concentration in the sub-slab system pipes had dropped to 35 pCi/L, showing that the sub-slab fill had been effectively flushed free of radon by the air forced beneath the slab.

In May 1986, the sub-slab system pipes and fan were removed, and the small centrifugal blowers were replaced by permanent wall mounted in-line centrifugal blowers of double the capacity. Following this, radon concentrations during times of no water use and with the HRV turned off, were in the region of 2 pCi/L. Water use gave short lived concentration spikes up to 15 pCi/L.

The concentration rose rapidly to range between 30 to 120 pCi/L when the fans were turned off.

2.4. PHASE 2B

As the radon contribution from water use was greater than the soil gas contribution, it was decided to study the effect of a radon-in-water absorption unit in this house. Charcoal adsorption beds were available locally for removal of organics from water. One of these units was installed in August 1986, using the standard charcoal.

Measurements by the Pennsylvania DER in August 1986 found that the radon concentration in the water was reduced from 67 000 to 3 200 pCi/L by passage through the unit. Water usage at this house was a few thousand litres per day, so an inventory of several hundred microCuries of radon was expected in the charcoal. This would give a radiation field of a few hundred microrem/h at 1 metre from the tank.

The radiation field around the tank was estimated by a scintillation meter. Most of the radiation came from the top 60 cm of the tank, showing that the 1.2 m high charcoal bed had considerable spare capacity. Indicated exposure rates were 3800 uR/h on contact, 380 uR/h at 60 cm from the tank surface, and 22 uR/h at 3.5 m. In the bedroom above the tank the field was 20 uR/h directly above the tank, but 26 uR/h in the centre of the room.

The Pennsylvania DER placed TLD detectors in the house to measure the exposure rates more accurately. The average exposure rates over a 33 day period were 8200 uR/h on contact, 180 uR/h at 125 cm, and 25.5 uR/h in the bedroom above the tank.

2.5. PHASE 3

A shielding structure of concrete blocks was built round the tank. So that the structure could be removed for access to the carbon unit, the blocks were not mortared, but locked together instead with vertical reinforcing bars placed in the block cavities and tied to the wall by metal straps. The block walls were 7 cm thick in total. A 5 cm thick paving slab was used for vertical shielding. Indicated exposure rates were reduced to 350 uR/h on contact with the structure, background (9 uR/h) at 3.5 m, and to 7 uR/h in the bedroom above the tank. The Pennsylvania DER placed TLD detectors and found exposure rates of 300 uR/h in contact with the tank, 30 uR/h at 125 cm, and 11 uR/h in the bedroom above the tank.

The radiation field and the radon removal efficiency was measured at intervals over the winter. The field on contact decreased slightly to about 300 uR/h, and then remained almost constant. The radon concentration in the well water was lower in the winter averaging about 37 000 pCi/L, and the concentration in water discharged from the unit averaged 8 000 pCi/L, for a removal efficiency of 80%.

3. OTHER MEASUREMENTS

Radiation fields in the house and over t e site were estimated with a scintillometer. The field in the basement was 11 uR/h in the workroom end, and 15 uR/h by the garage end wall. The field over undisturbed land at the front of the site ranged from 8 to 12 uR/h. At the rear and the garage side of the house, where the material removed from the basement excavation had been spread, fields ranged between 20 to 35 uR/h.

The average radon concentration measured by alpha-track detectors over the period December 1986 to March 1987 was 2.6 pCi/L in the basement, and 5.2 pCi/L in the living area.

MEASUREMENTS SUMMARY FOR HOUSE 2

PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON RANGE	(pCi/L) MEAN	COMMENTS
1	Central sub-slab ventilation; 100 L/s centrifugal fan	07/85	Fan off	80-503	243	over 56 hrs
			fan on	30- 53	41	over 12 hrs
	Central sub-slab +garage wall ventilation 100 L/s centrifugal fan	08/85	Fan on	12- 56	28	over 46 hrs
2	As above + HRV added by owner	12/85	Fan on/HRV on	90- 522	250	over 6 days*
			Fan on/HRV on	26- 692	400	over 3 days**
			Fan on/HRV off	13-1 476	1 000	over 8 days**
			Fan on/HRV on	203- 682	439	over 35 hrs**
2	Central sub-slab +garage + central wall ventilation 100 L/s centrifugal	01/86	Fan on/HRV on	287- 498	397	over 22 hrs
			Fan on/HRV off	87- 950	345	over 73 hrs
2A	As above + ventilation of wall/floor joint two 100 L/s centrifugal fans	01/86	Sub-slab fan off new fans on/HRV on	11- 90	43	24 hr fall to 15 pCi/L
			Sub-slab fan off new fan on/HRV on	7- 25	15	over 68 hrs
		02/86	Fans on/Hrv on	2- 10	5	over 46 hrs
		02/86	Fans on/HRV on	0.4- 8	3	over 4 days U
		02/86	Fans on/HRV on	1- 34	3	over 4 days U
	Ventilation of wall/floor joint only two 50 L/s centrifugal fans on blow	03/86	Fans on/HRV on	1- 17	5	over 4 days neglecting water peaks, mean 3 pCi/L
		01/86	Fans on/HRV off	2- 8	4	over 4 days

MEASUREMENTS SUMMARY FOR HOUSE 2

PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON RANGE	(pCi/L) MEAN	COMMENTS
2A	Wall/floor joint ventilation; two 150 L/s centrifugal fans on blow	05/86	Fans on/HRV off	0-4	2	over 12 hrs - water peaks to 15 pCi/L
			Fans off/HRV off	19-121	59	over 42 hrs
3	Wall floor joint ventilation two 150 L/s centrifugal fans on blow + radon adsorption	11/86	Fans on - adsorber in	1-4	2	
			Fans on - adsorber out	2-8	3	
			Fans on - adsorber out	1-5	3	

U = Upstairs measurement

SYSTEM MEASUREMENTS FOR HOUSE 2

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
2	Central sub-slab + garage wall ventilation 100 L/s centrifugal fans	12/85	75	4	4 100	Pipe 1
2	As above + central wall ventilation	01/86	10	1	10 700	Pipe 1
			5	2	2 350	Pipe 2
			15	8	4 300	Pipe 3
			10		165	Pipe 4
2A	As above + ventilation of wall/floor joint ; two 100 L/s centrifugals - baseboard fans only operating	01/86	43	15	280	A
			68	32		B
			25	18	1 550	C
			68	49		D
			40	24	950	E
			25	17		F
			15	16		G
					3 8000	H
	Three fans operating	01/36	25	17		rear baseboard at end wall
				13		rear baseboard right of door
				12		rear baseboard left of door
				9		rear baseboard caulked sect.
				2		central front baseboard
			8	6		central front sub-slab fan off
					3 900	Pipe 1
					5 000	Pipe 2
					8	basement air
				14		central wall
	Three fans operating	03/86			14 000	front wall near garage
					4 700	Pipe 1
					63	Fan 1
					150	Fan 2

SYSTEM MEASUREMENTS FOR HOUSE 2

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
2A	Ventilation of wall/floor joint only	04/86		1	38	Pipe 1
					33	Pipe 1 3.5 hr later
					4	general air
					30	Pipe 1, 2 days later
				1-2	35	Pipe 2 capped
2A	Wall/floor joint centrifugal two 150 L/s centrifugals on blow	05/86	88	18		A
			78	26		B
			30	27		C
			38	29		E
			23	19		G
			15	12		H
			25	21		I

A: Rear baseboard near fan 1.
B: Bypass around pipe.
C: Garage baseboard near fan 1.
D: Fan 2 riser duct.
E: End wall duct.
F: End wall corner.
G: Front wall near end wall.
H: Front wall near garage.
I. Centre of garage duct.

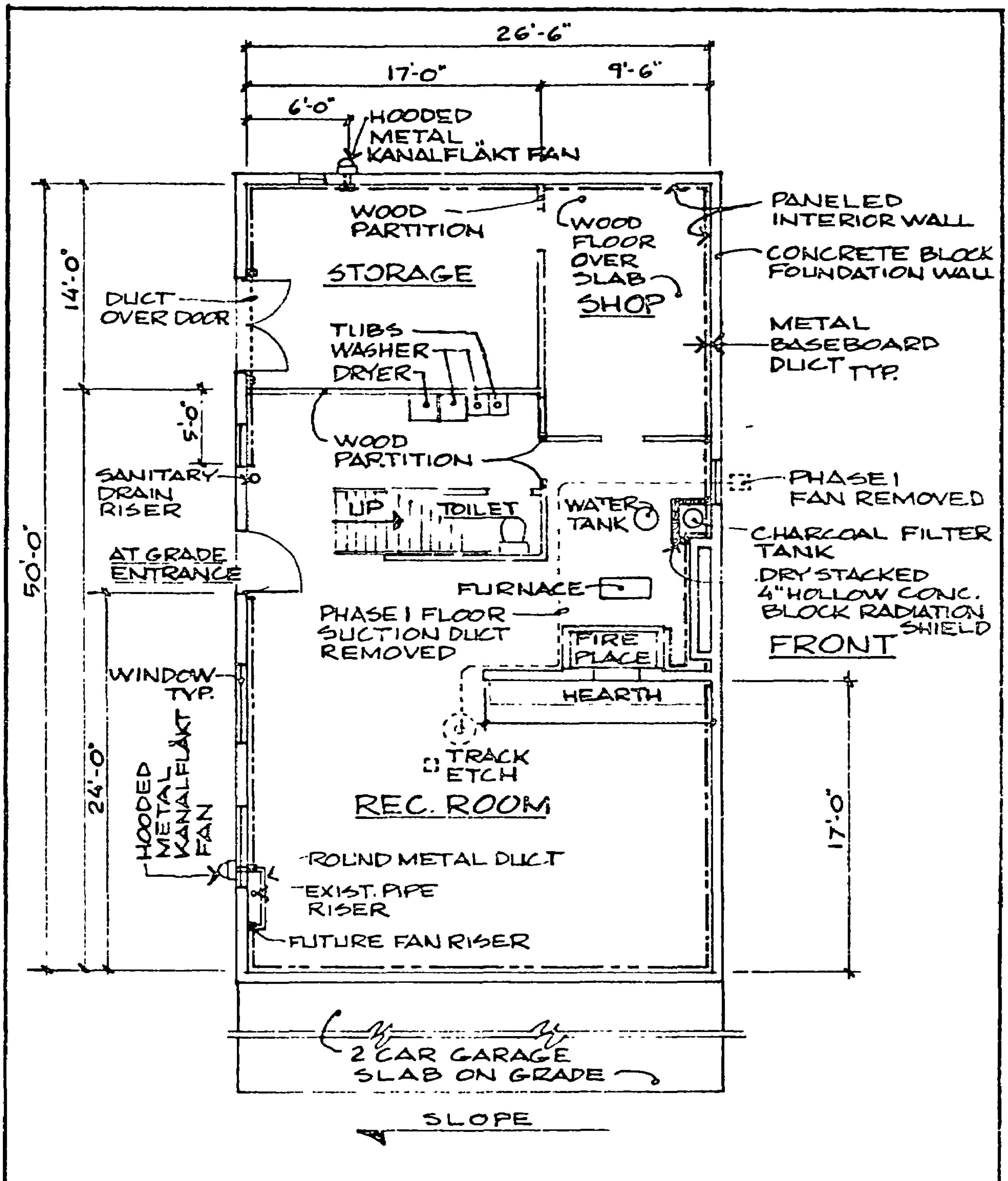
GAMMA MEASUREMENTS FOR HOUSE 2

PHASE	MITIGATION SYSTEM	DATE	MEASUREMENT LOCATION	GAMMA FIELD (uR/h)	COMMENTS
2B	Wall floor joint ventilation two 150 L/s centrifugal fans on blow plus water adsorption 55 L/s charcoal unit	08/86	Top of well pressure tank	380	@ 60 cm
			Top of charcoal tank	1 000	
			Distance from top of tank 0 cm	1 000	On contact
			20 cm	3 300	On contact
			40 cm	3 800	On contact
			60 cm	2 700	On contact
			80 cm	1 700	On contact
			100 cm	930	On contact
			120 cm	300	On contact
			At hot water boiler	14	
			Rear of house	9	
			Centre line nr boiler	22	@ 3.5 cm
			Workshop door	40	
			Bdrm front	20	over tank
			Bdrm left front	14	
			Bdrm right front	14	
			Bdrm centre	26	
			General upstairs	11	
		09/86	125 cm distant	80	DER 33 day TLD
			Contact	8 200	As above
			Bedroom	26	As above
	As above with concrete block shielding	12/86	At hot water boiler	13	
			Workshop door	19	
			Far end of basement	8	
		01/87	Near laundry	8	
			Centre line nr boiler	11	
			At DER TLD on shielding	198	On contact
			125 cm distant	30	62 day TLD by DER
			Contact	310	As above
			Bedroom	11	As above
			190 cm distant	19	As above
			130 cm distant	11	As above
		02/87	Wall	30	
			Workshop door	14	
		03/87	Workshop door	25	
			Centre line	15	
			Bedroom	7	

* At a distance of 1 m unless otherwise stated

GAMMA MEASUREMENTS
IN CONTACT WITH SHIELDING
FOR HOUSE 2

DATE	TOP	BLOCK 1	BLOCK 2	BLOCK 3	BLOCK 4	BLOCK 5	BLOCK 6
water adsorption 55 L/s charcoal unit with concrete block shielding							
12/86	25	73	210	345	360	265	155
01/87	24	60	172	274	278	194	122
02/87	19	60	170	260	295	210	130
03/87	19	62	200	310	315	245	145



ACRES Acres International Corporation	LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
	FOUNDATION PLAN	Date: 12/1/86	2
	Mitigation system: BASEBOARD TYPE WALL/SLAB SUCTION	PHASE: I THRU FINAL	

HOUSE 3

PENNSYLVANIA DER MEASUREMENTS

Working Level grab samples (Kusnetz)	3.00 WL
Heating season average radon (Terradex)	350 pCi/L
Radon concentration in water	low (municipal water)

1. DESCRIPTION

This small two-story house was built in the mid 1970's on a levelled site on steep hillside in a rural subdivision near Boyertown. The walls are siding. Heating is by electric baseboards upstairs only.

The basement walls are of hollow concrete block. While the house was under construction, the uphill basement wall had deflected inward, and had been reinforced by two vertical steel beams tied to the floor and joists. A second wall was constructed inside the basement to conceal this, and runs along the uphill wall and half way along the rear wall. A hollow concrete block column supporting the central beam penetrates the slab.

The end walls and the interior false wall are open at the top. The sill plate covers almost all of the block openings on the front and back walls. Services enter at an opening in the wall which has been cemented closed.

The concrete floor slab was placed in one pour and has some cracking. A sump hole in the uphill rear corner of the basement had been concreted over by the owner and had a ventilation pipe installed. The owner had also installed an active basement ventilation system, consisting of an exhaust vent of two screened 5 cm diameter holes through the header board and siding at one end of the basement, and a 15 cm duct with a 15 L/s booster fan to supply fresh air at the other end of the basement.

2. ACTION

2.1. PHASE 1

As the walls in this house had peculiar construction features, the mitigative action chosen for initial demonstration was sub-slab exhaust. The basement was small and rectangular, so only one central exhaust point was planned.

An electric Hilti drill was used to drill a 30 cm diameter ring of holes and an air hammer and compressor was used to break out the concrete. The hole was cleaned out, and the slab was found to be poured on bedrock, with 5 cm of broken rock beneath the slab. "Half-inch" crushed stone was placed in the hole and a "4 inch" lightweight plastic drain pipe was installed vertically in the stone. A beadboard cover was cut to fit the hole and round the pipe. All joints were caulked airtight with asphalt cement, and the hole was closed with concrete bag mix.

Piping was run from the riser to a window where a sheet of plywood replaced the window. A flexible duct passed through the plywood to a large centrifugal fan mounted outside on a box.

In July 1985, the radon concentration in the basement reached 1 478 pCi/L with the window closed. When the sub-slab exhaust fan was switched on, the concentration fell to an average value of 520 pCi/L. A lower value might have been reached, but the dog chewed the flexible hose off the fan. However, the reduction needed was so much larger than achieved that the final value was irrelevant.

This house was next door to house 8, where large reductions in radon concentration had been achieved by ventilating the walls alone. It was therefore decided to extend the system to ventilate the block walls as well as beneath the basement floor slab.

The tops of the end basement walls were closed by stuffing paper into the open block voids on both end walls as temporary supports. The voids were then filled with mortar.

On the front wall, and the part of the rear wall that was only one block thick, a strip of wood was nailed to the sill plate to extend it over the top of the block voids. This was then caulked to the top of wall with asphaltic cement.

The space over the top of the double walls was very limited, so the top of the wall was closed by nailing a board to the joists over the top of the wall. The board was caulked along the edge that touched the sill plate. The gap between the board and the top of the inner wall was filled with expanding urethane foam. Spaces around the vertical reinforcing steel beams on the end wall, the beam pockets and any other openings were also filled with foam.

A 10 cm hole was cut into the void of a top course block near the centre of each wall section. On the double walls, both skins of the inner block wall were penetrated to access the space between the walls. No further openings were made into the outer wall on the uphill side for large cracks were visible and air flow from the outer wall was assured. The outer rear wall was not as badly cracked, so a 10 cm (4") opening was also made into the outer block wall.

A 7.5 cm diameter hole was cut in the single thickness section of the rear wall.

An exhaust pipe of "4 inch" lightweight plastic drain piping was run from each hole to a "4 inch" header that ran along the central beam and connected to the existing sub-slab exhaust system pipe.

All wall cracks were filled with a vinyl/cement crack filler. The exhaust fan was replaced with a small high speed centrifugal exhaust fan capable of higher suction.

In August 1985, the radon concentration in the basement with the fan off ranged from 203 to 213 pCi/L, and fell to between 1 to 2 pCi/L when the fan was turned on. The airflow from the front wall was 7 L/s, from the uphill wall was 9 L/s, from the double portion of the rear wall 8 L/s, from the single section was 9 L/s, and from the garage wall 18 L/s. The floor pipe had a flow of 2 L/s. The high flows from the garage wall were caused by leakage through mortar joints and cracks in the unparged section of the wall above grade in the garage.

2.2. PHASE 2

In November 1985, when the system had been running continually for three months, the radon concentration in the basement ranged from 0.3 to 2.4 pCi/L, averaging 1.5 pCi/L. The system flows and radon concentrations were; uphill wall 9 L/s at 150 pCi/L, rear wall 8 L/s; garage wall 18 L/s at 30 pCi/L; front wall 7 L/s, and in the floor exhaust 2 L/s at 9 500 pCi/L and a suction of 10 Pa. Suctions in the walls ranged from 3 to 13 Pa, and a smoke test showed that the airflow was from the house into the wall.

Alpha Track detectors were placed in the house in December 1985, and left until March 1986.

As the system was operating in flow mode, the external fan and flexible duct was replaced by a large wall mounted centrifugal exhaust fan of higher flow capacity in May 1986. A "4 inch" duct was extended through the concrete block wall, the plywood sheet removed and the basement window replaced. As the weather had turned warm, further measurements were delayed until the fall.

2.3. PHASE 3

In December 1986 the radon concentration in the basement with the fan running was ranged from 3 to 10 pCi/L, averaging 6 pCi/L. This was slightly higher than measured previously, and so it was decided to replace the wall mounted exhaust fan with a plastic body in-line centrifugal fan of approximately double the capacity, and duct the discharge to above the roof line of the house.

The fan was exchanged in December 1986. The wall mounted fan was removed, and the in-line fan attached to the "4 inch" piping by an elbow and a "4 to 6 inch" adaptor. The fan was mounted with the axis vertical, and an "2 inch by 3 inch" aluminum rainwater downspout was attached to the fan outlet by a "4 to 6 inch" adaptor and a "4 inch to downspout" adaptor. The downspout ran to above the garage roof line. Both the fan and the downspout were secured to the siding.

In December with the new fan running the radon concentration in the basement ranged from 3 to 7 pCi/L, averaging 5 pCi/L.

Flows and radon concentrations from the garage wall were 16 L/s at 50 pCi/L; from the front wall were 6 L/s at 190 pCi/L; from the uphill wall were 6 L/s at 180 pCi/L; from the doubled part of the rear wall 6 L/s at 170 pCi/L; and from the single section of the rear wall 16 L/s. The floor pipe had a suction of 10 Pa, and a flow of 1.2 L/s at 12 000 pCi/L. Suctions were respectively 15, 5, 3, 3, and 9 Pa.

These flows and concentrations were very similar to those measured a year previously with the small centrifugal fan. This suggested that the backpressure generated by the large area change at the fan outlet limited its performance.

Alpha track dosimeters were issued in December 1986 for final long term measurements.

3. OTHER MEASUREMENTS

The radiation field in the house ranged from 5 to 11 uR/h, averaging 8 uR/h. The field on the site round the house ranged from a low of 5 uR/h on the asphalt driveway to 12 uR/h, averaging 9 uR/h.

The average radon concentration measured by alpha track detectors over the period December 1985 to March 1986 was 4.4 pCi/L in the basement, and 1.7 pCi/L upstairs in the living room.

The average radon concentration measured by alpha-track detectors over the period December 1986 to March 1987 was 3.5 pCi/L in the basement, and 2.1 pCi/L in the living area.

MEASUREMENTS SUMMARY FOR HOUSE 3

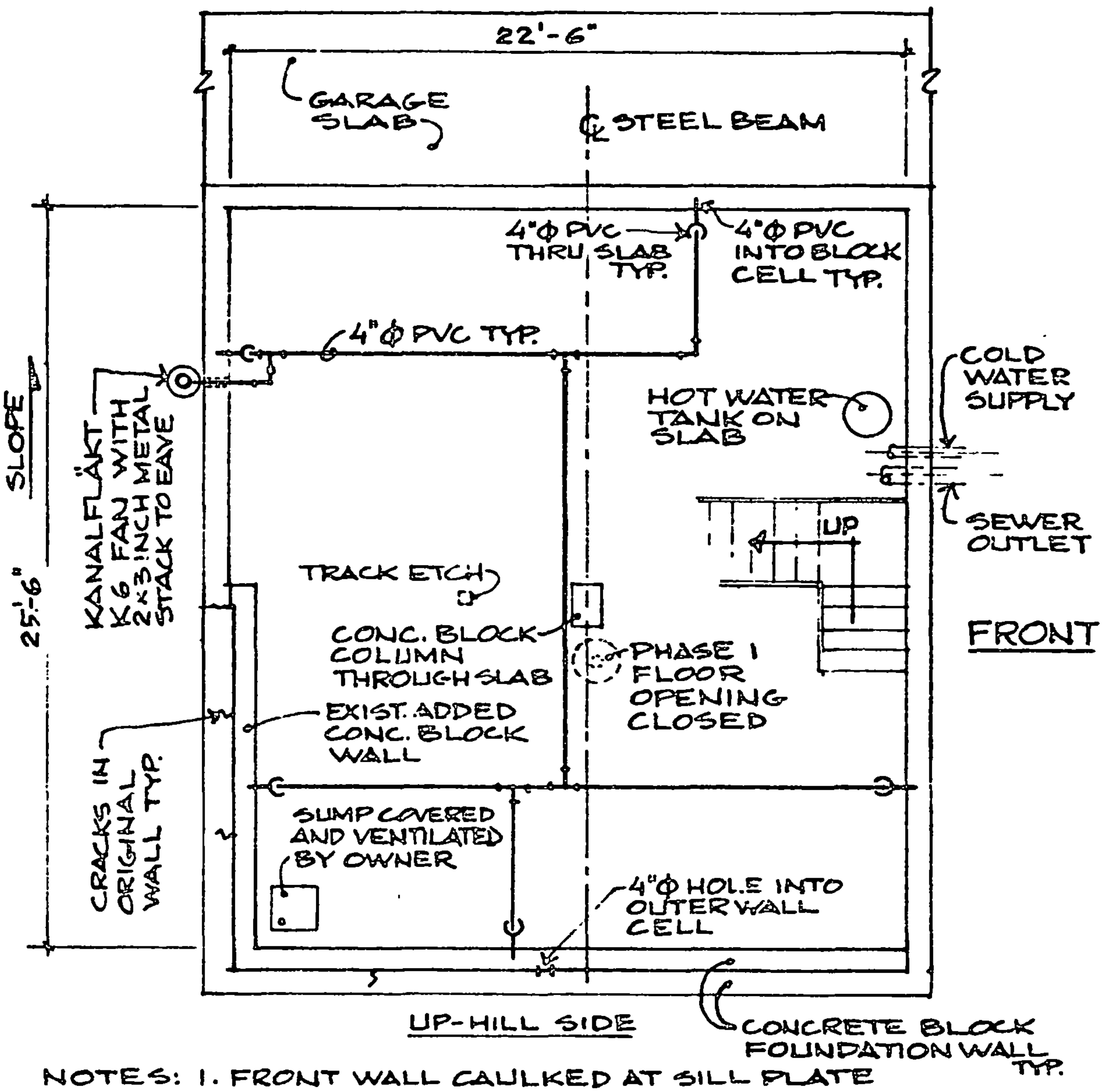
PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	MEAN	COMMENTS
1	Central sub-slab ventilation 100 L/s centrifugal fan	07/87	Fan off	348-1478	1097	over 66 hrs
			Fan on	234 1352	667	over 25 hrs - fall to equilibrium of 520 pCi/L
	Central sub-slab + wall ventilation 100 L/s centrifugal fan	08/85	Fan off	11- 232	141	over 26 hrs rise to equilibrium of 216 pCi/L
			Fan on	1- 175	22	over 23 hrs fall to equilibrium of 2 pCi/L
2	As above	11/85	Fan on for three months	0.3-2.4	1.5	over 48 hrs
		12/86	Fan on	3- 10	6	over 84 hrs
3	Central sub-slab + wall ventilation 150 L/s centrifugal fan	12/86	Fan on	3- 7	5	over 45 hrs

SYSTEM MEASUREMENTS FOR HOUSE 3

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
1	Central sub-slab ventilation 100 L/s centrifugal fan	07/85	94	47		At fan
2	Central sub-slab + wall ventilation 100 L/s centrifugal fan	11/85	3	7		Front wall
			3	9		Uphill wall
			3	8		Rear wall*
			8	9		Rear wall**
			13	18		Garage wall
			10	2		Floor pipe
				47		Near fan duct
2	As above	12/85			150	Uphill wall
					9 400	Floor pipe
					30	Garage wall
					0.2	Ambient
	Central sub-slab + wall ventilation 150 L/s centrifugal fan	12/86	5	6	180	Front wall
			3	6	190	Uphill wall
			3	6	170	Rear wall*
			9	16		Rear wall**
			15	16	30	Garage wall
			10	1	12 000	Floor pipe

* Double
** Single



NOTES:
1. FRONT WALL CAULKED AT SILL PLATE
2. END WALLS MORTARED
3. WOOD CUT TO FORM INSERTS ON UPHILL SIDE AND REAR WERE CAULKED IN PLACE
4. SPACES AROUND STEEL BEAMS WERE FOAMED
5. FOAM WAS USED TO SEAL REMAINING GAPS

ACRES Acres International Corporation	LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
	FOUNDATION PLAN	Date: 10/19/86	3
	Mitigation system: SUB-SLAB AND WALL SUCTION	PHASE: I THRU FINAL	

HOUSE 4

PENNSYLVANIA DER MEASUREMENTS

Working Level grab samples (Kusnetz)	0.252 WL
Short term average WL (RPISU)	0.033 WL
Heating season average radon (Terradex)	25 pCi/L
Radon concentration in water	8 000 pCi/L

1. DESCRIPTION

This one-story brick-faced home with attached garage was built in the late 1950's on a sloping site on the side of a hill in Bechtelsville. The walkout basement walls are of hollow concrete blocks. The walls are open at the top, but the voids are partially covered by the sill plate.

The concrete floor slab was poured in two halves and has a large construction joint running from front to back of the house. Penetrations of the slab include the sewer and oil lines, the stair stringers, the house jacks, and the well pressure tank support (concrete blocks on their side). There is also a basement shower and toilet. There are no cracks in the floor. The wall/slab joint opening is small.

2. ACTION

2.1. PHASE 1

As there were multiple openings in the floor, the mitigative action selected for demonstration at this site was subslab ventilation with two centrally located exhaust points.

A Hilti electric drill was used to drill guide holes on the circumference of a 60 cm circle, and the concrete was broken out with an air hammer.

It was found that the slab had been poured directly on the bottom of the excavation, and there was no added aggregate beneath the slab. The air hammer was used to break up the rock, and the holes cleaned out to bedrock. The bottom of each hole was filled with clean crushed stone, and a "4 inch" lightweight plastic riser pipe inserted vertically. The stone was covered with roofing felt cut to fit the holes, and caulked to the pipes and the edge of the concrete slab with asphaltic caulk to make the cove airtight. The holes were then filled with a bag mix concrete.

The risers were connected to a "4 inch" pipe run along the main beam. A flexible duct ran from the pipe through a plywood sheet replacing a basement window. A centrifugal fan was attached to the duct, and screwed to underside of a plywood cover cut to fit the window well.

When the fan was turned on, very little air was drawn from the system. The fan ran stalled with considerable vibration and noise.

In August 1985, the radon concentration in the basement averaged 33 pCi/L, and fell to less than 6 pCi/L when the fan was turned on.

2.2. PHASE 2

In January 1986, the concentration in the basement with the fan on ranged from 18 to 33 pCi/L, averaging 23 pCi/L. Due to the poor system performance, it was removed in February 1986, and the site restored.

2.3. PHASE 3

Considerable success had been achieved during Phase 2 at other sites with poor sub-slab permeability by sub-slab systems using multiple point perimeter suction together with increasing the airtightness of the floor, and a high suction fan. One of these systems was installed in December 1986.

The well pressure tank was removed from the concrete block base, and the voids in the blocks were filled with mortar. The construction joint between the two halves of the concrete floor slab was cleaned and filled with silicone caulk, and the hollow house jacks were drilled near the bottom and filled with expanding urethane foam. Six 12.5 cm diameter holes were cored through the floor slab about 5 cm away from the walls. Two holes were placed on the front and back walls about 1/3 of the way from each end, and one hole was placed near the centre of each end wall. The holes intersected the footing, but entered the subslab loose rock fill. A "4 inch" lightweight plastic pipe was inserted vertically in each hole, and the gap between the pipe and the concrete floor was filled with silicone caulk. The pipes were joined to a central duct of "6 inch" lightweight plastic pipe, which passed through the end wall of the house. A plastic body in-line centrifugal fan was attached to the duct.

As success of this system was not certain, preparations were made for easy installation of wall ventilation if needed. The tops of the walls were closed by stuffing fiberglass insulation into each void for a temporary support, and then injecting expanding urethane foam. A "T" was provided at 30 cm from the floor in each leg so that a ventilation pipe could be easily connected into the walls.

The fan gave a suction of 225 Pa in all floor pipes, but for 250 Pa at the pipe closest to the fan. Flows and radon concentrations in the rear wall pipes near the end wall were 7 L/s, 160 pCi/L; and near the garage wall were 20 L/s, 40 pCi/L; in the garage end wall pipe were 1.5 L/s, 1 000 pCi/L; in the front wall pipes near the garage wall were 8 L/s, 2 000 pCi/L; and near the end wall were 2 L/s, 620 pCi/L; and in the end wall pipe 2 L/s, 600 pCi/L. Most of the rear wall of the house is above grade, and the low radon concentrations and high flows in the rear wall pipes may be due to air drawn from outside beneath the footing.

In December 1986, radon concentrations in the basement with the fan on ranged from 1 to 7 pCi/L, averaging 3 pCi/L. When the fan was turned off, the concentration rose rapidly to range from 10 to 24 pCi/L, averaging 20 pCi/L.

Alpha track detectors were issued in January 1987 for final long term measurements.

OTHER MEASUREMENTS

The radiation field in the house ranged from 7 to 12 uR/h, averaging 10 uR/h. The field on the site ranged from 6 uR/h over the asphalt driveway, to 12 to 15 uR/h, averaging 14 uR/h over the rest of the site. Soil exposed at a road bank at the top of the hill gave 18 uR/h.

The average radon concentration measured by alpha-track detectors over the period January 1987 to March 1987 was 0.7 pCi/L in the basement, and 0.8 pCi/L in the living area.

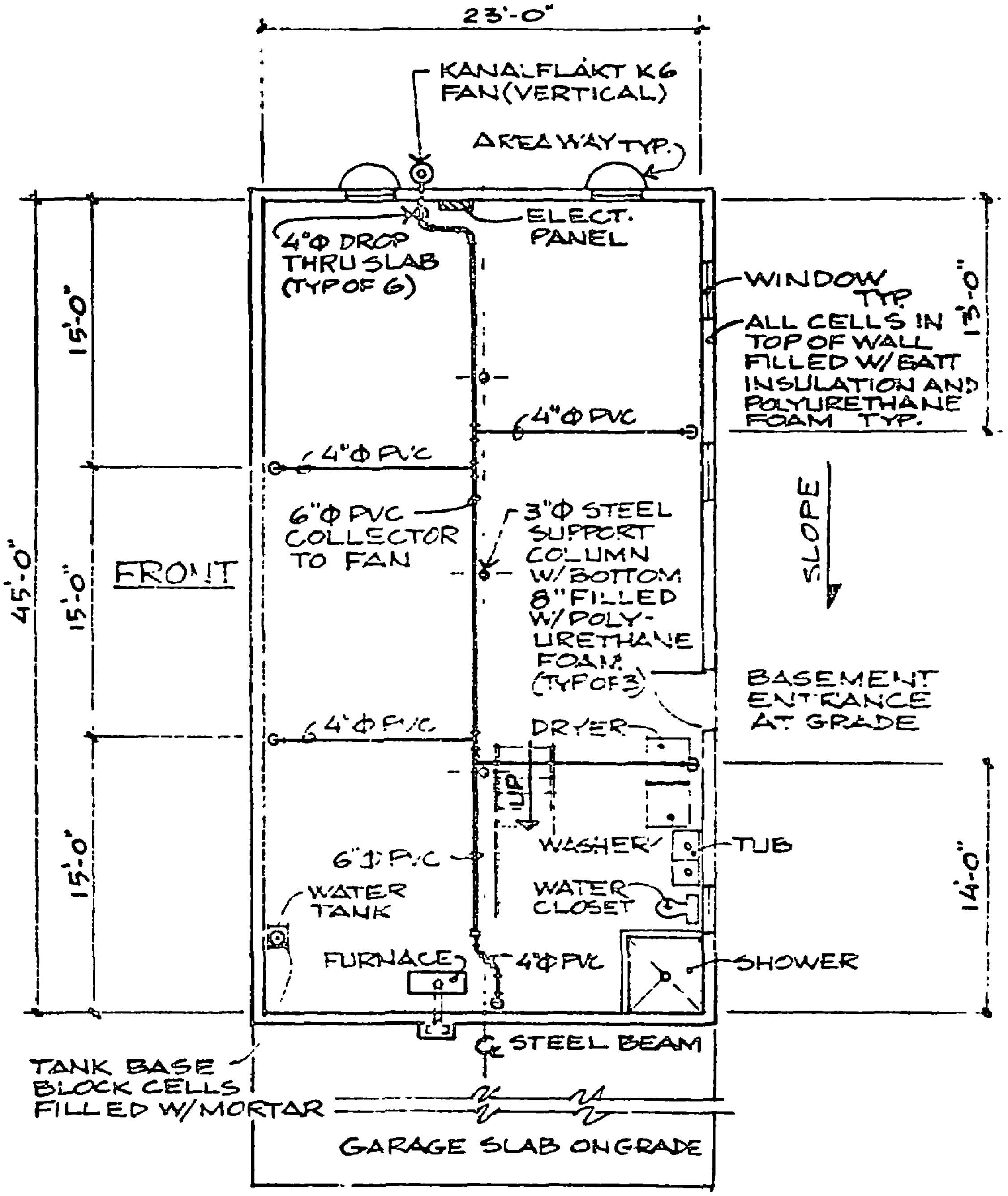
MEASUREMENTS SUMMARY FOR HOUSE 4

PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	MEAN	COMMENTS
1	Central sub-slab ventilation 50 L/s centrifugal fan	08/85	Fan off	7-36	33	over 36 hrs
			Fan on	6-30	10	over 36 hrs still dropping
2	As above	01/86	Fan on	18-33	23	over 46 hrs
3	Perimeter sub-slab ventilation 150 L/s centrifugal fan	12/86	Fan on	1- 7	3	over 40 hrs
			Fan off	10-24	20	over 20 hrs

SYSTEM MEASUREMENTS FOR HOUSE 4

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
3	Peripheral sub-slab ventilation 150 L/s centrifugal fan	12/86	225	2	620	Riser A front wall
			225	8	2 000	Riser B front wall
			225	2	1 000	Riser C garage wall
			225	20	40	Riser D rear wall
			225	7	160	Riser E rear wall
			250	2	600	Riser F end wall



LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
FOUNDATION PLAN	Date: 12/11/86	4
Mitigation system: SUBSLAB SUCTION	PHASE: FINAL	

HOUSE 5

PENNSYLVANIA DER MEASUREMENTS

Working Level grab samples (Kusnetz)	0.354 WL
Heating season short term average WL (RPISU)	0.257 WL
Heating season average radon (Terradex)	29 pCi/L
Radon concentration in water	4 200 pCi/L

1. DESCRIPTION

This rural single story dwelling was built in the early 1980's on a leveled site on the side of a hill several miles southwest of Boyertown. The unfinished basement has hollow concrete block foundation walls. The front wall of the house is brick veneer, the other walls are siding. There is an external stairway to the basement.

The basement walls are in generally good condition but with horizontal cracking in the kitchen end wall, and a diagonal crack visible from the outside in the front wall at the opposite end of the house. There is no sill plate on top of the walls, the floor joists rest directly on the blocks.

The poured concrete floor slab is in good condition with minor cracking, and is penetrated only by the sewer lines and the house jacks, which are filled with concrete. Heating is by electric resistance baseboard heaters upstairs, two forced air electric heaters in the basement, and is supplemented by a coal stove in the basement.

The owner said there was no perimeter drainage tile (weeping tile) around the foundations, just crushed stone. The untrapped floor drain discharges to daylight lower on the site.

2. ACTION

2.1. PHASE 1

The good concrete floor slab suggested that the walls were the major route of entry in this house. The mitigative action chosen for demonstration at this was to exhaust the concrete block walls. It was also the only one of the initial group with a significant amount of each basement wall exposed above ground, and so it was decided to test the concept of mounting a small fan in each wall, rather than using a collection system with a central fan.

In July 1985, five holes were cut in the exterior face of the upper course of the wall, one in the centre of each wall section. (The rear wall was divided in two sections by the door and steps to the exterior). A 1/4 inch drill was used to drill twelve holes on a 110 mm diameter circle, and the centre chipped out with a hammer and chisel. The holes were sized to take 6 to 4-inch light weight plastic drain pipe adapters which housed 50 L/s axial fans. The adapters were screwed to wooden backboards which were sealed with caulk against the blocks and around the 4-inch pipe section. Electrical connections to the fans were run through holes bored in the interior of the block walls.

The floor joists in this house rest directly on top of the walls, so there is no sill plate to close the open voids at the top of the block walls. The options for closing the voids were to fill them with cement, or else place a cover between each joist and caulk it to the top of the wall. The latter seemed easier for a homeowner to do, and was chosen.

The top of the block walls was closed by installing roofing felt "trays" fitted between the joists. The rear and sides of the trays were stapled to the wood and the front portions were caulked to the blocks with asphaltic roofing cement. A single component foam from a small aerosol can was tried as a sealant behind the electrical panel with only partial success, due to the difficulties in dispensing the foam. The can had to be used upside down, and the clearance to the joists and the underside of the floor was often insufficient for this. In July 1985, prior to turning on the fans the radon concentration averaged about 1 pCi/L. This was much lower than expected from the DLR measurements made during the heating season. When the fans were activated the average concentration rose to about 25 pCi/L, and fell when the fans were turned off. These results were so confusing, that work was suspended until Phase 2 of the program. Winter measurements were needed to confirm the validity of the previous high readings, and evaluate the effect of the coal stove.

2.2. PHASE 2

In November 1985, measurements with the coal stove in operation found radon concentrations in the basement that ranged between 100 to 200 pCi/L. Measurements in December 1985 found that concentrations with the stove off averaged about 75 pCi/L in the basement, and about 50 pCi/L upstairs. The basement door was kept closed when the stove was off. When the stove was lit, the basement door was left open to heat upstairs, and concentrations averaged 120 pCi/L on both floors. This verified the previous high DER readings, which were made in the winter.

A smoke stick check of the closure trays on top of the walls found many leakage points, so it was decided to close the walls properly with mortar, or expanding foam in those places where access was too poor to use mortar. By this time, experience at other sites had lead to the conclusion that a collection system with a central fan would be required at virtually all sites, so there was no point in keeping the individual fan system. A single large centrifugal fan was noticeably quieter than the 5 small fans operating together. Therefore a central collection system would be installed in place of the multiple fans.

This work was carried out in January 1986. As there was no sill plate on the top of the wall, access to the block voids was good and the voids were closed with mortar. The brick veneer exterior wall at the front wall meant that the header board was 100 to 120 mm closer to the inner edge of the block than elsewhere, and the opening into the block void was too small to get mortar into the void. The voids of this wall were stuffed with fiberglass as a temporary support, and an expanding single component urethane foam injected into the space. A long nozzle was used to ensure that foam was delivered to the side of the void away from the operator so that the void would be completely closed as the foam expanded.

A standard "octopus" collection network with two collection points on each long wall and one on each short wall was installed. The wall collectors were "4 inch" lightweight plastic drain pipe, and ran to a central collector duct of "6 inch" lightweight plastic drain pipe. A large centrifugal ventilator was mounted on the rear wall of the house in a window well. The weather was too cold for satisfactory external mortar work, and so the wall mounted fans were not removed, but taped closed. Before the fan openings were closed system pressures ranging from 8 to 38 Pa induced flows of radon concentrations ranging from 11 to 20 L/s and 40 to 80 pCi/L. Following closure of the fan openings induced flows generally increased by 2 to 3 L/s.

Initial measurements of the system were made in January 1986. Radon concentrations in the basement averaged more than 70 pCi/l with the fan running. Investigation found airflows into the walls except at either end of the front wall over a distance of 1.5 m and radon concentrations in the walls comparable to those in the house. This indicated that there were radon sources other than the walls, and that wall ventilation alone might not be sufficient.

There was a marked draft out of the untrapped floor drain of 10 L/s. This flow decreased to 5 L/s with the fan off and the basement windows open, suggesting it was largely driven by the temperature difference between the cold outside air and the relatively warm soil surrounding the drain pipe. The radon concentration in this air was 320 pCi/L, showing that it was connected to the soil in someway. The drain was closed with tape, and after an hour the concentration in the drain was 1600 pCi/L. Evidently, the drain piping was not continuous to the open air and probably was connected to the crushed stone exterior drain around the house walls.

This provided an explanation for the strange results observed in the summer. When the soil temperature was less than the air temperature, air would flow down the drain out of the house, and there would be no radon supply by this route. When the five small fans were turned on, they drew considerable amounts of air out of the basement via leaks in the wall closures. As both basement doors and windows were kept closed during the test, the resulting pressure drop was enough to draw air and radon up the drain into the basement while the fans were running. Once the fans were turned off, airflow in the drain returned to normal, cutting off the radon supply.

Radon concentrations in the basement during February 1986 with the floor drain closed by duct tape averaged less than 20 pCi/L, confirming that it was a major radon entry route, but not the only one.

In March 1986, the airtightness of the walls was increased. The wall mounted fans were removed and the holes in the walls mortared closed. The external portion of the front wall crack was closed to 300 mm below grade, and all of the internal crack was filled with silicone caulk. An expanding rubber plug was placed in the floor drain. As a test, the large centrifugal exhaust fan was replaced by a smaller centrifugal fan set to blow into the walls.

Radon concentrations in the basement varied from 1 to 15 pCi/L, averaging 7 pCi/L. Concentrations in the walls were 2 to 5 pCi/L at this time, indicating that floor radon entry routes were still present. Flows of 3 to 8 L/s were observed under pressures of 1 to 3 Pa.

A large wall mounted centrifugal pressure fan was ordered to see if higher pressures in the walls would increase the air flows into the sub-slab space, and decrease the radon supply from the floor. When it arrived, the design was unsuitable for unprotected outdoor mounting, so the large centrifugal exhaust fan was replaced in April 1986. By this time the weather had turned warm, and further measurements were deferred until the fall.

2.3. PHASE 3

In November 1986, the owner complained that the coal stove in the basement was hard to light and smoked when the exhaust fan was running. It was agreed that it would be replaced by a pressure fan. In December 1986, with the fan off, radon concentrations in the basement ranged from 12 to 82 pCi/L, averaging 55 pCi/L. Following this, a large plastic bodied in-line centrifugal fan was installed on the outside of the house below ground level in a window well. This produced pressures of 10 Pa in the walls, with a total air flow of 150 L/s. Radon concentrations of about 5 pCi/L were measured in the air delivery ductwork, presumably due to radon drawn from the exposed soil in the bottom of the window well.

Radon concentration in the basement with the new fan on ranged from 3 to 9 pCi/L, averaging 5 pCi/L.

Alpha-track detectors were issued in January 1987 for final long term measurements.

3. OTHER MEASUREMENTS

The radiation field in and around the house ranged from 4 to 7 uR/h in the basement, averaging 5 uR/h. On the site the field ranged from 6 to 10 uR/h, averaging 8 uR/h.

The average radon concentration measured by alpha-track detectors over the period January to March 1987 was 4.3 pCi/L in the basement, and 4.3 pCi/L in the living area.

MEASUREMENTS SUMMARY FOR HOUSE 5

PYLON AB-5 HOURLY MONITORING

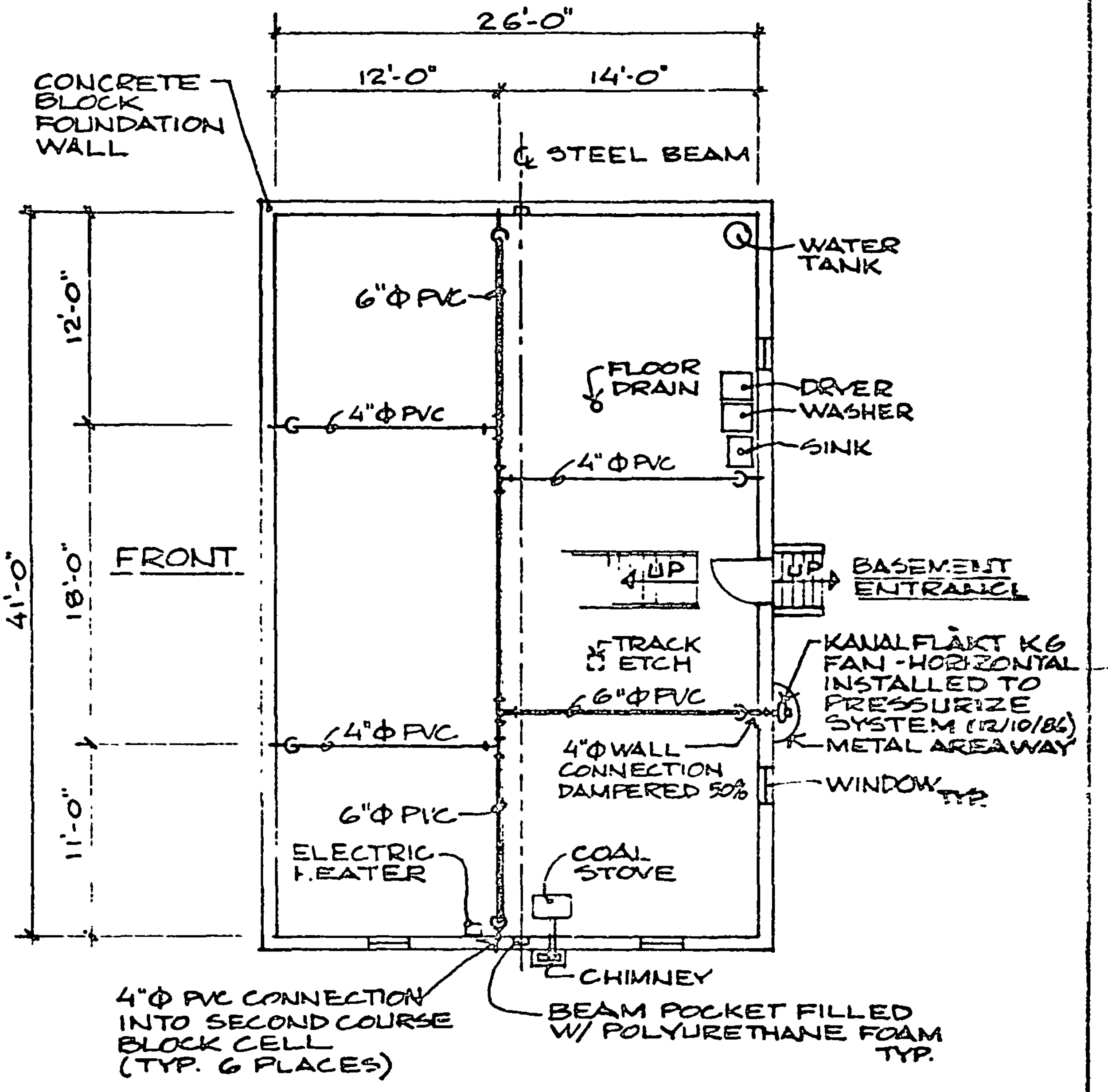
PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	MEAN	COMMENTS
1	Block wall exhaustion five 50 L/s axial fans	07/85	Fans off Fans on	0- 2 13- 50	1 35	over 27 hrs over 45 hrs
2	As above	11/85	Fans off/stove on continuously	60-200	138	over 44 hrs
2	As above	12/85	Fans off stove off	7- 85 7- 74	56 46	over 24 hrs B over 24 hrs U
			Fans off stove on	92-117 97-130	109 118	over 13 hrs B over 13 hrs U
2	Wall ventilation 100 L/s centrifugal	01/86	Fan on	26-153	109	over 4 days
		02/86	Fan on Fan on drain taped	30- 60 6- 29	51 19	over 7 hrs over 88 hrs
2	Wall ventilation 50 L/s centrifugal drain plugged axial openings mortared wall tightened	03/86	Fan on blow	1- 15	7	over 4 days
3	Wall ventilation 100 L/s centrifugal	12/86	Fan off	12-82	55	over 88 hrs
3	Wall ventilation 150 L/s centrifugal pressure fan	12/86	Fan on blow	3- 9	5	over 4 days

SYSTEM MEASUREMENTS FOR HOUSE 5

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
2	Wall ventilation	01/86	8	20/23	75	Pipe A
	100 L/s centrifugal		10	11/13	80	Pipe B
	-axials open taped		38	34/36	60	Pipe C
			10	20/19	60	Pipe D
			10	13/16	40	Pipe E
			8	13/15		Pipe F
2	Wall ventilation	02/86		10		Drain fan on
	100 L/s centrifugal			5		Drain fan off
					45	Basement air
					320	Drain air
					200	Drain air
					1 600	Air from capped drain
2	Wall ventilation	04/86	1	6	3	*Pipe A
	50 L/s centrifugal -		1	3		*Pipe B
	drain plugged walls		1	4	5	*Pipe C
	tightened		3	8	2	*Pipe D
			3	5	4	*Pipe E
			1	4	3	*Pipe F
3	Wall ventilation	12/86	15	26	6	*Pipe A
	150 L/s centrifugal		15	17	3	*Pipe B
	pressure fan		11	26	7	*Pipe C
			18	28	6	*Pipe D
			15	21	4	*Pipe E
			14	21	4	*Pipe F

A: Driveway wall
B: Rear wall
C: Rear wall
D: End wall
E: Front wall
F: Front wall

* Fan on blow throughout.



ACRES	LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
	FOUNDATION PLAN	Date: APR.86	5
	Mitigation system: WALL PRESSURIZATION	PHASE: 3 FINAL	

HOUSE 6

PENNSYLVANIA DER MEASUREMENTS

Working Level grab samples (Kusnetz)	0.461 WL
Heating season short term average WL (RPISU)	0.372 WL
Heating season average radon (Terradex)	60 pCi/L
Radon concentration in water	14 500 pCi/L

1. DESCRIPTION

This large one-story home with attached garage was built in the mid 1970's on a level site near the top of a hill a few miles northwest of Boyertown. The exterior walls are all of brick. Heating is by oil fired forced-air supplemented by a ductless kerosine heater in the basement.

Half the basement is finished, with a washroom, panelled walls, fireplace, and a tile ceiling. There is a large open construction joint across the middle of the basement floor slab in the unfinished half, and the floor is cracked across one corner of the basement near an external basement entrance. This house is unusual in that the basement head room is increased by a single course of 8" block standing on top of the 12" block walls behind the brick veneer. The sill plate and joists rest on top of the 8" block. As there is a gap between the 8" block and the brick veneer, soil gas can move out of the 12" block into the house via this gap. The tops of the front and back block walls are closed by the sill plate.

2. ACTION

2.1. PHASE 1

As the tops of the front and rear walls were closed by the sill plate, the mitigation method selected for demonstration at this house was to exhaust the hollow concrete block walls. No special effort was to be made to close the gap between the inner block wall and the brick veneer. It was hoped that as this gap is often partially filled with mortar droppings, the leakage area of these walls might be tolerable. The intention was to see how high a standard of wall closure would be required.

The top course of concrete blocks on the laundry room end wall was closed with a sheet of roofing felt caulked to the wall top with asphalt cement and stapled to the header board. As there were known inaccessible openings into the walls (the block/brick gap), the sill plate/wall joint was not caulked, and no work was carried out in the finished portion of the basement.

One hole was cut in the interior face of each of the three walls exposed in the unfinished section of the basement. The holes were located as close to the centre of the complete wall as possible. Collection ducts of "4 inch" lightweight plastic pipe were installed in the holes, and connected to a central "4 inch" pipe. A large centrifugal fan mounted in a box was connected to the pipe by a flexible duct passed through a hole in sheet of plywood placed in a basement window frame.

This treated three of the walls, but the fourth (garage) wall was concealed by paneling in the family room. A separate fan was installed from the outside of the wall. A small hole was broken through the concrete garage floor, and excavated to the middle of the top course of blocks. An 8 cm diameter hole was drilled and chiselled through the block. A small centrifugal fan was placed in the pit over the hole in the wall, and exhausted into the garage.

In July 1985, the average radon concentration in the basement fell from approximately 40 pCi/L to average 5 pCi/L when the fans were turned on.

The owner objected to the noise of the small centrifugal fan in the garage, and to keeping the garage windows open, so it was replaced by an external fan. A pipe was inserted in the wall opening, and a flexible duct was run along the wall through a plywood panel inserted in the garage window to a large centrifugal exhaust fan mounted in a wooden box.

2.2. PHASE 2

In January 1986, with both the fans running continually, the radon concentration in the basement ranged from 66 to 107 pCi/L, averaging about 90 pCi/L.

Flows and radon concentrations were; front wall pipe 9 L/s at 10 pCi/L; end wall pipe 14 L/s at 50 pCi/L; and rear wall pipe 8 L/s at 50 pCi/L. The garage wall fan discharged 28 L/s air at 60 pCi/L. The radon concentration in the basement at this time was 80 pCi/L. The lower concentrations in the wall exhaust pipes showed that the walls could not be the entry route for the radon in the basement, and that large amounts of outside air were being drawn into the system. Investigation with smoke tubes showed that the suction in the wall did not extend more than 1.5 m from each suction point.

No test was carried out with the fans off, as the occupants were concerned that even higher concentrations might result. These concentrations were comparable to those measured the previous winter, and so the system was ineffective.

To test if simple rearrangements of the system could improve the performance, the fans were replaced by centrifugal fans set to blow into the walls. In April 1986, with these fans running continually, the radon concentration in the basement varied from 21 to 36 pCi/L averaging 25 pCi/L. When the fans were turned off, the concentration rose slowly to an average of 60 pCi/L.

By this time, experience at other sites was that in general wall ventilation could not be expected to control soil gas entry through major floor openings, and that it would have to be combined with sub-slab ventilation.

To test this three 125 mm holes were cored through the floor slab about 50 mm out from the wall directly beneath the ventilation points in the walls. The holes cleared the footing and showed that the layer of aggregate beneath the slab was several cm thick. The pipes were Teed, and extended downward to the holes. The space between the pipe and concrete was filled with silicone caulk.

The centrifugal supply fan connected to the piping network was reversed. and the garage wall supply fan was disconnected. Although most of the air drawn from the fan came from the walls, suction did extend several metres under the floor from each pipe location, as shown by smoke tests.

In May 1986, the radon concentration in the basement with the fans off varied from 19 to 98 pCi/L, averaging 70 pCi/L. When the fan was turned on, the concentration varied from 3 to 14 pCi/L, averaging 10 pCi/L. This performance suggested that a higher suction sub-slab system might be the most effective solution for this house. As the weather had turned warm, further work was suspended until the fall.

2.3. PHASE 3

In December 1986 the radon concentration in the basement with the fan running continually ranged from 8 to 52 pCi/L, averaging 30 pCi/L. The system was modified to a full sub-slab system.

The pipes into the walls were removed, and the wall openings mortared shut. (The Tees that joined the wall pipes to the floor pipes were left in position so that wall ventilation could be added easily to the system if desired). The plywood sheet in the basement window was removed and replaced by transparent plastic with a hole to allow a rigid pipe to pass through to a large plastic body in-line centrifugal fan mounted on the wall. The fan system in the garage was removed and the hole filled with concrete.

The construction joint in the basement floor was cleaned out and filled with silicone caulk.

The suctions, flows and radon concentrations with the new fan in operation were; front wall pipe 210 Pa, 19 L/s, at 1 100 pCi/L; end wall pipe 175 Pa, 0.2 L/s, at 1 400 pCi/L; and rear wall pipe 200 Pa, 0.6 L/s, at 90 pCi/L.

Radon concentrations in the basement with the new fan operating ranged from 3 to 11 pCi/L, averaging 5 pCi/L. With the fan off, concentrations ranged from 24 to 55 pCi/L, averaging 38 pCi/L.

Alpha track dosimeters were issued in January 1987 for final long term measurements.

3. OTHER MEASUREMENTS

The radiation field inside the house ranged from 6 to 12 uR/h, averaging 10 uR/h. The field on the site around the house ranged from 6 to 12 uR/h, averaging 10 uR/h.

The average radon concentration measured by alpha-track detectors over the period January 1987 to March 1987 was 3.3 pCi/L in the basement, and 1.9 pCi/L in the living area.

MEASUREMENTS SUMMARY FOR HOUSE 6

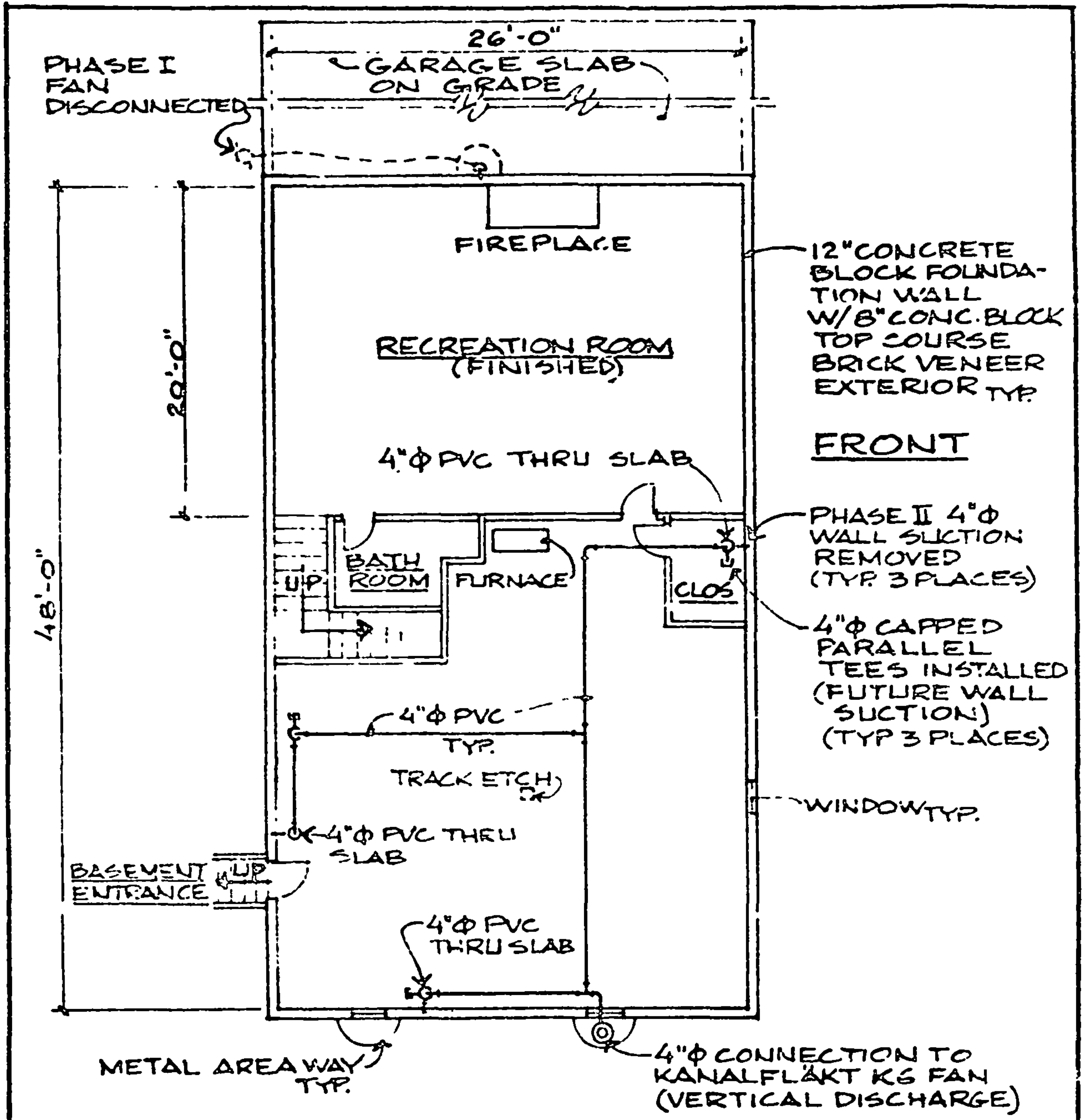
PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	MEAN	COMMENTS
1	Wall ventilation 100 - 50 L/s centrifugal fans	07/85	Fans off	27-48	36	over 21 hrs
			Fans on	3- 8	5	over 27 hrs
2	Wall ventilation two 100 L/s centrifugal fans	01/86	Fans on	66-107	90	over 48 hrs
2	Wall ventilation two 50 L/s centrifugal fans on blow	01/86	Fans on	21-36	25	over 51 hrs
			Fans off	51-68	60	over 22 hrs after 19 hr rise to equilibrium
2	Wall + sub-slab ventilation 50 L/s centrifugal on exhaust	05/86	Fan off	19-98	70	over 4 days
			Fan on	3-14	10	over 15 hrs
3		12/86	Fan on	8-52	30	over 4 days
3	Sub-slab ventilation 150 centrifugal fan	12/86	Fan on	3-11	5	over 48 hrs
			Fan off	21-55	38	over 13 hrs

SYSTEM MEASUREMENTS FOR HOUSE 6

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
2	Wall ventilation two 100 L/s centrifugal fans	01/86	5	8	50	Pipe A
			10	14	10	Pipe B
			3	9	50	Pipe C
			40	28	60	Pipe D
					80	Basement air
3	Sub-slab ventilation 150 L/s centrifugal fan	12/86	250	0.6	90	Pipe A
			175	0.2	1 100	Pipe B
			210	19	1 100	Pipe C

A = Rear wall B = End wall C = Front wall D = Garage wall



ACRES	LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
	FOUNDATION PLAN	Date: 12/10/86	6
	Mitigation system: SUBSLAB SUCTION	PHASE: I THRU FINAL	

HOUSE 7

PENNSYLVANIA DER MEASUREMENTS	
Working Level grab samples (Kusnetz)	1.712 WL
Heating season average (RPISU)	0.138 WL
Heating season average radon (Terradex)	25 pCi/L
Radon concentration in water	5 100 pCi/L

1. DESCRIPTION

This one-story house was built on in the early 1970's on a leveled site half way up the side of a hill slope in a rural area a few miles west of Boyertown. The house walls are all brick faced. Heating is by hot water baseboard radiators and an oil-fired furnace.

The basement walls are of concrete block. The exterior brick veneer rests on the outer edge of the basement block walls, and so the sill plate is set flush with the inner surface of the walls, and conceals the block voids except along the garage wall. There are vertical and horizontal cracks in the mortar joints of the rear back wall and horizontal cracks are found in the garage wall. Service entries are closed with mortar.

The concrete floor slab was placed in two pours with a large construction joint running the length of the house, and is in excellent condition with no significant cracking. The well pressure tank is mounted on concrete blocks which penetrate the floor slab. The slab is also penetrated by a floor drain, the oil supply line, an interior "L shaped" concrete block wall, and a furnace stack of concrete blocks.

The owner said that there was a perimeter drainage system, but it was just a bed of crushed stone without piping at the footing level around the house. The garage floor drain and the laundry sink drain discharge into this drain system.

2. ACTION

2.1. PHASE 1

As the top of the basement walls was generally closed by the sill plate, the remedial method selected for demonstration at this site was wall ventilation.

The presence of the interior wall and the floor openings would test if floor openings could be effectively controlled by wall ventilation.

System installation started in August 1985. Two 11 cm diameter holes were cut through the interior surface of the next-to-top course of blocks of each long wall. One hole was cut in each of the two short end walls. Guide holes were drilled with a "Hilti" electric percussion drill, and the centre knocked out by a chisel. Light weight "4 inch" plastic drain pipe was inserted into the holes, and run in the joist spaces, to a header of "4 inch" plastic drain pipe secured along the central house beam.

Each end of the header was extended to a window well where a flexible hose passed through a plywood window cover to a centrifugal fan housed in a box with a childproof exhaust pipe.

Where the sill plate covered the block voids (three walls), an asphaltic sealant was used to close the opening from the house to the wall at the junction of the sill plate and the wall. Along the garage wall the sill plate was set further out, and the voids were accessible. Access was good to half of the wall, and the top voids were covered there by nailing a 2 x 2 inch wood strip to the sill plate over the voids and caulking the gaps with asphaltic sealer. One quarter of the other half of the wall was covered by a wooden cover beside the stairs, and the remaining quarter was beneath the stairs, and access was difficult. The top voids in this half of the wall were closed by filling the block voids with a one-part expanding foam. Paper was stuffed into the voids to provide temporary support to the foam. The foam expanded out of the cavities, and was cut off flush with the blocks so that the cover could be replaced.

The basement wall is made of [illegible] block, and supports at the top a 4" brick veneer and a 6" wide sill plate. There is a gap of approximately 1" between the veneer and the sill plate, which was not closed by this procedure. The top of the internal block wall was also left open.

In August 1985, when the wall exhaust fans were turned on, radon concentrations in the basement fell from approximately 109 pCi/L to 1 pCi/L in less than one day.

2.2. PHASE 2

The house was remeasured in January 1986, and with the fans running, radon concentrations ranged from 100 to 701 pCi/L, averaging 20[illegible] pCi/L. A second measurement in January with the fans off ranged from 155 to 625 pCi/L, averaging 388 pCi/L.

The airflow was from the house into the wall, but the pressure differential was too small to measure directly (<3 Pa). The flows and radon concentrations from the walls were; end wall 14 L/s at 110 pCi/L; front wall 12 L/s at 200 pCi/L,and 14 L/s at 320 pCi/L; garage wall 21 L/s at 480 pCi/L, rear wall 17 L/s at 410 pCi/L, and 14 L/s at 170 pCi/L.

These high flows from the walls were interpreted as showing that the leakage area into the walls was too large for the installed fan system to produce a significant depressurization in the soil.

A two stage approach was proposed to deal with these problems. First, the fan system was to be upgraded. If this was insufficient to ensure that the walls were always under negative pressure relative to the house, then the leakage area of the walls would be reduced. This would involve closing the gap at the top of the walls between the brick and the header board by the injection of expanding single-component foam through holes drilled in the header board.

The asphaltic caulking was checked with smoke sticks, and leaking areas were caulked. The collection ducts in the walls were moved to the foot of the wall to improve their ventilation efficiency, and the central collection duct was changed from "4 inch" to "6 inch" pipe. The two centrifugal fans were retained, but provision was made to replace them with a large centrifugal exhaust ventilator of double their total capacity.

Measurements in March 1986 with the revised system in operation found radon concentrations in the basement averaging 75 pCi/L. Radon concentrations of 810 and 3 800 pCi/L were measured in the central "L" shaped wall, confirming that it was a route of radon entry. As a test, the fans were reversed to blow fresh air into the walls. This would eliminate the walls as an entry route, but would not affect entry routes in the floor. The average radon concentration in the walls was less than 10 pCi/L, but the basement radon concentration ranged from 22 to 88 pCi/L, averaging 70 pCi/L. Radon concentrations of 8 300 pCi/L were measured beneath the well pressure tank, and 900 and 1 000 pCi/L in the central wall.

This indicated clearly that the cause of the high radon concentrations was not that the wall ventilation system was inadequate, but that there were major routes of entry in the floor that were not influenced by wall ventilation. Depressurization of the walls was not producing sufficient depressurization of the sub-slab fill to prevent soil gas entry.

These floor entry routes were closed in March. The well tank was removed and the vertical voids i the concrete block support closed with mortar,topped with a 15 mm layer of asphaltic caulk. The top course of blocks in the interior wall was removed as the wall was not load-bearing, and the voids filled with mortar. A "4 inch" pipe was inserted into each section at the base, and connected to the central collection duct. The floor construction joint was not closed at this time.

When the fans were turned on again, still in blow, the radon concentration in the basement initially fell from 50 pCi/L to 6 pCi/L, then rose to 250 pCi/L, and finally stabilised at 44 pCi/L. This was attributed to radon loaded soil gas being forced from underneath the floor slab by the air blown into the walls. Smoke tests showed major air flows out of the central floor joint, so there was a connection from the walls to the sub-slab fill.

The fans were again reversed so that they exhausted the walls, and then the floor joint crack was enlarged to about 5 mm wide by 5 mm deep with a small abrasive wheel on a hand-held electric cutter, and filled with a silicone caulk.

Radon concentrations were about 50 pCi/L with the fans exhausting the walls and the floor joint open, but fell promptly to about 15 pCi/L when it was closed. Evidently the low suction produced in the sub-slab space by the low suction in the walls was insufficient to reverse the soil-house flows over openings in the floor.

As the floor routes of entry in this house seemed to be as important as the walls, it was decided to alter the system to test the relative affect of wall and floor ventilation. In April 1986, a concrete coring machine was used to bore 7 holes through the floor slab, one beneath each wall vent pipe. The thickness of crushed stone beneath the slab varied from 10 cm to 0 cm. The wall pipes were cut, and Teed into the wall and the floor holes.

The two centrifugal fans were removed, the basement windows replaced in their frames. A single large centrifugal fan was placed in a new window well at the rear wall and connected to the central duct by a "6 inch" plastic pipe passed through the wall.

The system was initially started with just the pipes connected into the floor space. The openings into the walls were closed with duct tape. Radon concentrations averaged 4 pCi/L, and rose to 290 pCi/L when the fan was turned off. There were connections from the sub-slab space into the walls, so some of the air drawn from beneath the slab came from the walls. To check how important this incidental ventilation was at preventing soil gas movement from the wall into the house, the tape was removed from the holes. Average radon concentrations were about 4 pCi/L before and after the tape was removed, indicating that the sub-slab suction was effectively preventing soil gas from entering the walls.

Finally the system was connected to ventilate both the walls and the floor. The suction in the pipes into the floor and into the wall was the same at each location, and ranged from 5 to 10 Pa, set by the airflow from the wall. Flows and radon concentrations in each pipe were; end wall 4 L/s at 40 pCi/L, floor 0.5 L/s at 3 000 pCi/L; rear wall 4 L/s at 60 pCi/L, floor 0.5 L/s at 12 000 pCi/L; rear wall 4.5 L/s at 25 pCi/L, floor 0.5 L/s at 12 pCi/L, central wall 10 L/s at approximately 10 pCi/L, floor 0.2 L/s at 1 000 pCi/L. These flows and concentrations showed that the floor ventilation was removing many times more radon than the wall ventilation.

In May 1986, average radon concentrations were 3 pCi/L, and rose to 170 pCi/L when the fan was turned off.

2.3. PHASE 3

The system was retested in cold weather in November 1986, and radon concentrations ranged from 5 to 22 pCi/L with an average of 9 pCi/L and rose to range between 166 to 310 pCi/L with an average of 260 pCi/L when the fan was turned off.

The tests in Phase 2 had shown that the sub-slab ventilation portion of the system was producing the greatest effect. Further tests were conducted in December 1986, the wall entries were dampered to decrease the pipe effective pipe diameter from 1 to 2 inches, which increased the average floor suction from 6 to 21 Pa, and made the flows from the wall and floor approximately equal. The flows and radon concentrations in the wall and floor pipes were; end wall 12 L/s at 10 pCi/L, floor 16 L/s at 330 pCi/L; front wall 22 L/s at 36 pCi/L, floor 12 L/s at 550 pCi/L; rear wall 5 L/s at 130 pCi/L, floor 7.5 L/s at 3 800 pCi/L; rear wall 17 L/s at 7 pCi/L, floor 7 L/s at 1 600 pCi/L; and central wall 13 L/s at 7 pCi/L, floor 11 L/s at 1 400 pCi/L. The dampers produced a highly turbulent and asymmetric flow in the pipes, which makes measurement of the average velocity difficult. The calculated values are probably biased high.

The average radon concentration in the basement fell from 8 pCi/L to 5 pCi/L when the dampers were installed.

Alpha Track detectors were issued to measure the long term average radon concentration during the heating season.

By February 1987 experience at other sites had been that sub-slab ventilation with high suction had reduced radon concentrations in other houses with concrete block walls. It was decided to investigate effect of converting this house to a high suction sub-slab ventilation system.

In late February 1987 the system fan was replaced by a large plastic bodied in-line centrifugal fan. New dampers were fabricated that would completely close the wall entry pipes, and these were installed in March 1987. Closure of the wall pipes increased suction in the floor pipes from 35 Pa to 220 Pa, but radon concentrations still averaged 4.5 pCi/L after the change. Flows and radon concentrations in the floor pipes were; end wall 7 L/s at 670 pCi/L, front wall 15 L/s at 110 pCi/L, garage wall 14 L/s at 2 400 pCi/L; rear wall 7 L/s at 620 pCi/L; and central wall 3 L/s at 360 pCi/L.

The dampers were withdrawn 25 mm to provide the equivalent of a two-inch pipe connection into the wall, the radon concentration increased rapidly to range between 16 to 48 pCi/L, and average 26 pCi/L. Suction in all the floor pipes was 30 Pa, and airflow was definitely into the walls. As this was a major decrease in performance, the flows and radon concentrations in the pipes were remeasured. In the end wall pipe the flow was 8 L/s at 4 pCi/L, floor was 13 L/s at 250 pCi/L; front wall 4.5 L/s at 5 pCi/L, floor 10 L/s at 230 pCi/L; garage wall 6 L/s at 35 pCi/L, floor 12 L/s at 2 000 pCi/L; central wall 20 L/s at 50 pCi/L, floor 1.2 L/s at 680 pCi/L. The high turbulence generated by the damper made it difficult to determine the average air velocity, so the calculated flows are biased high. However, the airflows and radon concentrations out of the sub-slab space are similar in each case, so there was no obvious reason for the marked increase in the basement radon concentration.

The system was permanently returned to a sub-slab ventilation system in March 1987, by closing all the wall dampers. This increased the suction in the floor pipes to 220 Pa. Flows and concentrations in the floor pipes were; end wall 6 L/s at 680 pCi/L; front wall 12 L/s at 130 pCi/L, and 12 L/s at 270 pCi/L; garage wall 20 L/s at 5 600 pCi/L; rear wall 13 L/s at 2 200 pCi/L, and 9 L/s at 2750 pC /L; and central wall 5 L/s at 590 pCi/L.

Following this the radon concentration from in the basement ranged from 1 to 10 pCi/L, averaging 4 pCi/L.

3. OTHER MEASUREMENTS

The radiation fields around and inside the house were 8 to 13 uR/h averaging 11 uR/h, on the site, 6 uR/h on the asphalt driveway, and 7 to 10 uR/h on the concrete basement floor, averaging 8 uR/h.

The average radon concentration measured by alpha-track detectors over the period January 1987 to March 1987 was 4.1 pCi/L in the basement, and 2.8 pCi/L in the living area.

MEASUREMENTS SUMMARY FOR HOUSE 7

PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	MEAN	COMMENTS
1	Wall ventilation two 50 L/s centrifugal fans	08/85	Fans off	3-140	16	over 21 hrs
			Fans on	3- 12	7	over 21 hrs
2		01/86	Fans on	109-30	207	over 1 days
			Fans off	135-675	388	over 1 days
		03/86	Fans on	50-100	75	over 18 hrs
			Fans reversed to blow	51- 90	67	over 18 hrs
	As above + water tank platform sealed + central wall ventilation	03/86	Fans on blow	22- 88	70	over 1 days B
			Fans on blow	13- 56	40	over 4 days U
				6-249	63	over 4 days B
				2- 50	15	over 47 hr. U
						Equilibrium region:
			Fans on blow	33- 54	44	over 20 hrs B
			Fans on blow	2- 7	5	over 12 hrs U
2	As above + floor joint caulked	03/86	Fans on exhaust before caulking	31-67	19	over 29 hrs
			Fans on exhaust after caulking	1-26	15	over 16 hrs
2	Sub-slab ventilation 100 L/s centrifugal fan -wall holes taped	04/86	Fan on	1- 9	1	over 11 hrs
			Fan off	5-287	126	still rising after 16 hrs

2	As above - tape on	05/86	Fan on	1- 7	1	over 45 hrs
	As above -tape off		Fan on	2- 7	1	over 51 hrs
2	Sub-slab +wall ventilation 100 L/s centrifugal fan	05/86	Fan on Fan off	1- 7 17-169	3 91	over 18 hrs over 19 hrs

MEASUREMENTS SUMMARY FOR HOUSE 7

PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	MEAN	COMMENTS
3	Sub-slab + wall ventilation 100 L/s centrifugal fan	11/86	Fan on	5- 22	9	over 50 hrs
			Fan off	166-340	259	over 38 hrs
3	As above + wall entries dampered to 2" pipe	12/86	Fan on not dampered	6- 10	8	over 43 hrs
			Fan on dampered	4- 6	5	over 49 hrs
3	Sub-slab + wall ventilation 150 L/s centrifugal fan wall entries dampered	03/87	Fan on; fully dampered	2- 9	5	over 50 hrs
			Fan on, dampers withdrawn 1"	16- 18	26	over 35 hrs
3	Sub-slab ventilation 150 L/s centrifugal fan	03/87	Fan on	1- 10	4	over 87 hrs

SYSTEMS MEASUREMENTS FOR HOUSE 7

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
2	Wall ventilation two 50 L/s centrifugal fans	01/86	3	14	110	P1-end wall
			3	12	200	P2-front wall
			4	14	320	P3-front wall
			15	0.21	480	P4-grge wall
			4	17	410	P5-rear wall
			5	14	170	P6-rear wall
			35	12		At front wall fan
			25	39	200	At end wall fan
2	As above fans reversed to blow	03/86		18		P1
				16		P2
				19		P6
2	Sub-slab + wall ventilation 100 L/s centrifugal fans	05/86	10	7		P1 wall
			8	2	160	P1 floor
			10	4	25	P2 wall
			8	0.5	12	P2 floor
			8	3		P3 wall
			6	1		P3 floor
			9	4	40	P4 wall
			8	0.5	3 000	P4 floor
			5	5		P5 wall
			5	2		P5 floor
			8	1		P6 wall
			5	0.5	3 000	P6 floor
			5	10	30	P7 wall
			5	0.2	1 000	P7 floor

3	Sub-slab + wall ventilation 100 L/s centrifugal fans - wall entries dampered to 2" pipe	12/86	5	12	10	P1 wall
			25	16	330	P1 floor
			8	11		P2 wall
			23	8		P2 floor
			8	10	36	P3 wall
			23	12	550	P3 floor
			3	5	130	P4 wall
			23	7	3 800	P4 floor
			3	11		P5 wall
			23	9		P5 floor
			3	17	7	P6 wall
			25	7	1 600	P6 floor
			25	13	73	P7 wall +floor
			23	11	1 400	P7 floor

SYSTEMS MEASUREMENTS FOR HOUSE 7

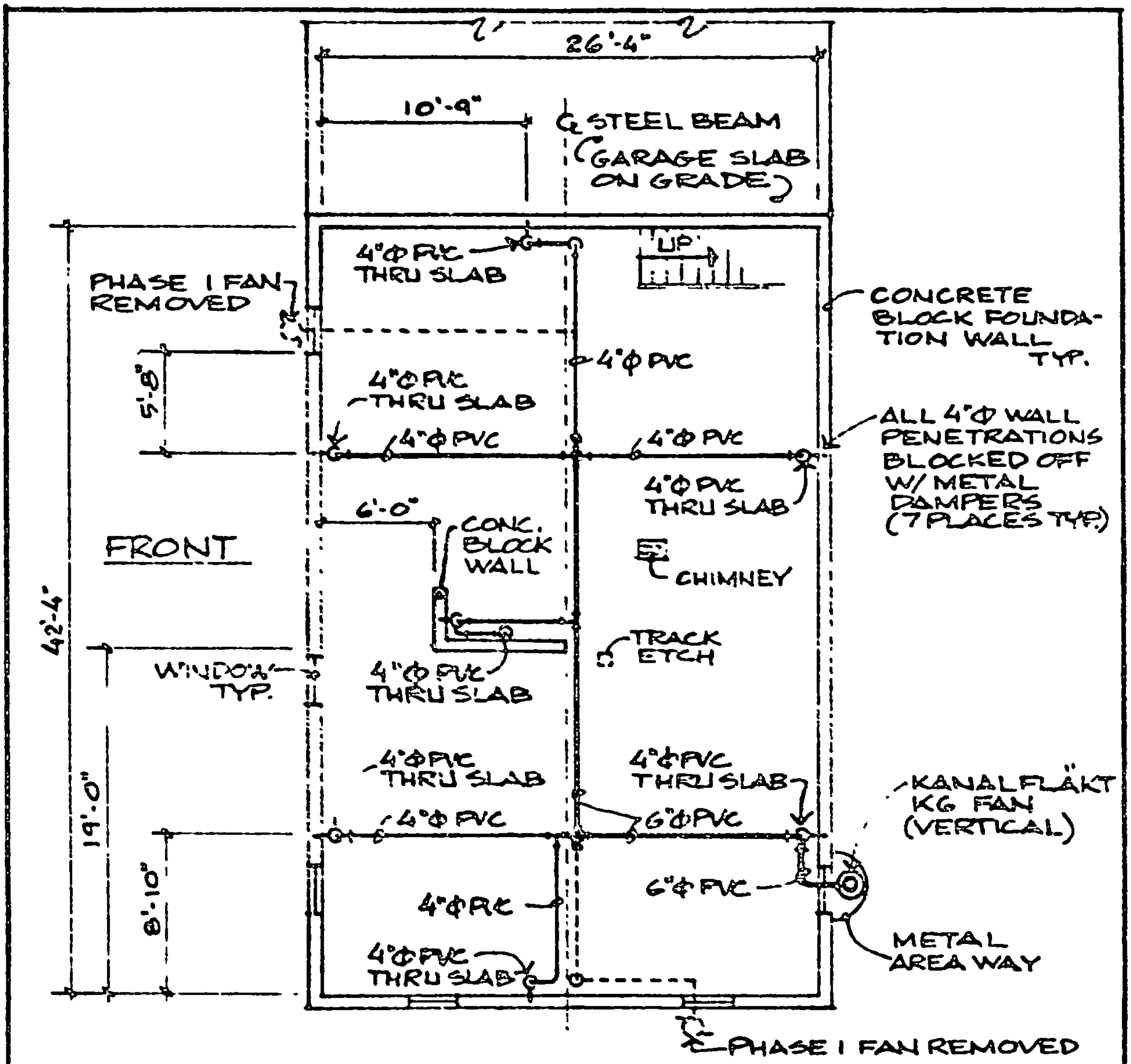
PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
3	Sub-slab + wall	03/87			8	P1 wall
	ventilation 150 L/s		250	7	670	P1 floor
	centrifugal -wall		15		6	P2 wall
	entries dampered		238	3	130	P2 floor
	fully closed				7	P3 wall
			225	14	110	P3 floor
					20	P4 wall
			225	14	2 400	P4 floor
					6	P5 wall
			238	7	620	P5 floor
					9	P6 wall
			188	7	2 300	P6 floor
			200	11	58	P7 wall+floor
			213	3	360	P7 floor
3	As above with	03/87	8	8	4	P1 wall
	dampers with drawn 1"		35	12	250	P1 floor
			15	8	13	P2 wall
			35	10	19	P2 floor
			10	4	5	P3 wall
			30	10	230	P3 floor
			10	6	35	P4 wall
			30	11	2 000	P4 floor
			5	7	4	P5 wall
			33	11	420	P5 floor
			8	9	16	P6 wall
			35	8	1 200	P6 floor
			38	20	47	P7 wall +floor
			30	1	680	P7 floor
3	Sub-slab ventilation	03/87	200	6	680	P1
	150 L/s centrifugal		250	12	130	P2
	fan		225	12	270	P3
			200	20	5 600	P4
			238	12	2 200	P5
			238	8	2 750	P6
			225	5	590	P7

P: pipe

ROUTE OF ENTRY MEASUREMENT FOR HOUSE 7

PHASE	MITIGATION SYSTEM	DATE	SAMPLE LOCATION	RADON (pCi/L)
2	Wall ventilation two 50 L/s centrifugal fans	03/86	Basement air	77*
			Central "L" wall long limb	810*
			Central "L" wall short limb	3 800*
	As above with fans reversed to blow	03/86	Beneath pressure tank	8 300
			Central wall long limb	900
			Central wall short limb	4 000
			Rear wall near end wall	50
			Front wall near end wall	2
			Garage wall near front wall	8
			Floor drain	330
			Basement air	70

* Grab sample



NOTES:
1. LONGITUDINAL CONSTRUCTION JOINT IN FLOOR SLAB SEALED WITH SILICONE SEALANT
2. INDIVIDUAL SLAB FRACTURES SEALED
3. WATER TANK SUPPORT BLOCK CELLS FILLED WITH MORTAR
4. STAIR END WALL SEALED WITH WOOD STRIP AT SILL PLATE. OPPOSITE END WALL SEALED WITH POLYURETHANE FOAM.

ACRES	LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
	FOUNDATION PLAN	Date: 6/25/85	7
	Mitigation system: SUBSLAB SUCTION	PHASE: I THRU FINAL	

HOUSE 8

PENNSYLVANIA DER MEASUREMENTS

Working Level grab samples (Kusnetz)	1.704 WL
Heating season average (RPISU)	0.128 WL
Heating season radon average (Terradex)	183 pCi/L
Radon in water	low (municipal water)

1. DESCRIPTION

This two-story house with attached garage was built in the mid 1970's on a sloping site on the side of a hill in a rural subdivision west of Boyertown. The walls are all covered with siding. The basement walls are of hollow concrete blocks, and there is a single concrete block pillar in the centre of the basement. The uphill side wall has horizontally cracked mortar joints. The block voids on the front and back walls are covered by the sill plate, but are fully open on the side walls. There is a large opening around the sewer exit in the front wall. The floor has minor cracking. Heating is by electric baseboards upstairs.

2. ACTION

2.1. PHASE 1

As the house was small, the top of the basement walls relatively accessible, and the floor in good condition, the mitigation measure selected for demonstration at this house was ventilation of the basement block walls.

Where the block voids at the top of the end walls were readily accessible, they were stuffed with paper and then filled with mortar. Where access was poor, eg behind the electrical panel, the voids were stuffed with paper and expanding urethane foam was injected with a long nozzle.

The sill plate was caulked to the top of the front and back walls with asphaltic roofing caulk. In addition, the large opening in the wall around the sewer, and other holes round service entries, were sealed with expanding urethane foam.

A hole was cut in a block in the second course from the top in the middle of each basement wall. A pipe of "4 inch" lightweight plastic drain pipe was inserted in each hole. The pipes were connected to a "C" loop of "4 inch" lightweight piping that ran round the basement perimeter and terminated in two flexible plastic ducts run through a plywood sheet placed in a basement window opening. Two centrifugal fans installed in wooden boxes were placed outside, and connected to the flexible ducts. This was a temporary set-up to allow changes to the system.

At first the fans were set to blow into the block cavities to test the feasibility of driving radon-bearing soil gas in the walls back into the soil. In July 1985, the radon concentration in the basement fell from 150 pCi/L to 1 pCi/L when both fans were turned on.

Pressurising the walls revealed a number of significant cracks and openings. These were all caulked or mortared, and the fans were then reversed to investigate the relative performance of the system with the walls under suction. Exhausting the walls was the preferred solution, since blowing cold outside air into the wall would make the interior surface cold in winter.

In August 1985, the basement radon concentration with two fans in exhaust averaged 2 pCi/L, and with just one fan in operation, averaged 3 pCi/L.

2.2 PHASE 2

In December 1985, the basement radon concentration with one exhaust fan in operation ranged from 2 to 5 pCi/L, averaging 3 pCi/L. The flows and radon concentrations from the garage wall were 19 L/s, 200 pCi/L; the front wall 12 L/s, 220 pCi/L; the uphill wall 6 L/s, 1 800 pCi/L, and the rear wall 10 L/s, 110 pCi/L. Suctions were respectively 18, 5, 8 and 5 Pa.

Alpha track detectors were issued in December 1985 to check on the longer term performance of the system.

In May 1986, the temporary fan was removed. The basement window was replaced, and a large wall mounted centrifugal fan was attached to the system instead. No measurements were made of the system performance as the weather had turned warm by this time.

2.3 PHASF 3

In the fall of 1986, it was decided to replace all the wall mounted centrifugal fans by plastic bodied in-line centrifugal fans of approximately double the capacity. At the same time, the air discharged from the fan would be ducted to the roof line, rather than released at ground level. This was done in December 1986. The wall mounted fan was removed, and the in-line fan attached to the "4 inch" piping by an elbow and a "4 to 6 inch" adaptor. The fan was mounted with the [illegible] vertical, and an "2 inch by 3 inch" aluminum rainwater downspout was attached to the fan outlet by a "1 to 6 inch" adaptor and a "1 inch to downspout" adaptor. The downspout ran to above the garage roof line. Both the fan and the downspout were secured to the siding.

With the new fan in operation suctions at the walls were approximately equal and ranged from 9 to 15 Pa. Flows and radon concentrations from the garage wall were 18 L/s at 170 pCi/L; from the front wall were 12 L/s at 170 pCi/L, from the uphill wall were 7 L/s at 1 400 pCi/L, and from the rear wall 8 L/s at 120 pCi/L.

These results were very similar to those obtained a year previously with just a single small centrifugal fan, and suggested that the backpressure on the fan caused by the restriction of the discharge pipe was a major limitation on the fan performance.

Basement radon concentrations in December 1986 with the new fan in operation ranged from 1 to 9 pCi/L, averaging 6 pCi/L.

Alpha track detectors were issued in December 1986 to provide a longer term evaluation of the system performance.

In March 1987, the discharge pipe was modified by replacing the downspout by 4 inch PVC pipe. Suctions and flows were increased to 25 Pa and 27 L/s for the uphill wall and 10 Pa and 10 L/s for the rear wall. Under those conditions, radon concentrations in the basement ranged from 2 to 12 pCi/L, averaging 6 pCi/L. When the discharge riser was removed the radon levels ranged from 0 to 3 pCi/L, averaging 2 pCi/L and when the discharge was replaced, ranged from 1 to 6 pCi/L averaging 3 pCi/L

A fan test in April 1987 showed a suction of 93 Pa in the fan riser providing a flow of 51 L/s whereas the fan exhaust was measured at 238 Pa.

3. OTHER MEASUREMENTS

The radiation field in and around the house ranged from 6 to 12 uR/h, averaging 9 uR/h in the basement, with the higher readings found close to the walls. On the site, the field ranged from 6 to 10 uR/h, averaging 9 uR/h.

The average radon concentration measured by alpha-track detectors over the period December 1985 to March 1986 was 3.1 pCi/L in the basement, and 1.[illegible] pCi/L in the living area.

The average radon concentration measured by alpha-track detectors over the period December 1986 to March 1987 was 3.9 pCi/L in the basement, and 1.8 pCi/L in the living area.

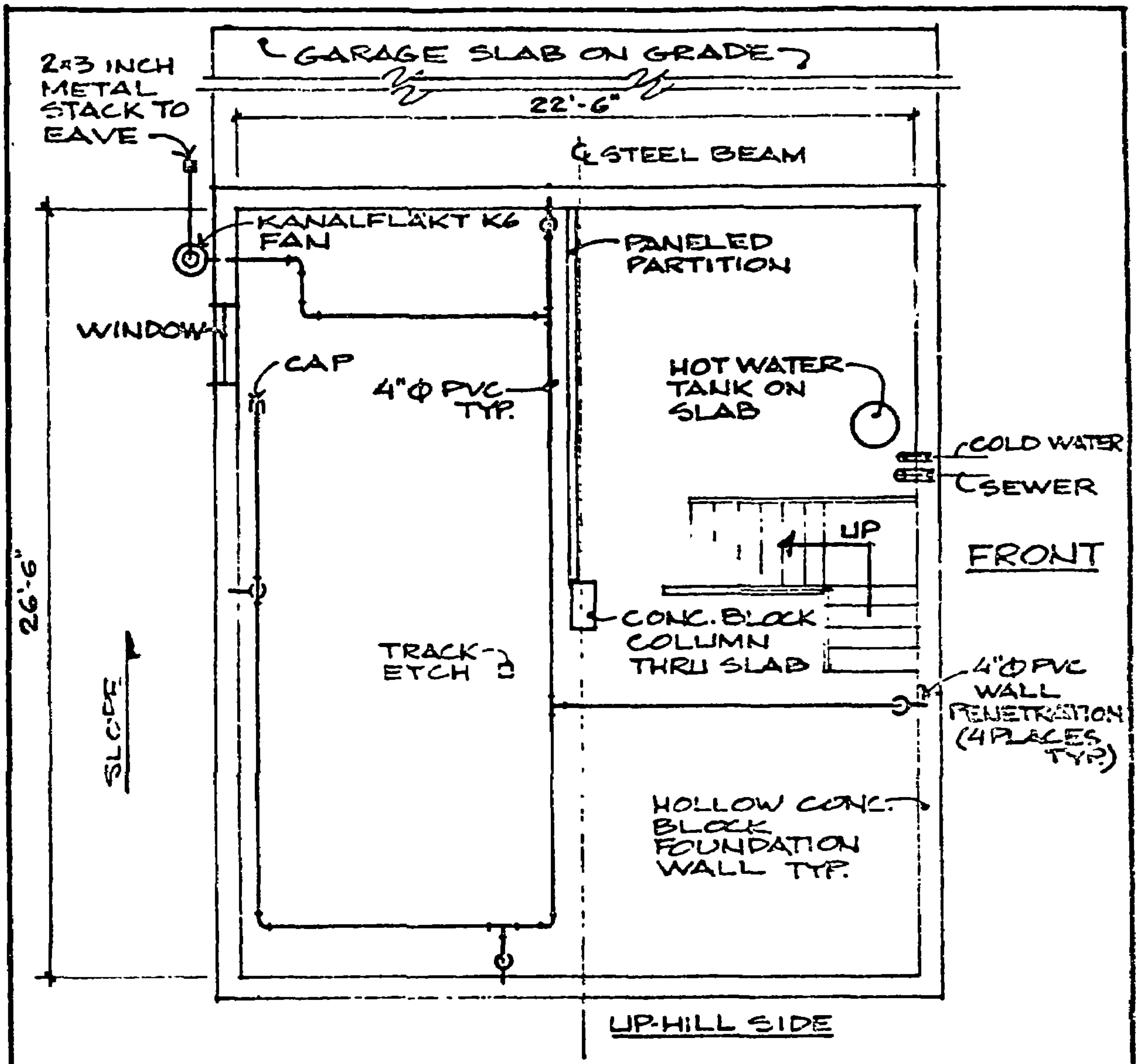
MEASUREMENTS SUMMARY FOR HOUSE 8

PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	MEAN	COMMENTS
1	Wall ventilation two 50 L/s centrifugal fans on blow	07/85	Fans on	0-159	9	over 33 hrs falling
				0- 2	1	~ 15 hrs equilibrium
1	Wall ventilation two centrifugal fans on exhaust	08/85	Fans on	1- 4	2	over 22 hrs
			One fan on	2- 5	3	over 20 hrs
2	As above	12/85	One fan on	2- 5	3	over 53 hrs
3	Wall ventilation 150 L/s centrifugal (downspout discharge)	12/86	Fan on	4- 9	6	over 45 hrs
3	As above with modified discharge	03/87	Fan on	2- 12	6	over 90 hrs
3	As above with free discharge	03/87	Fan on	0- 3	2	over 29 hrs
	As above discharge replaced	03/87	Fan on	1- 6	3	over 67 hrs.

SYSTEM MEASUREMENTS FOR HOUSE 8

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
2	Wall ventilation 50 L/s centrifugal	12/85	18	19	200	A
			5	12	220	B
			8	6	1 800	C
			5	10	110	D
3	Wall ventilation 150 L/s centrifugal fan	12/86	15	18	170	A
			10	12	170	B
			11	7	1 400	C
			9	8	120	D
3	As above	03/87	25	27		A
			15	16		B
			15	11		C
			10	10		D
	As above	04/87	93	54		Fan riser
			238			Fan exhaust



NOTES:

1. SIDE WALLS MORTARED ON TOP TO FILL TOP COURSE CAVITIES.
2. BACK AND FRONT WALL CAVITIES OF TOP COURSE SEALED AT SILL PLATE WITH TAR-BASED SEALANT
3. SOME FOAMING TRIED, BUT WITHOUT MUCH SUCCESS, AT BLOCK CAVITIES. FOAM APPLIED AT ELECTRICAL PANEL, SEWER OUTLET AND AS FILL FOR SMALL HOLES.

LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
FOUNDATION PLAN	Date: 10/18/86	8
Mitigation system: WALL SUCTION	PHASE: FINAL	

HOUSE 9

PENNSYLVANIA DER MEASUREMENTS

Working Level grab samples (Kusnetz)	0.340 WL
Heating season average (RPISU)	0.173 WL
Heating season radon average (Terradex)	533 pCi/L
Radon concentration in water	29 400 pCi/L

1. DESCRIPTION

This single story house with attached double garage was built in the early 1980's on a sloping site at the side of a ridge in a rural subdivision near Boyertown. The front and end walls are brick veneer, the rear wall of the house is siding.

The walk-out basement walls are of concrete blocks covered by polystyrene beadboard sheets, except for one quarter of the basement, where there is a laundry room and a bathroom, both with plasterboard walls.

Heating is by electric resistance baseboards upstairs, supplemented by a fireplace. In the basement there is a large concrete block and brick fireplace structure at the garage end with a wood stove which also supports the first floor fireplace. It rests on the slab, rather than penetrating the floor to a separate footing.

No cracks were evident in those parts of the walls where the insulation panels were partly removed. The walls are penetrated by service pipes for sewage and water. The sill plate partially covers the cavities in the front and rear block walls, and access is poor. The blocks are completely open at the top along the bathroom, laundry and garage walls. There is an internal concrete block wall supporting the recessed front wall at the porch.

The poured concrete slab has no construction joints, no cracks and no individual floor drains, but is penetrated by hollow steel house jacks. The well pressure tank is in a small alcove with a sand and brick floor.

There is an interior perimeter drain (french drain) about 4 cm wide between the walls and the slab perimeter around the entire perimeter of the basement.

2. ACTION

2.1. PHASE I

As this house was one of the few with an interior drain, the mitigative method selected for demonstration at this house was integrated ventilation of the french drain and the basement walls.

The lowest 50 cm of the insulating beadboard and framing on the basement walls was cut away to expose the lowest course of block. Holes of 10 mm diameter were drilled just above the floor level into each block void in this course. Locally manufactured sheet metal covers were placed over the french drain slot and the drilled holes, and secured to the wall and floor by screws placed in previously drilled anchor holes. An asphalt roofing caulk was used on the wall and floor junctions to make the cover airtight.

Continuous cover sections were placed along the entire front wall, the interior wall, and on about 50% of the end and rear walls. The drain in the laundry and bathroom area was not covered, for this would require removing the plasterboard and framing. The stairway at the other end of the basement is boxed in and finished with plasterboard. The french drain was not covered in this area for the same reason. There was a large sliding glass door in the centre of the rear wall. The drain was filled in this area.

The drain was open behind the fireplace structure, but could not be reached to put a cover over it. Cement grout was poured through tubes into this section of the french drain, and into small openings in the concrete block columns supporting the fireplace structure on the floor above.

There were four separate cover sections. These were connected in pairs by "4 inch" lightweight plastic piping to a temporary fan installed at each end of the basement. Pipes ran from the covers vertically to the joists, and from there to connect via a flexible duct passed through plywood panels in the laundry and garden windows with small centrifugal fans.

Where possible the tops of the block walls were closed by wood strips caulked to the sillplate. Access was too poor to close the tops of the bathroom, laundry and garage walls in this manner. For these walls the top block voids were first stuffed with paper for support, and then filled with an expanding single component urethane foam.

The sand and brick floor of the well tank above was removed, exposing an opening in the floor slab. Roofing felt was set into the opening and caulked into place. A metal cover connected to the front wall cover was placed over the wall-floor joint in this area, and the bricks replaced.

While the cold room floor was being removed, a thunderstorm took place. When lightning struck a hilltop about 300 m away, one of the workmen collapsed. It was believed that he was in contact with the metal well-head equipment, and the circulating ground currents induced by the strike flowed from the exposed soil beneath the building, through the man, and into the well. He recovered within a few moments, but was taken to hospital. There was no sign of permanent damage from the experience.

In August 1985, when the fans were turned on the average radon concentration fell from about 250 pCi/L to approximately 5 pCi/L in less than a day.

2.2. PHASE 2

In November 1985, radon concentrations in the basement with the fans running were varied from 7 to 40 pCi/L, averaging 20 pCi/L. Moisture in the soil gas was condensing in the flexible hoses to the fans, and reducing the airflow.

Additional work was carried out in January and February 1986 to improve the fans and the system performance, and to extend the covers over the sections that had not been treated previously. The temporary plywood panels taken out of the windows and the small centrifugal fans were removed . They were replaced by two large wall mounted centrifugal exhaust fans, and permanent metal ducts were mounted on the inside surface of the walls to connect them to the covers The caulking and wall closures were examined, and improved where needed.

The lower 18 cm of the plastered walls beneath the stairs and in the laundry room was cut off, holes were drilled in the lower course of the block wall, and new covers placed over the french drain exposed in these areas. The drain was now covered around the house perimeter except for the filled section behind the fireplace and a section behind a shower stall in the bathroom.

When the new fans were turned on, the owner complained that his wood stove was hard to light, and smoked, and that the upstairs fireplace had smoked badly - something that had never happened before. Turning off the fans stopped these problems. While the system was operating concentrations ranged from 2 to 32 pCi/L averaging 20 pCi/L.

The fans were obviously depressurizing the house, which was a disappointment as a large effort had been made to decrease the wall leakage area. Detailed investigation, including removal of beadboard panels from the walls, found that the walls were unusually porous. Most of the concrete blocks in the basement walls were typical modern steam cured blocks of low porosity, but there were still a large number of blocks that resembled cinder block. They had a very coarse aggregate, and a minimal amount of cement paste holding the aggregate together. Individual pores were as large as 3 mm in diameter. Smoke tests showed that air was drawn through the entire face of the block. As luck would have it, the ducts to the fans covered a number of these blocks, and there was a considerable airflow into the duct through the blocks. Pressures in the five risers ranged from 15 to 43 Pa and provided flows of 16 to 53 L/s of air with an average concentration of 10 pCi/L at a time when the ambient air in the basement was approximately 8 pCi/L. Measurements at various places along the baseboard duct provided ranges in pressure, flow and concentration of 1 to 8 Pa, 0.2 to 10 L/s and 25 to 100 pCi/L.

Since backdrafting the combustion appliances is dangerous, this state of affairs could not be allowed to continue. As a short term measure, the exhaust fans were removed, and replaced with small centrifugal fans set to blow into the walls.

In March 1986, when the new fans were turned on, radon concentrations in the basement fell from 300 pCi/L to 60 pCi/L in a few hours, and then fluctuated between 30 to 150 pCi/L over the next day, before stabilising at about 8 pCi/L on the third day. Further measurements in March found that concentrations varied between 5 to 60 pCi/L, averaging 20 pCi/L. This was similar to the performance achieved in November with the fans in suction. Using the wood stove made no difference to the concentrations, and there was no backdrafting. Large wall mounted centrifugal blowers were ordered to permanently replace the small fans.

In April 1986, after 3 days of continuous and heavy rain, the owner complained of water leakage onto the basement floor beside the bathroom. The concern was that the drain had become blocked in this area, and water leaking into the block walls was filling the drain and seeping out from beneath the cover.

The cover was removed from the drain in the area where the water had entered, and the drain was found to be unobstructed. The drainage was checked by running a hose into the drain at a rate of 10 l/min. The water ran away beneath the slab at this rate for 2 hours, and so it did not seem likely that the cause of the leakage was the drain filling with water. There was no sign that the blocks behind the cover had been wet, for fine drilling dust was still visible in the bottom of the drill holes into the block voids. The cover on a section of the front wall was removed. The drain there was completely dry, with no sign that it had ever had water in it.

The cover ended at a block in the centre of the end wall which had watermarks on it. This was directly beneath the house beam and was filled with cement. The site is steeply sloped from front to rear at this end of the house, and the brick veneer is stepped to follow the grade. In places the soil was well above the brick, so surface water could enter the wall at the mortar joints, and drain down inside the block wall.

It seemed likely that the cause of the water on the floor was that surface water had entered the end wall, was prevented from draining to the footing by the cement in the block void, and had leaked out of the wall above the cover. The cover prevented the water from entering the drain. The floor in this area was level, and so quite a small amount of water would make a large puddle.

To prevent this from happening again, the cover was shortened by 15 cm to expose the drain in this area.

This experience suggested that perhaps it was unwise to drill holes into the lowest course of blocks unless the drainage beneath the covers was known to be good. To judge from the water stains in some houses, the walls could leak badly enough to fill some of the lowest blocks with water. If there were holes into the voids, rather than this water being stored until it drained away or evaporated, this water might fill the soil gas collection system, and then leak out onto the floor.

In May 1986, the new blowers were delivered, and were wall mounted under a protective metal weather screen. The weather was too warm by this time to get a realistic picture of the system effectiveness, so measurements were deferred to the fall.

2.3. PHASE 3

In November 1986, the radon concentration in the basement with the fans operating ranged from 5 to 15 pCi/L, averaging 5 pCi/L. To improve the airtightness of the floor, and perhaps reduce the radon supply, the house jacks were drilled to fill with expanding foam. It was found that they only sounded hollow, and were in fact filled with sand. Foam was injected above the sand. The fans were turned off for two hours while this was done, and the radon concentration in the basement rose to 180 pCi/L. When the fans were turned on again, the concentration continued to rise, reaching a peak of 320 pCi/L about two hours after the fan restart, and then fell back to 10 pCi/L over a six hour period. Concentrations then ranged from 5 to 14 pCi/L, averaging 7 pCi/L. The peaks seemed associated with water use in the basement washing machine.

Alpha track detectors were issued in December 1986 for final long term measurements.

3. OTHER MEASUREMENTS

The general radiation field over the site was 12 uR/h. A swimming pool was under construction, and the field on the excavated material was 11 uR/h. In the excavation itself, the field at the shallow end (1.5 m depth) was 21 uR/h. A layer of rocks was exposed in the deep end, with "on contact" readings of 25 to 35 uR/h. The soil at the bottom of the deep end (2.5 m depth) read 14 uR/h, comparable to the excavated material, but one large rock on the bottom read 42 uR/h on contact. The field inside the house ranged between 7 to 10 uR/h, averaging 9 uR/h.

The average radon concentration measured by alpha-track detectors over the period December 1986 to March 1987 was 11.6 pCi/L in the basement, and 14.5 pCi/L in the living area.

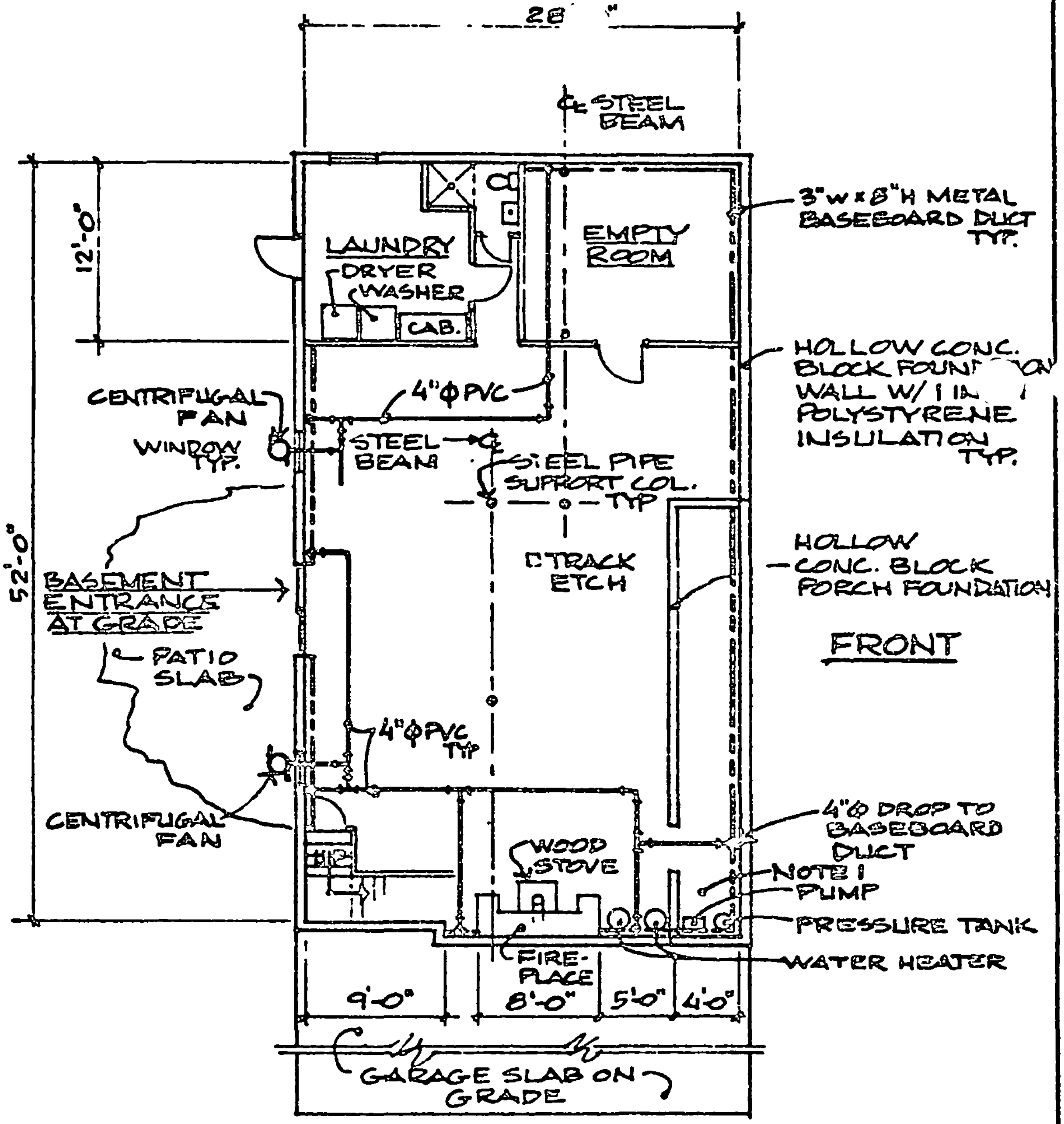
MEASUREMENTS SUMMARY FOR HOUSE 9

PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	MEAN	COMMENTS
1	Wall+ french drain ventilation two 50 L/s centrifugal fans	08/85	Fans on	2-479 2- 7	173 5	over 16 hrs fell to: 7 hr equilibrium
2	As above	11/85	Fans on	6- 10	20	over 47 hrs.
2	Wall+ french drain ventilation two 100 L/s centrifugal fans	02/86	Fans on	3- 32	10	over 4 days
2	As above with fans reversed to blow	03/86	Fans on blow Fans on blow	6-433 6- 10	123 8	over 1 days 12 hrs at equilibrium
			Fans on blow	2- 64	20	over 4 days
3	Wall + french drain ventilation two 150 L/s centrifugal fans pressurizing	11/86	Fans on blow Fans on blow	3- 15 5- 14	5 7	over 38 hrs over 38 hrs.

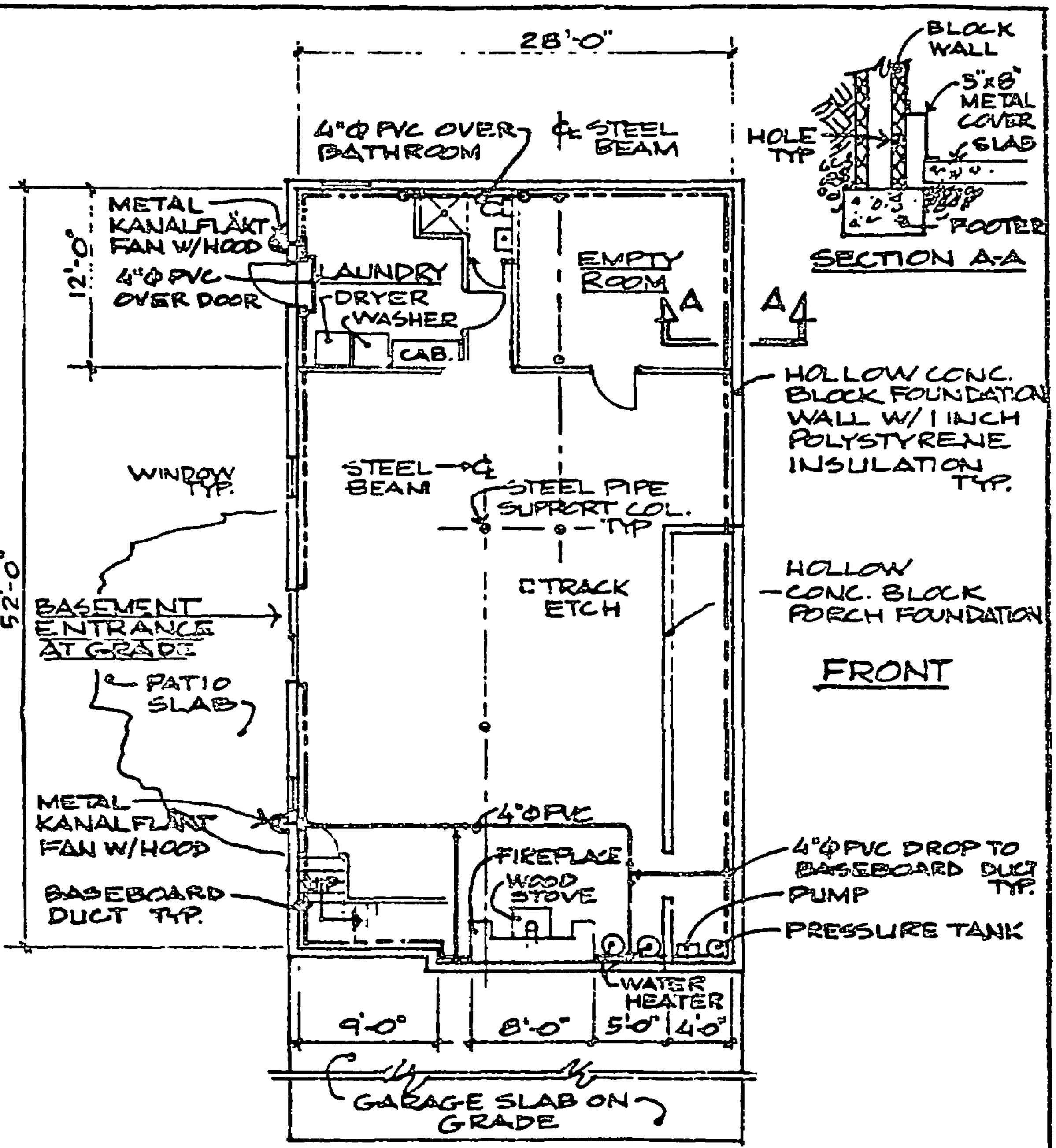
SYSTEM MEASUREMENTS FOR HOUSE 9

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
2	Wall and french drain ventilation ; two 100 L/s centrifugal fans	02/86	15	17	650	Riser A - fireplace wall
			18	23		Riser B - fireplace wall
			35	53	360	Riser C - rear at fan
			38	24	200	Riser D rear wall
			43	16		Riser E -end wall
					8	Basement air
			1	0.5		Baseboard duct rear wall
			3			Baseboard duct rear wall
			8	4		Baseboard duct end wall
			1	10		Baseboard duct end wall
				2	100	Baseboard duct front wall
				0.2	25	Baseboard duct front wall
				3	60	Baseboard duct front wall



NOTES: 1. ROOFING FELT INSTALLED UNDER BRICK FLOOR THIS AREA

ACRES	LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
	FOUNDATION PLAN	Date: AUG. '86	9
	Mitigation system: BASEBOARD TYPE WALL/SLAB PRESSURIZATION	PHASE: 1	



ACRES

LOW COST REDUCTION OF INDOOR RADON

FOUNDATION PLAN

Date: 5/6/86

Mitigation system: BASEBOARD TYPE WALL/SLAB PRESSURIZATION

PHASE: 2 AND FINAL

HOUSE NUMBER 9

HOUSE 10

PENNSYLVANIA DER MEASUREMENTS

Working Level grab samples (Kusnetz)	1.260 WL
Heating season short term average WL (RPISU)	1.088 WL
Heating season average radon (Terradex)	626 pCi/L
Radon concentration in water	35 200 pCi/L

1. DESCRIPTION

This one-story house with attached double garage was built in the mid 1970's on a sloping site at the top of a ridge in a rural subdivision to the west of Boyertown. The front wall is of brick, the other walls are of siding. The walkout basement is built of hollow concrete blocks.

There is a concrete block chimney structure in the basement that passes through the floor slab and contains a basement fireplace. The basement walls are in good condition, with no significant cracking, and are topped with a full width sill plate. The poured concrete floor slab is in good condition, with no significant floor cracking, and a small wall/floor joint. There are openings around roughed-in plumbing services, and around a toilet in the basement. Heating is by hot water baseboard convectors heated by an oil and coal fired boiler. The boiler stands on a pad separate from the floor slab.

The owner stated that the perimeter drain system (weeping tile) was bedded in crushed stone, and went completely around the outside of the house - including the garage wall. The garage floor drain is connected to the tile.

2. ACTION

2.1. PHASE 1

As this house was one of the few with a perimeter drain, the mitigation measure chosen for demonstration at this site was ventilation of the perimeter drain.

The perimeter drain discharge pipe was found at a low point of the site, and the line traced back to the house. An excavation was made at the estimated junction point, and the junction with the tile was uncovered. The depth of soil at this point was only 20 cm, insufficient to prevent freezing of a water trap. The drain was therefore uncovered for 2.5 m along the rear of the house till

60 cm of cover was available. At that point, a water trap was connected to the drain line and an extension run from the trap to join up with the original discharge line.

The downstream side of the trap was extended vertically for an inspection riser, and capped off. The other side of the trap was extended vertically for a fan riser. A flexible duct was provided to a centrifugal fan housed in a wooden box. A temporary electrical hook-up was made to an outdoor outlet. The garage floor drain was closed by placing a piece of rubber-backed carpet over it.

In August 1985, the radon concentration in the basement fell from 14 pCi/L to 6 pCi/L when the fan was turned on.

2.2. PHASE 2

The soil gas withdrawn by the fan is saturated with water vapour at the soil temperature. This was no problem in the warm summer months, but in the fall the vapour condensed, and filled the flexible hose with water, cutting off the airflow to the fan. Before any winter measurements were made, the centrifugal fan was removed from the protective box, and mounted directly on top of the vertical plastic riser. Condensation would run down the riser, and not block the fan. The suction in the weeping tile was increased from 25 to 70 Pa.

In November 1985, following the fan change, the radon concentration in the basement ranged from 0 to 6 pCi/L, averaging 1 pCi/L.

Alpha track detectors were issued in December 1985 to check on the long term performance of the system.

In February 1986, the radon concentration in the basement ranged from 1 to 20 pCi/L, averaging 4 pCi/L. The higher readings were associated with use of the washing machine, so at least part of the radon was supplied by the water.

In May 1986, the temporary centrifugal fan was replaced by a permanent plastic bodied in-line centrifugal fan. This increased the suction to 20 Pa, at a flow of 78 L/s, with a radon concentration in the discharged air of 1 200 pCi/L.

2.3. PHASE 3

In November 1986, the electrical connections to the fan were made permanent. The radon concentration in the basement ranged from 1 to 18 pCi/L, averaging 7 pCi/L. The higher concentrations were associated with use of the washing machine.

Alpha track detectors were issued in December for final long term measurements.

The fan performance was checked in January 1987. The suction was still 200 Pa, and the radon concentration in the discharged air was 2 100 pCi/L.

3. OTHER MEASUREMENTS

The radiation field inside and around the house ranged from 9 to 11 uR/h in the basement, averaging 10 uR/h. The field over the relatively undisturbed front lawn ranged from 10 to 20 uR/h, and at the rear of the site where the spoil from the basement excavation had been distributed, ranged from 20 to 35 uR/h. The overall outdoor average was 20 uR/h.

The average radon concentration over the period December 1985–March 1986 as measured by Alpha Track detectors was 3.0 pCi/L upstairs, and 5.3 pCi/L in the basement.

The average radon concentration measured by alpha-track detectors over the period December 1986 to March 1987 was 9.0 pCi/L in the basement, and 6.5 pCi/L in the living area.

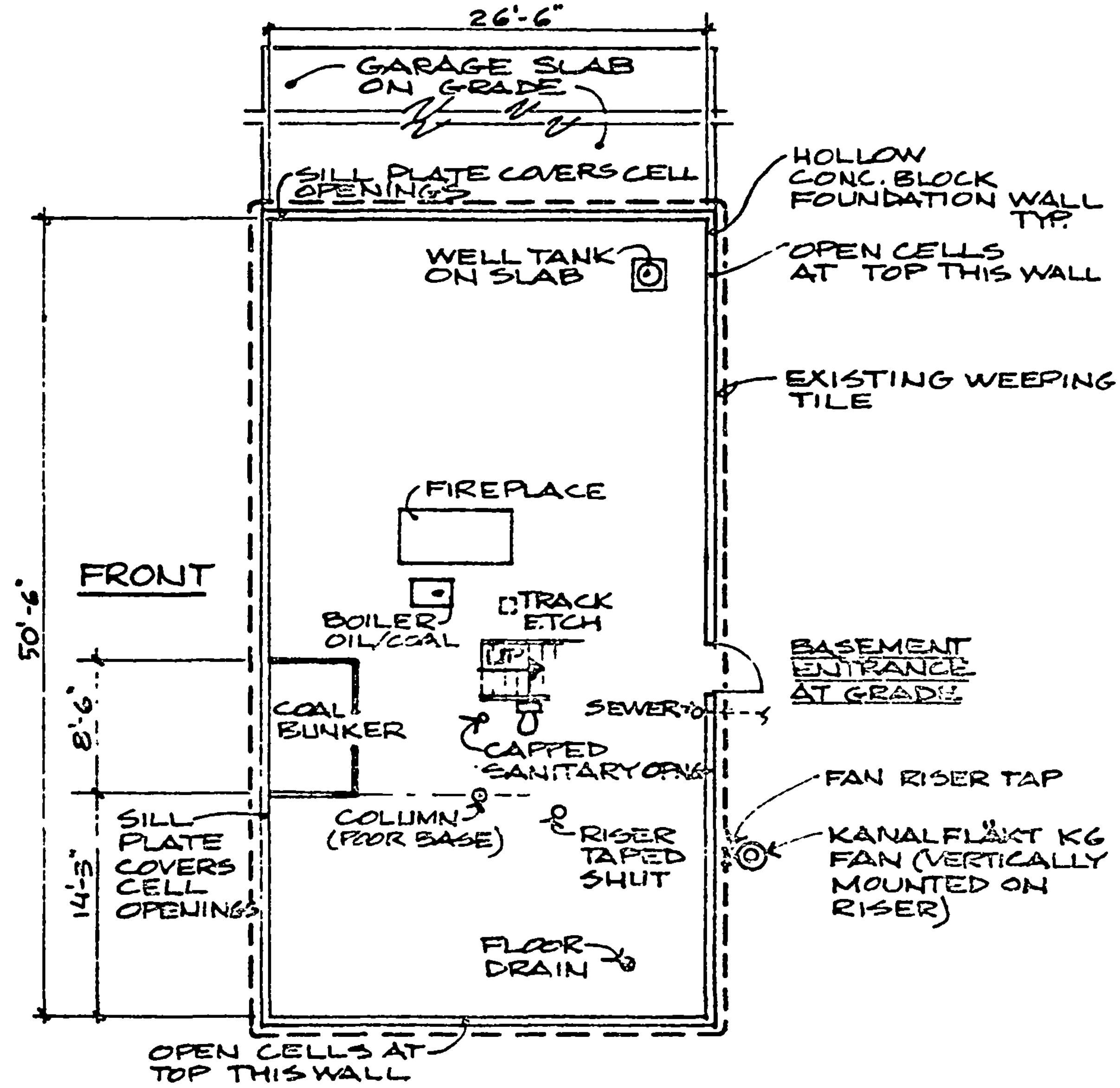
MEASUREMENTS SUMMARY FOR HOUSE 10

PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	MEAN	COMMENTS
1	Weeping tile ventilation 50 L/s centrifugal	08/85	Fan on	5-307	87	over 36 hrs fell to equilibrium of 6 pCi/L
2	As above	11/85	Fan on	2- 4	3	over 5 days
	Fan remounted	11/85	Fan on	0 6	1	over 4 days
	As above	02/86	Fan on	1- 20	4	over 4 days
3	Weeping tile ventilation 150 L/s	11/86	Fan on	1- 18	7	over 4 days

SYSTEM MEASUREMENTS FOR HOUSE 10

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
2	Weeping tile ventilation 50 L/s centrifugal	11/85	25	30		Temporary fan in box
			70	53		Direct mounted fan
2	As above	12/85	85	45	2 800 0.4	Fan riser Outdoor air
2	Weeping tile ventilation 150 L/s centrifugal	05/86	200	78	1 200	Fan riser
3	As above	01/87	200	75	2 100	



ACRES	LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
	FOUNDATION PLAN	Date: NOV. 86	10
	Mitigation system: WEEPING TILE SUCTION	PHASE: FINAL	

HOUSE 11

PENNSYLVANIA DER MEASUREMENTS

Working Level grab samples (Kusnetz)	0.748 WL
Heating season average radon (Terradex)	49 pCi/L
Radon concentration in water	low (municipal water)

1. DESCRIPTION

This two-story end row-house was built in the mid 1970's near the top of a small hill in Boyertown. All three outer house walls have the lower half of brick veneer, and the upper half of aluminum siding. The top of the basement walls is covered by the sill plate, which has been caulked to the blocks by the owner. The walls have been painted with sealer paint, and there are no wall cracks visible.

The basement floor is a floating slab with an open perimeter drain (french drain) against the three outside walls drained by an open pipe just visible at the front edge of the slab. The slab was tight against the party wall. There are no significant cracks in the slab, only surface crazing, and services penetrate the slab in one position. Heating is by electrical baseboard units upstairs only.

2. ACTION

2.1. PHASE 1

As the exterior walls in this house were partially closed at the top, and there was an open drain around the perimeter of the floor, the mitigation measure selected for demonstration in this house was ventilation of the hollow block walls and the french drain.

Holes were drilled in each block cavity of the exterior walls approximately 5 to 8 cm above the slab. Lower drill holes encountered mortar in the cavities. A commercial Channel Drain, (a rectangular plastic extrusion intended to collect water leaking through block walls) was screwed to the walls and floor to cover the drain and the holes drilled in the concrete blocks. Asphalt cement was used as caulk. The plastic shape was very rigid in a vertical plane, and large amounts of caulk were needed to fill the gaps between the uneven floor and the edge of the shape.

The plastic channel was only 8 cm high and 6 cm wide, so the usual "4 inch" pipe could not be attached. Instead, two "3 inch" pipes were attached, and joined to a "4 inch" riser. A flexible duct was run from the piping, through a piece of plywood placed in the rear basement window, to a small centrifugal fan mounted in a box and placed in the window well.

No work was carried out on the party wall. The reason for this was that cooperation from the neighbor would be required to reduce the open area of the wall, and they had not expressed any interest in the program.

In August 1985, the radon concentration in the basement was 90 pCi/L. When the fan was turned on radon levels fell to approximately 1 pCi/L.

2.2 PHASE 2

In January 1986, concentrations ranged from 15 to 30 pCi/L, averaging 20 pCi/L with the fan running. No measurements were made with the fan off, as the occupants were concerned that higher levels might result.

Investigation found that the fan was drawing 35 L/s from the system, which came mainly from the rear and side walls. The air in the duct along the front and side wall came from above grade (<4 pCi/L radon). The air going to the fan had 75 pCi/L, which must all have come out of the rear wall section. Smoke tests showed that airflow was definitely into these walls, preventing them from being a route of radon entry. Smoke tests showed that air was moving out of the party wall, with radon concentrations measured between 40 to 160 pCi/L depending on location.

This suggested that the party wall was the major remaining route of entry. Further work would include ventilation of the party wall. However there were large open areas at the top of the wall, and increasing the airtightness would be difficult. Access from both sides would be needed and the neighbors had not expressed an interest in participating in the program.

The owner was not interested in continuing in the experimental program, and said that he would get a HRV to solve the problem. No further work was carried out in this house.

Alpha track detectors were issued to the owner in January 1987, but were not returned.

3. OTHER MEASUREMENTS

The radiation field in the house ranged from 6 to 9 uR/h, averaging 8 uR/h, and the surface radiation field on the site ranged from 7 to 10 uR/h, averaging 9 uR/h. Deeper soil was exposed in a road cut at the top of the hill, and the radiation field at a depth of 1 m was 13 to 16 uR/h.

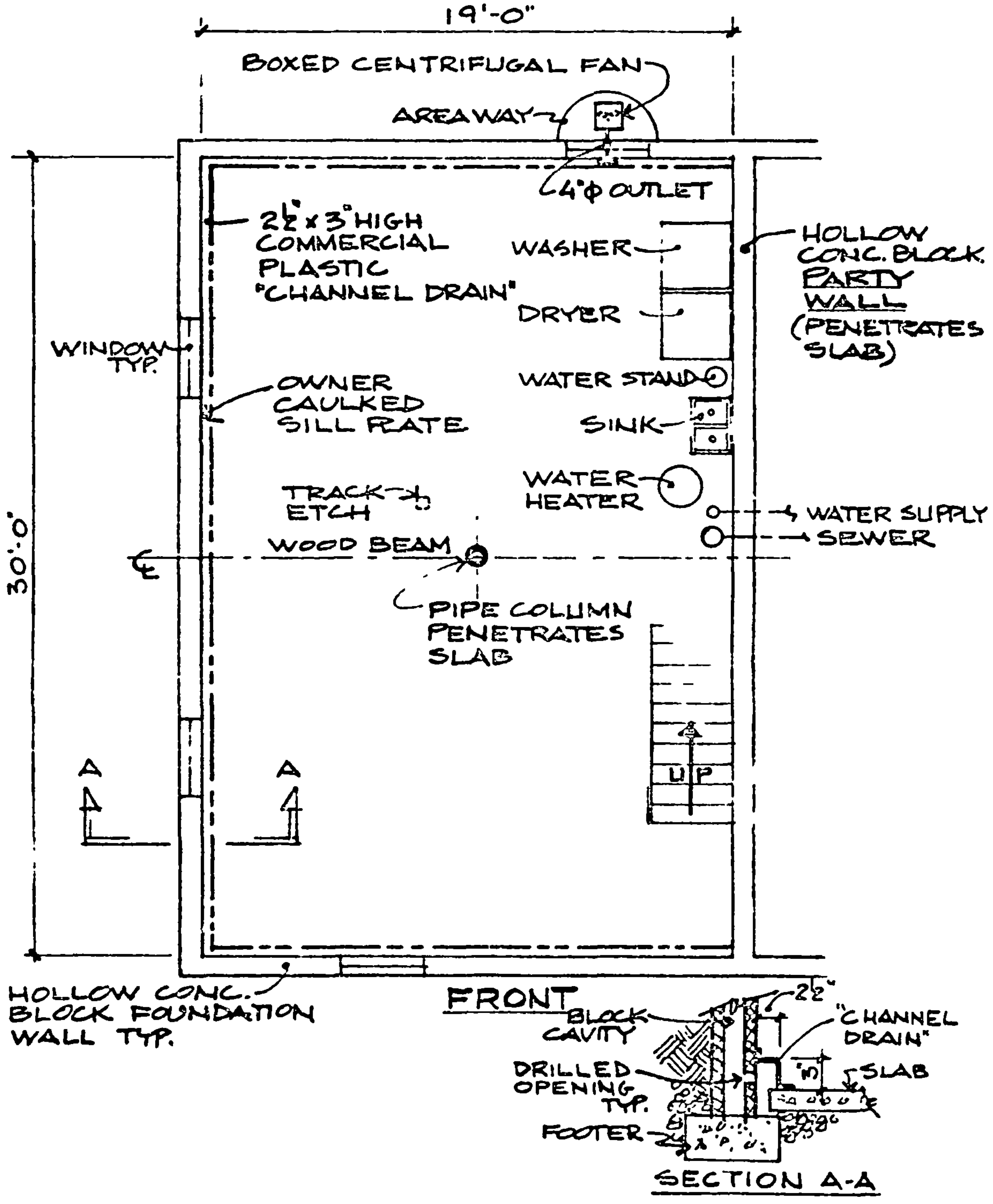
MEASUREMENTS SUMMARY FOR HOUSE 11

PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	MEAN	COMMENTS
1	Wall and french drain ventilation 50 L/s centrifugal fan	08/85	Fan off	7-104	90	over 36 hrs
			Fan on	1- 90	15	fell over 36 hrs
	As above	01/86	Fan on	15-28	20	over 14 hrs

SYSTEM MEASUREMENTS FOR HOUSE 11

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (l/s)	RADON (pCi/L)	COMMENTS
2	Wall and french drain ventilation 50 L/s centrifugal fan	03/86	50	35	75	Fan duct
			13	17	1	End wall duct
				2	2	Front wall duct
					160	Beam pocket
					60	Between beams
					40	Wall cavity
					14	Basement air



ACRES	LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
	FOUNDATION PLAN	Date: 10/20/86	11
	Mitigation system: BASEBOARD TYPE WALL/SLAB SUCTION	PHASE: FINAL	

HOUSE 12

PENNSYLVANIA DER MEASUREMENTS

Working Level grab samples (Kusnetz)	0.220 WL
Heating season short term average WL (RPISU)	0.033 WL
Heating season average radon (Terradex)	6 pCi/L
Radon concentration in water	4 300 pCi/L

1. DESCRIPTION

This rural single story dwelling is built on a sloping site on the side of a hill some miles to the west of Boyertown. The house walls are covered with siding, and the unfinished walk-out basement has concrete block walls. Some light floor cracking is visible, and there is a sleeved oil line entry through the basement wall. Heating is by forced air, and there is a fireplace on the main floor.

There is an external perimeter drainage (weeping tile) system, which discharges to a low point on the site. The owner had installed it himself; and said that it ran round all four walls at the junction of the footing and wall, and was covered with 30 cm of crushed stone.

2. ACTION

2.1. PHASE I

As this house was one of the few with a weeping tile system, the mitigative action selected for demonstration at this house was to exhaust the weeping tile.

A water trap was installed on the discharge pipe, a riser pipe was placed on the house side of the trap with an axial fan installed in the open end of a 6/4 inch sewer pipe reducer. An inspection riser was provided on the other side of the trap so that water levels could be checked.

The trap could not be installed close to the house as the ground was too rocky, and so it was placed about 2 m from the house. The fan riser pipe was run underground back to the side of the house. The ground cover in this area was only 30 cm, so there was a concern about the trap freezing in the winter and blocking the drain during the spring melt. It was agreed with the owner that insulation and extra ground cover would be provided if the installation was successful.

In July 1985, when the perimeter drain ventilation fan was turned on, the average radon concentration fell from 11 pCi/L to less than 1 pCi/L within one day.

2.2. PHASE 2

In November 1985, with the fan operating, the average radon concentration was 4 pCi/L, but rose to 32 pCi/L when the open fireplace on the upper floor was lit. To improve winter performance, the axial fan was replaced by a higher suction centrifugal fan mounted directly on the riser. Flows and suction were increased from 27 L/s, 50 Pa to 42 L/s, 110 Pa.

In January 1986, with the new fan operating, the average radon concentration in the basement was less than 2 pCi/L, with a brief peak to 9 pCi/L when the fireplace was lit.

Alpha Track monitors were installed in January 1986, but could not be found in March 1986.

During the summer when the windows were open, the owner was disturbed at night by the noise of the air discharged from fan. He dug a trench to run the fan riser pipe away from the house to the edge of the lawn, some 15 m distant from the house, installed an outdoor electrical outlet at that location to provide power to the fan, and reconnected the fan.

2.3. PHASE 3

The fan, mounting, and electrical hookup were not suitable for a permanent installation. In November 1986, the fan was replaced by a plastic body in-line centrifugal fan. The suction increased to 210 Pa at a flow of 65 L/s, with a radon concentration in the discharged air of 190 pCi/L.

In December 1986, the radon concentration in the basement ranged from 2 to 4 pCi/L, averaging 3 pCi/L. These results were good enough to issue alpha track detectors for final measurements.

3. OTHER MEASUREMENTS

The radiation field in and around the house ranged from 3 to 6 uR/h in the basement, averaging 5 uR/h. On the site the field ranged from 5 to 9 uR/h, averaging 7 uR/h.

The average radon concentration measured by alpha-track detectors over the period December 1986 to March 1987 was 3.0 pCi/L in the basement, and 2.5 pCi/L in the living area.

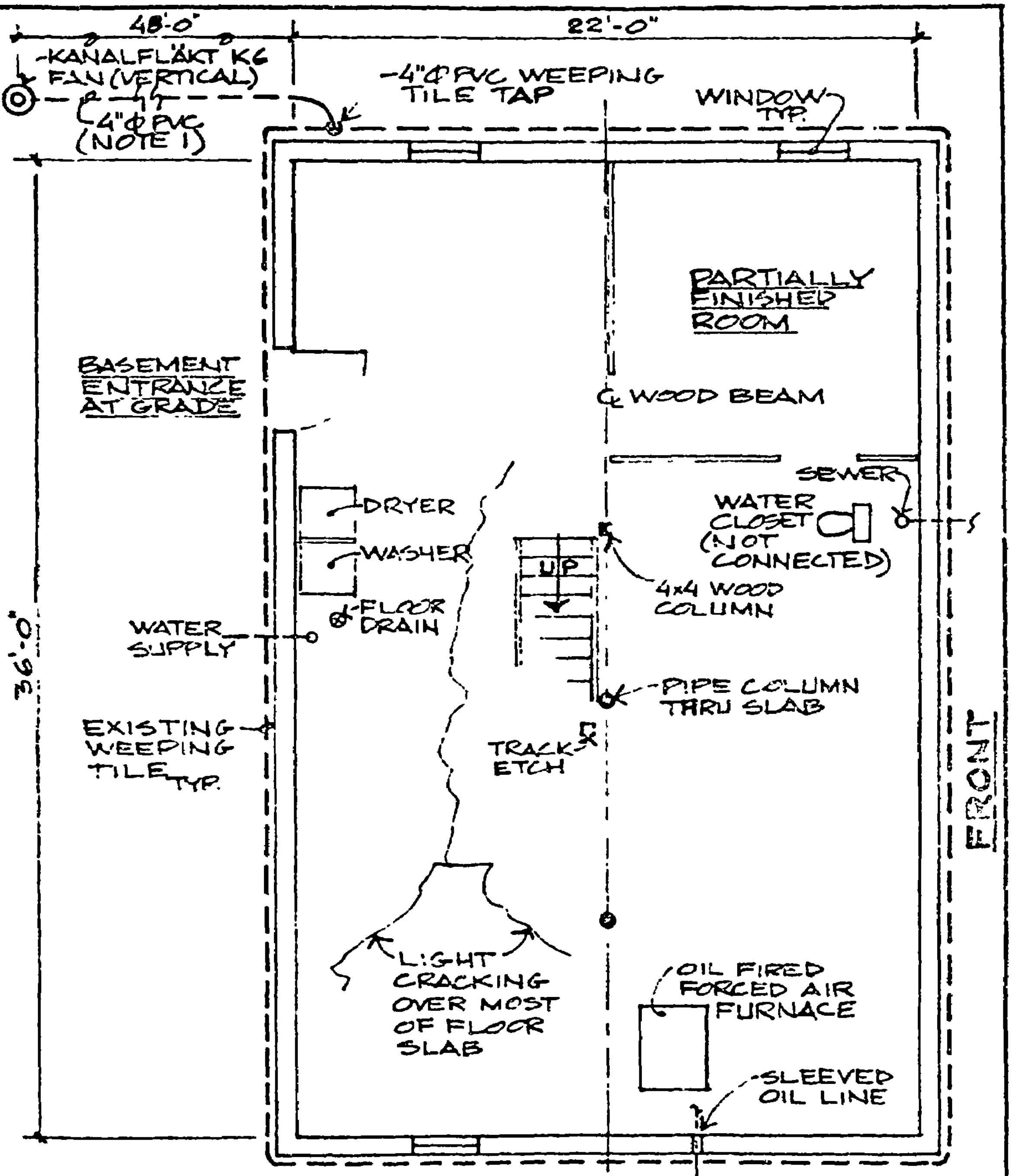
MEASUREMENTS SUMMARY FOR HOUSE 12

PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	MEAN	COMMENTS
1	Drain tile ventilation 50 L/s axial fan	07/85	Fan off Fan on	4-20 1- 4	11 2	over 24 hrs over 18 hrs
2	Drain tile ventilation 50 L/s axial fan	11/85	Fan on	2-32	7	over 46 hrs; levels highest when fire on
2	Drain tile ventilation 50 L/s centrifugal fan	01/86	Fan on	0.5-9	2	over 4 days; levels highest when fire on
3	Drain tile ventilation 150 L/s centrifugal fan	12/86	Fan on	2-4	3	over 68 hrs

SYSTEM MEASUREMENTS FOR HOUSE 12

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
2	Drain tile ventilation 50 L/s axial fan	11/85	50	27		
2	Drain tile ventilation 50 L/s centrifugal fan	11/85	110	42		Fan change
3	Drain tile ventilation 150 L/s centrifugal fan	12/86	210	65	190	Fan change



NOTE: 1. PVC PIPE BURRIED BY OWNER JUNE 1986. FAN INSTALLED ON TOP OF RISER APPROX. 2'-6" ABOVE GRADE.

	LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
	FOUNDATION PLAN	Date: 10/20/86	12
	Mitigation system: WEEPING TILE SUCTION	PHASE: FINAL	

HOUSE 13

PENNSYLVANIA DER MEASUREMENTS

Working Level grab samples (Kusnetz)	0.060 WL
Heating season average radon (Terradex)	64 pCi/L
Radon concentration in water	12 900 pCi/L

1. DESCRIPTION

This single story dwelling with attached garage was built in the late 1970's on a steeply sloping site on the side of a ridge in a rural subdivision to the west of Boyertown. The garage is attached at the low end of the house, and the floor is level with the basement floor. The front wall of the house is brick, the others are of siding. Heating is by oil fired hot water with baseboard convectors upstairs, supplemented by a wood stove in the basement.

Part of the basement is out of the ground, and there is an outside door. The interior walls are unfinished, but are insulated with beadboard sheets. The concrete floor slab is in good condition with no significant cracking. There is a brick fireplace in the basement.

The owner said that an exterior perimeter drainage pipe (weeping tile) ran round three sides of the basement and might run along the front wall of the garage. The tile discharge pipe was visible at a lower part of the site.

2. ACTION

2.1. PHASE 1

As this house had at least a partial weeping tile system, the mitigation measure chosen for demonstration at this site was weeping tile ventilation.

A trial excavation to a depth of 1.5 m beside the garage front wall did not find the tile or reach the footing in that area. The owner said the foundation was eighteen or nineteen courses of concrete blocks deep there, so if the tile existed there it could be buried up to 4 m deep and was inaccessible.

The line of the perimeter drain discharge pipe was traced back to the house. A small excavation near the back door found the junction with the tile at 60 cm depth. A water trap fabricated from standard 1" light weight plastic Tees and elbows was inserted at this point to prevent air being drawn up the discharge pipe. An inspection riser was provided at the downstream end of the trap, so that the water level in the trap could be checked.

This was not a suitable place to put the fan, so a second excavation to the tile was made at the rear corner of the house. A riser of 4" lightweight drain pipe was Teed onto the pipe. An axial fan was installed in the open end of a 4/6 inch adaptor joined to the riser by a 180 degree bend. Power was provided by an extension cord from an outside electrical outlet on the upper level balcony.

In July 1985, the radon concentration in the basement fell from 80 pCi/L to 15 pCi/L when the fan was turned on.

2.2. PHASE 2

In December 1985, the axial fan gave a suction of 35 Pa at a flow of 20 L/s with a radon concentration in the exhaust air of 770 pCi/L. To improve the performance before the winter season, the axial fan was replaced by a small centrifugal fan mounted directly on the riser. This increased the suction to 110 Pa at a flow of 36 L/s, and the radon concentration in the exhaust to 1 150 pCi/L.

In January 1986, the radon concentration in the basement with the fan in operation ranged from 9 to 30 pCi/L, averaging 20 pCi/L. Alpha track detectors were issued in January to check on the longer term performance of the system.

A more powerful fan was ordered, but did not arrive until March. The small centrifugal fan was replaced by a large plastic bodied in-line centrifugal fan in May 1986. This increased the suction to 250 Pa at 75 L/s, with an exhaust concentration of 850 pCi/L. Eight days later the concentration was 700 pCi/L. No short term radon measurements were made at this time as the weather was warm, and windows were open routinely.

2.3. PHASE 3

In November 1986 the radon concentration in the basement ranged from 3 to 25 pCi/L, averaging 11 pCi/L. This indicated that even the higher suction fan was not able to reverse the pressure differentials over all the basement surfaces.

Good results had been obtained at other sites by multi-point subfloor ventilation, and so it was decided to try a subfloor system here. A four point system using a large plastic bodied in-line centrifugal fan was installed in

January 1987. Basement radon concentrations with just the weeping tile system in operation ranged from 1 to 19 pCi/L, averaging 8 pCi/L, and when the subfloor system was turned on as well, concentrations ranged from 0.1 to 4 pCi/L, averaging 2.1 pCi/L.

Suctions flows and radon concentrations in the subfloor system pipes with both fans running were; garage wall 110 Pa, 9 L/s, 230 pCi/L; rear wall 110 Pa, 26 L/s, 20 pCi/L; end wall (by the fan) 175 Pa, 7 L/s, 2 100 pCi/L; and front wall 150 Pa, 7 L/s, 1 100 pCi/L at the front wall.

The performance of the subfloor system alone was tested by turning off the weeping tile fan. In January 1987, the basement radon concentration with both systems in operation ranged from 1 to 4 pCi/L, averaging 2.7 pCi/L. With the weeping tile fan turned off, and just the subfloor system fan running, concentrations ranged from 5 to 30 pCi/L, averaging 15 pCi/L over 24 hours. With both systems off, the range was from 22 to 117 pCi/L, averaging 91 pCi/L.

To check for transient effects, a second test was carried out in February. With just the subfloor system in operation, concentrations over a four day period ranged from 2 to 11 pCi/L, averaging 5 pCi/L. The higher concentrations were associated with use of the washing machine. Flows and suctions in the subfloor system pipes were measured with the weeping tile fan turned on and off. The flows did not change noticeably, but suctions were about 40 Pa higher with both fans in operation.

Alpha track detectors were issued in February 1987 to give a long term estimate of the radon concentration.

3. OTHER MEASUREMENTS

The radiation field in the basement ranged from a high spot of 12 uR/h directly over the floor drain, to general fields of 9 uR/h at the front of the basement to 5 uR/h at the rear. The owner said that the crushed stone layer under the floor was much thicker at the rear of the house. On the undisturbed soil of the front lawn, the field ranged from 8 to 19 uR/h and averaged 13 uR/h. At the rear of the house where the spoil from the basement excavation had been dumped the field ranged from 15 to 25 uR/h and averaged 20 uR/h. The general lot average was 16 uR/h and the driveway ranged from 1 to 10 uR/h

The average radon concentrations measured with alpha track detectors over the period December 1985 to March 1986 were 11.4 pCi/L upstairs, and 17 pCi/L downstairs.

The average radon concentrations measured with alpha track detectors over the period February 1987 to April 1987 were 2.3 pCi/L in the basement, and 2.0 pCi/L upstairs in the living area.

MEASUREMENTS SUMMARY FOR HOUSE 13

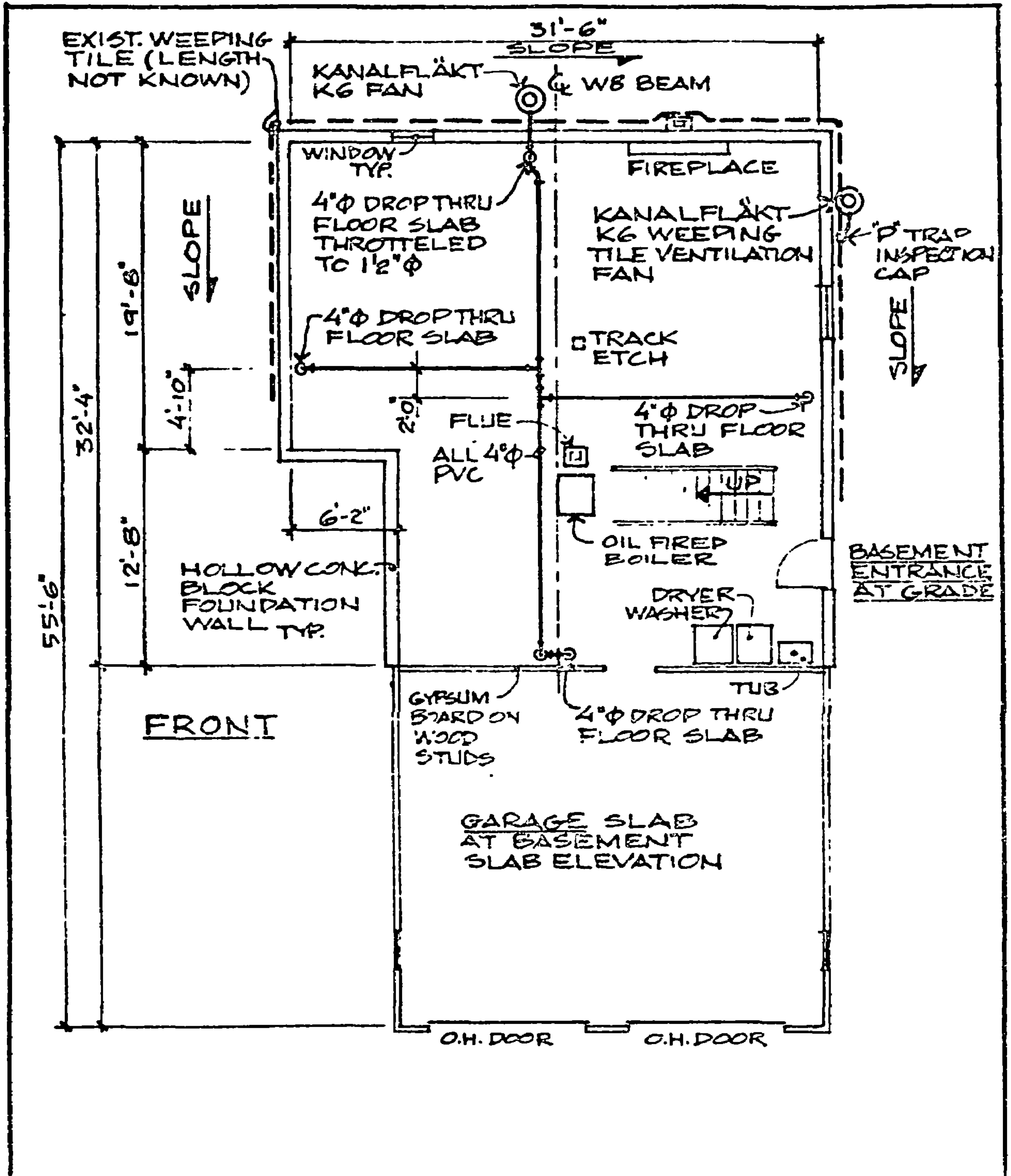
PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	MEAN	COMMENTS
1	Weeping tile ventilation 50 L/s axial fan	07/85	Fan on	10-88	35	over 21 hrs fall to equilibrium of 13 pCi/l
2	Weeping tile ventilation 50 L/s axial fan	01/85	Fan on	9-19	22	over 32 hrs
3	Weeping tile ventilation 150 L/s centrifugal fan	11/86	Fan on	3-25	11	over 1 days
3	Sub-slab weeping tile ventilation two 150 L/s centrifugal	01/87	Weeping tile fan only	4-19	8	over 18 hrs
			Both fans on	0.4-1	2.1	over 71 hrs
		01/87	Both fans on	1-4	2.5	over 22 hrs
			Weeping tile fan off	5-30	15	over 24 hrs
			Both fans off	22-117	91	over 48 hrs
		02/87	Sub-slab fan on	2-11	5	over 4 days

SYSTEM MEASUREMENTS FOR HOUSE 13

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
2	Weeping tile ventilation 50 L/s axial	12/85	35	20	770	fan riser
					0.3	ambient (outdoor) air
2	Weeping tile ventilation 50 L/s centrifugal	12/85	110	36	1 150	riser for new fan
2	Weeping tile ventilation 150 L/s centrifugal	05/86	250	75	860	fan riser
					690	fan riser 8 days later
3	Sub-slab + weeping tile ventilation 150 L/s centrifugal	01/87	140	9	230	Riser A
			140	26	20	Riser B
			150	7	1 100	Riser C
			175	7	2 100	Riser D
3	As above	02/87	112	10		A*
			160	30		B*
			190	8		C*
			240	8		D*
			160	11		A**
			160	27		B**
			200	7		C**
			240	7		D**
			125	9		A*
			140	27		B*
			160	7		C*
			200	7		D*

A: Garage wall.
B: Rear wall.
C: Front wall.
D: End wall.
* Sub-slab fan only.
** Both fans on.



LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
FOUNDATION PLAN	Date: 1/19/87	13
Mitigation system: WEEPING TILE AND SUB-SLAB SUCTION	PHASE: 1 THRU FINAL	

HOUSE 14

PENNSYLVANIA DER MEASUREMENTS

Working Level grab samples (Kusnetz)	0.418 WL
Heating season average (RPISU)	0.124 WL
Heating season radon average (Terradex)	36 pCi/L
Radon concentration in water	2 500 pCi/L

1. DESCRIPTION

This single story dwelling was built in the early 1980's on a sloping site on the top of a ridge some miles west of Boyertown. Half of the front house wall is brick veneer, the other walls are siding. Heating is by electric baseboard heaters upstairs only.

The walkout basement has concrete block walls, and the sill plate does not cover the open block voids. The concrete slab is poured to the walls and forms a tight joint but for a few slight perimeter cracks. The slab is penetrated by steel columns which stand upon their own footings, and two cracks which extend about half the width of the slab. There are two openings through the slab at sanitary drain stacks, where the concrete does not fill the space between the rear of the stack and the basement wall.

A perimeter drainage (weeping tile) system is installed along the two uphill sides of the house. Plastic sheet was also applied to the exterior of these walls during construction for waterproofing.

2. ACTION

2.1. PHASE 1

As this house was one of the few with weeping tile, the mitigative action chosen for demonstration at this site was to exhaust the perimeter drainage system.

The discharge pipe was uncovered and a water trap inserted at the junction with the drain tile. An inspection riser was provided at the downstream end of the trap. A fan riser was installed on the house side of the trap and an axial fan was inserted in the open end of a 6/4 inch adaptor joined to the riser by a

180° bend. Temporary power to the fan was provided from an electrical adaptor inserted in an exterior light fixture.

In July 1985, the concentration in the basement fell from 60 pCi/L to 9 pCi/L when the fan was turned on.

2.2. PHASE 2

In November 1985, the concentration ranged from 6 to 23 pCi/L, averaging 15 pCi/L with the fan running continually. As the system was not effective, replacing the axial fan with a higher suction fan was considered, but rejected as the tile did not go round the house, and increased suction had been ineffective at other locations where the tile was not continuous. It was decided to install a wall ventilation system, as they had been successful in Phase 1.

The top of the basement wall was readily accessible, except for the section where the front wall was brick veneer. In this section the sill plate was set flush to the inside edge of the block and covered the block voids completely. The sill plate was caulked to the wall in that area. Elsewhere, the voids were stuffed with fiberglass and filled with mortar.

A five point collection duct system was installed, using two "4 inch" collector pipes into each half of the front wall, a single collector in each of the other walls, a "6 inch" central duct and a large wall mounted centrifugal exhaust fan. Large flows were drawn from each wall,

In January 1986, the radon concentration in the basement with the wall ventilation fan running ranged between 0.4 to 2 pCi/L. The air flows were front wall 19 L/s and 15 L/s; end wall 17 L/s; rear wall 18 L/s, and fan end wall 31 L/s. The radon concentrations in the air flowing from the walls was front wall 1 pCi/L and 7 pCi/L, end wall 3 pCi/L, back wall 6 pCi/L, and fan end wall 15 pCi/L. A smoke test showed that the airflow was into the walls from the house.

The low radon concentrations indicated that much of the air was drawn from the house. The wall closures were checked, and found good, and the probable leakage paths were the pores in the blocks themselves, and the joints between the blocks, particularly on the exterior parts of the walls that were exposed above the ground. The floor openings were checked, and a strong airflow was found down into the subfloor space at the sanitary stacks, indicating that in this house at least, the walls were connected to the subfloor fill.

Subsequently the owner added a small sunroom extension to the rear of the house. Although concrete blocks were used for the foundation, the concrete slab was poured on top of and into the blocks so that there was no direct path for soil gas to enter the structure. The only entry route was the joint between the slab and the wall, and that area was likely to be well ventilated by air leaking into the wall. A vent pipe was included in the subfloor fill, but was not connected.

Alpha Track detectors were issued in February to check the system performance, and the effect of the sunroom extension. Radon concentrations were low, so the precautionary measures were effective.

2.3. PHASE 3

The system was checked and found to be operating normally. Alpha Track detectors were issued in December 1986 for a winter time measurement of average radon concentration.

3. OTHER MEASUREMENTS

The radiation field inside the house ranged between 6 to 10 uR/h, averaging 8 uR/h, and over the site ranged from 5 uR/h on the crushed stone driveway to 12 uR/h, averaging 10 uR/h.

The average radon concentration measured by Alpha Track detectors over the period February 1985 to April 1986 was 0.6 pCi/L in the basement and 0.6 pCi/L upstairs.

The average radon concentration measured by alpha-track detectors over the period December 1986 to March 1987 was 0.5 pCi/L in the basement, and 0.7 pCi/L in the living area.

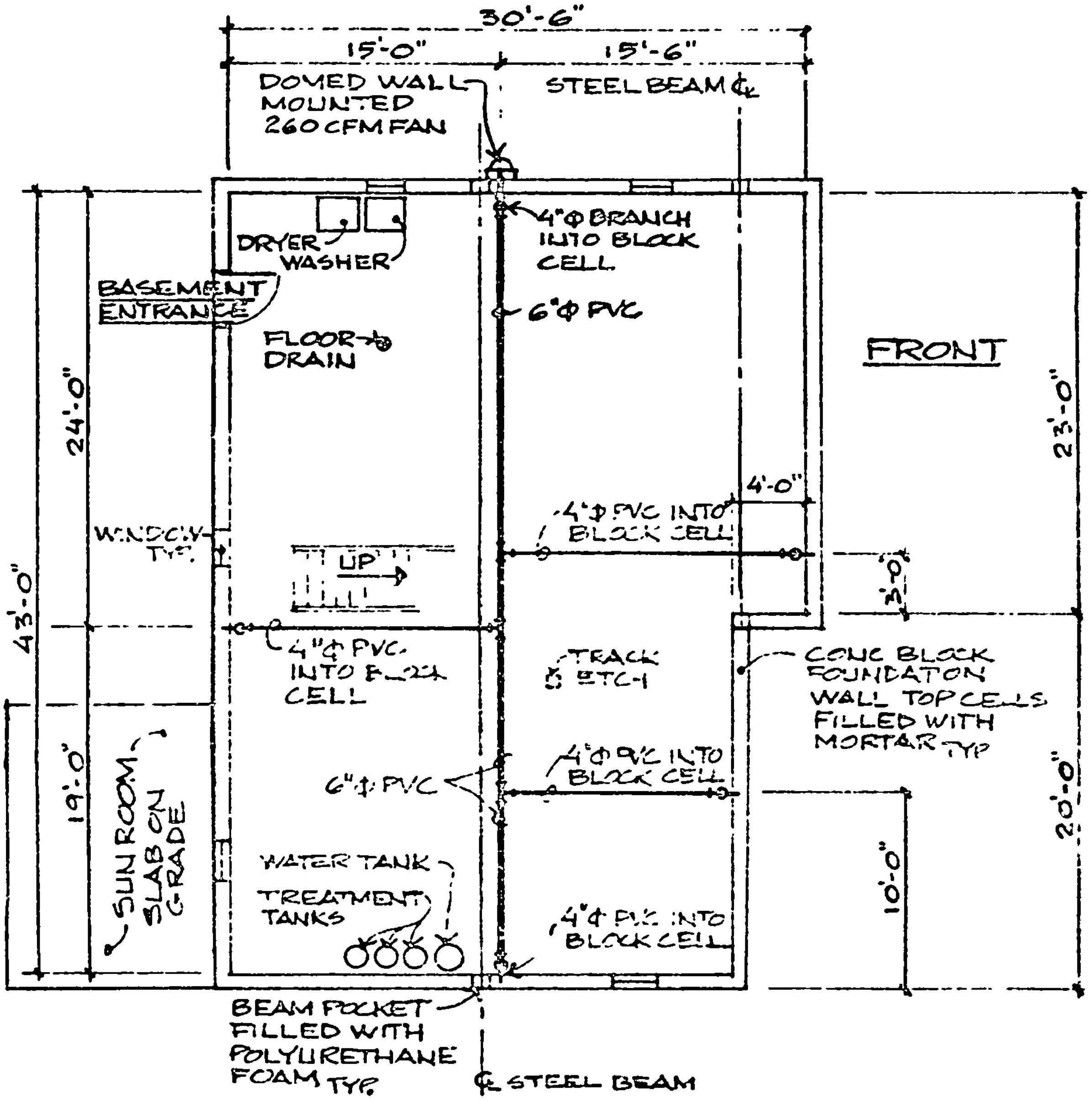
MEASUREMENTS SUMMARY FOR HOUSE 14

PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/l) RANGE	MEAN	COMMENTS
1	Drain tile ventilation 50 L/s axial	07/85	Fan off	10-67	47	over 24 hrs
			Fan on	14-58	28	over 22 hrs still falling
2		07/85	Fan on	6-23	15	over 10 hrs
2	Wall ventilation 100 L/s centrifugal	01/86	Fan on	0.4-2	1	over 4 days

SYSTEM MEASUREMENTS FOR HOUSE 14

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
2	Drain tile ventilation 50 L/s axial	11/85	38	17		Fan riser
2	Wall ventilation 100 L/s centrifugal	01/86	33	34	15	Fan wall riser
			25	64		Main duct run
			20	19	7	Front wall
			13	15	1	Front jog wall
			11	17	3	End wall
			13	18	6	Rear wall
					1	Room air
					1	Drain
					0	Sewer penetration



ACRES Acres International Corporation	LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
	FOUNDATION PLAN	Date: 7/15/86	14
	Mitigation system: WALL SUCTION	PHASE: 2	

HOUSE 15

PENNSYLVANIA DER MEASUREMENTS

Working Level grab samples (Kusnetz)	0.171 WL
Short term average WL (RPISU)	0.019 WL
Radon concentration in water	4 900 pCi/L

1. DESCRIPTION

This two-story house with attached garage was built in the early 1980's on a fairly level site near the top of a hill several miles southwest of Boyertown. The house walls are of siding. The partly finished basement is deeper than usual and has hollow concrete block walls 2.5 m (8 feet) high, and no basement windows. The walls have solid cap blocks. There are no visible cracks in the walls and the water service entry hole has been mortared closed. The concrete floor slab has no construction joints and shows no cracks. The perimeter wall/floor shrinkage crack is small. Heating is by forced air with an oil/wood fired furnace.

The owner said that the walls were reinforced internally every 2.5 m (8 feet) around the house by steel reinforcing bars and concrete poured into the blocks. (The builder usually did industrial construction). He also said that a weeping tile perimeter drain surrounded the entire house, including the house/garage wall.

2. ACTION

2.1. PHASE 1

As this house was one of the few with a complete weeping tile system, the mitigation method chosen for demonstration at this site was weeping tile ventilation.

The discharge pipe from the tile was found at a low point on the site. The pipe was excavated about 3 feet from the open end, and a water trap with inspection riser was installed.

The owner originally had the rain-water leaders connected to the perimeter drain. This led to wet walls at times of heavy rain, so he had put in a subsurface system just to collect rain water and lead it away from the house. The connections to the perimeter drain had been cut off just below ground level and capped.

One of these capped risers was located, excavated, and extended above ground with 4-inch plastic piping. A centrifugal fan in a box with a child-proof discharge was connected to this pipe with a flexible duct. The fan gave 25 Pa suction at 35 L/s.

In July 1985, the radon concentration in the basement varied between 5 to 49 pCi/L, averaging 18 pCi/L, when the fan was turned on the average radon concentration fell to 3 pCi/L.

2.2. PHASE 2

The performance of the weeping tile ventilation systems was compromised in cooler weather by condensation in the flexible hose reducing the air flow to the fan. In November 1985, the centrifugal fan was remounted directly on the riser so that condensation would drain back into the piping and not affect the fan. The suction was increased to 65 Pa, and airflow in the system to 52 L/s. In December 1985, the radon concentration in the basement with the new fan on ranged from 3 to 6 pCi/L, averaging 4 pCi/L. These results were good enough for alpha track detectors to be issued.

In May 1986, the fan was replaced by a permanent plastic body in-line centrifugal fan. The fan gave 175 Pa suction, 92 L/s flow. The radon concentration in the discharge air was 150 pCi/L. Further monitoring of radon concentrations was left till the return of cold weather.

2.3. PHASE 3

The electrical hookup of the fan was not satisfactory for a permanent installation, and in November 1986 it was replaced by a permanent electrical connection.

After the new connection, the radon concentration in the basement ranged between 0.2 to 3.8 pCi/L, averaging 1 pCi/L. These results were good enough for alpha track detectors to be issued for final measurements.

3. OTHER MEASUREMENTS

The radiation field in and around the house ranged from 4 to 10 uR/h, averaging 6 uR/h, in the basement; and from 8 to 12 uR/h, averaging 10 uR/h, on the site.

Track Etch detectors were placed in the house in December 1985, and removed in March 1986. The average radon concentration over this period was 3.8 pCi/L in the basement and 2.5 pCi/L upstairs in the living area.

Track Etch detectors were placed in the house in December 1986, and removed in March 1987. The average radon concentration over this period was 1.1 pCi/L in the basement and 1.0 pCi/L upstairs in the living area.

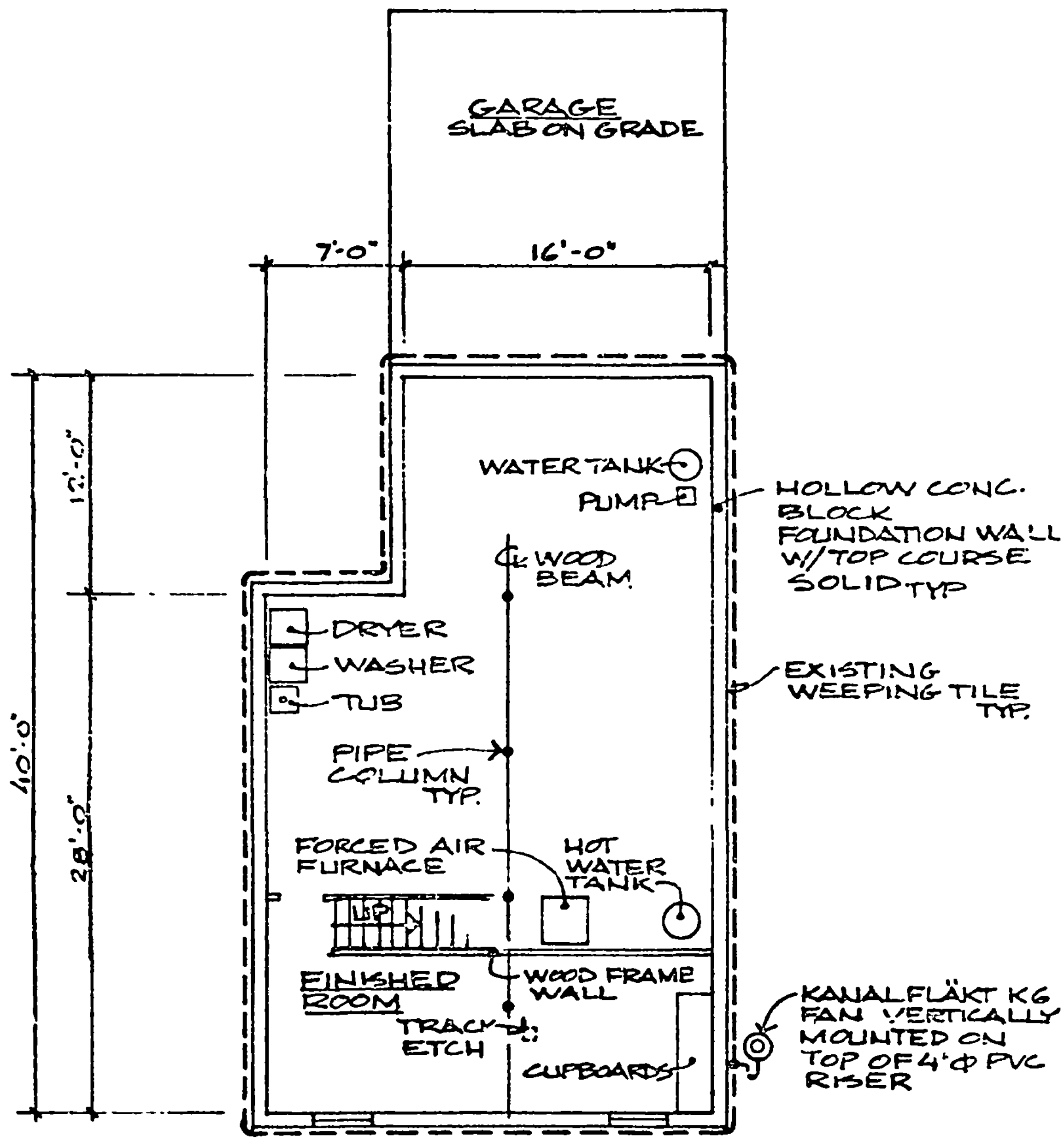
MEASUREMENTS SUMMARY FOR HOUSE 15

PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	MEAN	COMMENTS
1	Weeping tile ventilation 50 L/s centrifugal fan	07/85	Fan off	5-49	18	over 52 hrs
			Fan on	2-24	6	over 38 hrs
					3	12 hr equilb.
2	As above	12/85	Fan on	3-6	4	over 66 hrs
3	Weeping tile ventilation 150 L/s centrifugal fan	11/86	Fan on	0.2-3.8	1	over 4 days

SYSTEM MEASUREMENTS FOR HOUSE 15

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
1	Weeping tile ventilation 50 L/s centrifugal fan	11/85	26	35		Fan in a box
			65	52		Direct mounted fan
2	Weeping tile ventilation 150 L/s centrifugal fan	05/86	175	92	150	Fan riser
			238			At fan



LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
FOUNDATION PLAN	Date: NOV. '86	15
Mitigation system: WEEPING TILE SUCTION	PHASE: FINAL	

HOUSE 16

PENNSYLVANIA DER MEASUREMENTS

Working Level grab samples (Kusnetz)	0.63 WL
Heating season short term average WL (RPISU)	0.21 WL
Heating season average radon (Terradex)	395 pCi/L
Radon concentration in water	28 000 pCi/L

1. DESCRIPTION

This two-story house with attached double garage was built in the mid 1970's on a level site at the top of a ridge near Boyertown. The front wall is of brick, the other walls are of siding. The house has a rear family room extension. The room directly behind the garage is above a paved crawlspace.

The basement is unfinished, with hollow concrete block walls and the top course of the walls is largely covered by a full sill plate. One wall is penetrated by oil lines mortared in place. There are no major cracks in the walls. There is an external entrance into the basement, and a small paved crawlspace is attached to the basement. The crawlspace walls are closed by cap blocks.

The poured concrete floor slab has no cracks, and is penetrated by steel support jacks and a floor drain.

The owner stated that there was a perimeter drain (weeping tile) system around the house.

2. ACTION

2.1. PHASE 1

As this house was one of the few with a weeping tile, the mitigative action chosen for demonstration at this site was weeping tile ventilation.

The end of the discharge pipe from the weeping tile was located at a low part of the site, and traced back to the intersection with the house. An excavation approximately 2.5 m deep was required to reach the tile. Fortunately the intersection of the drain line and weeping tile was where estimated, so only a relatively small hole was needed.

The discharge pipe continued under the footing to beneath the basement floor, and the weeping tile was Teed into the pipe. The tile did not continue beyond this point, and probably does not make a complete loop round all walls.

A "U" water trap fabricated from lightweight plastic drain pipe and elbows was installed in the discharge line. The trap was extended vertically to the surface on the house side of the trap for a fan riser, and also extended on the other side of the trap for an inspection riser.

A flexible duct joined the fan riser to a centrifugal fan installed in a box with a child-proof discharge.

In August 1985, the radon concentration in the basement ranged from 230 to 320 pCi/L. When the fan was turned on the concentration fell to 3 to 6 pCi/L.

2.2. PHASE 2

In November 1985, cooler weather caused condensation of soil moisture in the flexible duct, blocking it completely. When the hose was emptied of water, the radon concentrations in the basement initially ranged from 32 to 73 pCi/L, and then rose to 106 to 250 pCi/L as the duct filled with water.

To stop condensation blocking the duct, the fan was remounted directly on top of the riser. Condensed moisture would drain back down to the tile. The suction increased only slightly from 105 to 110 Pa.

In November 1985, the concentration with the remounted fan running ranged between 120 to 220 pCi/L, falling to 80 pCi/L after steady rain at the end of the measurement period.

Alpha Track detectors were exposed in the house for January 1986. The weeping tile fan was in operation. Average radon concentrations were 78 pCi/L in the basement, and 22 pCi/L on the main floor and bedrooms. The owners agreed to participate in a field evaluation trial of Heat Recovery Ventilators for radon control sponsored by a manufacturer of HRV's, and one was installed in early January.

The performance of the weeping tile system could not be easily improved, so alternate mitigation methods were considered.

As the tops of the walls were covered by the sill plate, the mitigation method chosen for demonstration was wall ventilation.

In January 1986, the joint between the sill plate and the top of the walls was caulked with asphalt cement. A 10 cm diameter hole was cut approximately in the middle of each wall and 30 cm from the floor. In the crawl space the holes were 15 cm from the floor. A "1 inch" lightweight plastic pipe was inserted into each hole, and all pipes were joined to a "4 inch" central duct connected to a large wall-mounted centrifugal fan which drew 52 L/s at 62 Pa.

Following this work, radon concentrations in the basement ranged from 3 to 53 pCi/L, averaging 12 pCi/L. The HRV was operated intermittently during the period, but concentrations were so variable that it was difficult to estimate the reduction caused by HRV operation. It did no more than halve the basement concentrations while delivering 75 L/s of air.

Investigation found that airflows were generally into the ventilated basement walls, but not positively into the crawl space walls. One section of basement wall between a corner and the exterior entrance door was unventilated, and air flowed from the wall into the house. Concentrations of 1 000 pCi/L were found in the front wall, but the concentrations in the end walls were only 150 pCi/L, and the concentration in the rear wall was 1 pCi/L. The air drawn from the crawlspace walls only had 5 pCi/L, suggesting that it was house air, not soil gas that was being collected.

The floor slab in the crawl space was roughly finished, and there was a visible gap against the crawlspace walls. There was a small hole in a corner of the crawl space floor slab with a marked airflow from the soil to the house at a concentration of 380 pCi/L.

The system was modified to raise the suction in the walls. The central duct was changed from "4 inch" to "6 inch" pipe, a second "4 inch" pipe was run into the front wall, and a "3 inch" pipe was run to the isolated section of the rear wall that had not been ventilated previously. This placed all the walls positively under suction. The fan now drew 66 L/s at 80 Pa.

In January 1986, following this work, the radon concentration in the basement fell slowly from an average of 15 pCi/L to 5 pCi/L with the fan turned on. The concentration was variable, with spikes up to 16 pCi/L, not all of which were associated with water use in the washing machine.

The opening in the crawl space floor slab was filled with asphalt cement in February 1986. Following this, the radon concentration in the basement ranged from 2 to 16 pCi/L, averaging 4 pCi/L. The higher concentrations were associated with water use.

The family room in this house is on a grade level slab extension. Now that the radon supply via the basement had been reduced, there was a concern that the slab might have some significant radon entry routes. Measurements upstairs in February found that concentrations ranged from 0 to 9 pCi/L, averaging 2 pCi/L. The small peaks were associated with water use.

Alpha Track detectors were placed in the house in March and removed in May 1986.

2.3. PHASE 3

In November 1986 the basement radon concentration varied from 1 to 41 pCi/L, averaging 9 pCi/L. The highest concentration was associated with use of the washing machine, but some high values occurred when washing was not in progress, but at a time of high winds. The system was remeasured to see if there had been any major changes in flows or radon concentrations since February 1986.

The radon concentration in the front wall averaged 1200 pCi/L, in the garage side wall it was 190 pCi/L, and 60 pCi/L in the other side wall. Concentrations were higher in the rear wall, 120 pCi/L, and in the crawl space walls, averaging 90 pCi/L. The fan drew 93 L/s at 75 Pa. These readings were all close to those found in February, and smoke tests showed that the airflow was from house to wall.

In December 1986 the radon concentrations in the basement ranged from 1 to 19 pCi/L, averaging 1 pCi/L. The high value was associated with water use. These results were good enough to issue alpha track detectors for final measurements.

3. OTHER MEASUREMENTS

The radiation field in and around the house ranged from 4 to 10 uR/h in the basement, averaging 7 uR/h; and from 5 to 19 uR/h on the site, typically averaging 13 uR/h. The highest readings were found on the front yard, the lowest on the asphalt driveway.

Over the period March to May 1986, the average radon concentration in the basement was 2.9 pCi/L, and in the living quarters was 2.1 pCi/L.

The average radon concentration measured by alpha-track detectors over the period December 1986 to March 1987 was 3.1 pCi/L in the basement, and 1.7 pCi/L in the living area.

MEASUREMENTS SUMMARY FOR HOUSE 1C

PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	MEAN	COMMENTS
1	Weeping tile ventilation 50 L/s	08/85	Fan off	3-327	160	over 20 hrs
			Fan on	3-290	50	over 14 hrs falling
	centrifugal fan		Fan on	3- 6	4	17 hrs equilibrium
		11/85	Fan on	32- 73	61	over 18 hrs
			Fan on - condensation buildup	87-253	164	over 31 hrs
2	As above with direct mounted fan	11/85	Fan on	82-220	158	over 46 hrs
2	Wall ventilation 100 L/s centrifugal fan	01/86	Fan on	2-53	12	over 4 days
		01/86	Fan on	1-46	12	over 4 days
		02/86	Fan on	2-16	4	over 4 days
	As above. Crawlspace hole sealed	02/86	Fan on	0- 9	2	over 4 days
		11/86	Fan on	1-41	9	
		12/86	Fan on	1-19	4	

SYSTEM MEASUREMENTS FOR HOUSE 16

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
2	Weeping tile ventilation 50 L/s centrifugal fan	11/85	105	21		Fan in box
			110			Direct mounted fan
	As above + owner installed HRV	01/86				Flows in house:
				10	5	HRV off- floor drain
				13		HRV off-supply duct 1
			35	59		HRV low-supply duct 1
			38	65		HRV high - supply duct 1
				3		HRV off-supply duct 2
			43	32		HRV low - supply duct 2
			43	39		HRV high - supply duct 2
					60	Basement air
2	Wall ventilation 100 L/s centrifugal fan	01/86	20	26	160	Pipe A
			8	9	1 000	Pipe B
			5	5	130	Pipe D
			8	8	5	Pipe F
			15	13	1	Pipe I
			65	55		Fan duct
					920	Barodamper
				19		draft
					380	enclosed crawlspace hole
2	Crawlspace hole sealed	02/86	16	25		Pipe A
			13	12		Pipe B
			13	9		Pipe C
			10	10		Pipe D
			8	1		Pipe F
			8	7		Pipe G
			8	3		Pipe H
2	As above	07/86			350	Enclosed front wall/floor joint

SYSTEM MEASUREMENTS FOR HOUSE 16

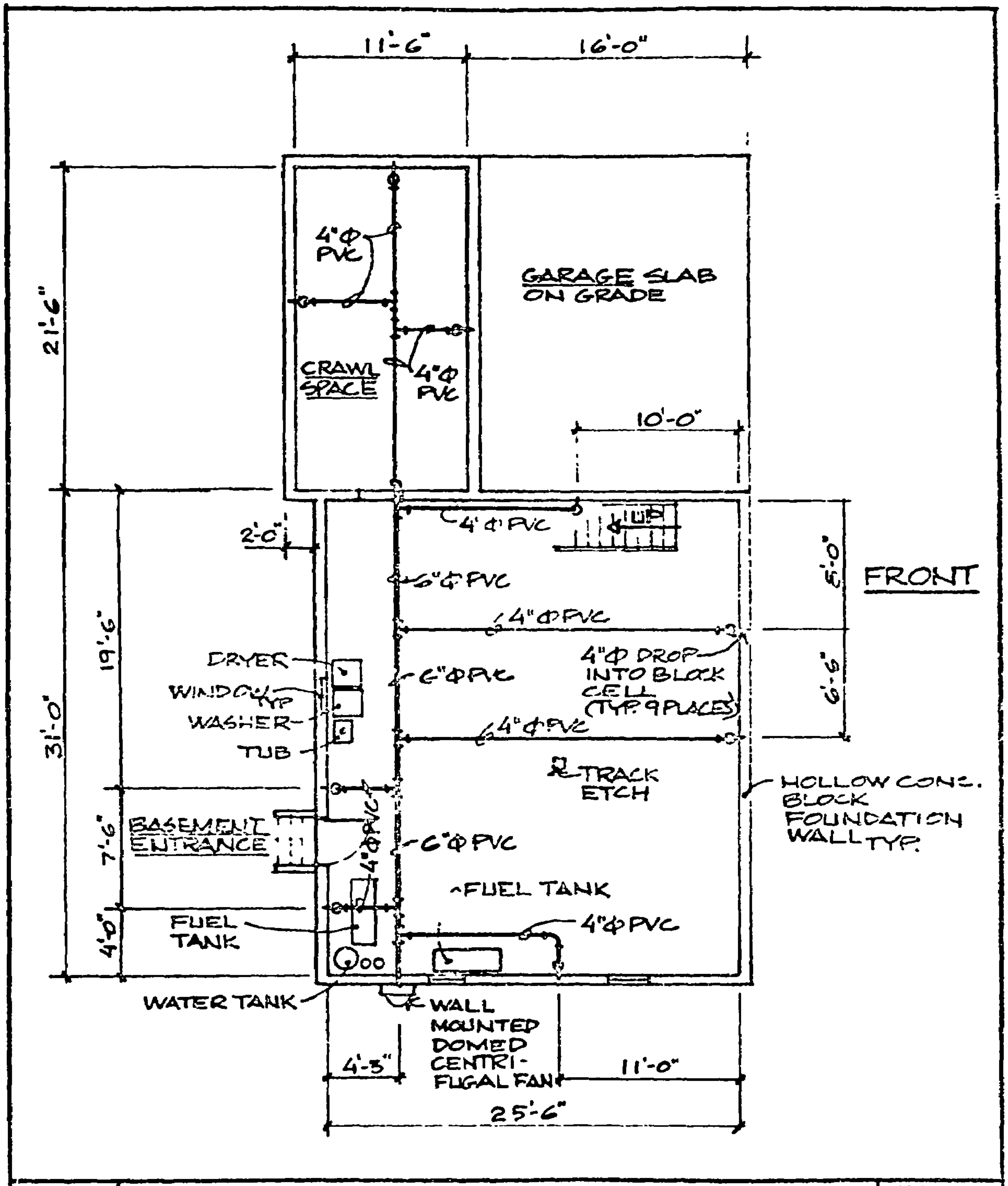
PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
3	Wall ventilation 100 L/s centrifugal fan	12/86	16	23	60	Pipe A
			11	11	720	Pipe B
			11	8	1 700	Pipe C
			11	8	190	Pipe D
			9	4	110	Pipe F
			10	9	9	Pipe G
			10	3	80	Pipe H
			15	13	120	Pipe I
			25	11	6	Pipe J
			75	93	170	Fan duct
3		03/87	13	9		Pipe B
			10	7		Pipe C
			38	87		Fan duct

A - End wall B - Front wall 1 C - Front wall 2

D - Garage wall E - Crawlspace header F - Crawlspace garage wall

G - Crawlspace end wall H - Crawlspace rear wall

I - Rear wall 1 J - Rear wall 2



ACRES	LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
	FOUNDATION PLAN	Date: 11/26/85	16
	Mitigation system: WALL SUCTION	PHASE: FINAL	

HOUSE 17

PENNSYLVANIA DER MEASUREMENTS

Working Level grab samples (Kusnetz)	0.130 WL
Short term average WL (RPISU)	0.045 WL
Heating season average radon (Terradex)	9 pCi/L
Radon concentration in water	4 600 pCi/L

1. DESCRIPTION

This one-story house with attached garage is built in the early 1970's on a level site about halfway up a hill a few miles east of Boyertown. The front wall is of brick, the other walls are of siding. The house is heated by hot water baseboard radiators with an oil-fired boiler, supplemented by a wood-burning stove in the basement.

The basement has concrete block walls, and is mostly finished, with panelled walls and a tile ceiling. In the unfinished laundry area, the block walls are visible, and are cracked around the door and windows. The sill plate covers the top of the block walls. There is a large opening around the sewer service exit. The basement floor slab is a replacement, poured over a layer of crushed stone and a pipe network that was placed over the original floor to deal with persistent water leakage into the basement. The pipe network leads to a sump where the water is collected and pumped outside. The floor slab is poured tight to the wall in the unfinished portion of the basement, but there is a perimeter drainage slot between the wall and the slab near the sump, hidden by cove molding at the base of the finished wall.

There is a walk-in cedar closet adjacent to the basement stairs with a suspended wood floor. The second floor slab is not continuous beneath this floor.

2. ACTION

2.1. PHASE 1

As this house had a sub-floor pipe network accessible via the sump, sump ventilation was chosen as the mitigation method to be demonstrated at this house.

The sump was in a corner of the basement at the foot of the basement stairs, and had been boxed in with panelling. The panelling, framing, and the wooden sump forms that had been left in the concrete floor, were removed. A three-sided plywood enclosure was placed in the corner over the sump and caulked to walls and floor. Expanding foam was used to fill the openings left by the wooden forms, and the accessible portions of the perimeter drainage slot.

One half of the top of the box was removable but sealed with weather stripping and screwed into place, and the other half was fixed in position and caulked. A 4" lightweight plastic pipe ran vertically from the box, through a hole cut in a ceiling tile, and through the header board into the garage. A centrifugal fan in a wooden box was attached to the pipe with flexible ducting.

In August 1985, the radon concentration in the basement fell from 40 pCi/L to 8 pCi/L when the fan was turned on.

2.2. PHASE 2

In November 1985, cooler weather caused the water vapour in the sump air to condense in the flexible duct leading to the fan, and block it with water. This was corrected, by perforating the hose to let the water drain out, but in January 1986, the concentration in the basement with the fan operating properly ranged between 12 to 28 pCi/L, averaging 20 pCi/L.

This was comparable to the premitigation values, and was not regarded as satisfactory performance. Alternative mitigation methods were considered. As the basement was extensively finished, and the average radon level was relatively low, installation of an air to air heat exchanger or heat recovery ventilator (HRV) seemed the most viable alternative.

A local contractor who had experience with installing HRV's for radon control was asked to install a unit. He suggested that the best results would be obtained if fresh air was delivered upstairs and stale air was exhausted from the basement (a split system).

In February 1986, the sump ventilation system was removed, and a HRV was hung from the floor joists in the unfinished laundry room between the wood stove and the boiler. This was the only location where the unit would not significantly affect headroom. The fresh air intake and stale air discharge were run through the rear wall header board and siding. A 7" divided duct hung beneath the floor joists carried fresh air to a floor grille in each of the two bedrooms above the laundry room. The discharge air was drawn directly from the laundry room, which was connected by an open doorway to the recreation room. That room was connected to the upstairs by the basement stairs. The stair door was normally left open.

The fresh air flow into the house was 81 L/s with the HRV on high, and 70 L/s on low. As the noise was much less on low, the standard setting was "low". The stale air flows were difficult to measure, as the duct had several bends close together, but the measured flows were close to the supply flows, so the HRV was in approximate balance.

In February 1986, with the HRV on low, the radon concentration upstairs varied between 1.5 to 3 pCi/L averaging 2 pCi/L, and in the basement ranged from 19 to 44 pCi/L, averaging 25 pCi/L. When the basement door was closed, the average concentration upstairs was unchanged, but basement concentrations varied between 41 to 58 pCi/L, averaging 45 pCi/L.

Although the results upstairs were satisfactory, the results in the basement suggested that the HRV had virtually no effect there.

A set of tests was carried out in April 1986. First, the HRV was run continually on high, turned off for a day, then run on low. Concentrations upstairs averaged 3 pCi/L regardless of fan speed, and averaged 10 pCi/L with the fan off. Concentrations in the basement averaged 57 pCi/L on high, 49 pCi/L with the fan off, and 38 pCi/L on low, confirming that the effect in the basement was negligible.

The manufacturer's representative visited the site with the contractor, rebalanced the unit, and suggested that greater reductions in the basement concentrations would be achieved if the HRV were installed to ventilate the basement alone. Accordingly, the layout was temporarily modified to close the discharge to upstairs, and deliver 110 cfm of fresh air to the far end of the recreation room. Stale air was still extracted from the laundry room.

In April 1986, concentrations upstairs averaged 6 pCi/L with the HRV fan on high, 8 pCi/L with the fan on low, irrespective of the basement door being open or closed and 20 pCi/L with the fan off. In the basement, concentrations averaged 80 pCi/L with the fan off, 15 pCi/L on both high and low, and 10 pCi/L on low with the basement door closed.

A final test was carried out in April 1986 by rerouting the stale air discharge from the HRV so that it discharged into the basement. The HRV now acted as a simple ventilation fan delivering 66 L/s to the basement, and recirculating 70 L/s in the laundry room.

When the fan was turned on at high the basement concentration initially varied between 6 to 35 pCi/L, but leveled off at 6 pCi/L. When the fan was turned off, concentrations rose rapidly to average 35 pCi/L. Concentrations upstairs averaged 5 pCi/L with the fan on, and rose to 10 pCi/L when the fan was turned off.

The ducting was modified in May 1986, with an additional fresh air discharge grille into the recreation room, and a stale air discharge into the basement. Both discharges, the ratio of the air flows to upstairs and downstairs, and the ratio of supply to discharge air could be adjusted over a wide range by dampers. No measurements of system performance could be made at that time for the weather was warm, and the "fan off" concentrations in the basement were less than 6 pCi/L. An attempt was made to measure if there was a change in the ratio of radon to its progeny with operation of the HRV. The low concentrations limited the accuracy of the measurements, but the result was that operation of the HRV did not seem to cause a major change in the ratio.

After the ducting change the owners remarked that the basement now had a marked "cat" smell when the unit was running. An exterior check found that the fresh air inlet was directly behind an evergreen bush. If the leaves were crushed, the smell was similar to that in the basement, and so the springtime growth of the bush was assumed to be the cause of the basement odour.

2.3. PHASE 3

Additional tests were carried out in January 1987. The radon concentrations were measured upstairs and downstairs in the family room and the furnace room with the HRV operating on high speed as a fan. This configuration had been the most effective in the spring. Airflows were divided 35 L/s to the family room and 35 L/s upstairs, with approximately 80 L/s recirculating in the furnace room.

The concentration upstairs varied from 2 to 9 pCi/L, averaging 5 pCi/L. In the family room concentrations ranged from 6 to 30 pCi/L, averaging 16 pCi/L, and in the furnace room they ranged from 5 to 18 pCi/L, averaging 11 pCi/L.

The damper on the unit was then closed in the middle of a second run so that stale air was discharged outside, not recirculated in the furnace room. The unit now operated as a HRV. Flows were approximately 10 L/s to the family room, 40 L/s to upstairs. Upstairs concentrations initially ranged from 2 to 9 pCi/L, averaging 6 pCi/L. After the change, they ranged from 2 to 7 pCi/L, averaging 4 pCi/L. In the family room, concentrations initially ranged from 14 to 32 pCi/L, averaging 22 pCi/L. After the change, they ranged from 1 to 26 pCi/L, averaging 21 pCi/L. In the furnace room initial concentrations ranged from 5 to 18 pCi/L, averaging 12 pCi/L. After the change, they ranged from 5 to 13 pCi/L, averaging 9 pCi/L.

The conclusion was that no significant improvement in performance was obtained by running the system on 100% fresh air, and the forced air flow into the basement was not sufficient to control the concentrations there.

The consistent difference between the family room and the furnace room was remarkable, as the two rooms are connected by an open doorway. Even when the HRV withdrew 80 L/s from the furnace room, this did not induce enough airflow from the family room to give similar concentrations in each room.

The airflows into the house and the inter-floor flows were measured during these tests with PFT passive samplers. The errors in the calculated flow rates were large (20%), due to the short time that the collectors were exposed in the house. When the HRV ran as a fan with no basement exhaust, the calculated fresh air flow into the basement was 9 L/s, with a flow of basement air to upstairs of 10.7 L/s. The main floor fresh air flow rate was 31 L/s, with a flow of upstairs air to the basement of 9 L/s.

When the HRV exhausted from the basement, the calculated fresh air flow into the basement was 8 L/s, with a flow of basement air to upstairs of 5 L/s. The main floor fresh air flow rate was 66 L/s, with a flow of upstairs air to the basement at 13 L/s. These calculated basement fresh air flows are much less than the ones measured at the HRV. The results were received too late to carry out further investigations to resolve these differences. The PFT's do indicate that the ventilation rate upstairs is higher than in the basement, and that the transfer flows between floors are affected more by changes in the system than the ventilation rates.

Alpha track detectors were issued in February 1987 for final long term measurements.

A final test of the spatial variability of radon concentration was carried out in April 1987. The HRV was set to supply fresh air at 19 L/s to upstairs, 57 L/s to the basement family room, and to exhaust 57 L/s from the basement laundry room. The radon concentrations in the basement family room ranged from 3 to 31 pCi/L, averaging 12 pCi/L, while radon concentration in the adjacent laundry room ranged from 3 to 13 pCi/L, averaging 8 pCi/L. With the HRV off, radon concentrations in the family room ranged from 30 to 47 pCi/L, averaging 40 pCi/L, and radon concentrations in the laundry room ranged from 25 to 37 pCi/L, averaging 31 pCi/L. Although operation of the HRV definitely reduced concentrations in both rooms to about 25% of the initial values, the ratio of the laundry room concentration to that in the family room was unchanged. This illustrates the difficulty of modifying the natural circulation patterns that exist in a house.

3. OTHER MEASUREMENTS

The radiation fields around and inside the house were 9 to 13 uR/h on the site, and 7 to 9 uR/h generally in the basement, averaging 10 and 8 uR/h respectively. Locally higher fields of 10 to 12 uR/h were found by the sump, in the cedar closet, and in other areas where a second floor slab had not been poured.

The average radon concentration measured by alpha-track detectors over the period February 1987 to April 1987 was 7.6 pCi/L in the basement, and 4.1 pCi/L in the living area.

MEASUREMENTS SUMMARY FOR HOUSE 17

PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	MEAN	COMMENTS
1	Sump ventilation 50 L/s centrifugal fan	08/85	Fan off	5-44	28	over 26 hrs
			Fan on	6-21	13	over 22 hrs still falling
2	As above	01/86	Fan on	12-28	20	over 69 hrs
2	HRV; 100 L/s centrifugal fan (upstairs supply basement exhaust)	02/86	HRV low	19-43	25	over 46 hrs B
			HRV low	1- 3	2	over 46 hrs U
			B door closed	41-58	45	over 15 hrs B
			B door closed	1- 3	2	over 15 hrs U
	As above	04/86	HRV high	36-70	57	over 22 hrs B
			HRV off	23-72	49	over 24 hrs B
			HRV low	13-56	38	over 23 hrs B
			HRV high	1- 4	2	over 23 hrs U
			HRV off	1-17	10	over 23 hrs U
			HRV low	1- 3	2	over 21 hrs U
	Basement supply and exhaust	04/86	HRV high	37-53	46	over 25 hrs B
			HRV off	45-91	72	over 24 hrs B
			HRV low	34-57	46	over 23 hrs B
			B door closed	22-48	37	over 26 hrs B
			HRV high	2- 7	5	over 24 hrs U
			HRV off	6-24	17	over 24 hrs U
			HRV low	6-11	8	over 22 hrs U
			B door closed	4-12	8	over 26 hrs U
2	Fresh air ventilation 100 L/s centrifugal HRV providing basement supply and stale air recirculation	04/86	HRV high	5- 7	6	over 17 hrs fall from 35 pCi/L B
			HRV off	30-47	35	over 21 hrs B
			HRV high	3- 7	5	over 43 hrs U
			HRV off	8-14	12	over 14 hrs U

MEASUREMENTS SUMMARY FOR HOUSE 17 (CONT)

PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	MEAN	COMMENTS
3	fresh air ventilation	01/87	HRV high	5-18	12	over 4 days furnace room
	100 L/s centrifugal fan			6-30	16	over 4 days family room
	HRV providing			2-10	5	over 4 days U
	upstairs and family room			6-16	11	over 46 hrs furnace room
	supply basement stale air			14-32	22	over 46 hrs family room
	recirculation			2-10	6	over 46 hrs U
3	As above HRV supplying	01/87	HRV high	5-13	9	over 4 days furnace room
	upstairs and family room			4-26	21	over 1 days family room
				2- 7	4	over 4 days U
		01/87	HRV high	3-13	8	over 46 hrs furnace room
			HRV off	25-37	31	over 18 hrs furnace room
			HRV high	3-31	12	over 46 hrs family room
			HRV off	30-47	40	over 48 hrs family room

B: Basement

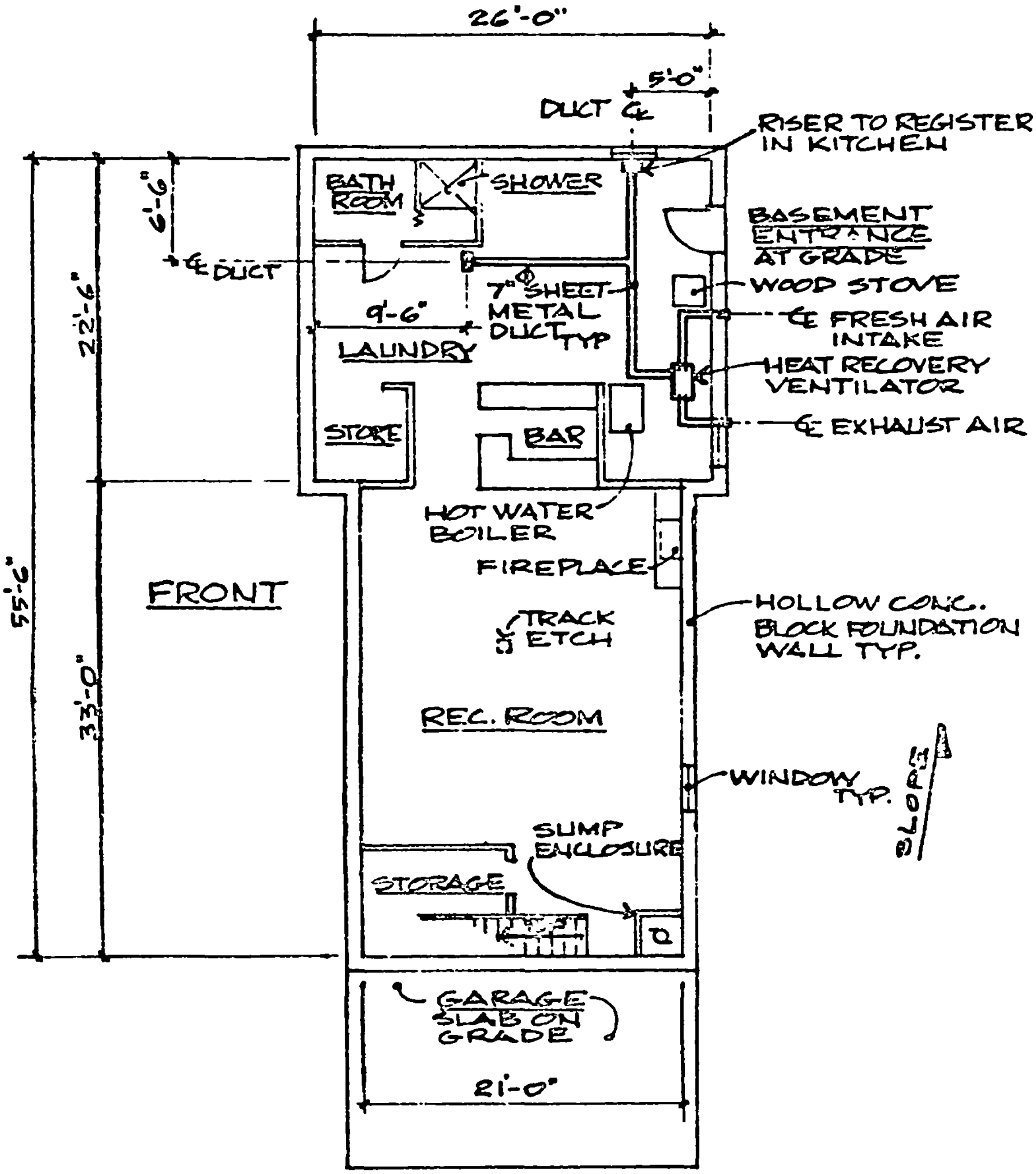
SYSTEM MEASUREMENTS FOR HOUSE 17

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
2	Heat Recovery	02/86	8	81		Intake*
	Ventilation 100 L/s		13	136		Intake*
	centrifugal -		13	78		Exhaust*
	upstairs supply		20	100		Exhaust**
	basement exhaust			69		Total supply*
			4	81		Total supply**
			3	31		Branch 1*
			3	45		Branch 2*
			3	42		Branch 2**
2	HRV 100 L/s	01/86		64		Total supply*
	centrifugal upstairs			25		Branch 1*
	supply basement					
	exhaust					
2	As above but basement	04/86	33	67		Total supply**
	supply and exhaust			63		supply to
						family room**
2	HRV 100 L/s	05/86	5	79		Exhaust**
	centrifugal fan		5	66		F supply**
	supply to			66		B supply**
	basement/family room		5	0.1		U supply**
	basement exhaust					
						Basement Measurements
						WL F
					3.9	0.018 0.16**
					3.0	0.011 0.36**
					3.6	0.019 0.54***
					3.5	0.015 0.43***
					4.2	0.022 0.52***
					6.1	0.021 0.39***
					5.8	0.026 0.45***
3	Fresh air ventilation	01/87		63-76		Intake **
	100 L/s centrifugal			76		Recirc.**
	fan HRV providing			35		F supply**
	upstairs and family			41		U supply**
	room supply basement			9		Branch 1**
	recirculation			23		Branch 2**

SYSTEM MEASUREMENTS FOR HOUSE 17

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS			COMMENTS
			PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	
3	Fresh air ventilation 100 L/s centrifugal fan HRV providing upstairs and family room supply basement recirculation	01/87		42		F supply**
				43		U supply**
				9		Branch 1**
				24		Branch 2**
	As above	01/87				Flows via PFT Samplers
				9		Into B**
				11		B to U**
				34		Fresh air to B**
				9		U to B**
3	HRV 100 L/s centrifugal fan supply to upstairs and family room basement exhaust	01/87		8		Into B**
				5		B to U**
				66		Fresh air to U**
				13		U to B**
	As above	01/87		56		Intake**
				57		Exhaust**
				57		F supply**
				19		U supply**
				54		Intake*
				48		Exhaust*
				49		F supply*
				17		U supply*

B: Basement
F. Family room
U: Upstairs
* HRV on low
** HRV on high
***HRV off



LOW COST REDUCTION OF INDOOR RADON			HOUSE NUMBER
FOUNDATION PLAN		Date: 2/16/86	17
Mitigation system: COMMERCIAL HEAT RECOVERY VENTILATOR		PHASE: FINAL	

HOUSE 18

PENNSYLVANIA DER MEASUREMENTS

Working Level grab samples (Kusnetz)	0.381 WL
Heating season short term average WL (RPISU)	0.014 WL
Heating season average radon (Terradex)	12 pCi/L
Radon concentration in water	1 800 pCi/L

1. DESCRIPTION

This two story house with attached double garage was built in the late 1970's on a level site on the top of a ridge in a rural subdivision west of Boyertown. The basement has concrete block walls and an external entrance. The house is heated by hot water radiators with an oil-fired boiler. There is a heat exchanger on the boiler chimney through which basement air is fan-driven to be heated when the burner is operating.

The poured concrete floor slab is unpainted but partially carpeted. There are no visible floor cracks, and no individual floor drains. There is an interior perimeter drain (french drain) between the edges of the slab and the outer basement walls, and a single construction joint down the centre of the floor slab. A brick fireplace is built on top of the floor slab.

The hollow concrete block walls are unfinished and in good condition, with no significant cracking of the mortar joints. The walls are open at the top, and are penetrated by service pipes for sewage and water. There is an external stairway into the basement at the rear of the house.

A front porch concrete slab runs along the front of the house, and the space beneath it is enclosed by concrete block walls to form an unventilated and unheated storage room, reached by a door in the front basement wall. There is no french drain in this space.

2. ACTION

2.1. PHASE 1

The mitigative action chosen for demonstration in this house was to increase the house ventilation rate. Radon concentrations were relatively low, and there were multiple potential routes of entry.

In July 1985, basement radon concentrations ranged from 6 to 31 pCi/L, averaging 16 pCi/L.

The basement ventilation was increased by routing a fresh air duct from the outside to the heat exchanger on the boiler chimney. When the burner was operating, it would draw in outside air to replace that lost up the stack. This would reduce the depressurization that draws in the soil gas. The air was warmed before it was discharged into the basement.

The performance of this system could not be tested in the summer, for the additional air supply would be proportional to the time that the boiler was operating, and should work best when the heating load was high. Testing was therefore deferred until the winter.

2.2. PHASE 2

In November 1985 with the exterior air supply operating, the radon concentration in the basement varied between 7 to 69 pCi/L, averaging 21 pCi/L. The air supply through the duct was about 22 L/s when the fan was off, and 36 L/s when the fan was on.

As this increased ventilation was not sufficient to reduce radon concentrations, a commercial heat recovery ventilator (air to air heat exchanger) was installed by a local contractor who had installed other units for radon control. His suggestion was that the unit be installed in the basement with split distribution. The fresh air would be delivered upstairs through two registers, one at each end of the house, and the exhaust air would be drawn directly from the basement. This would produce the lowest radon concentrations in the living space. Installation was carried out in February 1986. The HRV provided 85 L/s of fresh air to the upstairs on high and 70 L/s on low fan speed. The noise was much less on low speed, and the flows only slightly lower, so the owners normally operated the unit on low speed.

Radon concentrations were measured in February 1986 simultaneously in the basement and on the main floor. With the HRV on, main floor concentrations ranged from 1 to 1 pCi/L, averaging 2 pCi/L; and in the basement ranged from 5 to 21 pCi/L, averaging 12 pCi/L.

With the HRV off, main floor concentrations ranged from 1 to 11 pCi/L, averaging 8 pCi/L; and in the basement ranged from 10 to 20 pCi/L, averaging 15 pCi/L.

Performance of this system was regarded as satisfactory, for it had reduced main floor concentrations to less than 5 pCi/L. However, the experience of the installer and manufacturer with similar systems was that basement concentrations were generally reduced by more than the 20% observed here. Further investigations were carried out to see if a reason could be found for the lower than average reduction in the basement.

In March 1986, ventilation airflows into the basement via the outside air duct were 24 L/s with the burner off, and 40 L/s with the burner on. The house supply rate via the HRV on 'low' was 47 L/s. Switching the HRV to 'high' increased the supply to 53 L/s, and decreased the airflow through the outside air duct to 21 L/s, suggesting that the effect of the HRV was to pressurise the basement slightly.

In March 1986, radon concentrations in the basement and on the main floor were 10 pCi/L and 0.8 pCi/L respectively with the HRV on 'Low'; 10 pCi/L and 1.0 pCi/L with the HRV on 'high'; and 11 pCi/L and 2.1 pCi/L with the HRV off.

The HRV manufacturer's representative and the installer visited the site at the start of this test, and found that exchanger was apparently unbalanced, with the exhaust flow exceeding supply flow in the ratio of 3 to 2. A damper was readjusted to balance the flows.

A stiff breeze was blowing at the time of the measurements, and it was suggested that the change in HRV balance since installation may have been caused by a nonuniform wind pressure distribution on the HRV exterior intake and exhaust points. These were located on the rear wall of the house, near the corner, separated by about 3.5 m.

The representative recommended that the basement door undercut be increased from 2 to 4 cm to provide a greater return air flow from the main floor. This was done after the short term measurements were completed. He also suggested that the upstairs air might be travelling directly to the HRV rather than mixing with the basement air generally, and so the monitor at the other end of the basement would overestimate the average concentration in the basement, and that performance might be improved if some air was discharged into the basement to induce mixing.

Subsequent to this test the weather became warm enough that windows were frequently opened, so further tests were deferred till the following winter.

2.3. PHASE 3

In February 1987, the radon concentrations were measured upstairs and in the basement with the HRV set to ventilate the basement alone. The ducting was modified to deliver air to the far end of the basement from the HRV exhaust and angled to promote circulation in the basement. In this mode the upstairs radon concentrations ranged from 1 to 7 pCi/L, with an average of 4 pCi/L. The basement radon concentrations ranged from 7 to 26 pCi/L, with an average of 13 pCi/L.

The ducting was then returned to discharge air upstairs only. Radon concentrations upstairs ranged from 1 to 4 pCi/L, averaging 2.5 pCi/L, while concentrations in the basement ranged from 10 to 37 pCi/L, averaging 15 pCi/L. When the HRV was turned off, upstairs radon concentrations ranged from 2 to 15 pCi/L, averaging 9 pCi/L, and basement radon concentrations ranged from 16 to 35 pCi/L, averaging 24 pCi/L.

The basement and house ventilation rates and inter-floor transfer rates were measured with passive PFT tracer sources and collectors. The accuracy of these measurements was low (20%) as only one source was used on each floor, and the detectors were deployed for only two or three days.

When the HRV was set to ventilate only the basement, the airflow into basement was 185 L/s, with a transfer flow to upstairs of 39 L/s. The airflow out of the main floor was 265 L/s, with a flow into the basement of 1 L/s. When the HRV was set to deliver air upstairs, and exhaust from the basement, the airflow into the basement was 253 L/s, with a flow to upstairs of 50 L/s. The airflow out of the main floor was 157 L/s, with a flow into the basement of 4 L/s.

During these tests the HRV delivered air to the basement at 67 L/s, and to the upstairs at 67 L/s, and exhausted at about 80 L/s. The airflow out of the basement via the basement door undercut was measured at 39 L/s, when the HRV was discharging air upstairs. Even though the calculated flows are only good to about 20%, it is plain that the basement and main floor airflows are much larger than those produced by the HRV, and the effect of changes in the mode of operation are small - perhaps smaller than those caused by weather changes. This may be the explanation why the measured fresh air flow to upstairs should be smaller when the HRV is discharging 67 L/s upstairs than when there is no additional fresh air supply at all.

This series of tests showed that the poor basement performance of the HRV was not a measurement artefact caused by inadequate circulation, or by insufficient return airflow from the upper floors, it was simply that the natural basement ventilation rate was higher than that produced by the HRV, and the percentage reduction in radon concentration was correspondingly lower.

Alpha track detectors were issued in February 1987 for final long term measurements.

3. OTHER MEASUREMENTS

The radiation field in and around the house was 5 uR/h in the basement and 6 to 7 uR/h on the site.

The average radon concentration measured by alpha-track detectors over the period February 1987 to April 1987 was 8.8 pCi/L in the basement, and 2.1 pCi/L in the living area.

MEASUREMENTS SUMMARY FOR HOUSE 18

PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	MEAN	COMMENTS
1	Premitigation	07/85	Survey	6-31	16	over 48 hrs
2	Increased ventilation fresh air ducted to heat exchanger on boiler chimney	11/85	Vent unit on	7-69	21	over 66 hrs
2	HRV upstairs supply	02/86	HRV on	5-21	12	over 18 hrs B
			HRV on	1- 4	2	over 18 hrs U
			HRV off	10-21	15	over 41 hrs B
			HRV off	4-11	8	over 45 hrs U
2	HRV upstairs supply	03/86	HRV on low	7-14	10	over 15 hrs B
			HRV on low	0.1-1.4	0.8	over 15 hrs U
			HRV on high	7-11	10	over 21 hrs B
			HRV on high	0.3-1.9	1.0	over 24 hrs U
			HRV off	7-18	11	over 29 hrs B
			HRV off	0.1-4.6	2.1	over 29 hrs U
3	HRV basement supply	02/87	HRV on high	7-26	13	over 4 days B
			HRV on high	1-7	1	over 4 days U
3	HRV upstairs supply	02/87	HRV on Low	10- 37	15	over 11 h B
			"	1- 4	2.5	" U
			HRV off	16- 35	24	over 14 h B
			"	2- 15	9	" U

B: Basement
U: Upstairs
HRV Heat Recovery Ventilator

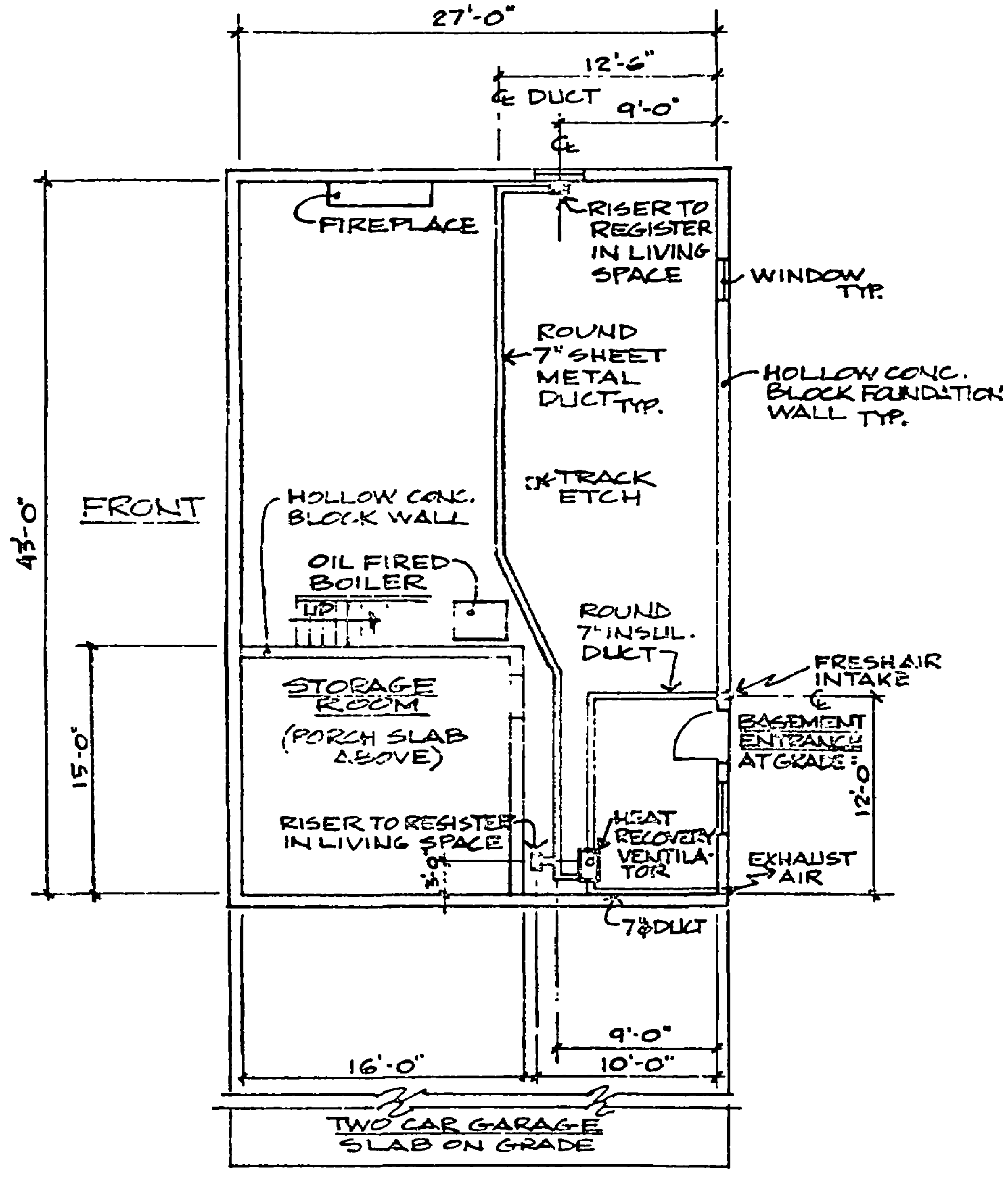
SYSTEM MEASUREMENTS FOR HOUSE 18

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
2	HRV upstairs supply	02/86	18	87		A -High
			10	71		A -Low
			17	101		B -High
			13	83		B -Low
			5	83		C -High
			3	63		C -Low
			10	54		D -High
			5	43		D -Low
2	HRV upstairs supply	03/86	5	24		Outside Airduct
			11	47		Blower off HRV supply low
			4	39		OAB off
			9	39		HRV supply high
			9	21		OAB off
			15	17		HRV supply high
			4	33		OAB on
			14	15		HRV supply high
			8	0.5		OAB blocked
			8	44		HRV supply low
			10	0.5		OAB blocked
			13	56		HRV supply high
3	HRV basement supply	02/87		88		High supply
				67		Low supply
		02/87				PFT results
				185		into basement
				59		basement to upstairs
				265		out of upstairs
				1		upstairs to basement

SYSTEM MEASUREMENTS FOR HOUSE 18

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
3	HRV upstairs supply	02/87		24		K -supply low
				43		D.Rm -supply low
	HRV upstairs supply					PFT results
				253		into basement
				50		basement to upstairs
				157		out of upstairs
				1		upstairs to basement
3	HRV upstairs supply	03/87	18	66		A - high
			13	57		A -low
			13	92		B -high
			10	79		B -low
			10	78		C- high
			8	75		C-low
				59		outflow via undercut

A: Fresh air intake
B: Exhaust
C: Total supply
D: Far supply branch
K: Kitchen
D.Rm: Dining room
HRV: Heat Recovery Ventilation
OAB: Outside Airduct Blower



ACRES	LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
	FOUNDATION PLAN	Date: FEB, 1987	18
	Mitigation system: COMMERCIAL HEAT RECOVERY VENTILATOR	PHASE: FINAL	

HOUSE 19

PENNSYLVANIA DER MEASUREMENTS

Working Level grab samples (Kusnetz)	0.327 WL
Short term average WL (RPISU)	0.003 WL
Average radon (Terradex)	32 pCi/L
Radon concentration in water	80 pCi/L

1. DESCRIPTION

This small two story house with attached garage was built in the late 1970's on a sloping site part way up the side of a hill near Boyertown. The walls are covered with aluminum siding. The basement walls are hollow concrete blocks. The central wooden beam is supported on notched blocks at the ends and a block pillar in the centre of the basement. Heating is by electric baseboards upstairs and a first floor fireplace.

The floor slab has a major crack that runs from front to rear of the house. The unfinished walls are free of cracks but are penetrated by sewer and water lines. The sill plate does not cover the voids in the top course of blocks.

2. ACTION

2.1. PHASE 2

The original intent in this house was to install a subfloor ventilation system and seal the walls. However, discussion with the owner after selection found that he had major plans for basement alteration including installation of a doorway into the garage, which would require cutting through the garage wall. It was unlikely that the seals could be maintained. As a result, the plan was changed to wall ventilation since that could deal with increased leakage area, the house was small, the top of walls was accessible and the floor was in good condition. This house was only a few doors down the street from house #8, and was of identical design, so it was expected that equally good results could be obtained with wall ventilation in this house.

The top block voids were stuffed with fiberglass insulation as support material and closed with mortar. The beam pockets were filled with expanding urethane foam.

Holes were cut in the second course of each wall and a 4-inch lightweight plastic pipe installed in each hole and sealed in place with silicone caulk. These wall entry pipes were connected to a 4-inch pipe running the length of the central beam. The central pipe was exhausted through a 4-inch PVC pipe to a wall mounted centrifugal fan installed on the outside of the rear block wall.

In April 1986, with the system fan turned off radon concentrations rose slowly to reach an average of 40 pCi/L and with the fan on concentrations fell slowly to average around 12 pCi/L.

System measurements in April 1986 showed flows of 6 and 7 L/s out of the three subgrade walls and 17 L/s out of the garage wall. Fan suction was 13 Pa. Radon concentrations measured 12 pCi/L in the front wall, 15 pCi/L in the rear wall, 45 pCi/L in the garage wall and 40 pCi/l in the end wall. The basement air radon concentrations was 2.5 pCi/L at that time.

A smoke stick survey of the walls found that the airflow was positively from the house into the walls, but there seemed to be a small flow into the house from the floor crack. This was confirmed by a small enclosure taped over the floor crack which accumulated 140 pCi/l in 15 minutes. A sample of sub-slab air taken through a hole drilled in the slab gave 800 pCi/L.

In May 1986 the owner refused permission to extend the wall ventilation system to subslab ventilation. Concern was expressed that breaking through the floor slab would lead to leakage of water from below the slab. Since warm weather had arrived it was elected to await the heating season for further measurement of radon concentrations.

2.2. PHASE 3

In December 1986 with the system fan off, the radon concentrations in the basement were 1 pCi/L, and rose to 17 pCi/L when the fan was turned on. This suggested that the air leakage into the walls was depressurizing the basement slightly and encouraging the entry of soil gas through the floor crack. The suction in the walls was not transmitted to the subfloor space.

Since no additional work was permitted by the owner, Alpha Track detectors were issued in December 1986 to determine long term averages upstairs and in the basement during the heating season.

3. OTHER MEASUREMENTS

The radiation field within the house ranged from 5 to 9 uR/h, averaging 7 uR/h. On the site the field ranged from 5 to 8 uR/h, averaging 6 uR/h.

The average radon concentration measured with Alpha Track detectors over the period December 1986 to March 1987 was 32.0 pCi/L in the basement and 0.6 pCi/L in the living area.

MEASUREMENTS SUMMARY FOR HOUSE 19

PYLON AB-5 HOURLY MONITORING

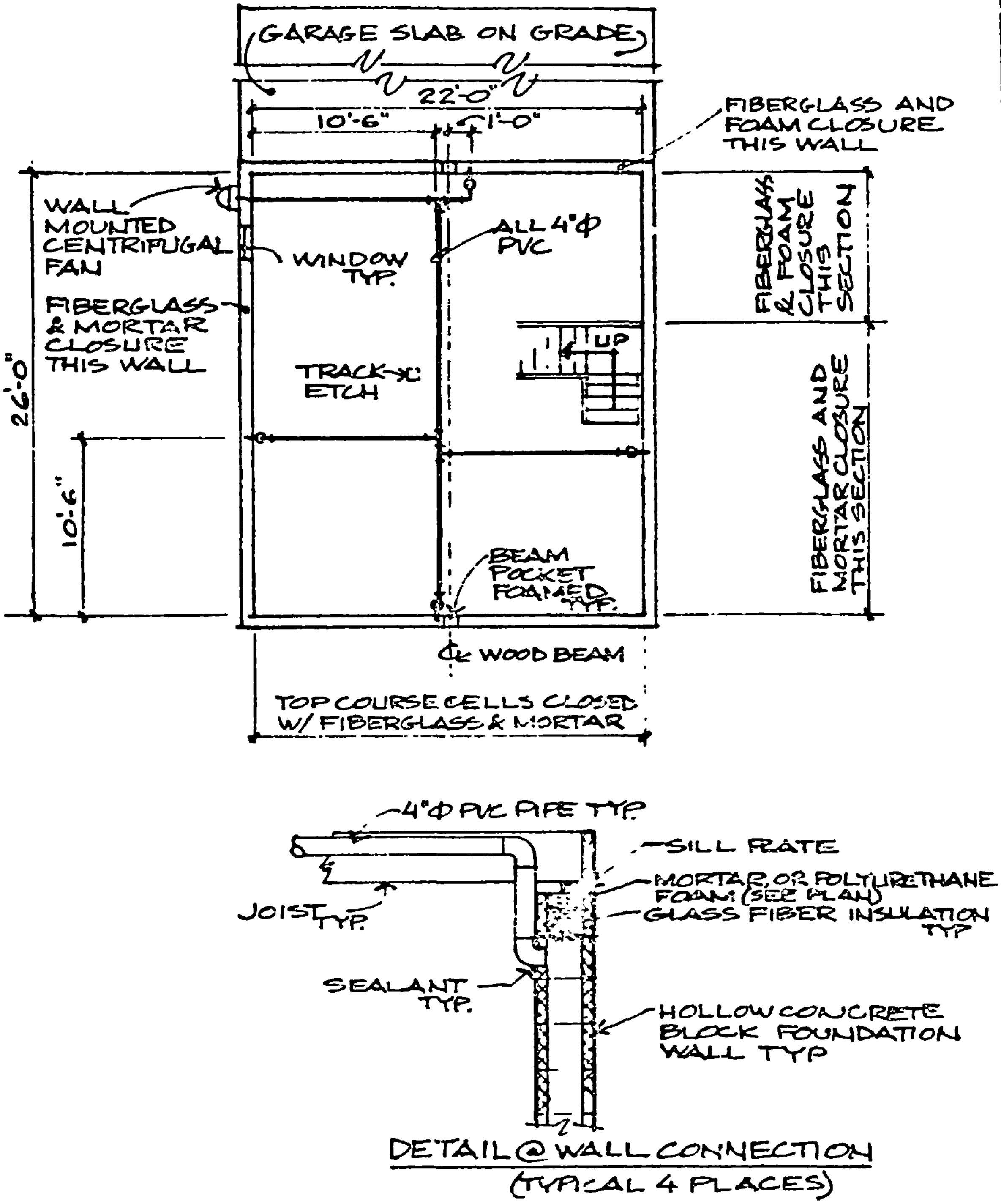
PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	RADON (pCi/L) MEAN	COMMENTS
2	Wall ventilation 100 L/s centrifugal fan	04/86	Fan off	6-43	40	10 hr mean after 43 hr rise to equilibrium.
			Fan on	11-51	12	7 hr mean after 39 hr fall to equilibrium
3	As above	12/86	Fan on	1-17	10	Rose slowly over 4 days.

SYSTEM MEASUREMENTS FOR HOUSE 19

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
2	Wall ventilation 100 L/s centrifugal fan	01/86		6	28	Pipe A
				7		Pipe B
				17		Pipe C
				7		Pipe D
				21		Main duct for Pipes A,B&D
			43		59	At fan
2		04/86			12	Pipe A
					15	Pipe B
					45	Pipe C
					40	Pipe D
					3	Basement air
					800	Floor crack-direct sample
					120	Floor crack-15 min. bag
					100	Floor crack - 15 min.bag

Pipe A - Front wall
Pipe B - Rear wall
Pipe C - Garage wall
Pipe D - End wall

Owner refused further work.



AGRES	LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
	FOUNDATION PLAN	Date: 4/11/86	19
	Mitigation system: WALL SUCTION	PHASE: FINAL	

HOUSE 20

PENNSYLVANIA DER MEASUREMENTS

Working Level grab samples (kusnetz)	1.021 WL
Heating Season short term average WL (RPISU)	0.170 WL
Long Term average radon (Terradex)	210 pCi/L
Radon concentration in water	68 800 pCi/L

1. DESCRIPTION

This single story house was built in the late 1970's on a sloping site on the side of a hill some miles west of Oley. The walls are of siding, and heating is by oil fired forced warm air, supplemented by wood stoves on the main floor and basement.

The basement walls are of concrete block. Three walls are buried, the fourth (end) wall contains a garage door and an entry door. The sill plate covers the block voids. About 80% of the walls are covered with cement-based paint. There is a basement washroom.

The basement floor slab is in good condition, penetrated by 4 hollow house jacks, a basement floor drain, and a garage floor drain.

2. ACTION

2.1. PHASE 2

As the floor slab in this house was in one piece, the mitigation measure chosen for demonstration in this house was sub-slab ventilation. As the basement was rectangular, the initial design was for two exhaust points located on the centre line of the basement.

Two 20 cm diameter holes were cut through the floor slab by a coring drill. The subslab fill was of crushed stone. A "6 inch" vertical pipe of lightweight plastic was placed in the hole, the space between the pipe and concrete closed with asphalt cement, protected with a layer of quick-set grout. The vertical pipes were joined to a horizontal "6 inch" lightweight plastic pipe which ran along the main beam to the garage wall and was connected to a large centrifugal fan mounted on that wall.

In April 1986, the radon concentration in the basement with the fan on ranged from 20 to 33 pCi/L, averaging 27 pCi/L. When the fan was turned off, the concentration rose slowly reaching a maximum of 700 pCi/L after 24 hours, at which time the fan was turned on again, causing the concentration to fall slowly over the next 40 hours to 2 pCi/L.

Investigation found that air was drawn down into the sub-slab space through the hollow house jacks and at the wall/floor joint. The fan drew 1.5 L/s at 90 Pa suction at each pipe, and the radon concentration in the pipes was 2 200 pCi/L and 2 800 pCi/L. Samples from the floor drains in the garage and laundry areas respectively showed radon concentrations of 6 and 60 pCi/L.

The central location of the exhaust pipes produced the greatest suction in the middle of the under floor space where there were few openings to allow soilgas entry. The smallest suction was at the edge of the slab, where the wall/floor joint was a large potential entry route. If the exhaust pipes were near the edge of the floor slab, then the greatest suction would be near the large entry routes of the wall/floor joint and the base of the concrete block walls. This layout had not been considered previously, for a large amount of work would be needed to cut multiple holes with an air hammer. As the coring drill could produce holes rapidly, this layout could now be achieved at lower cost and with less mess.

Accordingly, the layout was changed to test if the performance could be improved. Exhaust locations were selected on the basis of two equally spaced holes on each long wall, and one on the short wall. An exhaust pipe could not be located conveniently by the garage door wall, and so there were only five exhaust points. The core drill was used to cut 12.5 cm holes about 2 cm from the wall. These holes partially intersected the footing, which was broken away to ensure that at least 50% of the hole area was unobstructed. There was about 1 cm of fine material between the top of the footing and the floor slab, and at least 6 cm of crushed stone under the floor. The fan and central collection pipes were still in operation when the holes were drilled. Suction extended to the walls, for smoke was drawn down each hole.

A "1 inch" lightweight plastic pipe was placed in each hole and the space between the pipe and concrete filled with asphaltic cement. The pipes reached to the basement ceiling and ran in the joist space to the "6 inch" central pipe.

In May 1986, the radon concentration in the basement with the fan on ranged from 9 to 35 pCi/L, averaging 20 pCi/L. When the fan was turned off concentrations ranged from 150 to 280 pCi/L, averaging 220 pCi/L.

Investigation found that the suction at each pipe was 85 Pa. The flow and radon concentration in the five pipes varied greatly; front wall 0.15 L/s at 270 pCi/L; front wall 3 L/s at 480 pCi/L; end wall 4.3 L/s at 120 pCi/L; rear wall 6.5 L/s at 6 500 pCi/L; rear wall 2.2 L/s at 780 pCi/L. Either the soilgas concentration varied greatly from place to place under the floor slab, or else there was considerable dilution of the soilgas at some locations. This could be caused by house air drawn into the subslab space at openings in the floor slab or by wall air drawn through joints between the concrete blocks and the footing.

A smoke stick check found that airflow was into the sub-slab space at all visible floor openings, but air flowed into the house from the upwind sections of the basement walls. There was a marked airflow from the end wall at the pilaster supporting the main beam, with a radon concentration of 16 pCi/L. This confirmed that radon was entering the walls in addition to outside air.

The sub-slab system had made a major reduction in radon supply rate, but there was still a significant supply. To check that this was not due to minor floor entry routes, water was poured into the floor drain traps to ensure that they were closed, and the hollow steel house jacks were filled with expanding foam, after sampling. Radon concentrations within the four jacks were measured as 8, 9, 1 and 1 pCi/L.

If the exhaust pipes were drawing air from the walls (as the low soilgas radon concentrations suggested), then there was a possibility that the airflow and radon supply from the walls could be reduced simply by increasing the airtightness of the walls. To check this, the sill plate was caulked to the top of the walls, and the openings in the pilaster around the main beam were filled with expanding foam.

In May 1986, the airtightness of the walls was increased, radon concentrations in the basement with the fan running ranged from 1 to 22 pCi/L, averaging 12 pCi/L. After the work was completed, the range was from 1 to 22 pCi/L, averaging 12 pCi/L.

The conclusion was that the floor system was working well, and that more positive steps to ventilate the wall would be required to reduce the radon supply from that route. This work was left until the fall, when measurements could be made under more challenging conditions.

2.2. PHASE 3

During the summer of 1986 the owner extended the house to the rear, almost doubling the floor area by adding two bedrooms and a dining room on the main floor level. The extension had a suspended floor, and the foundation walls were made of concrete block, but the soil beneath the floor was covered with concrete with a loop of perforated pipe laid beneath and brought outside so that subslab ventilation could be added easily.

In November 1986, the existing sub-slab system was modified to ventilate the original basement walls as well. The exhaust pipes were cut at 30 cm from the floor, and a 'Tee' inserted. A 6 cm diameter hole was cut in the block wall about 25 cm from the pipe, and a "1.5 inch" plastic drain pipe placed in the hole and connected to the exhaust pipe by a series of plumbing reducers.

Testing of the slab and wall ventilation system showed the flows and suctions in the five wall entry pipes to be front wall 12 L/s at 88 Pa; front wall 5 L/s at 50 Pa; end wall 12 L/s at 88 Pa; rear wall 10 L/s at 75 Pa; rear wall 8 L/s at 58 Pa. High turbulence in the ducts made it difficult to measure flows, but the flows and suctions for floor entries were found to be . front wall 3 L/s at 63 Pa; front wall 2 L/s at 50 Pa; end wall 2 L/s at 55 Pa; rear wall 3 L/s at 50 Pa; rear wall 1 L/s at 63 Pa.

With the system so modified and operating radon concentrations were found to range from 7 to 11 pCi/l and averaged 10 pCi/l. When the fan was turned off, radon concentrations in the basement rose rapidly to a high of 257 pCi/L and averaged 177 pCi/l. They returned to an average of 10 pCi/L when the fan was turned on again, ranging from 6 to 13 pCi/L. These levels were comparable to those observed previously, so the change in the system had not made any major performance improvement.

The effect of the new extension on radon concentrations in the house was investigated by measurements in a bedroom in the extension. Concentrations varied from 5 to 60 pCi/L about a mean of 27 pCi/L. When a temporary centrifugal fan was connected to the extension subslab perforated pipe system below the crawl space slab, concentrations ranged from 2 to 37 pCi/l, averaging 11 pCi/l. The temporary fan delivered 1050 pCi/L air at flow rate of 52 l/s.

In January a more complete set of measurements were made both in the basement and upstairs with the extension fan on, then off. Basement levels averaged 12 pCi/L irrespective of fan condition, whereas the upstairs average increased from 11 to 31 pCi/L when the fan was turned off. Large peaks in basement concentrations (54, 88, 42 pCi/L) were found to coincide with laundering of clothes in the basement. Smaller residual peaks appeared on a delayed basis in the upstairs levels. This was consistent with the reported DER radon in water concentration of 69 000 pCi/L, and showed that water usage at this home could be a significant route of radon entry. None of the previous measurements had shown this peaking, but when questioned, the owner revealed that clothes washing had been avoided during all previous test periods.

In March 1987, a large plastic bodied centrifugal fan was installed to replace the basement system and provide the additional flow capacity needed to integrate the extension subslab ventilation system with the basement wall plus floor ventilation. The two systems were teed together at the top of a basement riser near the extension. This gave a flow of 52 L/s from the extension at 1 100 pCi/L of radon and 65 Pa suction. At the same time the basement riser connected to the tee showed a flow of 12 L/s at a concentration of 1700 pCi/L under a suction of 30 Pa. The new fan operated at a suction of 150 Pa to provide a flow in the main duct of 96 L/s at 550 pCi/L.

With the combined system in operation, radon concentrations upstairs averaged 12 pCi/L, with range 3 to 47 pCi/L, and in the basement radon concentrations averaged 8 pCi/L, with range of 2 to 65 pCi/L. Once again there were radon peaks when clothes were washed in the basement. At times when there was no water use for several hours, basement concentrations ranged from 2 pCi/L to 10 pCi/L about a mean of 5 pCi/L. Very large peaks were observed upstairs following showers and baths. This explains why the upstairs mean is larger than the basement mean, since with a family of four children, baths and showers are frequent occurrences.

In late March 1987 radon concentrations upstairs and in the basement were monitored while changes in the system were introduced. First, the average suction in the basement system was increased from 80 Pa to 110 Pa by closing a damper in the pipe linking the basement system to the extension. Neglecting peaks due to water usage, radon concentrations upstairs increased from an 11 hour average of less than 5 pCi/L to an 11 hour average of over 1[illegible] pCi/L, and in the basement increased from a 24 hour average of 3 pCi/L to a 9 hour average of 25 pCi/L, despite the increase in system suction.

The pipes into the walls were then disconnected, turning the system into a sub-slab system only. This increased the average suction at the floor from 110 Pa to 220 Pa. There was no significant change in the lowest radon concentrations measured in the basement which averaged 7 pCi/L, or upstairs which averaged 8 pCi/L. The improvement in sub-slab system suction did not seem to decrease the radon entry rate from the crawl space either. Flows and radon concentrations in the floor pipes under these conditions were; front wall 0.3 L/s at 260 pCi/L, 6 L/s at 330 pCi/L; end wall 10 L/s at 400 pCi/L; rear wall 12 L/s at 5 800 pCi/L, 3 L/s at 680 pCi/L. Smoke testing showed that air flowed from the house into the walls through the openings left by removal of the pipes, except at the first opening on the front wall, where there was a steady airflow of 0.5 L/s at 17 pCi/L into the house.

To determine if an optimum setting of the extension line damper existed, the damper was opened, and the flow varied from 27 to 38 to 51 L/s, still with the wall pipes disconnected. When radon peaks caused by water usage were removed from consideration the upstairs averages lay between 5 and 6 pCi/L and the basement averages lay between 4 and 5 pCi/L. Therefore, provided the extension system damper was at least partly open, no significant difference in radon concentration was observed. This was understandable as the system suction remained high, decreasing only from 212 Pa to 167 Pa as the damper position was varied from nearly closed to completely open.

As a final test, the damper was left fully open, and openings in the walls where the exhaust pipes entered were first taped closed, to check the effect of closing the walls, and then wall suction pipes were reconnected. Upstairs radon concentrations (discounting water peaks) showed minimal change from a range of 3 to 9 pCi/L and an average of 5 pCi/L; to a range of 4 to 5 pCi/L and average of 6 pCi/L. Basement concentrations fell from a range of 3 to 10 and an average of 6 pCi/L; to a range of 2 to 6 and an average of 4 pCi/L when the walls were ventilated, thereby confirming the hollow block walls as a small route of radon entry.

Alpha track detectors were issued in March 1987 to measure a longer term average radon concentration.

3. OTHER MEASUREMENTS

The well water radon concentration was remeasured by DER in April 1987. They found that the concentration was 112 500 pCi/L, significantly higher than the previous value of 68 800 pCi/L. This concentration was comparable to that measured in house #30, where the water was the major route of radon entry.

The radiation field in the house ranged from 6 to 15 uR/h, averaging 9 uR/h. The higher fields were in the vicinity of the hot water tank, which gave 39 uR/h on contact. The radiation field around the outside of the house ranged from 11 to 27 uR/h, averaging 16 uR/h. The highest readings were near the bank into which the house extension had been set.

The average radon concentration measured by alpha-track detectors over the period of March 1987 was 5.8 pCi/L in the basement, and 9.9 pCi/L in the living area.

MEASUREMENTS SUMMARY FOR HOUSE 20

PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	MEAN	COMMENTS
2	Central sub-slab ventilation, 100 L/s centrifugal fan	04/86	Fan on Fan off Fan on	20- 33 98-696 527- 22	27 - -	over 25 hrs. over 24 hrs of rise over 40 hrs. of fall
2	Peripheral sub-slab ventilation; 100 L/s centrifugal fan	05/86	Fan on Fan off	9- 35 150-280	20 220	over 46 hrs. over 46 hrs after 4 hrs. rise to equilibrium
		05/86	Fan on Fan on	4- 22 4- 22	12 12	wall airtightness increased
3	Basement sub-slab and wall ventilation; 100 L/s centrifugal fan	11/86	Fan on Fan off Fan on	7- 14 96-257 6- 13	10 177 10	over 18 hrs. over 18 hrs. over 34 hrs. after 18 hr return to equilibrium
	Plus crawl space sub-slab ventilation; 50 L/s centrifugal	01/87	Fan on	5- 60	27	over 2 days U
		01/87	Fans on	2- 55	11	over 2 days U
		01/87	Fans on	3- 88	12	over 2 days B
			Fans on	2- 18	11	over 2 days U
			*Fan off	4- 6	12	over 2 days B
			*Fan off	13- 82	31	over 2 days U

PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	MEAN	COMMENTS
3	crawl space +basement sub-slab and wall ventilation 150 centrifugal fan	03/87	Fan on	2- 65	8	over 4 days B
			Fan on	3- 47	12	over 4 days U
			Fan on	2- 10	5	basement neglecting water peaks

Neglecting water peaks from here onward

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	MEAN	COMMENTS
3	crawl space line dampered	03/87	Damper opn	1 5	3	over 24 hrs B
			Damper opn	2- 4	3	over 11 hrs U
			Damper clsd	4- 9	7	over 9 hrs B
			Damper clsd	11-14	13	over 11 hrs U
	line dampered +wall pipes removed	03/87	Damper clsd	5- 8	7	over 20 hrs B
			Damper clsd	6-10	8	over 22 hrs U
		04/87	Damper sl.opn	3- 9	5	over 37 hrs B
			Damper sl.opn	3- 9	6	over 25 hrs U
			Damper more.opn	3- 7	4	over 41 hrs B
			Damper more.opn	3- 7	5	over 22 hrs U
			Damper flly.opn	3- 7	1	over 42 hrs B
			Damper flly.opn	4- 7	6	over 10 hrs U
	line dampered + wall openings closed	04/87	Damper flly.opn	3-10	6	over 15 hrs B
			Damper flly.opn	3- 9	5	over 31 hrs U
	line dampered + wall pipes reconnected	01/87	Damper flly.opn	2- 6	1	over 35 hrs B
			Damper flly.opn	4- 9	6	over 20 hrs U

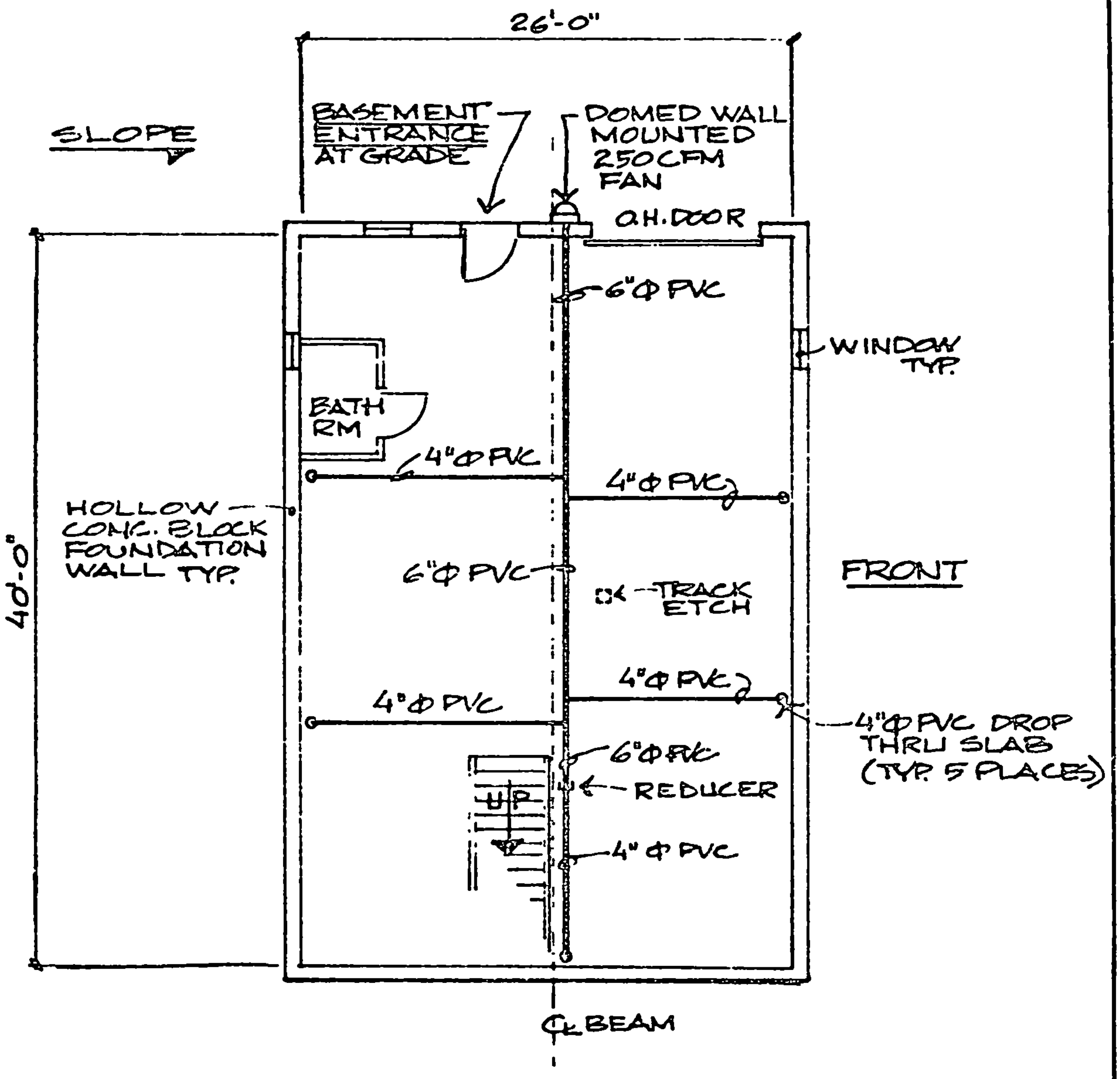
* Crawl space fan
B Basement
U Upstairs

SYSTEM MEASUREMENTS FOR HOUSE 20

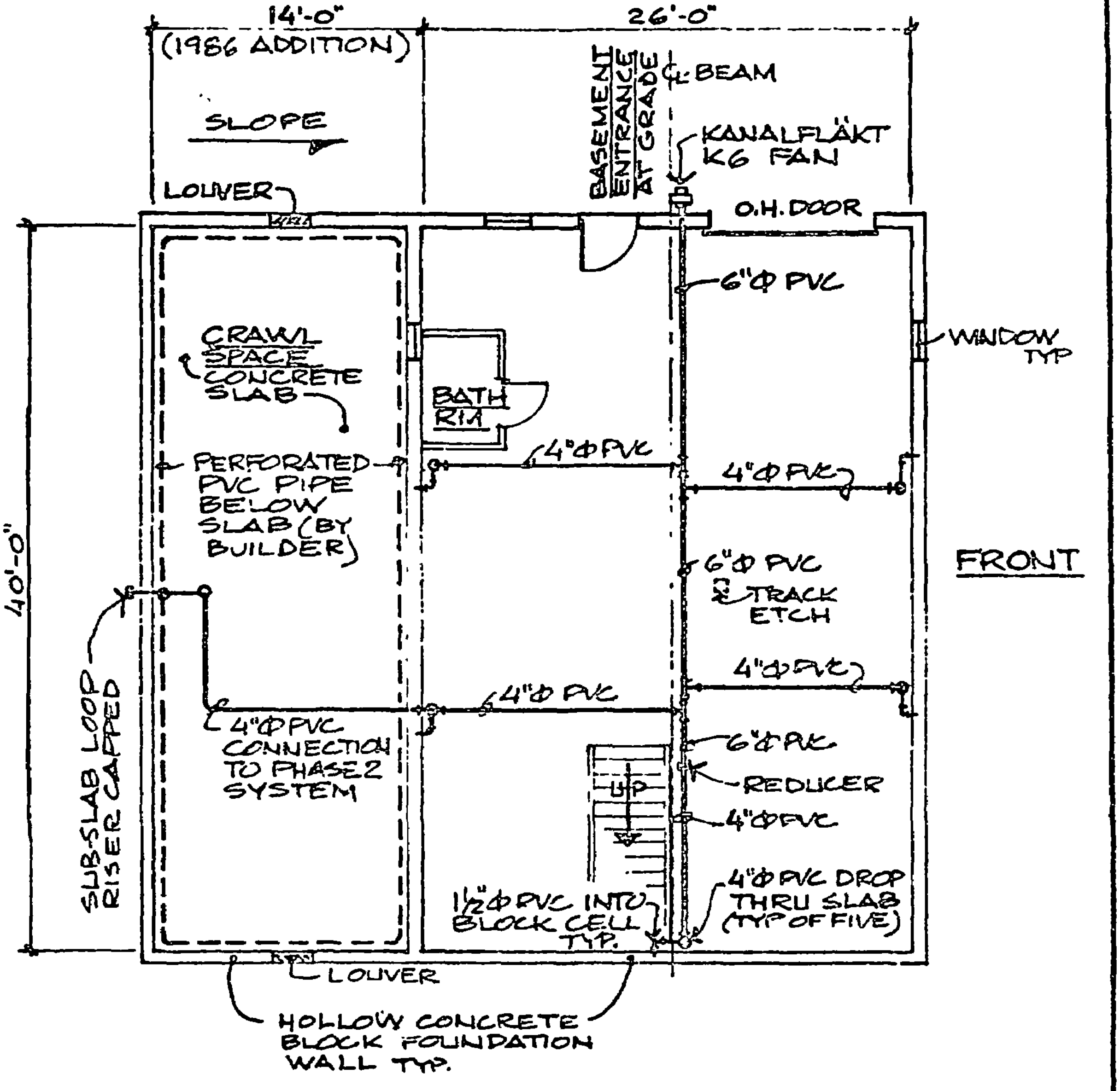
PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
2	Central sub-slab ventilation; 100 L/s centrifugal fan	04/86	90	1.5	2 200	Riser 1
			90	1.5	2 800	Riser 2
					6	Floor drain garage
					60	Floor drain laundry
	Peripheral sub-slab ventilation 100 L/s centrifugal fan	05/86	85	0.2	270	Riser A-Front
			85	3	480	Riser B-Front
			85	4	420	Riser C-End
			85	7	6 500	Riser D-Rear
			85	2	780	Riser E-Rear
					6	End wall pilaster
		05/86			8	House Jack 1
					9	House Jack 2
					4	House Jack 3
					4	House Jack 4
3	Basement sub-slab and wall ventilation; 100 L/s centrifugal fan	01/87	88	12		A- wall entry
			63	3		A- slab entry
			50	5		B- wall entry
			50	2		B- slab entry
			88	12		C- wall entry
			55	2		C- slab entry
			75	10		D- wall entry
			50	3		D- slab entry
			38	8		E- wall entry
			63	1		E- slab entry
3	As above plus crawl space ventilation; 50 l/s centrifugal fan	01/87		52	1 050	At crawl space fan
3	Crawl space + basement sub-slab and wall ventilation; 150 L/s centrifugal fan	03/87	65	52	1 100	Crawlspace pipe to tee
			50	12	1 700	D riser to tee
			150	96	530	Main duct run

SYSTEMS MEASUREMENTS FOR HOUSE 20

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
3	Crawl space damper open	03/87	95	16		A-Riser
			62	12		B- Riser
			100	17		C-Riser
			50	12		D-Riser
			95	13		E-Riser
			70	45		D-Horizontal
					2	D-Wall
	Crawl space damper closed	03/87	112	17		A-Riser
			100	13		B-Riser
			112	17		C-Riser
			100	16		D-Riser
			112	16		E-Riser
			75	4	560	B-floor
			67	7	8 500	D-Riser
				34		D-Horizontal
					310	A-Floor
					560	C-Floor
					2 200	E-Floor
	Damper closed + wall pipes removed	03/87	237	0.3	260	A-Riser
			212	6	330	B-Riser
			224	10	400	C-Riser
			249	12	5 800	D-Riser
			187	3	680	E-Riser
			199	41	2 900	D-Horizontal
	Pipes + damper partly open	04/97	212	9		D-Riser
			199	38		D-Horizontal
			212			Main Duct
	Pipes + damper more open		162	7		D-Riser
			167	45		D-Riser
			174			Main Duct
	Pipes + damper fully open		117	7		D-Riser
			122	61		D-Horizontal
			167			Main Duct



ACRES	LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
	FOUNDATION PLAN	Date: 4/29/86	20
	Mitigation system: SUB-SLAB SUCTION	PHASE: 2	



ACRES	LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
	FOUNDATION PLAN	Date: 2/27/87	20
	Mitigation system: WALL/SUB-SLAB SUCTION	PHASE: FINAL	

HOUSE 21

PENNSYLVANIA DER MEASUREMENTS

Working Level grab samples (Kusnetz)	0.553 WL
Heating season short term average WL (RPISU)	0.465 WL
Heating season average radon (Terradex)	172 pCi/L
Radon concentration in water	1 100 pCi/L

1. DESCRIPTION

This single story house with attached garage was built in the early 1960's on a sloping rural site on the side of a ridge a few miles west of Boyertown. The house walls are faced with brick, and heating is by oil fired hot water.

The garage floor is on the same level as the basement floor, and there is a door from the basement into the garage. The basement walls are of concrete block. The block voids are open at the top, and are partially covered by the sill plate. Almost all of the basement is partly finished. The walls are painted, there is a suspended ceiling, and a carpet is glued to the floor, except for a basement washroom that is tiled, and a small laundry area where the concrete floor is exposed. The well pressure tank is supported by two concrete blocks laid on their side. The voids penetrate the floor.

The owner said that there was a weeping tile drain round the house, which drained to a lower part of the site. There is an untrapped floor drain in the laundry room that probably connects to the weeping tile. There is a gap between the edge of the drain and the concrete.

2. ACTION

2.1. PHASE 2

As this house had a weeping tile drain, the mitigative action chosen for demonstration was weeping tile ventilation. An examination of the site could not find the discharge pipe from the weeping tile.

The situation was reviewed in detail. The garage slab was at basement floor level, and the garage had been added to the house. It was likely that the path of the original drain line was below the garage slab, and the drain tile along the house wall might well have been damaged or removed during the garage floor slab installation. It now seemed as if a major excavation would be required to reach the tile, rather than a simple job requiring only a minor amount of digging. There was no assurance that the tile would be continuous round the house as needed for a satisfactory soil gas collector.

In light of this, it was decided not to pursue the weeping tile route, but to examine alternative mitigation methods. The gap around the floor drain was large enough that crushed stone aggregate could be seen beneath the floor slab. A concrete coring machine had just been made available, so it was decided to demonstrate sub-slab ventilation as the mitigation method in this house.

The only part of the basement floor that was not covered with glued carpet or tile was the laundry area. An 20 cm diameter hole was cored through the floor adjacent to the furnace and out of the main traffic pattern, and a "6 inch" lightweight plastic pipe was installed in the hole. The sub-slab fill was a layer of coarse crushed stone 8 to 10 cm thick. The gap between the slab and the pipe was filled with asphaltic cement and protected with a layer of fast-set grout. The other end of the pipe ran to a large centrifugal fan mounted on a sheet of plywood that replaced a basement window. The untrapped floor drain was closed with an expanding rubber plug.

In April 1986, the radon concentration in the basement with the fan off but the untrapped floor drain closed, ranged from 26 to 201 pC/L, averaging 160 pCi/L. When the fan was turned on, concentrations fell for 15 hours to a new equilibrium which ranged from 8 to 16 pCi/L, averaging 12 pCi/L over the next 12 hours.

Investigation found that the fan developed 85 Pa suction at 12 L/s, with a radon concentration of 2 300 pCi/L in the exhaust. Smoke tests showed airflow was down into the sub-slab space at all cracks in the laundry room end and round the edge of the floor drain. When the plug was removed from the untrapped floor drain, there was a flow of 0.7 L/s out of the drain at 2 000 pCi/L. Glued carpet and baseboard heating units prevented smoke tests on the remainder of the basement floor.

2.2. PHASE 3

The fan installation was not satisfactory for a permanent installation, so in November 1986 the fan was replaced with a large plastic body in-line centrifugal fan attached to the wall. The plywood panel was replaced by a sheet of plexiglas with a hole for the duct to pass through. The gap between the edge of the floor drain and the concrete was closed with silicone caulk.

The new fan produced 300 Pa suction at a flow of 77 L/s, and a radon concentration of 1 100 pCi/L.

In December 1986, after the fan change, the radon concentration in the basement was monitored. When the fan was turned off, concentrations ranged from 38 to 116 pCi/L, averaging 76 pCi/L. When the fan was turned on again, concentrations fell over 8 hours to an equilibrium ranging from 1 to 4 pCi/L, and averaging 3 pCi/L over 38 hours.

Alpha track detectors were issued in December for final long term measurements.

3. OTHER MEASUREMENTS

The radiation field in and around the house ranged from 4 to 7 uR/h in the basement, averaging 5 uR/h. On the site the field ranged from 7 to 12 uR/h, averaging 9 uR/h.

The average radon concentration measured by alpha-track detectors over the period December 1986 to March 1987 was 3.1 pCi/L in the basement, and 2.6 pCi/L in the living area.

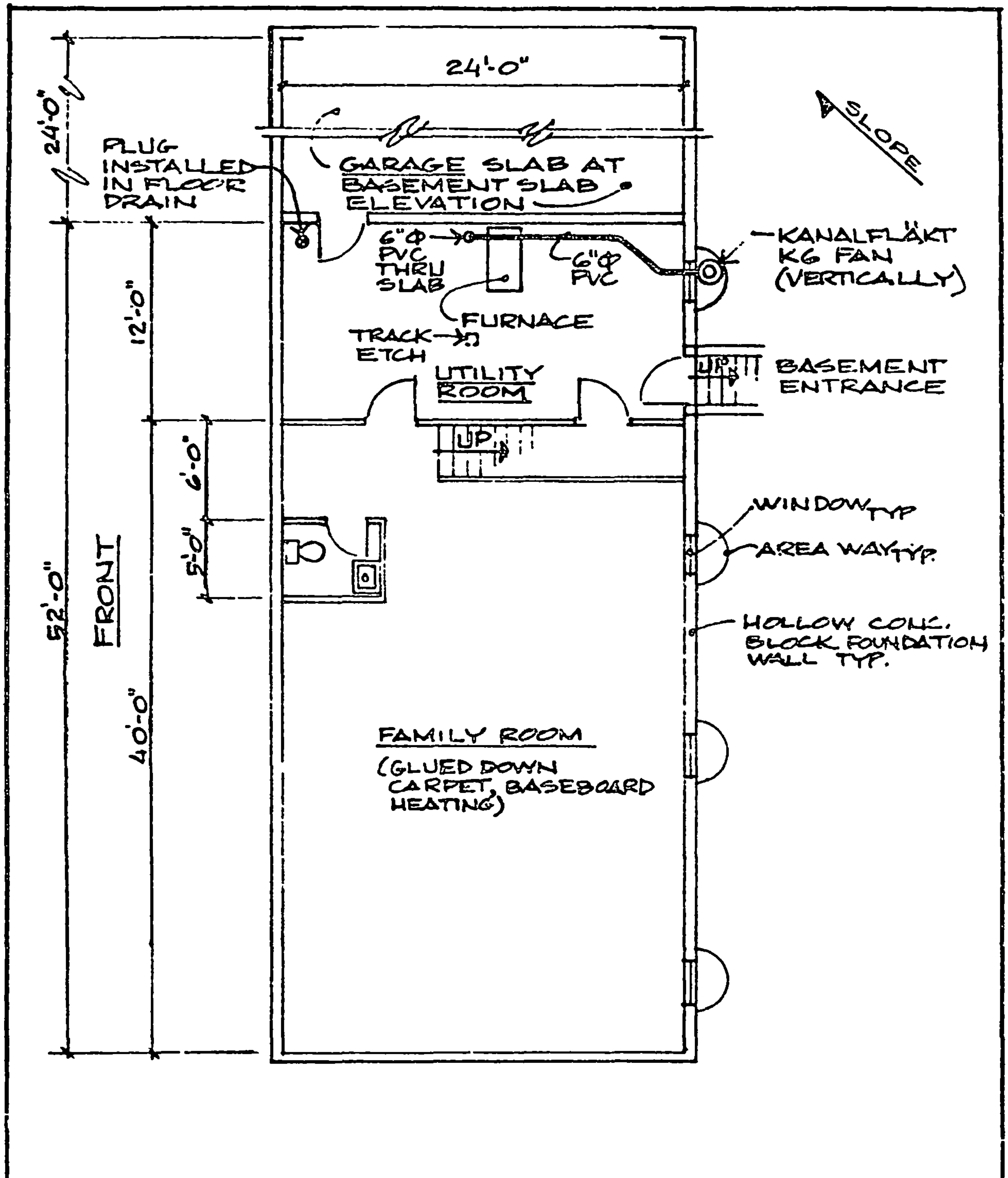
MEASUREMENTS SUMMARY FOR HOUSE 21

PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	RADON (pCi/L) MEAN	COMMENTS
2	Sub-slab ventilation; 100 L/s centrifugal; untrapped floor drain plugged	04/86	Fan off Fan on	26-201 8- 16	160 12	over 44 hrs. over 31 hrs. after 15 hr climb to equilibrium
3	Sub-slab ventilation; 150 L/s centrifugal; untrapped floor drain plugged	12/86	Fan off Fan on	38-116 1- 4	76 3	over 17 hrs. over 38 hrs. after 8 hrs.

SYSTEM MEASUREMENTS FOR HOUSE 21

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
2	Sub-slab ventilation; 100 L/s centrifugal fan; untrapped floor drain plugged	01/86	85	12 0.7	2 300 2 000	at fan drain when unplugged
3	Sub-slab ventilation; 150 L/s centrifugal; untrapped floor drain plugged	11/86	300	77	1 100	At fan



LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
FOUNDATION PLAN	Date: NOV. 86	21
Mitigation system: SUB-SLAB SUCTION	PHASE: 2 THRU FINAL	

HOUSE 22

PENNSYLVANIA DER MEASUREMENTS

Working Level grab samples (Kusnetz)	0.170 WL
Short term average WL (RPISU)	0.029 WL
Heating season average radon (Terradex)	24 pCi/L
Radon concentration in water	8 000 pCi/L

1. DESCRIPTION

This two story side-split house with attached garage was built in the early 1980's on a gently sloping site in a rural subdivision near the top of a hill a few miles west of Oley. The lower half of the walls are of brick, the upper half are of siding. The garage and a family room are on a slab at grade level, and only the living room is over the basement. Heating is by oil-fired hot water in baseboard convectors, with an upstairs fire place in the family room.

The basement walls are of poured concrete, and there is an external entrance. There are water stains on the concrete in the right-hand corner of a step in front of the external doorway. There are no cracks in the floor or walls, and the wall/floor joint crack is small. The family room floor slab lies partly on top of the basement stub wall. The junction is largely concealed by the doubled 'two by four' sole plate of the dividing frame wall which stands on top of the stub wall in front of the slab. In the few places where the joint was visible, there was a large gap between the top of the stub wall and the underside of the slab. The boiler chimney is made of concrete blocks and passes through the family room slab adjacent to the stub wall.

The owner said that there was a weeping tile drain around three sides of the house outside the concrete walls.

2. ACTION

2.1. PHASE 2

As the joint between the stub wall and floor slab was the largest potential opening into the basement, the initial mitigation measure chosen for demonstration at this house was a modified wall/floor joint collection system. This was not expected to be the final solution, but would provide a measure of the relative importance of the stub wall joint to the other routes of entry.

The sole plate of the frame wall was enclosed by a plywood box. The top of the box above the sole plate was cut to fit round the vertical studs and butted against the basement side of the wallboard, which formed the back of the box. The front of the box covered the joint between the sill plate and the stub wall, and was screwed to a furring strip attached to the wall. There was not enough room to box over the joint behind the stairs, so the stairs were removed and the joint in this area closed with caulk. All joints were caulked to increase the airtightness of the box as much as possible.

The stairs divided the collection box into two separate sections, which were connected by ducts of "4 inch" lightweight plastic pipe to a similar collection duct. A 50 L/s axial fan mounted on a sheet of plywood in a basement window was joined to the collection duct with a flexible hose.

In April 1986, the radon concentration in the basement with the wall joint ventilation on ranged from 27 to 54 pCi/L, averaging 43 pCi/L. When the fan was turned off, the concentration ranged from 26 to 42 pCi/L, averaging 34 pCi/L. The radon concentration in the three legs of the collection system with the fan off was 2 to 5 pCi/L, and increased respectively to 23, 74 and 66 pCi/L when the fan was turned on. At that time the respective pressures and flows in the legs were 23, 18 and 20 Pa and 12, 7 and 9 L/s; the concentration in the basement at this time was 38 pCi/L. An air sample taken from the hollow concrete chimney structure had a concentration of 32 pCi/L. Clearly, although there were connections to the soil in the slab/stub wall joint area, neither it nor the chimney was a major entry route.

Enclosures placed over the floor/wall joint on the right and left side of the external basement doorstep were sampled on two occasions with system running. The radon concentrations one after 24 hours were 380 and 1 600 pCi/L on the right side, and 80 and 80 pCi/L on the left. This suggested that the basement wall/floor joint was an entry route, but the relative importance of that joint and other joints in the slab-on-grade section was unknown.

In light of this, the second mitigation method chosen for demonstration at this house was subslab ventilation of the basement slab alone.

Four 12.5 cm diameter holes were drilled through the floor slab, two adjacent to the stub wall and two in the corners of the opposite (end) wall near where the enclosures had shown high values. There was a plastic sheet beneath the slab, and at least 5 to 8 cm of crushed stone. The existing "1 inch" piping was extended to the holes, and caulked in place. The axial fan was retained for testing.

In May 1986, the radon concentration in the basement with the fan on ranged from 2 to 7 pCi/L, averaging 4 pCi/L. With the fan off, concentrations rose rapidly, and ranged between 21 to 54 pCi/L, averaging 35 pCi/L.

Radon concentrations measured in the floor pipes with the fan off were; stub wall 3 800 pCi/L (front half), 300 pCi/L (rear half), rear corner 8 000 pCi/L; and front corner 17 000 pCi/L. At that time the radon concentrations in the basement air was 36 pCi/L

When the fan was turned on the concentrations in the pipes dropped. Suctions, flows and radon concentrations in the floor pipes were; stub wall (front half) 12 Pa, 0.1 L/s (no radon measurement); stub wall rear half 15 Pa, 1.2 L/s at 300 pCi/L; rear corner 22 Pa, 1.2 L/s at 5 800 pCi/L; and front corner 20 Pa, 0.7 L/s at 7 500 pCi/L.

Further testing was halted by the onset of warm weather.

2.2. PHASE 3

In November 1986 the system was modified to just sub-slab exhaust by disconnecting the collection box, and a large plastic body exhaust fan was installed on a temporary mounting with flex hose. Suction was increased to 130 Pa in each of the floor pipes. Following this work, radon concentrations in the basement ranged from 4 to 30 pCi/L, averaging 9 pCi/L.

Flows and radon concentrations in the pipes measured in December 1986 were; stub wall (rear half) 1.5 L/s at 260 pCi/L; stub wall (front half) 0.7 L/s at 1 200 pCi/L; rear corner 5 L/s at 2 900 pCi/L; front corner 4 L/s at 3 000 pCi/L.

In December 1986, radon concentrations in the basement ranged from 2 to 19 pCi/L, averaging 5 pCi/L. Simultaneously, concentrations upstairs ranged from 6 to 13 pCi/L, averaging 10 pCi/L. This indicated that there were radon supplies to the upstairs independent of those in the basement, and that treatment of the slab on grade portion of the house was required.

The system suction was only 12 Pa at the end of this measurement period, for the flexible hose to the fan had become blocked by accumulated condensation, so it was expected that better performance could be obtained if the fan was permanently mounted so that it would not be blocked with condensation.

In February 1987 the system was modified to provide suction beneath the upper floor slab. Two suction points were drilled horizontally through the stub wall so that the fill beneath the slab could be ventilated without installing ducts in the finished upstairs space. The sub-slab pipes at the stub wall were 'Teed into these holes. The fan was permanently mounted so that condensation would not block the ducts.

The system suction was an uniform 210 Pa in all the pipes. The flows and radon concentrations in the pipes were; stub wall (floor) 1 L/s, 670 pCi/L; stub wall (front) 2 L/s, 30 pCi/L; stub wall (floor) 1 L/s, 400 pCi/L; stub wall (rear) 7 L/s, 110 pCi/L; rear corner 8 L/s, 1 900 pCi/L; front corner 7 L/s, 1 500 pCi/L. In February 1987, the radon concentration in the basement ranged from 5 to 22 pCi/L, averaging 9.6 pCi/L. Simultaneously, the concentration upstairs varied from 1 to 8 pCi/L, averaging 3 pCi/L. Alpha track detectors were issued for final long term measurements in late February, at which time grab samples of basement air and air behind the polyethylene enclosure of the cellar steps gave concentrations of 17 and 19 pCi/L.

Most, but not all, of the higher basement concentrations were associated with use of the washing machine. The radon concentration in the water for this house is only 8 000 pCi/L, which did not seem high enough to explain the size of the peaks. Basement depressurization produced by operation of the clothes dryer with the door to the rest of the house closed was ruled out, for the dryer air in this house is recirculated back into the basement.

The wall/floor joint was tight enough that smoke tests did not indicate any air movement. Enclosures were placed over the wall floor joint on two walls, at the external basement entrance steps, the sewer pipe exit, the beam pocket, and over two windows that were covered by window well bubbles. Radon concentrations in the bags at the wall/floor joint were 0 and 15 pCi/L, at the steps 15 pCi/L, sewer pipe 0 pCi/L, beam pocket 0 pCi/L, and 3 pCi/L and 1 pCi/L over the windows. None of these indicated a significant radon entry route. The entry route for the higher radon concentrations remained unidentified.

3. OTHER MEASUREMENTS

The radiation field in the basement ranged from 3 to 6 uR/h, averaging 5 uR/h. The field on the site ranged from 5 to 10 uR/h, averaging 8 uR/h.

The average radon concentration measured by alpha-track detectors over the period February 1987 to April 1987 was 7.6 pCi/L in the basement, and 2.7 pCi/L in the living area.

MEASUREMENTS SUMMARY FOR HOUSE 22

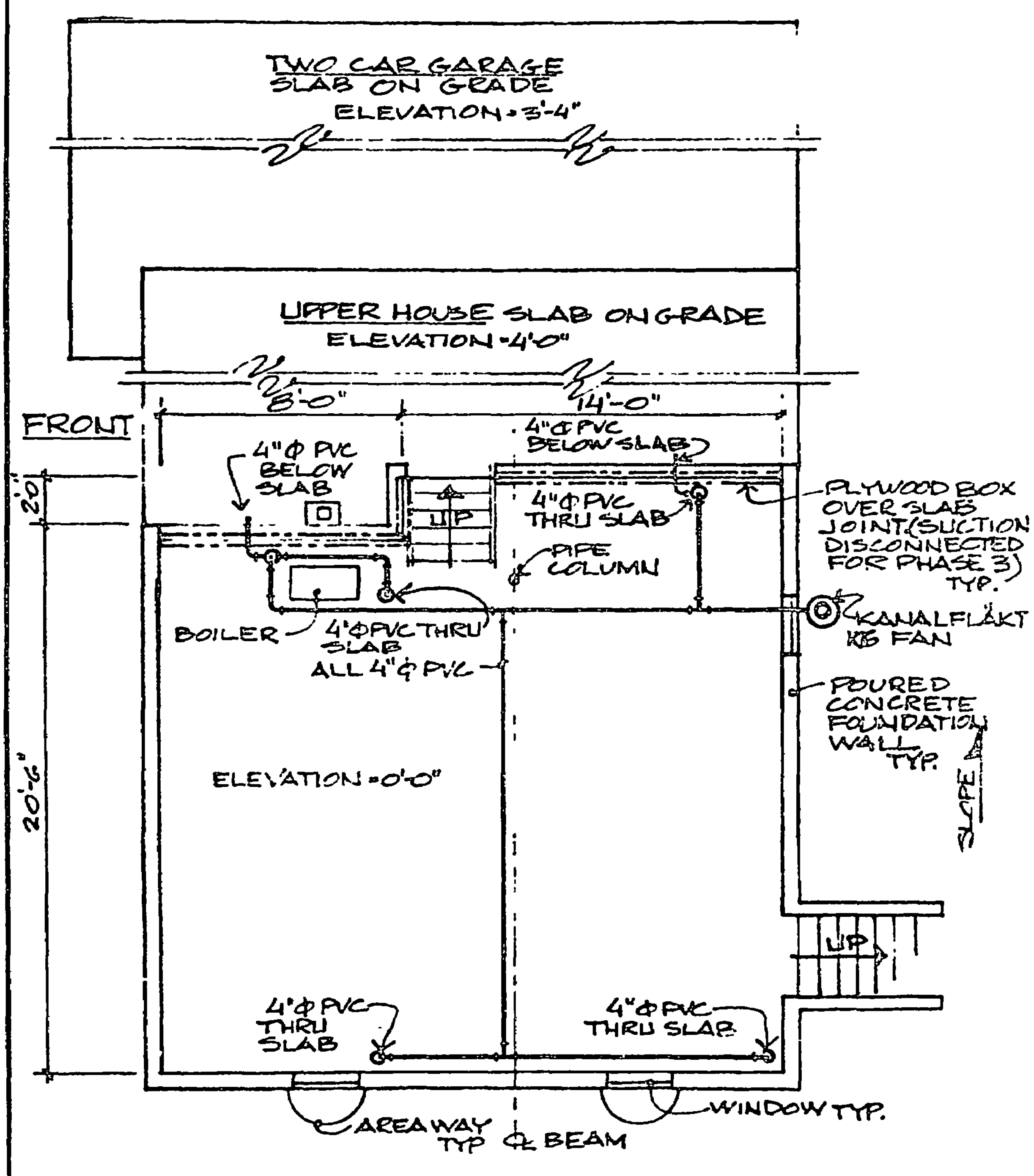
PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	MEAN	COMMENTS
2	Stub wall joint ventilation; 50 L/s axial fan	01/86	Fan on	27-51	43	over 24 hrs
			Fan off	26-42	34	over 41 hrs
2	Basement sub-slab ventilation; 50 L/s axial fan	05/86	Fan on	2-7	1	over 16 hrs
			Fan off	21-51	35	over 45 hrs
3	Basement subslab ventilation; by 150 L/s centrifugal	11/86	Fan on	4-30	9	over 18 hrs
		12/86	Fan on	2-19	5	over 4 days
			Fan on	6-13	10	over 1 days upstairs
	Basement + split level subslab ventilation, 150 L/s centrifugal	02/87	Fan on	5-22	10	over 4 days
			Fan on	1-8	3	over 4 days upstairs

SYSTEM MEASUREMENTS FOR HOUSE 22

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
2	Stub-wall joint ventilation 50 L/s axial fan	04/86			2	Fan off-A
					5	Fan off-B
					3	Fan off-C
			23	12	23	Fan on -A
			20	9	66	Fan on -B
			18	7	74	Fan on -C
					38	Basement air fan on
					32	Fan on - chimney block
2	Subslab ventilation 50 L/s axial fan	05/86			3 800	Fan off-Leg 1
					300	Fan off-Leg 2
					8 000	Fan off-Leg 3
					17 000	Fan off-Leg 4
					36	Fan off-basement air
			12	0.1	N/A	Fan on-Leg 1
			15	1.6	300	Fan on-Leg 2
			22	1.2	5 800	Fan on-Leg 3
			20	0.7	7 500	Fan on-Leg 4
3	Basement subslab ventilation; 150 L/s centrifugal	12/86	130	1.5	260	Fan on-Leg 1
			130	0.7	1 200	Fan on-Leg 2
			130	5	2 900	Fan on-Leg 3
			130	4	3 000	Fan on-Leg 4
3	Basement + split level subslab ventilation; 150 L/s centrifugal	02/87	200	1	670	Fan on-Leg 1
			210	2	30	Fan on-Leg 1*
			210	1	400	Fan on-Leg 2
			205	7	110	Fan on-Leg 2*
			210	8	1 900	Fan on-Leg 3
			210	7	1 500	Fan on-Leg [illegible]
					17	Fan on-basement air
					19	Fan on- cellar air

Wall box ventilation pipes A - rear B - centre C - front
Sub-slab ventilation pipes Leg 1 - Stub wall front
Leg 2 - Stub wall rear
Leg 3 - rear basement corner
Leg 4 - front basement corner



ACRES	LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
	FOUNDATION PLAN	Date: FEB. '87	22
	Mitigation system: SUB-SLAB SUCTION	PHASE: FINAL	

HOUSE 23

PENNSYLVANIA DER MEASUREMENTS

Working Level grab samples (Kusnetz)	0.836 WL
Heating season short term average WL (RPISU)	0.102 WL
Heating season average radon (Terradex)	98 pCi/L
Radon concentration in water	17 900 pCi/L

1. DESCRIPTION

This two story side-split house was built in the early 1980's on a fairly level rural site near the top of a ridge a few miles north of Hereford. The front and end walls of the lower story are of brick, the other walls are of siding. The family room and garage are at grade on a concrete floor slab, only the living room and kitchen are over the basement. Heating is by oil fired hot water baseboard convectors upstairs, supplemented with a wood stove in the family room.

The basement and foundation walls are of poured concrete. The upper floor slab rests on top of the stub wall. The dividing frame wall was erected before the upper floor slab was poured, and is supported by a row of "4 inch" solid concrete blocks laid on their side. When the slab was poured, these held back the concrete, producing many openings at the edge of the floor slab. The floor is in good condition, with minor cracks filled with silicone caulk by the owner. The well pressure tank stands on concrete blocks, but these rest on the slab. The water line passes out through the wall in a sleeve. The house jacks are hollow, but closed by a welded plate.

2. ACTION

2.1. PHASE 2

The initial mitigation measure chosen for demonstration at this house was a modified wall/floor joint collection system at the top of the stub wall. This was not expected to be the final solution, but would provide a measure of the relative importance of the stub wall joint to the other routes of entry.

A plywood box was built to enclose the floor slab/stub wall junction. As the sole plate of the frame wall was above the top of the slab, this was used as the top of the box. A furring strip was nailed to the plate, and a second strip was nailed to the concrete below the top of the stub wall. A 30 cm wide strip of plywood was nailed to the strips, forming a box duct over the junction. All joints were closed with silicone caulk.

The wallboard on either side of the stairs was cut back so that the plywood could be fitted in, but there was not enough space around the head of the stairs to run a continuous box duct there. The openings there were closed by injecting expanding urethane foam. Each half of the duct was ventilated with a "4 inch" lightweight plastic pipe, connected to a header of similar pipe. A 50 L/s axial fan, mounted on a sheet of plywood replacing the basement window, was connected to the header by flexible ducting.

In May 1986, the radon concentration in the basement while the fan was running ranged between 17 to 55 pCi/L, averaging 35 pCi/L. When the fan was turned off, the concentration ranged from 40 to 120 pCi/L, averaging 82 pCi/L. This indicated that the stub wall joint was a significant route of radon entry, but that there were other entry routes present as well. The onset of warm weather prevented further measurements, and further work was delayed until the fall.

2.2. PHASE 3

In November 1986, a separate sub-slab ventilation system was installed in the basement. A 12.5 cm diameter hole was drilled through the concrete floor slab 5 cm from the approximate centre of each basement wall, exposing the sub-slab aggregate. A vertical pipe of "4 inch" lightweight plastic was placed in each hole and the space between the pipe and concrete was filled with silicone caulk. The four pipes were connected to a central collection duct of similar pipe run along the main beam. A central vacuum line had to be rerouted to allow this. A length of flexible ducting passed through a sheet of plywood in a basement window frame connected the collection duct to a small centrifugal fan mounted in a box.

In November 1986, the radon concentration in the basement with both fans running ranged from 5 to 15 pCi/L, averaging 9 pCi/L. When the stub wall fan was turned off, leaving the basement sub-slab fan running, the concentration ranged from 10 to 39 pCi/L, averaging 23 pCi/L. When the sub-slab fan was turned off as well, the concentration ranged from 52 to 103 pCi/L, averaging 90 pCi/L. When both fans were turned on again, the concentration fell to the original 5 to 15 pCi/L range.

Investigation found a suction of 20 Pa in the collection box, and flows and radon concentrations of 9 L/s, 30 pCi/L; 30 L/s, 200 pCi/L from the rear and front boxes. The suction in the sub-slab system piping was 160 Pa in all pipes. Flows and radon concentrations were; rear wall 2.5 L/s at 12 000 pCi/L; end wall 4 L/s at 5 500 pCi/L; front wall 2 L/s at 50 000 pCi/L; stub wall 2.4 L/s at 1 800 pCi/L. The concentration of 50 000 pCi/L in an exhaust pipe was the highest measured to that time.

In late December, 1986 radon concentrations in the basement ranged from 7 to 21 pCi/L, averaging 14 pCi/L with the stub wall fan on, and from 11 to 16 pCi/L, averaging 13 pCi/L with it off. This suggested that the stub wall joint was not a major route of entry.

Condensation accumulated in the lowest part of the exterior flexible ducting, and inhibited the sub-slab fan performance. This was cured by drilling a weephole in the flex duct at the lowest point.

In view of the very high radon concentrations in the soil gas beneath the floor slab, the sub-slab fan was reversed in January 1987 to blow fresh air into the sub-slab space as a test. If radon concentrations close to the building could be reduced, then the soilgas leakages might produce smaller radon supplies.

With both fans in exhaust, the radon concentrations in the basement ranged from 3 to 15 pCi/L, averaging 8 pCi/L; and in the living area ranged from 1 to 9 pCi/L, averaging 5 pCi/ With just the floor fan running in pressure, the basement concentrations ranged from 4 to 23 pCi/L, averaging 13 pCi/L; and in the living area ranged from 3 to 7 pCi/L, averaging 5 pCi/L. These measurements were interpreted as showing that the sub-slab system performance was not improved by operation in pressure.

As leaks are easier to detect in pressure, a smoke stick survey of the accessible basement joints and cracks was carried out at this time, but found no sign of air leaking in, except from the very top of the house jacks. These are of hollow pipe closed at the top by a welded metal plate.

In late January, the house jacks were drilled and filled with expanding urethane foam, and a permanent in-line plastic body centrifugal fan was installed on the floor exhaust system. The axial fan and plywood sheet were removed from the window frame, and the window replaced. The collection box duct was connected to the floor exhaust system via a damper to control the airflow. Minor openings between the wallboard in the stair opening and the collection box were caulked.

The suction in all the floor pipes was increased to a uniform 250 Pa. Flow in the rear floor pipe was now 5 L/s, in the side wall pipe 4 L/s, in the front wall pipe 3 L/s, and in the stub wall pipe 2 L/s. Suction in the collection box was set to 10 Pa by a slide damper in the connecting line to the central duct. Flows in the box ventilation pipes totaled 3 L/s, which was sufficient to ensure a positive airflow into the box.

In January following this work, the radon concentrations in the basement ranged from 4 to 15 pCi/L, averaging 8 pCi/L. The higher concentrations were associated with use of the washing machine. These results were regarded as good enough to justify issuing alpha track detectors in late January 1987 for final long term measurements.

Alpha track results were received in May 1987, and showed higher concentrations in the upstairs family room than in the basement. This might have been due to recirculation of subslab exhaust into the upstairs. The exhaust fan was reversed to remove all possibility of recirculation, and radon levels in the basement and the family room were monitored at the same time. The fan was off to start with, and basement concentrations at the start of the monitoring were high as 175 pCi/L in the basement and 261 pCi/L upstairs. Concentrations fell slowly over the next three days to 30 pCi/L in the basement and 80 pCi/L upstairs.

Further radon monitoring was implemented in June 1987 when the system had been under pressurization for a couple of weeks. The upstairs concentrations were found to range from 2 to 28 pCi/L, averaging 14 pCi/L. The basement radon concentrations ranged from 1 to 25 pCi/L, averaging 12 pCi/L. Evidently the upstairs concentrations could not be due to recirculation, and had to be due to an entry route on the family room slab.

The system was reconstructed. The fan was relocated to the roof to reduce noise and exhaust recirculation. A suction point was placed beneath the stairway to the kitchen to access the fill beneath the family room slab. The stub wall exhaust system was retained.

A check of the revamped system found a suction of 88 Pa in all pipes. Flows and radon concentrations from the rear collection box were 16 L/s at 29 pCi/L; the flow from the front collection box could not be measured as the pipe was now inaccessible. The flows and radon concentrations from the floor pipes were; rear wall 2 L/s at 5 100 pCi/L; end wall 3 L/s at 3 300 pCi/L; front wall 1 L/s at 14 000; stub wall 2 L/s at 5 400 pCi/L; family room slab 0.8 L/s at 200 pCi/L.

The collection box pipe was dampered to reduce the flow rate, and increased the subslab suction to 100 Pa. The owner revised the piping layout after this.

Radon monitoring under those conditions found that both the basement and the upstairs family room generally averaged 2 pCi/L, except for lower concentrations found in the family room while windows were left open and concentration peaking in the basement during times of clothes washing.

3. OTHER MEASUREMENTS

The radiation field in the house was 7 uR/h in the basement, and 5 uR/h on the split level slab. A field of 13 uR/h was found on contact with the well pressure tank, but fell off rapidly with distance to 8.5 uR/h at 1 m. The field on the site was 6 uR/h over the crushed stone driveway; 12 uR/h at the sides and rear; and 516 uR/h on the front lawn. The site average was 12 uR/h.

The average radon concentration measured by alpha-track detectors over the period January 1987 to March 1987 was 7.6 pCi/L in the basement, and 11.6 pCi/L in the living area.

MEASUREMENTS SUMMARY FOR HOUSE 23

PYLON AB-5 HOURLY MONITORING

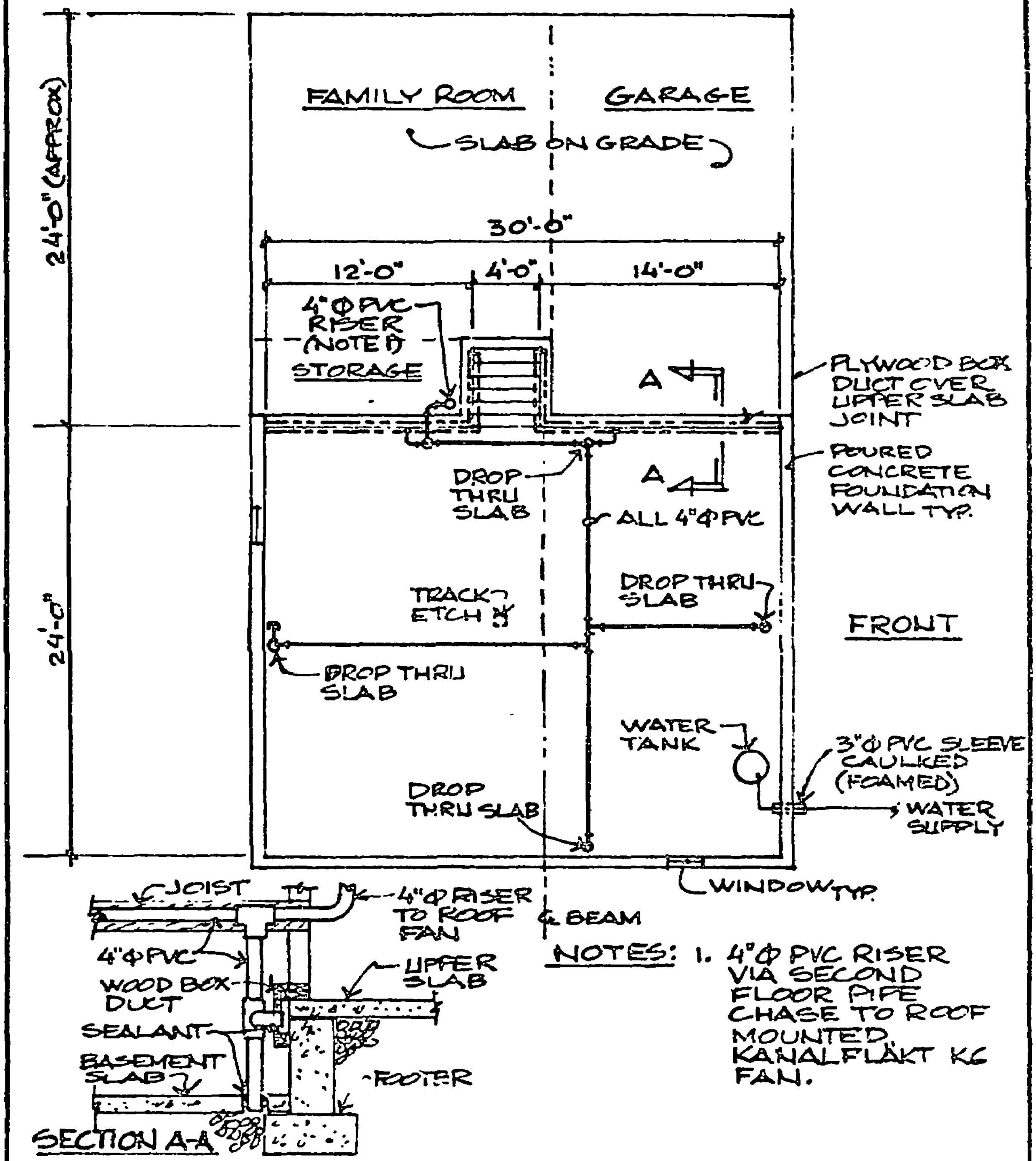
PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	MEAN	COMMENTS
2	Stub wall joint ventilation; 50 L/s axial fan	01/86	Fan on	17- 58	39	over 35 hrs.
			Fan off	40-120	82	over 32 hrs.
3	Stub wall joint + sub-slab ventilation 50 L/s axial + 50 L/s centrifugal	11/86	Both fans on	5- 15	9	over 23 hrs.
			Sub-slab fan only	12- 39	23	over 17 hrs.
			Both fans off	52-103	90	over 19 hrs.
			Both fans on	5- 15	12	over 18 hrs. - after 8 hrs to equilibrium
		12/86	Stub wall fan on	7- 21	14	over 24 hrs.
			Stub wall fan off	11 16	13	over 22 hrs.
		01/87	Fans exhausting	3- 15	8	over 45 hrs-B
			Fans exhausting	1 9	5	over 45 hrs-U
			Sub-slab fan	4- 23	13	over 49 hrs-B
			reversed to blow	3- 7	5	over 19 hrs-U
3	stub wall joint + sub-slab ventilation; 150 L/s centrifugal	01/87	Exhaust fan on	1- 15	8	over 90 hrs-B
		05/87	Reversed fan blowing	20-175	26	B-fell over 31 hrs to 15 hr average
				37-261	157	U-great variation over 47 hrs.
		06/87	Reversed fan blowing	1 25	12	over 1 days-B
				2- 28	14	over 4 days-U
		06/97	Fans on exhaust	1 5	2	over 89 hrs-B
				0.3- 5	2	over 41 hrs-U

B: Basement; U: Upstairs

SYSTEM MEASUREMENTS FOR HOUSE 23

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
3	Stub wall joint + sub-slab ventilation;	12/86	20	9	31	Rear stub wall joint
	50 L/s axial + 50 L/s centrifugal both on		20	30	200	Front stub wall joint
			160	3	12 000	Riser A
			160	4	5 500	Riser B
			160	2	50 000	Riser C
			160	2	1 800	Riser D
3	Stub-wall join + sub-slab ventilation;	01/ 87	10	1		Rear stub wall joint
	150 L/s centrifugal exhaust fan		10	2		Front stub wall joint
			250	5		Riser A
			250	4		Riser B
			250	3		Riser C
			250	2		Riser D
3	As above with revamped piping	06/87	88	16	29	Rear stub wall joint
			88	N/A	110	Front stub wall joint
			88	2	5 100	Riser A
			88	3	3 300	Riser B
			88	1	14 000	Riser C
			88	2	5 400	Riser D
			88	0.8	200	Riser E
					20	Basement air
			100			Sub-slab suction after dampering at rear stub wall to 50 Pa

A: Rear wall
B: End wall
C: Front wall
D: Stub wall
E: Family room slab



AGRRS	LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
	FOUNDATION PLAN	Date: 1/26/87	23
	Mitigation system: SUB-SLAB SUCTION	PHASE: FINAL	

HOUSE 24

PENNSYLVANIA DER MEASUREMENTS

Working Level grab samples (Kusnetz)	0.178 WL
Short term average WL (RPISU)	0.002 WL
Heating season average radon (Terradex)	66 pCi/L
Radon concentration in water	11 600 pCi/L

1. DESCRIPTION

This single story house with attached garage was built in the early 1980's on a gently sloping site in a rural subdivision on top of a hill a few miles west of Oley. The house walls are of brick. Heating is by oil-fired forced warm air, supplemented by a basement fireplace.

The basement is unfinished, with walls of solid concrete, except at the fireplace. A 3 m section of the basement wall is part of the chimney structure, and is made of concrete block. This is concealed by a brick facing around the fireplace. The floor slab has a construction joint running lengthwise and is in good condition. It is penetrated by roughed-in plumbing. The owner had sealed the construction joint and a large portion of the wall/floor joint with silicone caulk. A 6 m section near the fireplace was unsealed as that wall had foamboard insulation attached to it inside strapping, and access to the joint was difficult.

2. ACTION

2.1. PHASE 2

As this house had concrete basement walls (except for the fireplace section), and the owner had already closed many of the floor openings, the mitigative action chosen for demonstration was sub-slab ventilation.

The location of the sub-slab ventilation pipes was severely constrained by the owner's desire to finish the basement, and his concerns about the aesthetic impact that the vertical pipes might have - even if built-in, or that the horizontal connecting pipes might restrict the headroom available. A second limitation was that a sewer line ran beneath the floor adjacent to the entire rear wall footing. A second sewer line joined this somewhere in the rear corner of the house. Holes could not be drilled through the slab in these areas without a risk of damaging the sewer line.

Finally, three satisfactory exhaust locations were agreed upon. Two of these were on the fireplace end wall, one in the front corner directly adjacent to the fireplace, the other close to the rear corner. The third was at the centre of the opposite end wall.

Holes were drilled through the floor slab at the agreed locations with a concrete coring machine. At the corner near the fireplace the footing extended 30 cm from the wall, and several overlapping cores had to be taken to connect to the sub-slab fill of 5 to 8 cm of crushed stone. At the other locations the hole entered the sub-slab fill directly. The pipes were linked to a single 50 L/s centrifugal fan via a length of flex hose passed through a sheet of plywood placed in a basement window opening at the rear of the house.

In May 1986, the radon concentration in the basement with the fan running ranged from 3 to 17 pCi/L, averaging 10 pCi/L. When the fan was turned off for two days, concentrations rose slowly over the first 24 hours to an equilibrium ranging from 42 to 65 pCi/L, averaging 50 pCi/L.

System measurements found suctions flows and radon concentrations in the pipes were; fireplace 100 Pa, 3.5 L/s at 2 100 pCi/L; rear wall 100 Pa, 9 L/s at 270 pCi/L; end wall 80 Pa, 8 L/s at 550 pCi/L. The highest concentration was found in the pipe by the fireplace. Smoke testing at that time indicated general suction at the open perimeter wall/floor joint.

2.2. PHASE 3

In February 1987, the temporary fan was replaced by a permanent large plastic bodied fan. The basement window was replaced, and the ducting rearranged so that the permanent fan could be placed on an end wall of the house away from bedroom windows. The new fan produced a suction of 275-325 Pa in all pipes. Flows and radon concentrations were; fireplace wall 3 L/s at 3 100 pCi/L; rear wall 4 L/s at 3300 pCi/L; end wall 10 L/s at 1 100 pCi/L.

By this time the owner had completed sealing the wall/floor joint, the central floor joint and the larger floor cracks with silicone caulk. A smoke survey found that the airflow was from house to sub-slab space at 3 widely separated locations (two small floor cracks and at the wall/floor joint) where the caulk had not completely closed the openings.

In March radon concentrations with the fan on ranged from 2 to 5 pCi/L, averaging 3 pCi/L. When the fan was turned off, radon concentrations rose to range between 14 to 29 pCi/L, with an average of 20 pCi/L.

The difference between the fan-off concentration of 20 pCi/L in this test, and the value of 50 pCi/L obtained in Phase 2 can be attributed in part to the painstaking sealing job that the owner had carried out. The quality of work was excellent, and almost all of the accessible joints and cracks had been covered neatly with caulk.

Alpha track detectors were issued in March to provide a long term measurement of radon concentration.

3. OTHER MEASUREMENTS

The radiation fields in the house ranged from 2 to 6 uR/h, averaging 4 uR/h. The fields on the site ranged from 6 to 10 uR/h, averaging 9 uR/h. The difference between these fields is attributed to the basement concrete not containing local aggregate, and therefore having lower radioactivity.

The average radon concentration measured by alpha-track detectors over the period March to April 1987 was 4.3 pCi/L in the basement, and 4.6 pCi/L in the living area.

MEASUREMENTS SUMMARY FOR HOUSE 24

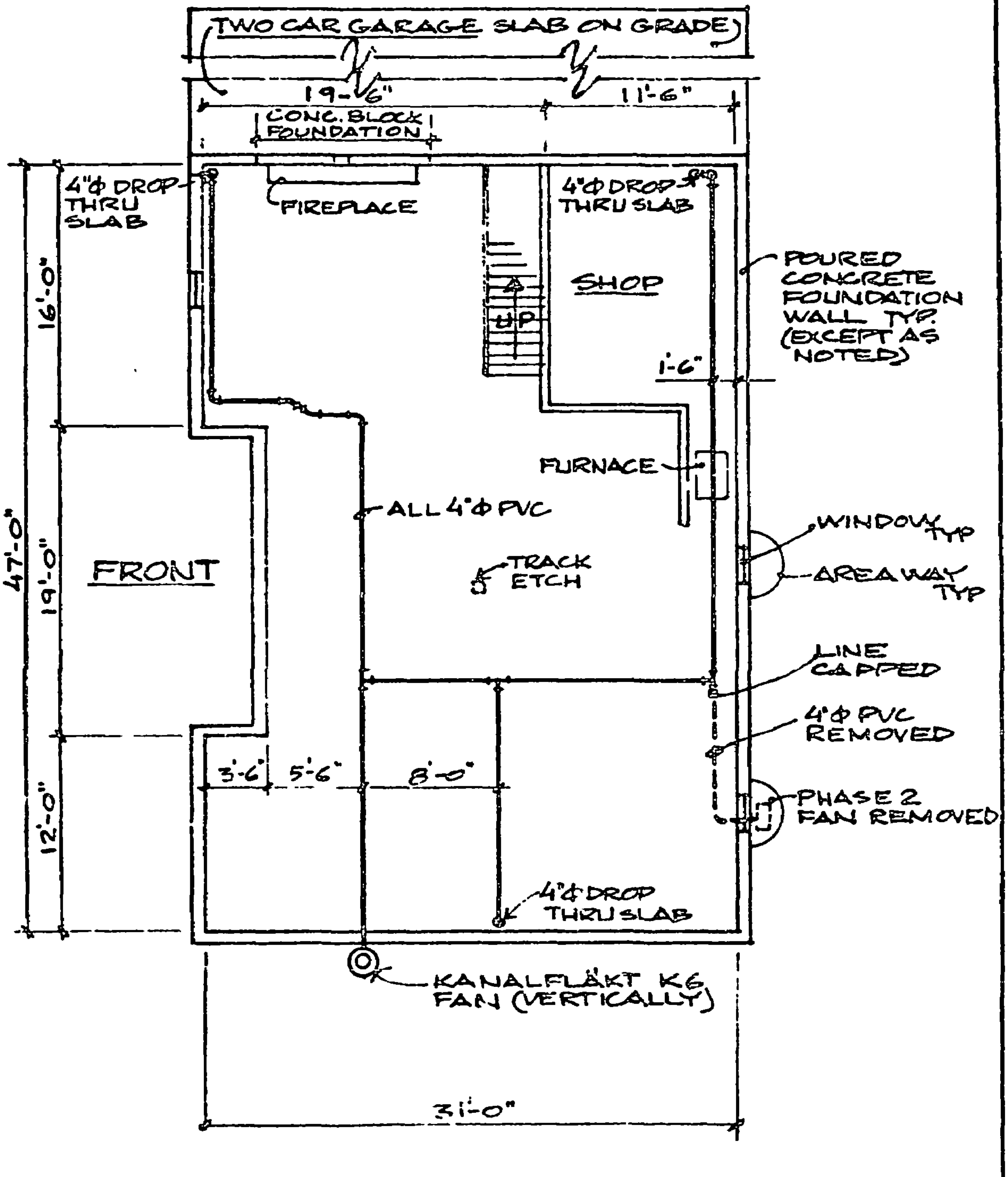
PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	RADON (pCi/L) MEAN	COMMENTS
2	Sub-slab ventilation; 50 L/s centrifugal fan	05/86	Fan on	3-17	10	over 17 hrs.
			Fan off	42-65	50	over 22 hrs. after 24 hrs rose to equilibrium
3	Sub-slab ventilation; 150 L/s centrifugal fan	03/87	Fan on	2-5	3	over 48 hrs.
			Fan off	14-29	20	over 40 hrs. after 5 hrs.

SYSTEMS MEASUREMENTS FOR HOUSE 24

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
	Sub-slab ventilation	05/86	100	3.5	2 100	Leg 1
2	50 L/s centrifugal		100	9	270	Leg 2
			80	8	530	Leg 3
3	Sub-slab ventilation	03/87	275	3	3 100	Leg 1
	150 L/s centrifugal		300	4	3 300	Leg 2
			325	10	1 100	Leg 3

Leg 1: near fireplace
Leg 2: rear wall
Leg 3: end wall



ACRES	LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
	FOUNDATION PLAN	Date: 2/24/87	24
	Mitigation system: SUB-SLAB SUCTION	PHASE: 2 AND FINAL	

HOUSE 25

PENNSYLVANIA DER MEASUREMENTS

Working Level grab samples (Kusnetz)	0.986 WL
Short term average WL (RPISU)	0.243 WL
Heating season average radon (Terradex)	122 pCi/L
Radon concentration in water	3 700 pCi/L

1. DESCRIPTION

This two story house with attached garage was built in the mid 1980's on a steeply sloping rural site on the side of a hill some miles southwest of Boyertown. The house walls are covered with siding. Heating is by forced hot air and heat pump.

The basement walls are of poured concrete and have no cracks. The basement floor slab is in good condition with minimal cracking, but there is a major wall/floor joint 1 to 2 mm wide around most of the floor. The owner said that there was a layer of crushed stone beneath the floor, and that in the summer insects entered the basement via the wall/floor joint opening. There are roughed in connections for a shower and toilet near the rear wall, covered with six bricks mortared together.

2. ACTION

2.1. PHASE 2

As this basement had solid concrete walls, the mitigation method chosen for demonstration at this site was sub-slab ventilation.

A minimum four point system was installed consisting of lightweight "1 inch" plastic pipe. A 12.5 cm diameter hole was cored through the floor slab in the approximate centre of each wall. The floor slab was a full 10 cm thick, and the stone layer beneath was 1 to 8 cm thick. A vertical pipe was inserted in each hole and connected to a central "1 inch" header. The space between the pipe and concrete was filled with silicone caulk. The header ran to a window, where a flexible duct passed through a sheet of plywood mounted in a basement window frame to a centrifugal fan mounted outside in a box.

The fan produced suctions of about 90 Pa in each pipe at the floor, and flows and radon concentrations were; end wall 11 L/s at 700 pCi/L; front wall

7 L/s at 640 pCi/L; garage wall 3 L/s at 670 pCi/L; rear wall 0.2 L/s at 15 pCi/L. Basement radon was measured as 6 pCi/L. Smoke tests showed that air flowed down the wall/floor joint except in a region between the front wall and garage wall pipes.

The high suction, moderate radon concentrations and low airflows in the system indicated that the sub-slab fill was not very permeable, and that much of the air was being drawn from the house rather than from the sub-slab fill.

In May 1986, the radon concentration in the basement with the fan running ranged from 1 to 6 pCi/L, averaging 3.5 pCi/L. When the fan was turned off, the concentration rose slowly over 16 hours ranged between 110 to 310 pCi/L, averaging 220 pCi/L over the next 30 hours.

2.2. PHASE 3

In November 1986, detail improvements were made to the system. The fan was replaced by a large plastic bodied centrifugal fan of higher suction hung from the joists of a deck at the rear of the house, and the plywood panel in the window was replaced with a plexiglas sheet. The wall/floor joint was caulked with silicone caulking to reduce the amount of air withdrawn from the house.

System measurements in December found that condensation was blocking the flexible duct. When the water was drained out of the duct, the suctions, flows and radon concentrations in the pipes were; side wall 175 Pa, 17 L/s at 2 100 pCi/L; front wall 175 Pa, 10 L/s at 2 900 pCi/L, garage wall 240 Pa, 1 L/s at 1400 pCi/L, rear wall 185 Pa, 1 L/s at 130 pCi/L. These pressures and flow fit well with measurements at the fan of 240 Pa and 34 L/s. The increased radon concentrations indicated that closing the wall/floor joint had decreased the leakage of air from the house. Radon concentrations in the basement following the test ranged from 5 to 47 pCi/L, averaging 25 pCi/L. This was attributed to condensation blocking the hose, despite a weephole at a low point to allow it to drain away.

The system was modified in March 1987 with rigid piping to prevent water accumulating in the pipe to the fan. Basement radon concentrations in March 1987 with the fan on ranged from 2 to 17 pCi/L, averaging 8 pCi/L. With the fan off, radon concentrations ranged from 23 to 39 pCi/L, averaging 30 pCi/L. The nights might have been cool enough to cause condensation, but examination of the system did not find any sign of water accumulation.

Alpha track detectors were issued in March 1987 to give a long term measurement of the radon concentration.

An extensive route of entry survey was carried out in April. Enclosures were taped over six sections of the wall/floor joint, the open chimney outlet, the sill plate in the region of the front porch slab, and over the unconnected bath and toilet service entries, and sampled after 24 hours. The radon concentrations in all these enclosures were less than 25 pCi/L, indicating that there were no major flows of soil gas into the house in any of the areas covered by the enclosures.

3. OTHER MEASUREMENTS

Radiation fields in the house and on the site were measured with a scintillometer. The field in the basement ranged from 10 to 16 uR/h, averaging 13 uR/h, and on the site ranged from 8 to 14 uR/h, averaging 11 uR/h. The site was so extensively graded that there was no undisturbed soil.

The average radon concentration measured by alpha-track detectors over the period March 1987 to April 1987 was 5.4 pCi/L in the basement, and 3.0 pCi/L in the living area.

MEASUREMENTS SUMMARY FOR HOUSE 25

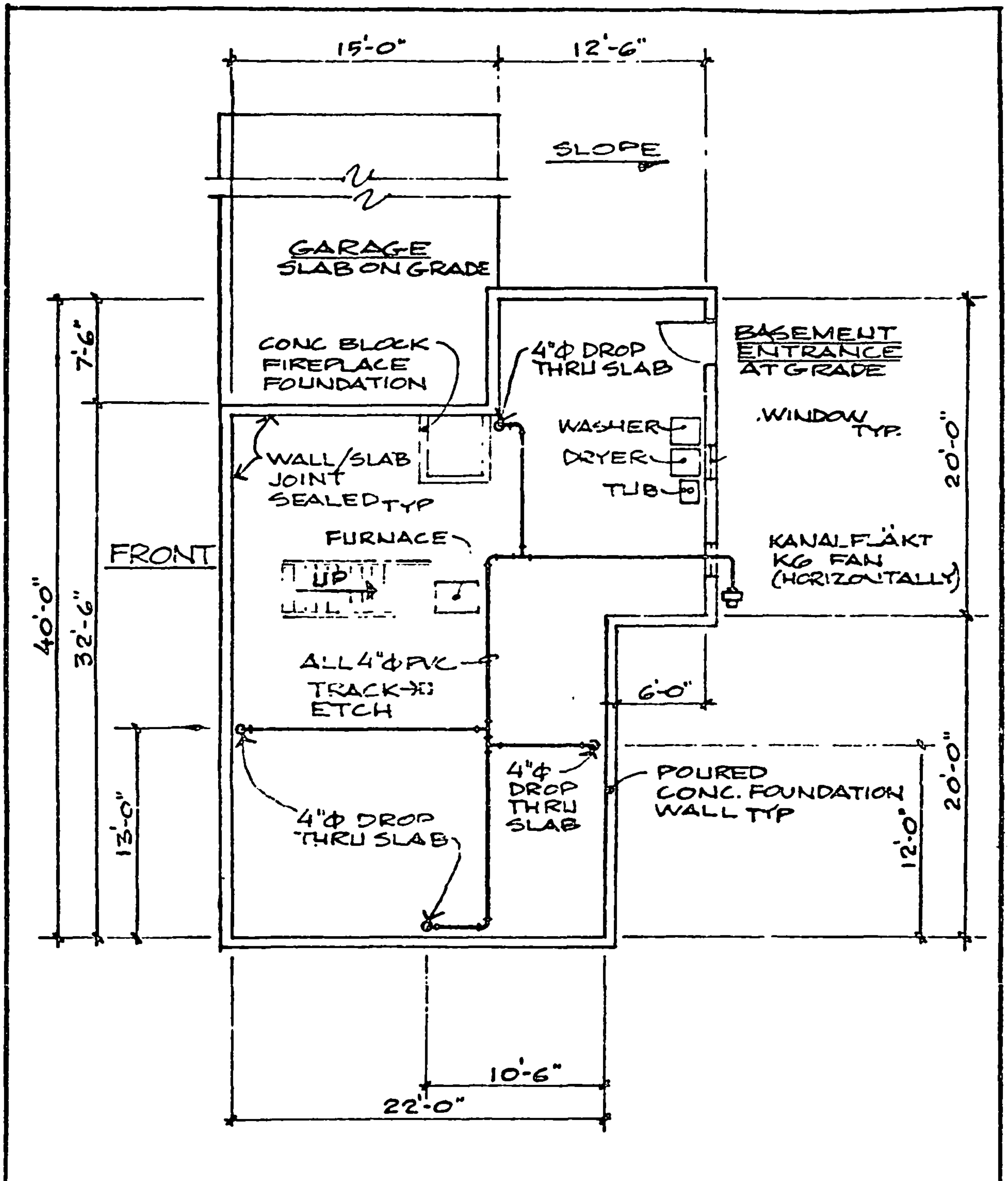
PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	MEAN	COMMENTS
2	Sub-slab ventilation; 50 L/s centrifugal fan	05/86	Fan on	1-6	4	over 48 hrs
			Fan of	110-320	220	over 30 hrs - following 16 hr rise to equilibrium
3	Sub-slab ventilation; 150 L/s centrifugal fan wall/floor joint caulked	12/86	Fan on	5-47	25	over 4 days-condensation blocking flexible duct
		03/87	Fan on	2-17	9	over 88 hrs
			Fan on	4-17	8	over 48 hrs
			fan off	23-39	30	over 41 hrs after a 5 hr rise

SYSTEM MEASUREMENTS FOR HOUSE 25

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
2	Sub-slab ventilation; 50 L/s centrifugal fan	05/86	90	15	500	Riser A
			88	7	640	Riser B
			100	3	670	Riser C
			100	0.2	15	Riser D
					6	Basement air
3	Sub-slab ventilation; 150 L/s centrifugal fan	12/86	175	17	2 400	Riser A
			175	10	2 900	Riser B
			240	4	1 400	Riser C
			185	1	130	Riser D
			210	34		At fan

A: End wall
B: Front wall
C: Garage wall
D: Rear wall



ACRES	LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
	FOUNDATION PLAN	Date: 12/2/86	25
	Mitigation system: SUB-SLAB SUCTION	PHASE: FINAL	

HOUSE 26

PENNSYLVANIA DER MEASUREMENTS

Working Level grab samples (Kusnetz)	0.134 WL
Short term average WL (RPISU)	0.013 WL
Average radon (Terradex)	11 pCi/L
Radon concentration in water	5 000 pCi/L

1. DESCRIPTION

This two story detached house was built in the early 1980's on a gently sloping rural site near the top of a hill several miles to the northwest of Boyertown. The walls are covered with vertical wood siding. Heating is by electric baseboards upstairs, supplemented with a small coal stove in the basement.

The basement walls are of concrete block, open at the top. The sill plate partially covers the voids on each wall. Three walls are covered with earth, the fourth is exposed, and contains the door to the single car garage in the basement. The front porch is supported on a block structure, and is reached from the basement via a door, and is used as a cold cellar. The floor is of crushed stone.

The basement floor was poured in several pours, and has some cracking as well as construction joints. The owner said that there was a complete perimeter drain (weeping tile) system round all four walls.

2. ACTION

2.1. PHASE 2

As this house had a weeping tile system, the mitigation method chosen for demonstration was weeping tile ventilation.

Two discharge pipes from the weeping tile system were located on the lower part of the site, traced back to the house, and excavated. The weeping tile was found to run in a 'U' only around the buried walls.

On the west side of the house a water trap of "1 inch" plastic pipe and elbows was inserted in the discharge pipe. On the other side, a similar water trap was placed in the pipe. The house side of the trap was extended vertically to grade level, run back to the house at grade level, and then turned vertically adjacent to the wall for a fan riser.

The excavation around each trap was filled with plastic popcorn and covered with a 5 cm sheet of beadboard for insulation to prevent the water freezing in the winter. The excavations were filled to grade, and sod replaced. A 50 L/s axial fan was attached to the riser at the front wall of the house. This produced 55 Pa suction, 25 L/s flow, with 1 400 pCi/L of radon in the exhaust. In mid April 1986, the radon concentration in the basement with the fan running ranged from 3 to 11 pCi/L, averaging 5 pCi/L. When the fan was turned off, concentrations rose rapidly to vary between 9 to 77 pCi/L, averaging 60 pCi/L. Turning on the fan dropped concentrations to the original range(2 to 8 pCi/L).

In late April 1986, 5 cm of concrete was placed over the crushed stone floor of the cold room to increase the air tightness of the substructure. Following this, the radon concentration in the basement with the fan running ranged from 0.2 to 7 pCi/L, averaging 4 pCi/L, and rose to range from 60 to 191 pCi/L, averaging 100 pCi/L when the fan was turned off. Turning on the fan rapidly dropped concentrations to the original range of 0.4 to 7 pCi/L, averaging 3 pCi/L over 25 hours.

2.2. PHASE 3

The axial fan was scheduled for replacement by a weather-proof in-line centrifugal fan in the fall. Over the summer of 1986 the owner modified the house. The garage door into the basement was removed, and replaced by a window. The garage space was turned into a sitting room. A porch roof was constructed along the front of the house.

With these changes, current fan location was no longer suitable, for it discharged beneath the porch about 1.5 m from the house corner. The fan replacement plan was upgraded to a fan relocation plan. In December 1986, the area was excavated, and a new "4 inch" pipe run horizontally from the trap to the corner of the house, and then vertically to 50 cm above grade. The new fan was attached to the pipe, and the discharge led above the porch roof by a "4 inch" pipe.

The new fan produced 210 Pa suction, 50 L/s flow, with a radon concentration of 110 pCi/L in the exhaust. In December 1986, following the fan change, the basement radon concentration ranged from 0.1 to 1.9 pCi/L, averaging 1 pCi/L. These results were good enough for alpha track detectors to be issued in December 1986.

In April the owner complained that the fan had become noisy. It was replaced. The noise level had increased, but the performance had not been affected, and there was no obvious reason for the higher noise.

3. OTHER MEASUREMENTS

The radiation fields in and around the house were 4 to 8 uR/h, averaging 6 uR/h in the basement; and 5 to 10 uR/h, averaging 7 uR/h over the site.

The average radon concentration measured by alpha-track detectors over the period December 1986 to March 1987 was 2.1 pCi/L in the basement, and 1.5 pCi/L in the living area.

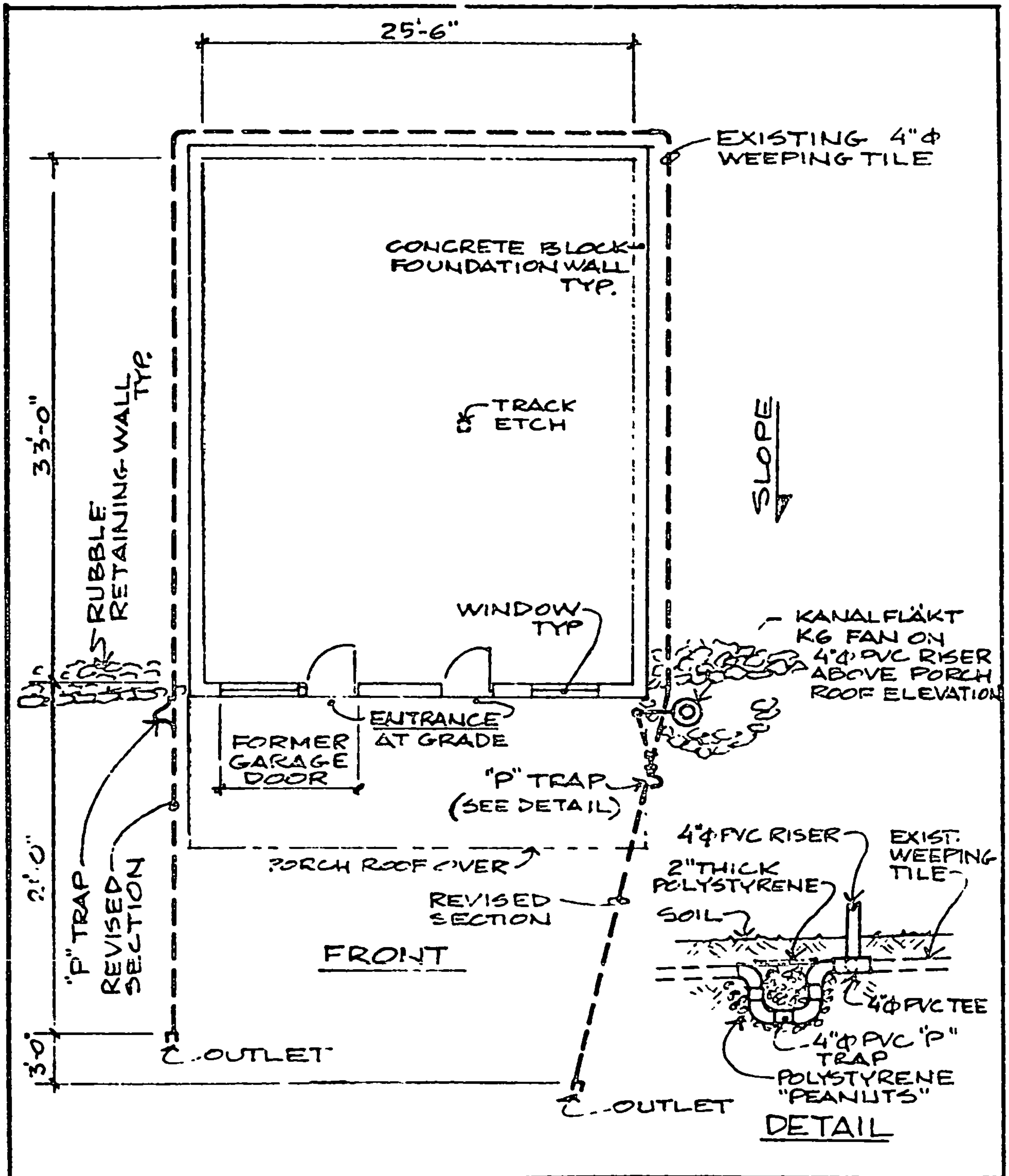
MEASUREMENTS SUMMARY FOR HOUSE 26

PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	MEAN	COMMENTS
2	Drain tile ventilation; 50 L/s axial fan	04/86	Fan on	3-12	5	over 48 hrs.
			Fan off	9-77	60	over 24 hrs.
			Fan on again	2-8	5	over 24 hrs.
	cold room soil floor concreted to increase air tightness	04/86	Fan on	0.2-7	4	over 40 hrs.
			Fan off	60-191	100	over 30 hrs.
			Fan on again	0.4-7	3	over 25 hrs.
3	Fan replaced by 150 L/s cent fugal	12/86	Fan on	0.1-1.9	1	over 74 hrs.

SYSTEM MEASUREMENTS FOR HOUSE 26

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
2	Drain tile ventilation; 50 L/s axial fan	01/86	55	25	1 400	In riser
3	Fan replaced by 150 L/s centrifugal	12/86	210	50	110	In riser



ACRES	LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
	FOUNDATION PLAN	Date: DEC. 86	26
	Mitigation system: WEEPING TILE SUCTION	PHASE: FINAL	

HOUSE 27

PENNSYLVANIA DER MEASUREMENTS

Working Level grab samples (Kusnetz)	0.412 WL
Short term average WL (RPISU)	0.008 WL
Heating season average radon (Terradex)	21 pCi/L
Radon concentration in water	14 300 pCi/L

1. DESCRIPTION

This two story house was built in the early 1980's on a leveled site on the side of a hill several miles to the west of Boyertown. The house walls are of vertical wood siding. Heating is by electric baseboards upstairs, supplemented by wood stoves in the basement and upstairs.

The basement walls are of concrete block, open at the top. The sill plate partially covers the voids. There is a large central concrete block structure in the basement which contains the stove flues and supports the concrete pad on which the upstairs stove stands. The walls have no major cracks.

The floor is almost completely covered with stored materials, but appears to be in good condition with no cracks. There is a construction joint down the middle of the slab.

The owner said that there was a complete external drainage system (weeping tile) around the basement.

2. ACTION

2.1. PHASE 2

As this house had a weeping tile system, the mitigation action chosen for demonstration was weeping tile ventilation.

The discharge pipe from the weeping tile was located at a low part of the site close to the house. The line was traced back to the house and the junction with the drain pipe excavated. A 'U' trap made from '1 inch' lightweight plastic pipe and elbows was inserted in the discharge pipe. The house side of the trap was extended vertically to grade level, and run back to the side wall of the house for a fan riser. The excavation was back filled. The trap was deep enough (70 cm) that insulation was not needed to prevent freezing.

A 50 L/s axial fan was attached to the riser. Suction was 35 Pa at 27 L/s, and the radon concentration in the exhaust was 800 pCi/L.

In April 1986, the radon concentration in the basement when the fan was off ranged from 20 to 64 pCi/L, averaging 45 pCi/L. When the fan was turned on, concentrations fell quickly for 8 hours to range from 3 to 9 pCi/L, averaging 6 pCi/L.

In April 1986, the owner reported that the fan was making rattling noises, and it was assumed that the bearing had failed. The fan was replaced. When the old unit was cut off the riser, several snails were found in the pipe, and shell fragments were found on the fan protective screen. The rattling noise had been caused by snails trapped in the weeping tile crawling toward the light, and falling into the fan blades. The snails were removed before the new fan was installed.

2.2. PHASE 3

In December 1986 the axial fan was replaced by a permanent plastic bodied centrifugal fan. This gave a suction of 320 Pa at a flow of 40 L/s. The radon concentration in the exhaust air was 500 pCi/L. Basement radon concentrations with the new fan running ranged from 1 to 9 pCi/L, averaging 3 pCi/L.

Alpha track dosimeters were issued for final long term measurements in December 1986.

3. OTHER MEASUREMENTS

The radiation field in the basement ranged from [illegible] to 9 uR/h, averaging 6 uR/h. Two radium dial aircraft compasses stored in the basement had fields of up to 150 uR/h in contact with their boxes. The fields over the site ranged from 12 to 25 uR/h, averaging 16 uR/h.

The average radon concentration measured by alpha-track detectors over the period December 1986 to March 1987 was 3.8 pCi/L in the basement, and 2.2 pCi/L in the living area.

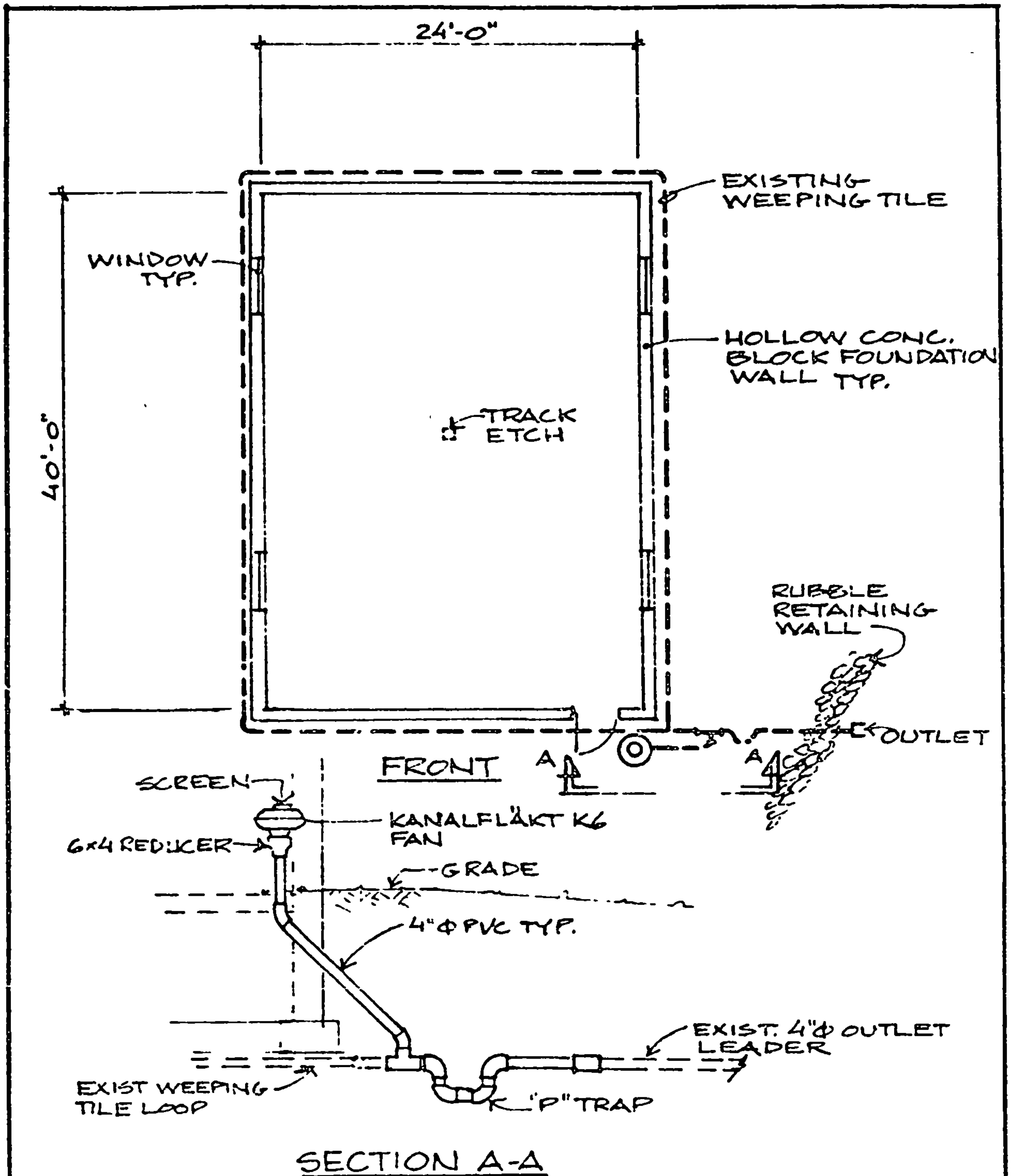
MEASUREMENTS SUMMARY FOR HOUSE 27

PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	MEAN	COMMENTS
2	Drain tile ventilation; 50 L/s axial fan	01/86	Fan off	20-64	45	over 39 hrs
			Fan on	3-9	6	over 38 hrs
3	Axial replaced by 150 L/s centrifugal	12/86	Fan on	1-9	3	over 40 hrs

SYSTEM MEASUREMENTS FOR HOUSE 27

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
2	Drain tile ventilation; 50 L/s axial fan	04/86	35	27	800	In riser
3	Axial replaced by 150 L/s centrifugal	12/86	325	100	500	In riser



ACRES	LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
	FOUNDATION PLAN	Date: DEC. 86	27
	Mitigation system: WEEPING TILE SUCTION	PHASE: FINAL	

HOUSE 28

PENNSYLVANIA DER MEASUREMENTS	
Working Level grab samples (Kusnetz)	0.155 WL
Short term average WL (RPISU)	0.118 WL
Heating season average radon (Terradex)	21 pCi/L
Radon concentration in water	N/A

1. DESCRIPTION

This two story house with attached garage was built in the late 1970's at the foot of a gently sloping site in a rural subdivision on the top of a hill a few miles west of Oley. The lower part of the front wall is brick, the other walls are of siding. Heating is by oil-fired forced warm air with an electronic air cleaner, supplemented by basement and main-floor fireplaces.

The basement walls are of concrete block, and most of the area is finished. There are water marks on the visible portions of the walls. The floor slab has two cracks visible, and there is an open sump with sump pump in the unfinished part of the basement.

The owner said that there was a complete weeping tile system with an external drain all around the house, even on the garage wall. He did not know to what the sump was connected. The site had been regraded several times to reduce water leakage in the block walls.

2. ACTION

2.1. PHASE 2

As this house had a weeping tile system the initial mitigation action chosen for demonstration was weeping tile ventilation.

The weeping tile discharge pipe exit could not be found on the site. In fact the gentle slope of the land in the area made it impossible for a drain at footing level to reach the surface within 15 m of the house, well off the site. The conclusion was that the tile, if present, probably drained to a buried on-site soakaway pit. The water stains on the walls suggested that the drain tile system was not very effective. Rather than disturb the drainage system by digging and perhaps aggravate water problems, the decision was made to pursue other mitigation avenues.

The sump offered a potentially easy route to ventilate the sub-slab space. The mitigation method selected for an initial demonstration was therefore sump ventilation.

A submerged sump pump with a "2 inch" plastic discharge line was in the sump. Screw anchors were placed in the concrete around the sump and a plywood cover, split to pass round the discharge line, was screwed and caulked into place. A "4 inch" lightweight plastic ventilation pipe was attached to the cover with a toilet flange. The other end of the pipe ran to above grade and out through the block wall to a 50 L/s axial fan mounted in a "6 to 4 inch" reducer attached to the pipe. A second capped pipe stub was attached to the cover to provide access to the sump for drainage.

In April 1986, the radon concentration in the basement with the sump fan in operation ranged from 13 to 30 pCi/L, averaging 20 pCi/L. Investigation found the fan gave 68 Pa suction at 6.5 L/s, but the radon concentration in the exhaust was only 57 pCi/L, at a time when the basement concentration was 20 pCi/L. These results indicated that the sump did not effectively access the sub-slab space.

2.2. PHASE 3

In November 1986, the radon concentration in the basement with the sump ventilation fan running ranged from 10 to 68 pCi/L, averaging 22 pCi/L. Water was leaking into the basement through the block wall in the sump area, and was not able to drain into the sump because of the screwed and caulked sump cover. As the system was ineffective and was inconveniencing the home owner, it was removed in December.

As this house had a finished basement and relatively low radon levels, the alternative mitigation method selected for demonstration in this house was increased ventilation by an air to air heat exchanger (HRV).

A HRV was installed by a local contractor who had installed a number of HRV's for radon control. As the basement was finished and used extensively, he recommended a basement flood system to reduce radon levels both in the basement and upstairs. The unit was installed in the storage area, exhausted from there, and discharged fresh air into the family room at 78 L/s on high and 63 L/s on low fan speed.

In February 1987, radon concentrations in the basement with the HRV running on high ranged from 7 to 17 pCi/L, averaging 10 pCi/L. When the HRV was turned off, radon concentrations ranged from 10 to 21 pCi/L, averaging 10 pCi/L.

Alpha track detectors were issued in February 1987 to provide a long term measurement of the average radon concentration.

Another set of measurements were made in February to check the effect of the HRV on internal air circulation. Measurements were made in the family room with the door to the unfinished area closed to isolate the fresh air delivery area from the exhaust area, and upstairs in the sitting room. With the HRV on high, the radon concentration in the family room ranged from 7 to 12 pCi/L, averaging 9 pCi/L, comparable to the whole basement value measured on the previous run. Simultaneously the upstairs concentration ranged from 5 to 10 pCi/L, averaging 7 pCi/L. When the HRV was turned off and after a delay of seven hours, the family room radon concentration ranged from 10 to 22 pCi/L, averaging 16 pCi/L. At the same time the upstairs concentration ranged from 5 to 13 pCi/L, averaging 9 pCi/L. The effect of the HRV appeared to be confined to the basement, for halving the concentration there made only a slight reduction in the upstairs radon concentrations.

3. OTHER MEASUREMENTS

The radiation field in the house ranged from 4 to 8 uR/h, averaging 6 uR/h. The field over the site ranged from 4 to 10 uR/h, averaging 7 uR/h.

The average radon concentration measured by alpha-track detectors over the period February 1987 to April 1987 was 2.4 pCi/L in the basement, and 5.3 pCi/L in the living area.

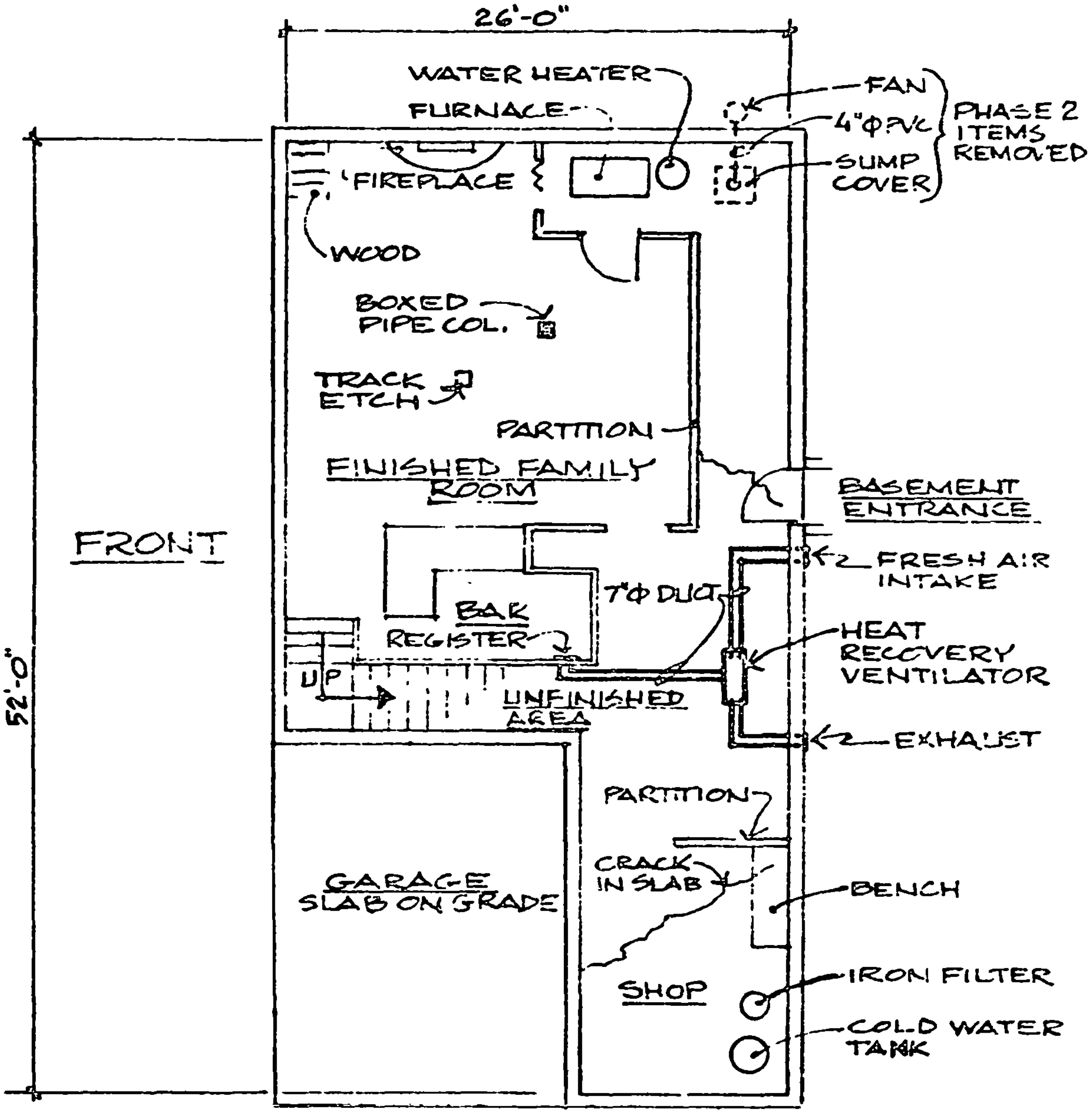
MEASUREMENTS SUMMARY FOR HOUSE 28

PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	MEAN	COMMENTS
2	Sump ventilation 50 L/s axial fan	04/86	Fan on	13-30	20	over 4 days
		11/86	Fan on	10-68	22	over 1 days
3	Heat recovery ventilation; 100 L/s unit	02/87	On-high	7-17	10	over 37 hrs.
			Off	10-21	16	over 42 hrs.
		02/87	On-high	7-12	9	over 10 hrs.
			On-high	5-10	7	over 40 hrs upstairs
			Off	10-22	16	over 47 hrs.
			Off	5-13	9	over 47 hrs. upstairs

SYSTEM MEASUREMENTS FOR HOUSE 28

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
2	Sump ventilation; 50 L/s axial	04/86	68	7	57	Fan on - riser pipe
					20	Fan on - basement air
3	Heat Recovery Ventilation; 100 L/s unit	02/87		63		low speed - fresh air discharge
				78		high speed - fresh air discharge



ACRES	LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
	FOUNDATION PLAN	Date: NOV. 85	28
	Mitigation system: COMMERCIAL HEAT RECOVERY VENTILATOR	PHASE: FINAL	

HOUSE 29

PENNSYLVANIA DER MEASUREMENTS

Working Level grab samples (Kusnetz)	0.580 WL
Short term average WL (RPISU)	0.032 WL
Heating season average radon (Terradex)	61 pCi/L
Radon concentration in water	23 000 pCi/L

1. DESCRIPTION

This two-story side-split house with attached garage was built in the late 1970's on a level site near the top of a ridge a few miles west of Oley. The lower half of the house walls are of brick, the upper half of siding. Heating is by an oil-fired forced air system with an electronic air cleaner. There is an upstairs fireplace in the family room.

The basement walls are of concrete block painted with waterproof paint. There is a dirt floor crawl space with unpainted block walls beneath the family room. The block walls are open at the top, and the voids on the front and back walls are partially concealed by the sill plate.

The floor is in fair condition with some cracking and there is an open sump with water in it in one corner of the basement. There were openings in the plastic sump liner, but the owner did not know if they connected to sub-slab drains.

2. ACTION

2.1. PHASE 2

As this house had a sump, the first mitigative action chosen for demonstration was sump ventilation. The large area of exposed soil in the crawl space also required treatment, and the second action chosen for demonstration was soil covering plus ventilation.

The sump held a submerged sump pump with a "2 inch" plastic discharge line. Screw anchors were placed in the concrete around the sump, a ring of expanding urethane foam was put round the top of the sump as a gasket. A plywood cover, split to pass round the discharge line, was screwed in place. A "4 inch" lightweight plastic pipe was attached to the cover with a toilet flange. The other end of the pipe ran to a nearby window opening, and was connected by flexible hose to a 50 L/s axial fan mounted on a plywood sheet in the opening. A capped "1 inch" pipe stub was attached to the cover to provide access to the sump for drainage.

A 1.5 by 3 m loop of perforated "1 inch" lightweight plastic pipe was placed on the open soil in the crawl space, and was connected to "1 inch" pipe that ran to a second 50 L/s axial fan mounted on plywood in the window opening. The open soil in the crawlspace was covered with two layers of 6 mil polyethylene sheet. The edges of the sheet were fastened to the block basement walls by "1 by 3 inch" wooden furring strips, and all joints were covered with asphaltic caulk.

In April 1986, with both the sump and crawlspace fans on, radon concentrations in the basement ranged from 5 to 22 pCi/L, averaging 15 pCi/L.

Investigation found that the sump fan was developing 60 Pa suction, at a flow of 8 L/s, and a radon concentration of 1 000 pCi/L. The crawl space fan developed 20 Pa at a flow 25 L/s, with a radon concentration of 16 pCi/L. The basement air concentration was 12 pCi/L at the time and air drawn from the floor drain showed a concentration of 17 pCi/L. Smoke testing of the open blocks around the opening to the crawl-space gave possible indications of flow into some and flow out of others, with no apparent pattern.

The similar radon concentrations in the basement air and the crawlspace soil exhaust air indicated that most of the soil exhaust air was house air that had leaked beneath the cover through the cracks and openings in the block walls. It also suggested that the crawlspace soil was not the major radon supply route.

This was tested directly in May 1986, when the crawlspace fan was turned off. With both fans running, the radon concentration varied from 1 to 21 pCi/L, averaging 15 pCi/L. When the crawl space fan was turned off, concentrations varied from 2 to 41 pCi/L, averaging 20 pCi/L. With both fans off, concentrations ranged from 7 to 90 pCi/L, with marked diurnal cycling, and averaged 35 pCi/L.

In July 1986 with no fans on and the sump open so that a dehumidifier could drain into it, the basement concentration ranged from 20 to 111 pCi/L, with marked diurnal cycling, and averaged 90 pCi/L.

2.2. PHASE 3

In January 1987 the two existing fans were removed, the sump and crawl space suction lines joined through a "T" connection and a large plastic bodied in-line fan installed to increase the exhaust suction.

With the new fan operating, radon concentrations ranged from 1 to 3 pCi/L, averaging 2 pCi/L. When the fan was turned off the radon concentrations ranged from 19 to 43 pCi/L, averaging 30 pCi/L. The suction in the sump was 120 Pa, with a flow of 15 L/s at 600 pCi/L. The radon concentration in the air from the crawlspace was 13 pCi/L a suction of 95 Pa and a flow of 60 L/s.

Alpha track detectors were issued in February 1987 to provide a long term estimate of the radon concentration.

3. OTHER MEASUREMENTS

The radiation fields in and around the house were 8 to 9 uR/h in the crawl space, and 5 to 7 uR/h in the basement over most of the slab, but increased to 12 to 14 uR/h in the area of the sump, and 10 to 13 near the well pressure tank. The field outside ranged from 8 to 14 uR/h, averaging 12 uR/h.

The average radon concentration measured by alpha-track detectors over the period February 1987 to April 1987 was 1.9 pCi/L in the basement, and 1.4 pCi/L in the living area.

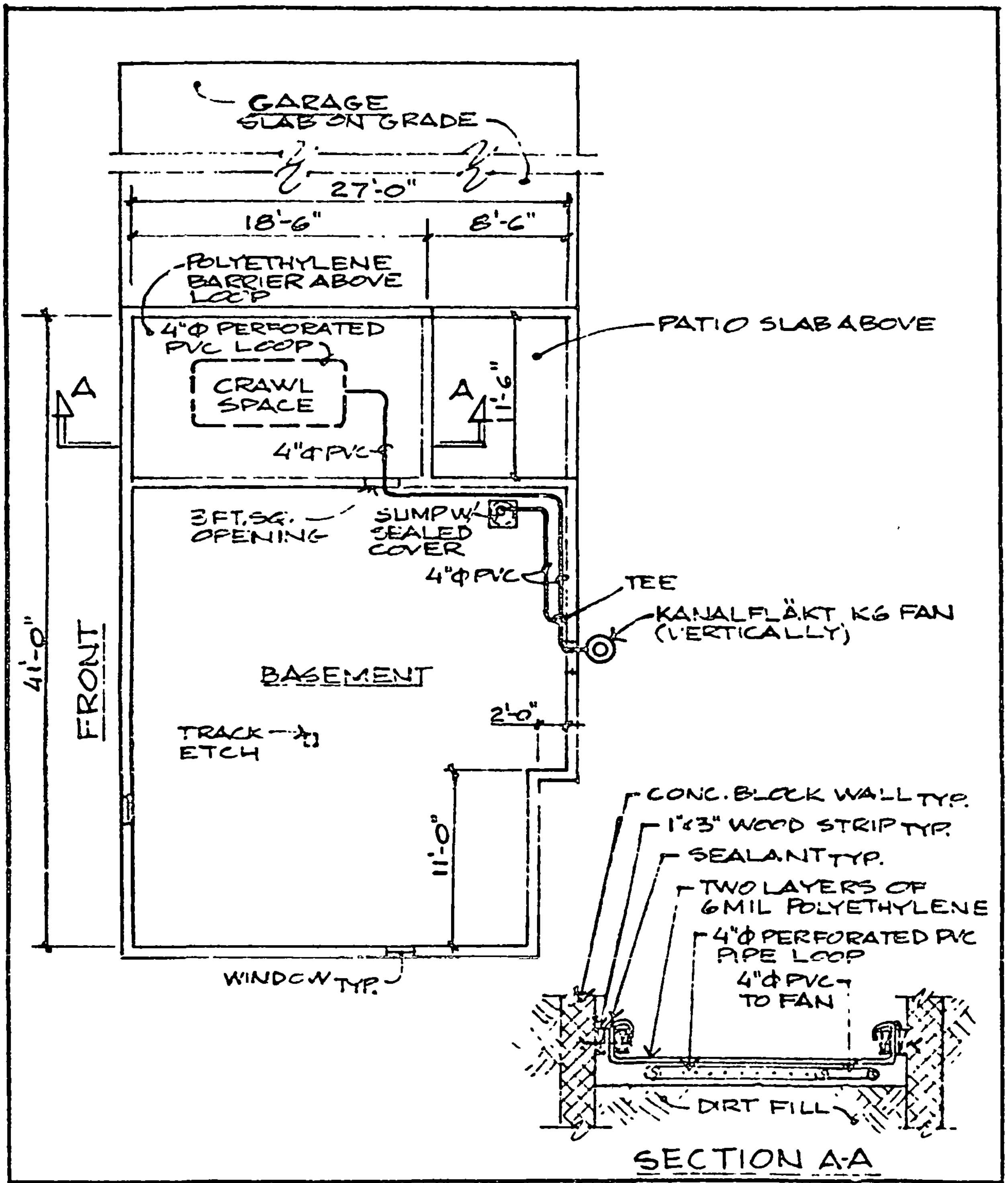
MEASUREMENTS SUMMARY FOR HOUSE 29

PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	MEAN	COMMENTS
2	Sump + crawl space ventilation; two 50 L/s axial fans	04/86	Sump and crawl space fans on.	5-22	15	over 46 hrs.
		05/86	Both fans on	4-21	15	over 48 hrs.
			Crawl off/sump on	2-14	20	over 42 hrs.
			Crawl off/sump off	7-90	35	over 4 days
		07/86	Both off/sump open	20-114	90	over 4 days
3	Suction lines teed together; fans replaced by 150 L/s centrifugal	01/87	Fan on	1-3	2	over 47 hrs.
			Fan off	19-43	30	over 37 hrs.

SYSTEM MEASUREMENTS FOR HOUSE 29

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
2	Sump +crawl-space ventilation; two 50 L/s axials on	01/86	60	8	1 000	Sump fan line
			20	23	10	Crawl-space line
					12	Basement air
					17	Floor drain
3	Lines teed; fans replaced by 150 L/s centrifugal	02/87	120	15	600	Sump line
			95	80	13	Crawl-space line



ACRES	LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
	FOUNDATION PLAN	Date: JAN. 87	29
	Mitigation system: PERFORATED LOOP AND SUMP SUCTION	PHASE: FINAL	

HOUSE 30

PENNSYLVANIA DER MEASUREMENTS

Working Level grab samples average (Kusnetz)	0.137 WL
Heating season average radon (Terradex)	17 pCi/L
Radon concentration in water	266 000 pCi/L

1. DESCRIPTION

This single story house was built in the late 1970's on a gently sloping rural site near the foot of a steep hill several miles south of Oley. The walls are covered with siding, and heating is by electric baseboard units. The owner has added an oil fired boiler with hot water convectors. The basement walls are of concrete block, and there is an external entrance into the basement.

2. ACTION

2.1. PHASE 2

This house had the highest concentration of radon in water of all the houses in the Reading Prong area tested by the DER, and it was probable that most of the radon in the house air came from the water. The mitigation measure selected for demonstration was removal of water borne radon by adsorption on activated charcoal.

Preliminary radon concentration measurements in the basement during May 1986 found that the baseline radon concentration was in the region of 3 to 5 pCi/L, but there were peaks to 67, 68, 122, 210 pCi/L associated in time with operation of the washing machine, and in size with the amount of water used. This was consistent with the water being the major radon route of entry.

A commercial charcoal adsorption unit was ordered from a specialist company in Maine, who used an activated coconut charcoal with a very high claimed efficiency for radon adsorption. The unit was a 30 cm diameter by 170 cm high fiberglass reinforced plastic tank, containing 55 L of charcoal. All piping was connected to a back-flush valve mounted on top of the tank.

The system was effective. A test in August 1986 found that water concentrations were reduced from 178 000 to 1 100 pCi/L (99.4% removal) by passage through the unit. Radon concentrations in the basement ranged from 3 to 6 pCi/L, averaging 5 pCi/L, and showed no signs of variation with water use.

The radon removed from the water is stored on the charcoal in the tank, and during its decay emits gamma rays. The basement radiation field from the tank was estimated with a scintillation meter at 10 000 uR/h on contact, 1 100 uR/h at 60 cm, and 42 uR/h at 3.5 m from the tank. In the child's bedroom upstairs above the tank, readings varied from 25 uR/h directly above the tank, to 55 uR/h near the bed, to 93 uR/h on the floor at the centre of the room. For comparison, the background radiation over the ground outside the house was 10 uR/h, and had been about 6 uR/h in the basement before the unit was installed.

Scintillation meters do not estimate radiation fields reliably if the radiation spectrum differs greatly from that used to calibrate the instrument. To provide a better estimate of exposure rate, the Pennsylvania DER placed TLD dosimeters in contact with the tank, at 60 cm and 3.5 m from the tank. The average exposure rates over a 29 day period were 16 700 uR/h on contact, 320 uR/h at 60 cm, and 41 uR/h at 3.5 m. These results were close to those estimated by the scintillometer.

The owners were pleased that the radon level in the water had been reduced, but were concerned about the increase in gamma radiation, especially in the child's bedroom. They moved the child into their own bedroom where the field was lower.

2.2. Phase 3

As an interim measure while permanent shielding was designed, the tank was wrapped with 1.6 mm (1/16 inch) lead sheet. The first layer halved the meter reading, but the second layer produced only a further 20% reduction. Four additional layers of lead wrapped around the meter were needed to reduce the reading at 4 m to background (13 uR/h), suggesting that 10 mm of lead would be needed for complete shielding.

Three additional layers of lead sheet were placed on the top of the tank and wrapped around the back-flush valve to reduce the vertical component of the radiation that reached the child's bedroom. The field was reduced to 15 uR/h directly over the tank, and to 25 uR/h (50% above background) at the bed by this shielding.

The radiation measurements suggested that 1 cm of lead shielding would be needed to reduce the field in the house to near background. Fabricating and installing lead sections of 1 cm thickness would be difficult and expensive. A review of the options led to the conclusion that concrete would be a better material than lead for a permanent shield. Six cm of concrete would provide about the same shielding as 1 cm of lead, and this thickness could be provided conveniently by standard concrete blocks, which have a minimum total wall thickness of 60 mm. A concrete block enclosure round the tank, topped with one or two concrete pavers or patio blocks seemed a cost effective alternative more in keeping with the general skills and experience of the building trades.

In November 1986, the lead was removed, and the tank was moved slightly so that standard concrete blocks would fit around it and touch the basement wall without cutting blocks. A rectangular structure 60 cm by 60 cm by 160 cm high was built round the tank of "4 inch" concrete blocks. Larger blocks would not have given more shielding, for they do not have thicker walls, just larger voids. The blocks were mortared together, and the structure was secured to the wall with metal strapping to ensure stability. The top of the structure was covered with "2 inch" solid concrete pavers, cut to fit round the water line.

Continuous radon measurements were made upstairs while this work was in progress. While the unit was on line, baths and showers were taken, the dishwasher run, and radon concentrations varied between 0 and 2.6 pCi/L, averaging 1.5 pCi/L. The unit was bypassed for two hours while it was moved by the workmen. During this period, a bath was taken with untreated water, and the upstairs radon concentration peaked to 11 pCi/L at the same time and returned to normal within 5 hours. Basement concentrations previous to the work ranged from 4 to 6 pCi/L, averaging 5 pCi/L and showing no signs of variation with water usage.

The concrete shielding reduced the radiation field at 3.5 m to 11 uR/h, and the field in the bedroom to 15 uR/h over the tank, and 11 uR/h at the bed. The maximum field in contact with the concrete shield was 600 uR/h and background radiation in the basement was measured at 6 uR/h.

Alpha track detectors were issued in December 1986 to determine the long term average radon concentration.

Arrangements were made to monitor the unit for radon removal efficiency and to check for bacterial growth on a monthly basis. When the first test was made in January 1987, the maximum radiation field in contact with the concrete had increased to 1 300 uR/h, indicating that the amount of radon stored in the tank had doubled. This probably was due to increased water use, for there was a new baby in the house. The radon concentration in the untreated water was 240 000 pCi/L, and was 12 000 pCi/L in the treated water, so the removal efficiency had decreased to 95%.

This increase in source term made the existing shielding marginal. As a first step to increase the shielding, the lead sheet that had been removed from the tank was hung on the inner side of the blocks. This reduced the radiation field by about 20%, but additional shielding was still needed.

The effective thickness of the blocks could be doubled to 120 mm concrete equivalent by filling the voids with sand. This was tried, but the sand available from the local builders' supply had been stored outside, and was too damp to flow through the voids, which were partially obstructed by the mortar between the blocks. The sand was therefore placed in the space between the inner face of the blocks and the tank, this provided from 8 to 20 cm of sand. The maximum field in contact with the shielding was reduced to 320 uR/h, from 1 200 uR/h. The radiation field at 3.5 m was reduced to 11 uR/h from 25 uR/h.

About two weeks later, in early February, the owner reported water was leaking from the bottom of the shielding walls around the carbon unit onto the basement floor. The paving stones on top of the unit were removed, and sand removed to expose the plumbing and the top of the tank. No leaks were visible in the tank or piping, but the sand was very damp and there was condensation on the water lines inside the shield. The top of the shield was left open for a few days, the sand dried up and the leakage stopped. It is believed that water was frozen into the sand, which had been stored outside, and had melted, saturating the sand and causing the leakage.

When the system was reassembled the radiation fields were remeasured. The maximum field in contact with the concrete shield was 215 uR/h and the field at 3.5 m was 9 uR/h. Clearly there had been a reduction in source strength. The radon concentration in the water was measured at 235 000 pCi/L, so this was not due to a decrease in radon concentration. The radon concentration in the treated water was 3 000 pCi/L, a removal efficiency of 98.7%.

The radon concentrations in the water were measured in March 1987, and were 110 000 and 3 500 pCi/L before and after the unit, for a removal efficiency of 97%.

Gamma monitoring during the visits to collect the water samples found that the radiation field was fairly constant in time. The maximum fields on contact with the shielding were 230 uR/h in March, and 247 uR/h in June 1987. The corresponding values at 3.5 m were 11 and 9 uR/h, and in the bedroom above the tank 8 and 7 uR/h.

The DER placed TLD dosimeters in the house, and found the average field from March to June 1987 to be 12 uR/h at 3.5 m, and a maximum of 16 uR/h in the bedroom.

The removal efficiency of the charcoal was high, but apparently varied with time from 95% to 99.4% removal. The performance was not as good as claimed by the manufacturer (99%+). The volume of water used may have been too high for 55 L of charcoal to achieve that level of performance.

The combination of high water use and high radon concentrations in the water lead to the storage of micro-Curies of radon in the tank, with correspondingly increased radiation fields in the house. Shielding against these fields is not a trivial task. The installed shielding is adequate, but if the water should consistently reach the concentration of 250 800 pCi/L initially measured, coupled with high water use, it would be only just acceptable.

3. OTHER MEASUREMENTS

The radiation field in the house prior to installation of the carbon unit ranged from 6 to 12 uR/h, and averaged 8 uR/h. The highest field was found in the vicinity of the well pressure tank. The field over the site ranged from 7 to 13 uR/h, averaging 10 uR/h.

The average radon concentration measured by alpha-track detectors over the period December 1986 to March 1987 was 3.0 pCi/L in the basement, and 1.3 pCi/L in the living area.

MEASUREMENTS SUMMARY FOR HOUSE 30

PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON RESULTS RANGE	MEAN	COMMENTS
2	Premitigation	05/86	N/A	0.2-210	27	over 4 days baseline 3-5 pCi/L - peaks of 67, 68, 122 and 210 pCi/L
2	radon adsorption 55 L charcoal unit	11/86	On line	4 - 6	5	over 34 hrs
				0-2.7	1.5	over 86 hrs U
			Two hours off line		11	peak - untreated bathwater

U: Upstairs

SYSTEM MEASUREMENTS FOR HOUSE 30

PHASE	MITIGATION SYSTEM	DATE	RADON IN WATER (PCi/L) BEFORE	AFTER	REDUCTION %	COMMENTS
2	Radon adsorption 55 L charcoal unit	08/86	178 700	1 100	99.4	
3	Radon adsorption 55 L charcoal unit + concrete block shielding	01/87	240 000	12 000	95	
3	Radon adsorption 55 L charcoal unit + sandfilled lead lined concrete block shielding	02/87	236 000	3 000	98.8	
3	As above	03/87	110 000	3 500	97	

GAMMA MEASUREMENTS* FOR HOUSE 30

PHASE	MITIGATION SYSTEM	DATE	MEASUREMENT LOCATION	GAMMA FIELD (uR/h)	COMMENTS
2	Water adsorption 55 L/s charcoal unit	08/86	On top tank	500	On contact
			Distance from top of tank 0 cm	1 700	On contact
			20 cm	5 100	On contact
			40 cm	9 600	On contact
			60 cm	8 600	On contact
			80 cm	4 400	On contact
			100 cm	1 800	On contact
			120 cm	500	On contact
			<u>Basement</u>		
			60 cm from unit	1 065	
			2 m from unit	132	
			House Jack 3.5 m	12	
			Opposite (back wall)	19	
			Chimney	19	
			Driveway wall	9	
			<u>Upstairs Child's Room</u>		
			Above tank	25	
			Centre	54	
			Toychest	56	
			Bed	50	
			Doorway	25	
			Centre	93	On floor
			Kitchen	8	
			Driveway	7	
			Adjacent soil	13	
		09/86	Tank - contact	16 700	29 day TLD by DER
		10/86	- 100 cm	320	
			- 3.5 m	11	
3	Water adsorption 55 L/s charcoal unit plus temporary lead shielding	10/86	<u>Basement</u>		
			House Jack 3.5 m	50	Without lead
				25	1 lead sheet (1.6 mm)
				19	2 sheets
				15	3 sheets
				9	6 sheets
			<u>Upstairs</u>		
			Above tank wrapped in two sheets	32	No lead on top
				22	1 lead sheet on top
				17	2-3 sheets folded

GAMMA MEASUREMENTS* FOR HOUSE 30

PHASE	MITIGATION SYSTEM	DATE	MEASUREMENT LOCATION	GAMMA FIELD (µR/h)	COMMENTS
3	Water adsorption 55 L/s charcoal unit plus temporary lead shielding	10/86	Upstairs		2-3 sheets folded
			Childs room	25	
			Living room	7	
			Outside	11	
3	Water adsorption 55 L/s charcoal unit plus concrete block shielding	12/86	Childs Room		
			Over tank	15	
			Bed	11	
			Centre	20	On floor
			Doorway	11	
			Living room	6	
			Basement		
			Driveway wall	6	
			House Jack 3.5 m	14	
		01/87	House Jack 3.5 m	24	
			Driveway wall	6	
3	Water adsorption 55 L/s charcoal unit plus lead-lined concrete block shielding	01/87	House Jack 3.5 m	22	
3	Water adsorption 55 L/s charcoal unit plus sand-filled lead-lined concrete block shielding	01/87	House Jack 3.5 m	11	
			at 1 m	50	
		02/87	House Jack 3.5 m	9	
		03/87	House Jack 3.5 m	11	
			Child's Bedroom		
			Over tank	7	
			Doorway	5	
			Centre	6	On floor
			Kitchen	5	
		06/87	Basement	11	
			House Jack 3.5 m	9	
			Driveway wall	6	

GAMMA MEASUREMENTS* FOR HOUSE 30 (CONT)

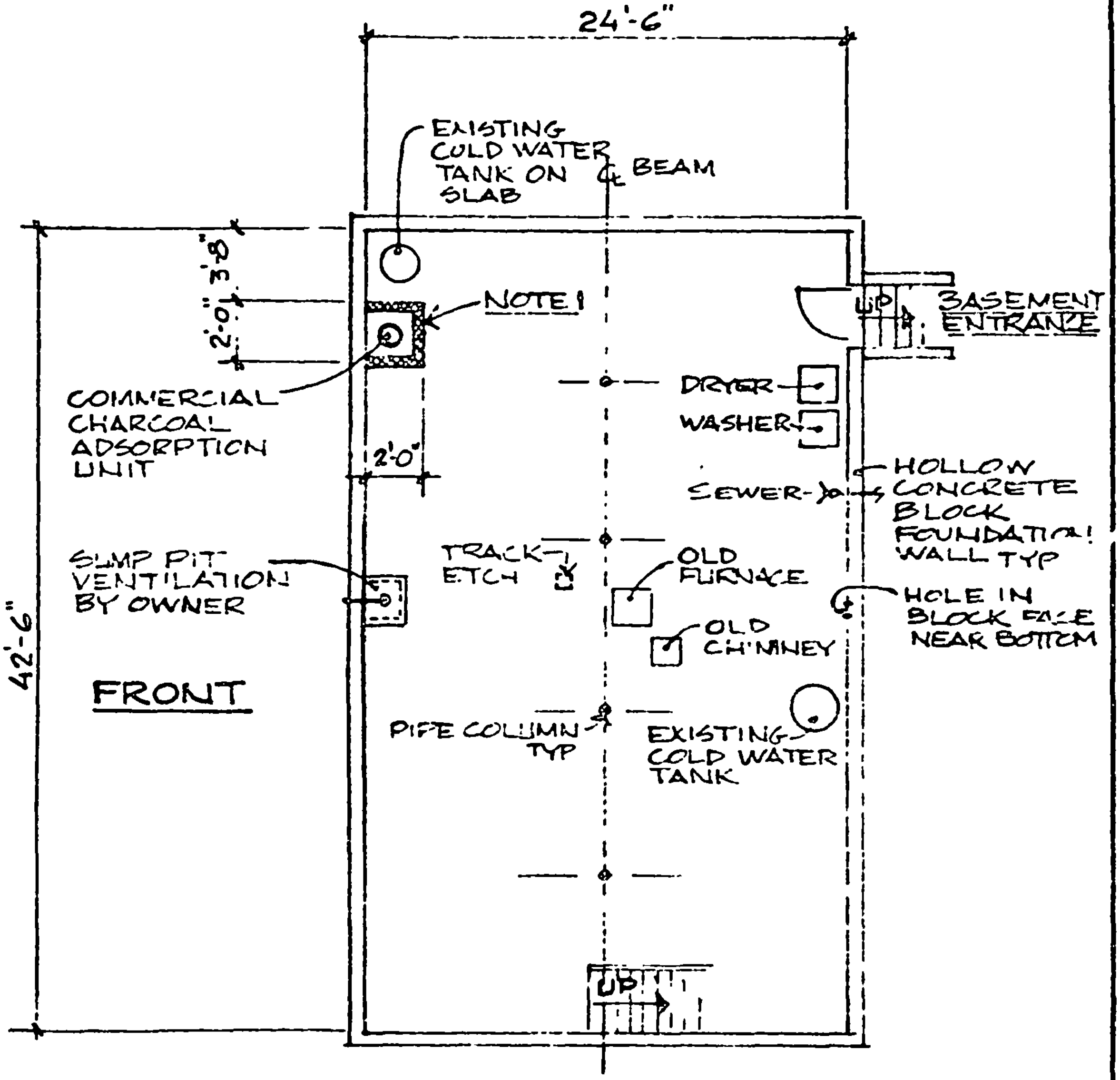
PHASE	MITIGATION SYSTEM	DATE	MEASUREMENT LOCATION	GAMMA FIELD (uR/h)	COMMENTS
		06/87	House Jack 3.5 m	12	102 day TLD by DER
			Child's Bedroom	16	102 day TLD by DER

* At a height of 1 unless otherwise stated.

GAMMA MEASUREMENTS IN CONTACT WITH SHIELDING FOR HOUSE 30

DATE	TOP	BLOCK 1	BLOCK 2	BLOCK 3	BLOCK 4	BLOCK 5	BLOCK 6
Water adsorption 55 L/s charcoal unit plus concrete block shielding							
12/86	57	133	290	490	600	600	361
01/87	115	254	574	960	1 216	1 330	844
01/87	113	227	562	867	1 160	1 208	762
Water adsorption 55 L/s charcoal unit plus lead lined concrete block shielding							
01/87		177	468	730	973	970	643
Water adsorption 55 L/s charcoal unit plus sand-filled lead-lined concrete block shielding							
01/87	23	33	105	210	320	303	173
02/87		27	85	180	245	225	115
03/87	13	30	80	160	230	215	120
06/87	16	33	82	165	217	237	143
06/87	17*				111*	111*	111*

* DER 102 day TLD measurements are marked with an asterisk.



NOTES: 1. FOUR INCH NOMINAL HOLLOW CONCRETE MASONRY UNITS LAID AND MORTARED IN RUNNING BOND. MASONRY STRAP ANCHORS EVERY SECOND COURSE AT WALL JOINTS. COVER CONSISTS OF TWO INCH NOMINAL SOLID CONCRETE MASONRY UNITS OVER 1" WIDE STEEL BARS. VOID BETWEEN FILTER AND MASONRY FILLED WITH SAND.

ACRES	LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
	FOUNDATION PLAN	Date: 11/19/85	30
	Mitigation system: CHARCOAL ADSORPTION UNIT W/RADIATION SHIELD	PHASE: FINAL	

HOUSE 31

PENNSYLVANIA DER MEASUREMENTS

Working Level grab samples (Kusnetz)	1.880 WL
Heating season short term average WL (RPISU)	0.509 WL
Heating season average (Terradex)	85 pCi/L
Radon concentration in water	N/A

1. DESCRIPTION

This single story house with attached garage was built in the late 1950's on a sloping rural site on the side of a ridge a few miles west of Boyertown. The house walls are of brick. Heating is by oil fired hot water circulated through radiators, supplemented by a wood stove in the basement.

The unfinished basement has hollow concrete block walls which are closed at the top with cap-blocks. There is a small root cellar with a wooden door at one end of the basement, and an exterior entrance door at the other end. The floor of this room is covered with a concrete slab. There are no cracks in the walls. The floor slab is poured tight against the walls, but it was placed in three pours with two construction joints up to 6 mm wide. The floor slab is penetrated by concrete filled steel columns which support the main steel beam and the walls are penetrated by a well water line and a sanitary line to a septic tank.

The owner reported that the concrete slab is poured on a good base of crushed rock, but that there was no weeping tile drain around the perimeter of the house.

2. ACTION

2.1. PHASE 1

This house had been one of the candidate houses for Phase 1. It had been considered as a demonstration house for wall ventilation, but had not been selected because the cap-blocks on the walls were an unusual feature for the area. The root cellar at that time was a complicating factor, for it was unpaved then, with a floor of crushed stone. The owner had paved the floor in 1986, but the radon level had been unaffected.

2.2. PHASE 3

By this stage of the program there was confidence that the multipoint sub-slab ventilation system with high suction fan could deal with hollow concrete block walls particularly if there was a sub-slab layer of crushed rock. The mitigation method chosen for demonstration at this site was subslab ventilation.

A six-inch PVC pipe was run along the central beam main duct of the subslab ventilation system and six 4-inch down pipes of PVC were installed in perimeter holes cored in the slab, one at each end wall and two at each long wall. Suction was applied to the main duct by an external plastic bodied centrifugal exhaust fan.

The suction at each subslab entry point was 250 Pa. Flows and radon concentrations in each pipe were; end wall 2 L/s at 1 400 pCi/L; rear wall 5 L/s at 1 400 pCi/L, rear wall 0.5 L/s at 570 pCi/L; garage wall 12 L/s at 1 600 pCi/L; front wall 3 L/s at 770 pCi/L; and front wall 3 L/s at 2 200 pCi/L.

In January 1987, radon concentrations in the basement ranged from 5 pCi/L when the basement door was open, and rose to between 450 to 530 pCi/L at night when the door was closed. When the fan was turned on the basement radon concentrations with the door closed varied between 2 to 7 pCi/L, averaging 3 pCi/L.

Alpha Track detectors were issued in January to obtain long term average radon concentrations.

3. OTHER MEASUREMENTS

Indoor gamma fields ranged from 5 to 13 uR/h, averaging 8 uR/h. The gamma fields around the site varied from 5 to 14 uR/h, averaging 11 uR/h.

The average radon concentration measured with Alpha Track detectors over the period January to March 1987 was 1.8 pCi/L in the basement and 5.7 pCi/L in the living area.

MEASUREMENTS SUMMARY FOR HOUSE 31

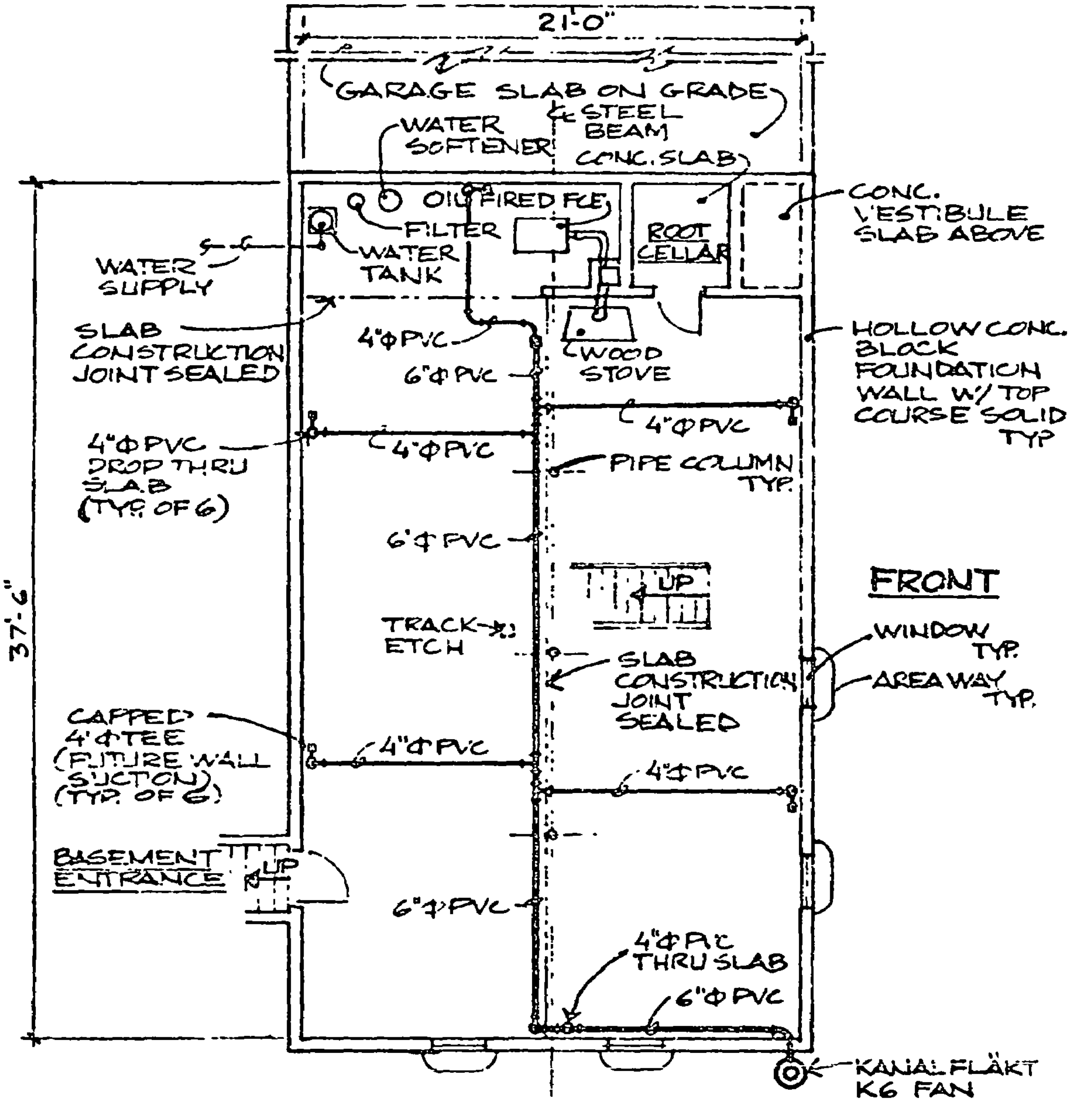
PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	MEAN	COMMENTS
3	Sub-slab ventilation; 150 L/s centrifugal fan	01/87	work in progress	5-529	290	over 50 hrs. no fan
			Fan on	2- 7	3	over 42 hrs

SYSTEM MEASUREMENTS FOR HOUSE 31

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (l/s)	RADON (pCi/L)	COMMENTS
3	Sub-slab ventilation; 150 L/s centrifugal fan	01/87	250	2	1 400	Riser A
			250	5	4 400	Riser B
			250	0.5	570	Riser C
			250	12	4 600	Riser D
			250	3	770	Riser E
			250	5	2 200	Riser F

A: End wall
B: Rear wall
C: Rear wall
D: Garage wall
E: Front wall
F: Front wall



ACRES	LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
	FOUNDATION PLAN	Date: 1/13/87	31
	Mitigation system: SUB-SLAB SUCTION	PHASE: FINAL	

HOUSE 32

PENNSYLVANIA DER MEASUREMENTS

Working Level grab samples (Kusnetz)	0.06 WL
Average radon (Terradex)	200 pCi/L
Radon concentration in water	22 300 pCi/L

1. DESCRIPTION

This single story prefabricated house was built in the early 1920's on a level site on a large ridge northeast of Reading. The house walls are of siding. Heating is by hot water baseboard convectors.

The unfinished basement walls are of hollow concrete blocks with a sill plate covering the top block voids along the front and back walls, and with open voids at the end walls. Significant floor cracks exist but the perimeter wall/floor joint is tight everywhere.

A sump, a well penetration and two well tanks are located in a pit 1.25 m square, and 1 m deep in the centre of the basement floor area. The pit has hollow concrete block walls and a concrete floor slab and is covered with a sheet of plywood.

2. ACTION

2.1. PHASE 3

The mitigation system chosen for demonstration at this site was sub-slab ventilation. The system was modified to access not only the perimeter of the basement slab but also the central pit.

In January 1987, a standard six-point subslab ventilation system was installed, together with a tightly fitting plywood cover over the pit and three inch ventilation line. All pipes connected to a six inch central pipe which led to a plastic bodied centrifugal exhaust fan mounted on an end wall. The fan gave an almost constant suction between 218 and 255 Pa at each pipe. The flows and radon concentrations in the pipes were; front wall 3 L/s at 9 pCi/L, 0.3 L/s at 10 pCi/L, end wall 0.2 L/s at 8 pCi/L; rear wall 6 L/s at 260 pCi/L, 8 L/s at 190 pCi/L; garage wall 3 L/s at 160 pCi/L; and the pit exhaust was 42 L/s at 25 pCi/L.

In January, with the system fan off, radon concentrations in the basement averaged about 7 pCi/L, and with the fan running, concentrations dropped to an average of 1-2 pCi/L.

A second check of basement radon concentrations confirmed the previous results with an average of 1-2 pCi/L with the fan on and 5 pCi/L with the fan off. It was found that the DER Alpha Track detector that measured the previous high concentrations had been exposed in the pit with the cover on, and did not represent a valid measurement of the basement radon concentrations. If this had been known at the time, the house would not have been selected for the project.

Alpha Track detectors were installed upstairs and in the basement to measure long term averages during the heating season.

3. OTHER MEASUREMENTS

Indoor gamma radiation varied from 2-18 uR/h, averaging 5 uR/h. Gamma radiation about the site ranged from 2 to 12 uR/h, averaging 5 uR/h. In each instance the maximum of the range was associated with a hot spot along the rear wall, close to the basement window.

The average radon concentration measured with Alpha Track detectors over the period March to April 1987 was 1.0 pCi/L in the basement and 3.2 pCi/L in the living area.

MEASUREMENTS SUMMARY FOR HOUSE 32

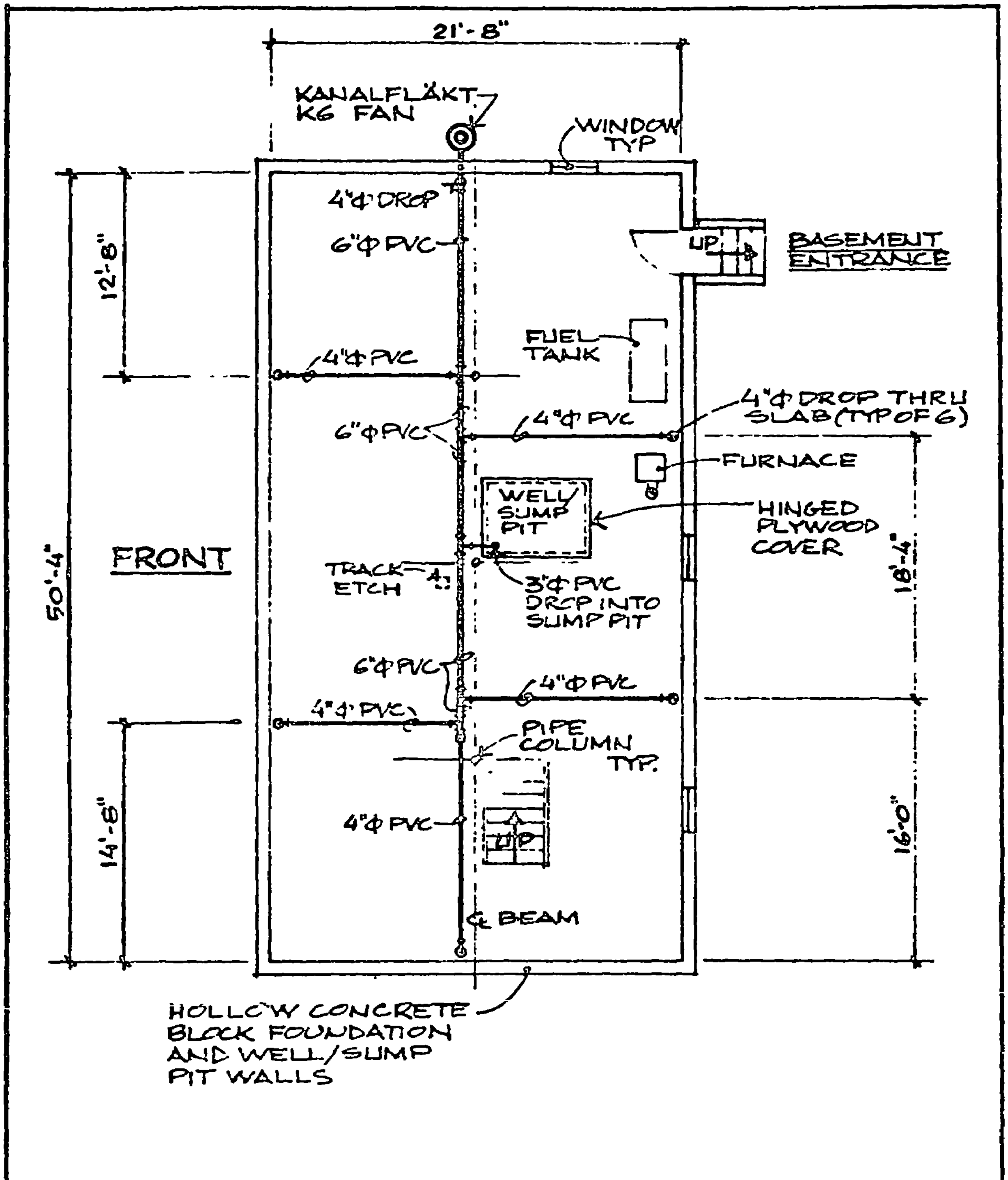
PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	MEAN	COMMENTS
3	Sub-slab + pit ventilation; 150 L/s centrifugal fan	01/87	Work in progress	1-11	7	over 42 hrs
			Fan on	0.7-2.2	1.3	over 53 hrs
		01/87	Fan on	0.5-2.7	1.2	over 17 hrs
			Fan off	3-6	1	over 42 hrs

SYSTEM MEASUREMENTS FOR HOUSE 32

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
3	Sub-slab + pit ventilation; 150 L/s centrifugal fan	01/87	215	0.2	8	Riser A
			243	0.3	10	Riser B
			213	6	260	Riser C
			218	12	25	Riser D
			243	8	190	Riser E
			250	2	9	Riser F
			255	3	160	Riser G

A: End wall
B: Front wall
C: Rear wall
D: From pit
E: Rear wall
F: Front wall
G: Garage wall



ACRES	LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
	FOUNDATION PLAN	Date: 1/15/87	32
	Mitigation system: SUB-SLAB AND WELL PIT SUCTION	PHASE: FINAL	

HOUSE 33

PENNSYLVANIA DER MEASUREMENTS

Working Level grab samples (Kusnetz)	0.313 WL
Heating season average radon (Terradex)	82 pCi/L
Radon concentration in water	660 pCi/L

1. DESCRIPTION

This two story house with attached garage was built in the mid 1980's on a leveled site on the side of a ridge to the south of Bethlehem. The front wall of the house is brick, the other walls are siding.

The basement walls are of poured concrete. The basement floor has two large cracks, one across the entry to a small basement enclosure, the other across the centre of the floor. The gap at the wall/floor joint is generally small. There is an open dry sump with crushed stone in the bottom in one corner of the basement.

2. ACTION

2.1. PHASE 3

As this house was one of the few with a sump, the mitigation method chosen for demonstration was sump ventilation.

The system consisted of a plywood pit cover sealed to the floor, with a four inch ventilation pipe through the header board to a large plastic bodied centrifugal fan.

System testing showed a radon concentration of 170 pCi/L in the air flowing through the riser at 5 L/s under 350 Pa suction. Smoke testing gave ambiguous results along the front wall. Although definite flows to below the slab were noted at floor cracks and the perimeter joint close to the sump, there was no indication of flow at distances greater than 3 m, suggesting poor access to the subslab.

Measurements in February 1987 found radon concentrations in the basement with the fan on ranged from 12 to 57 pCi/L, averaging 50 pCi/L, and ranged from 69 to 97 pCi/L, averaging 81 pCi/L, with the fan off, clearly an unsatisfactory performance.

The owner's father, who had built the house, advised that the sump consisted of a solid concrete pipe sitting on soft rock. Holes were drilled in the wall of the sump crock to improve the connection to the subslab space. The bottom of the sump crock was set in a layer of concrete, covered with 70 mm of crushed stone. Holes were drilled through the concrete into the fill beneath to improve the connection to the sub-slab space.

In March 1987, with the fan in operation, radon concentrations in the basement averaged 5 pCi/L, ranged from 3 to 7 pCi/L, averaging 5 pCi/L. When the fan was turned off the radon concentrations ranged from 16 to 79 pCi/L, averaging 65 pCi/L.

Alpha Track dosimeters were installed upstairs and in the basement to determine long term average radon concentrations.

3. OTHER MEASUREMENTS

Indoor gamma radiation varied from 6 to 8 uR/h averaging 7 uR/h. Exterior radiation about the site ranged from 7 to 9 uR/h, averaging 7 uR/h.

The average radon concentration measured with Alpha Track detectors over the period March to April 1987 was 2.2 pCi/L in the basement and 1.1 pCi/L in the living area.

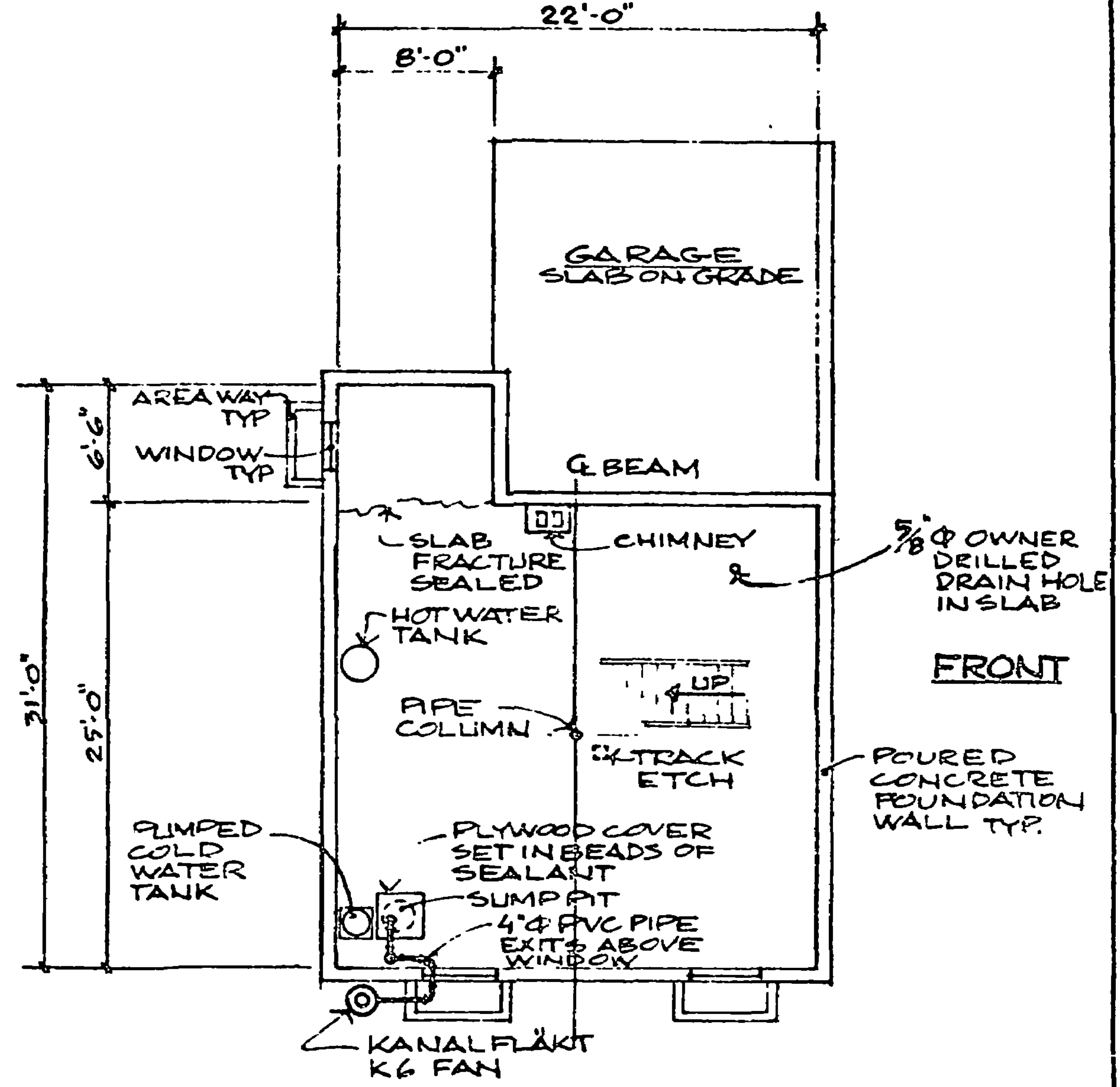
MEASUREMENTS SUMMARY FOR HOUSE 33

A. PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON RESULTS RANGE	RADON RESULTS MEAN	COMMENTS
3	Sump ventilation; 150 L/s centrifugal fan	02/87	Fan on	42-57	50	over 41 hrs
			Fan off	68-97	84	over 41 hrs, after 6 hour rise
	Improved sub-slab connection	03/87	Fan on	3- 7	5	over 41 hrs.
			Fan off	46-79	65	over 34 hrs after 15 hr rise

SYSTEM MEASUREMENTS FOR HOUSE 33

PHASE	MITIGATION SYSTEM	DATE	PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
3	Sump ventilation; 150 l/s centrifugal fan	02/87	350	5	170	Sump riser
	Improved connection to sub-slab	03/87	350	30		Sump riser



LOW COST REDUCTION OF INDOOR RADON		**HOUSE NUMBER**
FOUNDATION PLAN	**Date:** 1/30/87	33
Mitigation system: SUB-SLAB SUCTION VIA SUMP	**PHASE:** FINAL	

HOUSE 34

PENNSYLVANIA DER MEASUREMENTS

Working Level grab samples (Kusnetz)	2.186 WL
Average radon (Terradex)	470 pCi/L
Radon concentration in water	46 300 pCi/L

1. DESCRIPTION

This two story colonial house with aluminum siding and attached garage was built in the late 1970's on a sloping lot at the top of a small ridge several miles south of Allentown. The foundation walls are of poured concrete with no evident cracks. The basement floor is also poured concrete but forms a floating slab with a wide perimeter french drain.

The house is heated by oil fired hot water circulating through convectors and cooled through central air conditioning. The site slopes from front to back, so the back wall is largely above grade and has a walkout sliding door

2. ACTION

2.1. PHASE 3

As this house had poured concrete walls, the mitigation measure selected for demonstration at this site was multipoint subslab ventilation.

A standard six point subslab ventilation system was installed using the coring machine. Four inch PVC pipe risers were caulked into the slab entry point and led through the joist space to a main duct fashioned from 6 inch PVC pipe. The system was connected to a large plastic bodied centrifugal fan installed through the header board of the back wall.

The 80% of the interior french drain that was directly accessible was closed with mortar. The other 20% was in a workroom, concealed behind closed-in benches and pegboard covered framed walls.

Radon monitoring in February 1987 indicated that before the fan was turned on levels ranged from 112 to 811 pCi/L, averaging 531 pCi/L. However with the fan running levels fell dramatically to range from 3 to 8 pCi/L and average 4 pCi/L. Since basement radon concentrations had been reduced significantly, Alpha Track detectors were installed upstairs and in the basement to obtain long term averages during the heating season.

System measurements found suctions in the pipes were between 150 and 180 Pa. Flows and radon concentrations in the pipes were; front wall 1.2 L/s at 15 000 pCi/L, 2 L/s at 27 000 pCi/L; end wall 5 L/s at 68 pCi/L; rear wall 38 L/s at 820 pCi/L, 25 L/s at 260 pCi/L; garage wall 1.5 L/s at 610 pCi/L. The high flow rates in the pipes on the rear wall near the unclosed section of the french drain suggested that overall performance could be improved by closing it. This was done by injecting expanding foam through holes drilled in the wall covering at the base of the wall.

After this the suction in all the pipes was between 213 to 210 Pa. Flows in the pipes were now front wall 2 L/s, 2 L/s; end wall 3 L/s; rear wall 6 L/s, 16 L/s, garage wall 2 L/s.

3. OTHER MEASUREMENTS

Indoor gamma radiation ranged from 5 to 10 uR/h, averaging 7 uR/h. Site radiation ranged from 5 to 10 uR/h, averaging 7 uR/h.

The average radon concentration measured with Alpha Track detectors over the period February to April 1987 was 5.5 pCi/L in the basement and 3.7 pCi/L in the living area.

MEASUREMENTS SUMMARY FOR HOUSE 34

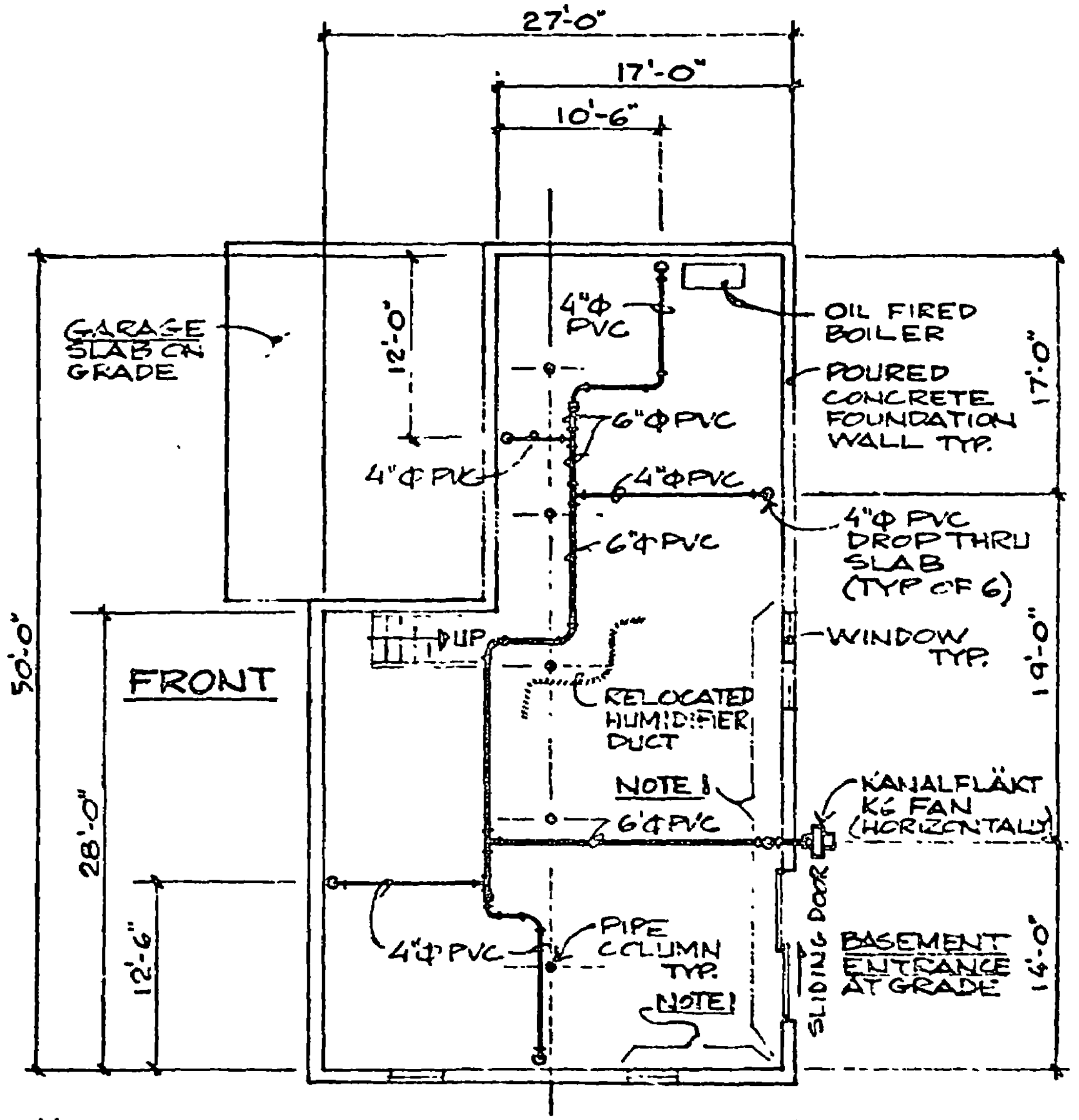
PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	MEAN	COMMENTS
3	Sub-slab ventilation;	02/87	Fan off	112-811	531	over 20 hrs
	150 L/s centrifugal fan (french drain partly closed)		Fan on	3- 8	1	over 62 hrs

SYSTEM MEASUREMENTS FOR HOUSE 34

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L	COMMENTS
3	Sub-slab ventilation; 150 L/s centrifugal fan	02/87	158	1	15 000	Riser A
			170	2	27 000	Riser B
			170	5	68	Riser C
			180	38	820	Riser D
			150	25	260	Riser E
			158	2	610	Riser F
	Further closure of french drain	01/87	230	2		Riser A
			235	2		Riser B
			235	3		Riser C
			240	6		Riser D
			225	16		Riser E
			213	2		Riser F

A: Front wall
B: Front wall
C: End wall
D: Rear wall
E: Rear wall
F: Garage wall



NOTES: 1. NOTED AREAS HAVE EXISTING "FRENCH DRAIN" FILLED WITH POLYURETHANE FOAM DUE TO INACCESSIBILITY FOR MORTARING. REMAINDER OF PERIMETER DRAIN WAS MORTARED CLOSED.

ACRES	LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
	FOUNDATION PLAN	Date: 2/26/87	34
	Mitigation system: SUB-SLAB SUCTION	PHASE: FINAL	

HOUSE 35

PENNSYLVANIA DER MEASUREMENTS

Working Level grab samples (Kusnetz)	0.931 WL
Heating season average radon (Terradex)	144 pCi/L
Radon concentration in water	527 pCi/L

1. DESCRIPTION

This detached two story colonial house with built in garage was built in the late 1970's on a steeply sloping site at the top of a ridge a few miles from Coopersburg. Heating is by electric baseboard convectors upstairs alone, and there is a forced air central air conditioning system.

The basement contains a double garage, and a small work room. The garage walls are bare concrete and there is a crack at one corner. Three work room walls are of concrete covered with styrofoam behind panelling, the fourth is a frame wall covered with wall-board between it and the garage. The wall/floor joint is visible in the garage, and about 1 mm wide. The floor was poured in two pours, and the joint is visible in the garage. The sewer line leaves through the garage wall. There is an opening in the work room wall for the water-line entry, and the slab is penetrated by stair supports and house jacks filled with concrete.

2. ACTION

2.1 PHASE 3

As this house had a reasonably well ventilated garage, and solid concrete foundation walls, the mitigation system chosen for demonstration at this site was sub-slab ventilation applied only to the work room portion of the basement.

A four-point sub-slab ventilation system with a large plastic bodied centrifugal exhaust fan was installed in February 1987.

The suction in the pipes was similar, about 260 Pa on average. Flows and radon concentrations were; end wall 2 L/s at 2 500 pCi/L; front wall 8 L/s at 770 pCi/L; garage wall 5 L/s at 600 pCi/L; and rear wall 3 L/s at 900 pCi/L. By comparison, room air was 1 pCi/L, and the water line entry opening 6 pCi/L.

In February 1987 the basement radon concentration ranged from 0 to

1.6 pCi/L, averaging 0.9 pCi/L. Alpha Track detectors were therefore installed in the basement and upstairs to evaluate the long term averages.

As confirmation test of system performance was conducted in March 1987. With the fan on basement radon concentrations ranged from 0.1 to 1.3 pCi/L, averaging 0.7 pCi/L. When the fan was turned off levels rose quickly to range from 87 to 298 pCi/L, averaging 164 pCi/L.

3. OTHER MEASUREMENTS

The interior gamma radiation field varied from 1-5 uR/h, averaging 5 uR/h. The exterior field over the site ranged from 3-4 uR/h.

The average radon concentration measured with Alpha Track detectors over the period February to April 1987 was 0.7 pCi/L in the basement and 0.8 pCi/L in the living area.

MEASUREMENTS SUMMARY FOR HOUSE 35

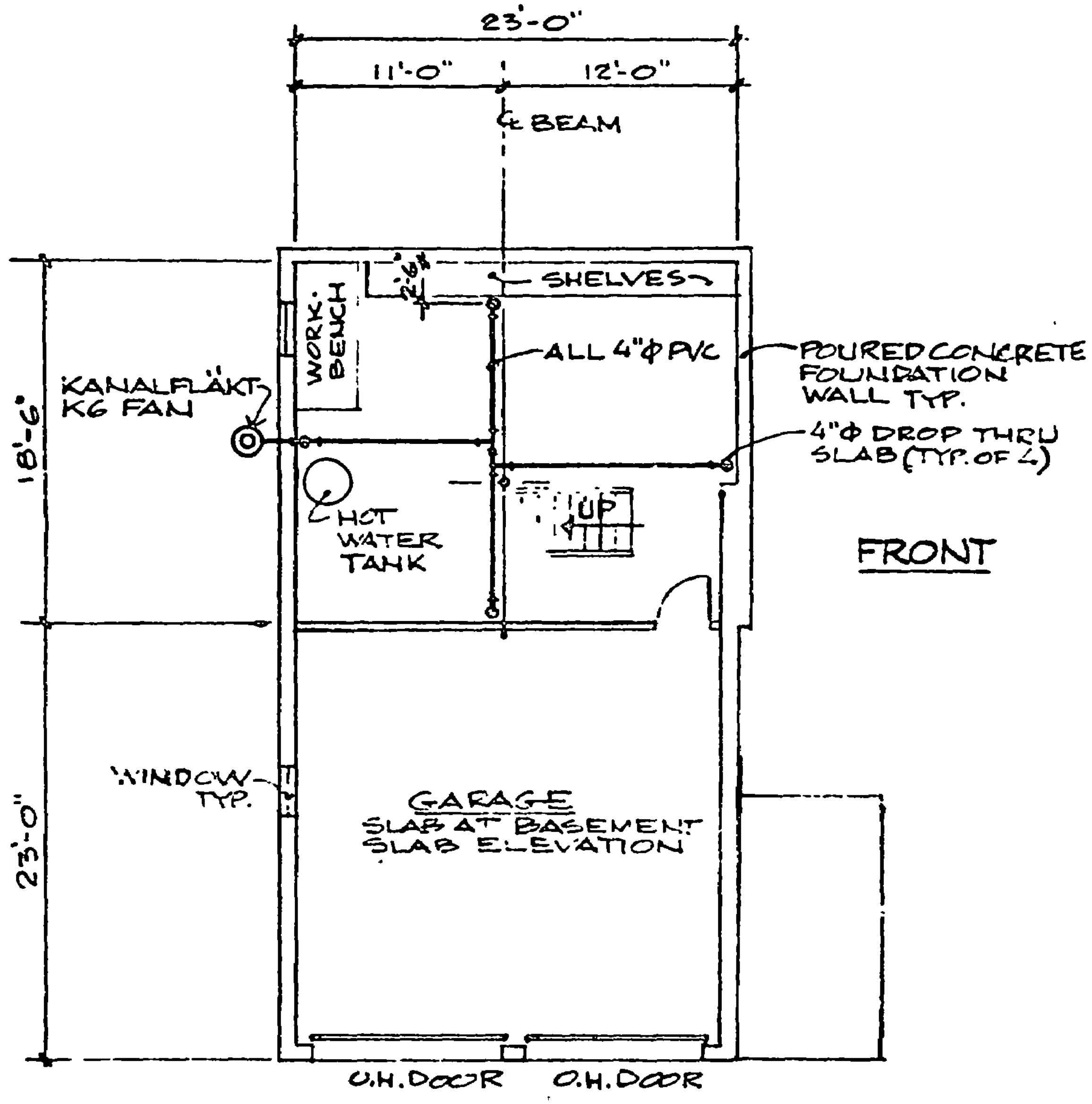
PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	MEAN	COMMENTS
3	Sub-slab ventilation; 150 L/s centrifugal fan	02/87	Fan on	0.0-1.6	0.9	over 4 days
		03/87	Fan on	0.1-1.3	0.7	over 17 hrs.
			Fan off	87-298	164	over 37 hrs.

SYSTEM MEASUREMENTS FOR HOUSE 35

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
3	Sub-slab ventilation 150 L/s centrifugal fan	02/87			2 500	Riser A
					770	Riser B
					600	Riser C
					900	Riser D
					4	Basement air
					6	Water line entry opening

A: End wall B: Front wall
C: Garage wall D: Rear wall



ACRES	LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
	FOUNDATION PLAN	Date: 1/30/87	35
	Mitigation system: SUB-SLAB SUCTION	PHASE: FINAL	

HOUSE 36

PENNSYLVANIA DER MEASUREMENTS

Working Level grab samples (Kusnetz)	0.405 WL
Average radon (Terradex)	300 pCi/L
Radon concentration in water	970 pCi/L

1. DESCRIPTION

This two story sidesplit house with built in garage was built in the early 1980's on a sloping site on the side of a hill south of Allentown. The walls are of wood siding. The entrance foyer and garage are at grade level, but on separate slabs. The garage has been converted into a bed/sitting room. A large sitting room is over the basement.

The basement has poured concrete walls. There were no visible floor cracks but much of the floor is covered with carpet and stored material. The gap at the wall/floor joint is large, over 1 mm wide in most places. There is a sump in one corner, which the owner had covered with a metal plate and passively vented to the outside, and a brick fireplace on its own slab. The top half of the basement stairs were set into a recess in the house/basement wall.

The foyer slab is poured inside the concrete foundation walls, and has sunk 2 mm, cracking the vinyl tile in places around the slab perimeter.

2. ACTION

2.1. PHASE 3

The mitigative action selected for demonstration at this house was integrated subslab ventilation beneath both the basement and the foyer slabs.

A diamond coring drill was used to drill four 125 mm diameter holes in the floor slab at the approximate centre of each wall, and two 125 mm holes in the stub wall to access the fill beneath the upper level slab. Some difficulty was experienced in drilling the first hole through the stub wall, for the area on the other side of the 200 mm thick concrete wall was filled to a depth of more than 450 mm with solid concrete. The coring machine gearbox failed after drilling to this depth, and a second machine had to be obtained.

Four inch PVC pipe was installed at each floor and wall entry point and connected via a six inch PVC pipe to a large plastic bodied centrifugal fan located outside the back wall. The existing sump ventilation system was teed into the new system with a damper. There was a 1 m square area of exposed soil covered with crushed rock in the recess beneath the basement stairs. A 30 mm thick layer of concrete was poured over this to decrease the exposed soil area in the house.

In February 1987, while work was in progress, radon concentrations ranged from 66 to 170 pCi/L, averaging 125 pCi/L in the basement, but fell rapidly when the fan was turned on to range from 1 to 4 pCi/L, averaging 2 pCi/L.

The suction in the system pipes was about 112 Pa, and 42 Pa in the sump pipe. The flows and radon concentrations in the pipes were; end wall 13 L/s at 80 pCi/L; front wall 14 L/s at 440 pCi/L; stub wall 22 L/s at 700 pCi/L, garage end wall 2 L/s at 1 500 pCi/L, teed slab plus wall entry at garage end wall 9 L/s at 160 pCi/L, sump 3 L/s at 580 pCi/L, and front wall 20 L/s at 280 pCi/L. Smoke testing showed all cracks, the basement perimeter wall/floor joint and the perimeter joint round the upper slab were all at lower pressure than the house.

Alpha Track detectors were issued in March 1987 to determine longer term averages upstairs and in the basement.

The exhaust fan here was installed in the opening that the owner had made for the sump exhaust, and pointed upwards towards an overhanging soffit. When warmer weather came, the owner opened the kitchen windows, and complained that the exhaust air from the fan, which smelt of soil molds, was blown into the house.

The opportunity was taken to investigate recirculation of the fan exhaust. In April 1987, alpha track detectors were exposed for three weeks on the soffit immediately above the fan, and 3 m on either side of that position, and on the opposite side of the house to determine the average radon concentration produced by the fan exhaust. In addition a PFT source was placed inside the fan to quantify the exhaust entry rate. Adsorption collectors were placed in the basement and the upstairs living space together with other PFT sources to measure the ventilation rate.

The Alpha Track measurements showed the average radon under the soffit 2 m above the fan was 15 pCi/L, and was 11 pCi/L at 3 m on either side. The measured background at the front of the house was 1 pCi/L. This suggests that the average external radon concentration produced by the ground mounted fans is not high enough to increase the average interior radon concentration significantly, as long as the discharged air is only a fraction of the air that enters the house. This can be expected to be the case in winter when windows are closed, but might not be true in summer time when windows on the fan side of the house might be open. A horizontal discharge along the ground away from the house might have given lower concentrations.

As a test, the fan was reversed to pressurize the system, and eliminate the discharge. Radon concentrations in May 1987, showed an average of 1 pCi/L in the basement, and a high of 4 pCi/L. Despite the low radon levels, the reversed system drove enough soil gas into the basement to return the smell there to the level that existed before the system was installed. The owner did not like the musty smell and requested that the fan be returned to its original orientation. This was done.

In June 1987, as a final solution to recirculation of exhaust gases, a 4 inch PVC riser was attached to the fan through a 6/4 inch reducer and was run underneath the soffit to the end of the house to exhaust above the roof. The piping was painted to match the wood siding.

C. OTHER MEASUREMENTS

The gamma radiation field in the house ranged from 6 to 9 uR/h, averaging 7 uR/h. Outdoor gamma fields around the site ranged from 3 uR/h on the asphalt driveway, to 10 uR/h and averaged 7 uR/h.

The average radon concentration measured with Alpha Track detectors over the period March to April 1987 was 1.6 pCi/L in the basement and 1.7 pCi/L in the living area.

MEASUREMENTS SUMMARY FOR HOUSE 36

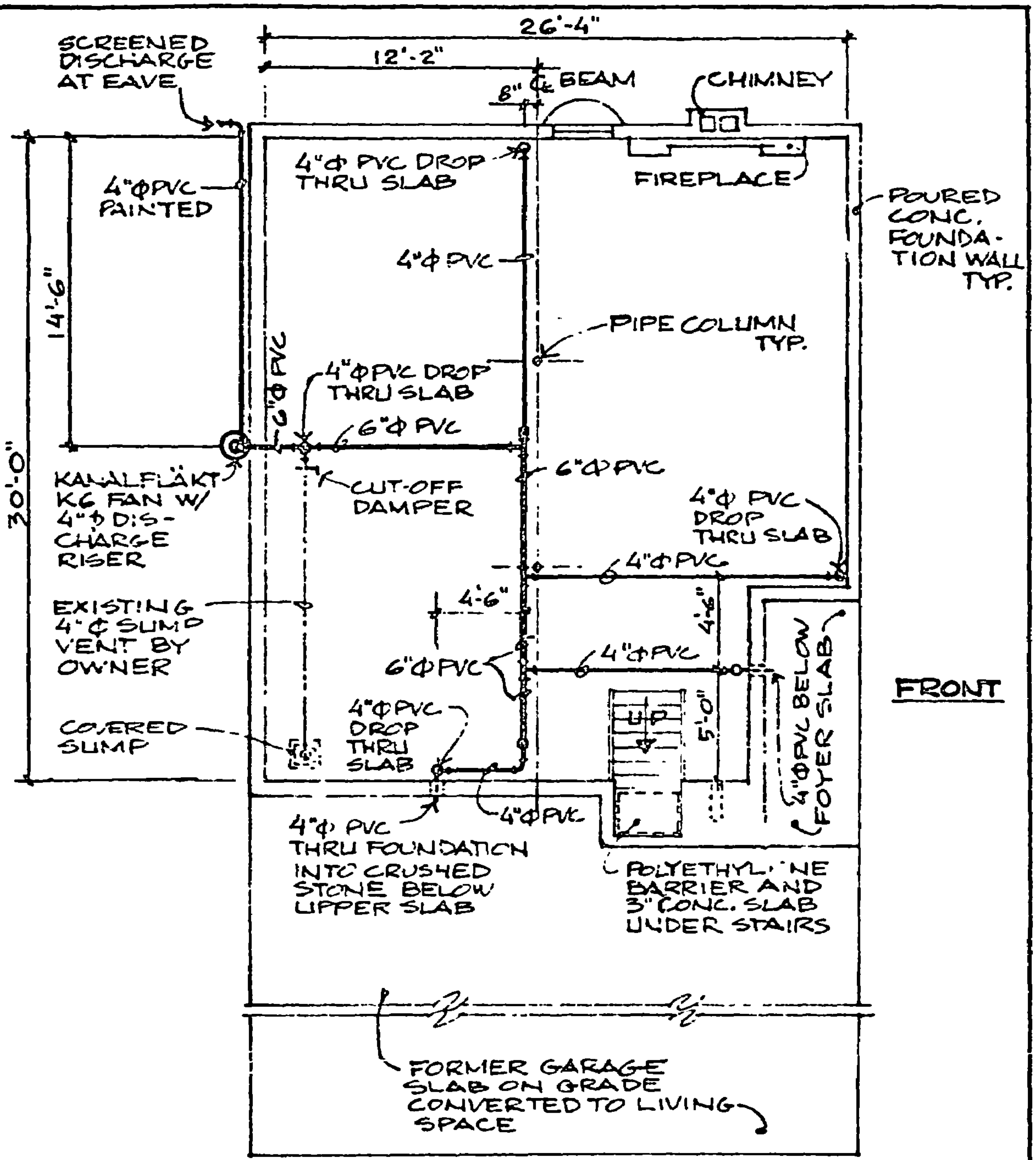
PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	MEAN	COMMENTS
3	Sub-slab ventilation 150 L/s centrifugal fan	02/87	Work in progress	66-170	125	over 3 days
			Fan on	1 4 2		over 3.5 days
		05/87	Fan reversed to blow	0- 1 1		over 88 hrs
						returned to suction at owners' request

SYSTEM MEASUREMENTS FOR HOUSE 36

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
3	Sub-slab ventilation; 150 L/s centrifugal fan	02/87	112	13	80	Riser A
			137	18	280	Riser B
			112	14	410	Riser C
			117	22	790	Riser D
			112	2	1 500	Riser E
			112	9	160	Riser E-F
			42	3	580	Sump line dampered

A: End wall
B. Rear (fan) wall
C: Front wall
D. Stub wall
E: Garage wall
F. Wall entry



ACRES	LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
	FOUNDATION PLAN	Date: 2/17/87	36
	Mitigation system: SUB-SLAB SUCTION	PHASE: FINAL	

HOUSE 37

PENNSYLVANIA DER MEASUREMENTS

Working Level grab samples (Kusnetz)	0.256 WL
Average radon (Terradex)	87 pCi/L
Radon concentration in water	2 200 pCi/L

1. DESCRIPTION

This two-story house with family room on attached slab and attached double garage was built in the mid 1980's on a rural site on top of a ridge to the south of Macungie. The front wall is faced with random stone and the other walls are clad with aluminum siding. Heating is by a coal-fired basement furnace providing hot water in baseboard convectors and a small coal-burning stove in the family room.

The foundation walls are of poured concrete, and there is an external entrance to the basement. The walls are penetrated by sewer, water, and oil-fill lines. The poured concrete floor slab has a major crack and is penetrated by two hollow steel jacks, but no floor drains. The owner said that there was an under-slab loop of perforated pipe connected to a sump, which was sealed as there was no water problem.

2 ACTION

2.1. PHASE 3

As this house had solid concrete basement walls, the mitigation system selected for demonstration at this site was multipoint subslab ventilation. A standard six-point system was installed in late January 1987. The exhaust point cored through the floor on the furnace wall struck the furnace footing, which extended out from the wall. Holes were drilled through the concrete footing to improve the connection to the soil.

On average the fan gave a suction of 116 Pa in each pipe. The flows and radon concentrations were; end wall 9 L/s at 75 pCi/L, rear wall 17 L/s at 150 pCi/L, 23 L/s at 61 pCi/L, garage wall 0.2 L/s at 9 pCi/L; front wall 21 L/s at 110 pCi/L, 20 L/s at 82 pCi/L. The low flow pipe was the one in the footing.

Basement radon concentrations in February 1987, ranged from 0.6 to 2.0 pCi/L, with an average of 1.5 pCi/L.

On the basis of these low radon concentrations, Alpha Track detectors were installed upstairs and in the basement to obtain long term averages during the heating season.

However, the flow rates in the system were large, and the radon concentrations in the exhaust air were low, so the wall/floor joint was closed by caulking to test if the air was coming from the house via the wall/floor joint, or was drawn directly through the soil. This increased the suction to approximately 145 Pa at each pipe. The flows and radon concentrations were, end wall 7 L/s, 900 pCi/L; rear wall 13 L/s at 420 pCi/L, 18 L/s at 210 pCi/L, end wall 0.02 L/s at 1 pCi/L; 14 L/s at 130 pCi/L, 14 L/s at 110 pCi/L. Although closing the wall/floor joint did reduce the total system flow from 70 to 66 L/s, the flows were still large, and the radon concentrations low. This indicated that the soil permeability at this site was higher than usual for the area generally.

In March 1987 the basement concentrations were remeasured. With the fan on the levels ranged from 0.0 to 1.9 pCi/L, averaging 0.6 pCi/L. When the system was turned off, radon concentrations rose to range from 10 to 33 pCi/L, averaging 19 pCi/L. This maximum was less than might be expected from the DIR measurements, and is probably lower because the wall/floor joint had been caulked. That radon concentrations were still in the 20 pCi/L region after closing this large and obvious opening shows the difficulty of effectively sealing a basement against soil gas entry.

Further radon monitoring was conducted in April 1987 in the attached slab-on-grade family room. All concentrations over a four day period in April were less than 1 pCi/L.

7. OTHER MEASUREMENTS

Indoor gamma fields ranged from [illegible] to 9 uR/h, averaging 6 uR/h. Site gamma radiation ranged from 5 to 8 uR/h, averaging 7 uR/h.

The average radon concentration measured with Alpha Track detectors over the period February to April 1987 was 0.6 pCi/L in the basement and 0.6 pCi/L in the living area.

MEASUREMENTS SUMMARY FOR HOUSE 37

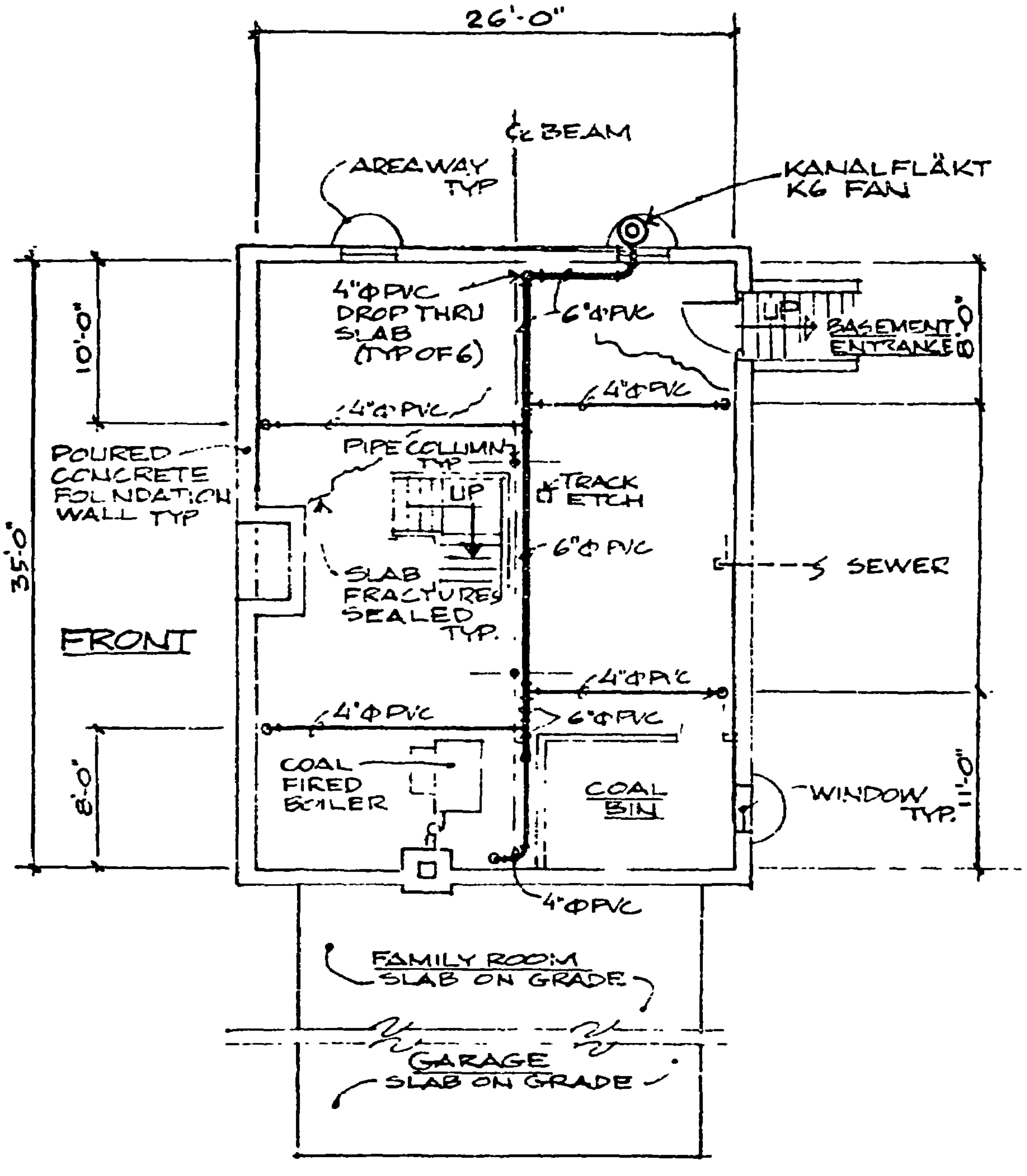
A. PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	RADON (pCi/L) MEAN	COMMENTS
3	Sub-slab ventilation; 150 L/s centrifugal fan	02/87	Fan on	0.6-2.0	1.5	over 4 days
	As above + wall/floor joint caulked	03/87	Fan on	0.0- 1.9	0.6	over 44 hrs
			Fan off	10 - 33	19	over 41 hrs
		01/87	Fan on	0.0 -1.0	0.2	over 4 days - upstairs family room

SYSTEM MEASUREMENTS FOR HOUSE 37

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
3	Sub-slab ventilation; 150 L/s centrifugal fan	02/87	138	9	75	Riser A
			125	17	150	Riser B
			108	23	64	Riser C
			105	0.2	9	Riser D
			105	21	110	Riser E
			113	20	82	Riser F
	As above + wall/floor joint caulked	01/87	115	7	900	Riser A
			163	13	120	Riser B
			113	18	210	Riser C
			130	0.02	1	Riser D
			138	11	130	Riser E
			133	11	110	Riser F

A: End wall
B: Rear wall
C: Rear wall
D: Garage wall
E: Front wall
F: Front wall



ACRES	LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
	FOUNDATION PLAN	Date: 1/29/87	37
	Mitigation system: SUB-SLAB SUCTION	PHASE: FINAL	

HOUSE 38

PENNSYLVANIA DER MEASUREMENTS	
Working Level grab samples (Kusnetz)	0.595 WL
Heating season average (RPISU)	0.370 WL
Heating season radon average (Terradex)	309 pCi/L
Radon concentration in water	11 800 pCi/L

1. DESCRIPTION

This two-story house was built in the early 1980's on a sloping site on the side of a hill some miles northeast of Boyertown. The lower front wall is sheathed in brick, and the other walls are covered with siding. The basement walls are of hollow concrete block, closed at the top with cap blocks, and half of the basement is a garage with a central floor drain. The other half is finished with a laundry room which has a trapped floor drain, bathroom and a family room with panelled walls, brick fireplace, plaster ceiling and tiled floor.

The concrete floor slab was poured in two sections, and about half of the joint is visible in the garage. There is an open french drain visible in the garage at the end wall and along the rear wall, which the owner said extended beneath the rear and end walls in the finished half of the basement. The owner said that there was 5-6 inches of crushed rock beneath the slab, a crushed stone drain around the footings, and that the floor drain in the garage discharged to daylight on the bank in front of the house.

2. ACTION

2.1. PHASE 1

As the owner said that the house had an exterior drain, the mitigation method selected for demonstration in this house was drain tile ventilation. Later information from the house builder was thet there was no crushed rock round the footing. This made the success of the selected method doubtful, and work in this house was suspended until Phase 2 of the program, when more would be known about alternate successful mitigative methods.

2.2. PHASE 2

The mitigation method selected for demonstration in this house was wall plus floor ventilation. However, the expense and difficulties met with other

Phase 2 installations led to a re-evaluation of the value of this mitigation method, and consequently work at this house was suspended until later in the program, when more would be known about alternative successful mitigative methods.

2.3. PHASE 3

The success in Phase 2 of sub-slab ventilation for houses with concrete block walls led to the selection of sub-slab ventilation as the mitigation method to be demonstrated in this house.

In February 1987, radon concentrations in the basement varied from 190 to 860 pCi/L, averaging 375 pCi/L. Radon measurements in the garage and laundry floor drains gave radon concentrations comparable to those in the house air, and were not regarded as likely entry routes. A two point sub-slab exhaust system was selected for this house to take advantage of the thick layer of crushed stone beneath the basement floor and to minimise the work in the finished area. The exhaust points were to be placed in the half of the slab that lay under the finished rooms.

The system was installed in March 1987. The initial positions selected for the exhaust pipes were at the rear of the laundry room and in a closet beneath the front stairs which also contained the well tank. However, there was not enough space in the closet to use the coring machine, and so the second point was placed outside the closet by the front wall. Both pipes were teed together, and connected to a large plastic bodied centrifugal fan placed on the rear wall.

The french drain was closed in the garage by placing gravel in the bottom so that it could still drain water from the wall footing to the sub-slab space, and then filling the trough to level with the floor with mortar. The visible part of the floor joint was closed with silicone caulk.

The fan produced a suction of 238 Pa in the laundry room pipe with a flow of 27 L/s at 930 pCi/L; and a suction of 238 Pa in the front pipe with a flow of 16 L/s at 340 pCi/L in the front wall pipe. With the fan in operation, radon concentrations in the basement ranged from 8 to 77 pCi/L, averaging 40 pCi/L; and upstairs radon concentrations ranged from 2 to 55 pCi/L, averaging 30 pCi/L. The lower concentrations were associated with the doors being open.

A smoke test through joints in the paneling found that the fan suction did not extend across the finished area floor. The french drain behind the paneling was filled with expanding urethane foam, injected through 20 mm holes drilled at

500 mm intervals through the bottom of the paneling and the sole plate into the drain. A long nozzle was placed diagonally into a hole, and foam injected until it appeared at the next hole in that direction. The foam continued to expand over time, and a 10 to 15 cm diameter bubble of foam was forced out of most holes. A layer of self-adhesive painter's edging paper had been laid by the wall, so the foam lay on top of this and did not adhere to the tile. When it was fully set, the foam was cut off flush to the wall with a bread knife. The holes were then concealed by placing a prefinished 2 inch baseboard along the base of the walls.

This reduction in floor leakage area did not change the suction in the laundry room pipe which remained at 238 Pa with a flow of 25 L/s at 1 500 pCi/L. The suction at the front pipe increased to 350 Pa, but the flow remained at 16 L/s at 390 pCi/L. This suggested that the air was being drawn into the sub-slab space through openings in the walls at footing level, and perhaps through the soil itself.

In March 1987, following this work, the radon concentrations in the basement ranged from 2 to 14 pCi/L, averaging 5 pCi/L, while radon concentrations upstairs ranged from 2 to 12 pCi/L, averaging 5 pCi/L. The highest values were associated with water use.

Alpha track detectors were issued in March to provide a longer term estimate of average radon concentration.

3. OTHER MEASUREMENTS

The radiation field in the house ranged from 3 to 12 uR/h, averaging 10 uR/h in the family room. The field over the site ranged from 8 to 12 uR/h, averaging 10 uR/h.

The average radon concentration measured by alpha-track detectors over the period March to April 1987 was 14.1 pCi/L in the basement, and 11.2 pCi/L in the living area.

MEASUREMENTS SUMMARY FOR HOUSE 38

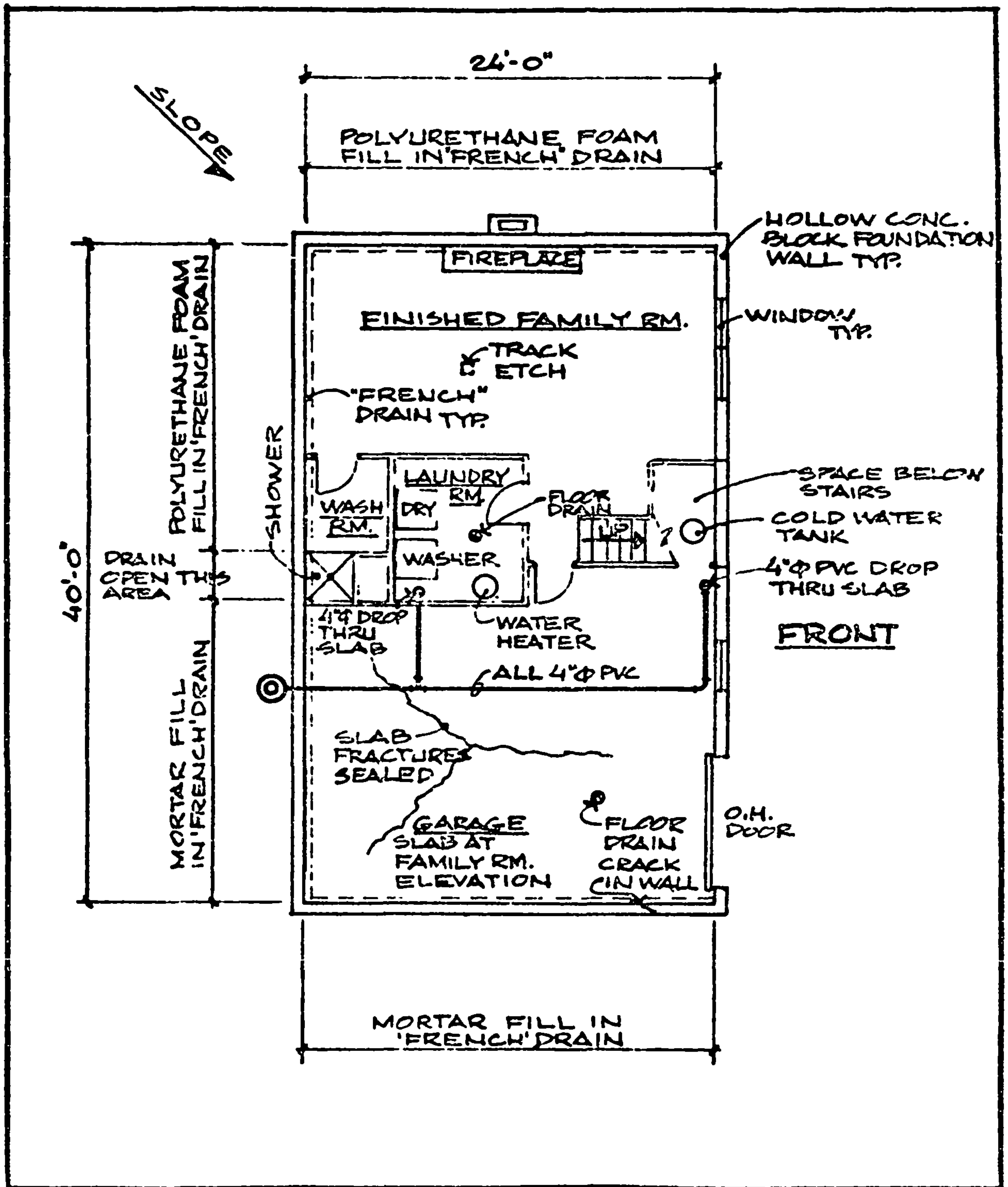
PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	MEAN	COMMENTS
3	Premitigation	02/87	Survey	189-862	375	over 4 days
3	Sub-slab ventilation 150 L/s centrifugal fan	03/87	Fan on	8- 77	40	over 48 hrs B
			Fan on	2- 55	30	over 48 hrs U
3	As above with closure of french drain completed	03/87	Fan on closure in progress	2- 7	5	over 26 hrs B
			Fan on closure complete	2- 9	5	over 26 hrs U
				3- 14	5	over 66 hrs B
				2- 12	5	over 66 hrs U

SYSTEM MEASUREMENTS FOR HOUSE 38

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
3	Premitigation	01/87			60	garage drain
					150	washroom air
3	Sub-slab ventilation 150 L/s centrifugal fan	03/87	238	16	340	Riser A
			238	27	980	Riser B
					16	basement
					8	upstairs
3	Closure of french drain completed	03/87	350	16	390	Riser A
			238	25	1 500	Riser B

A: Front wall
B: Basement
C: Laundry room
U: Upstairs



AGRES	LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
	FOUNDATION PLAN	Date: 3/6/87	38
	Mitigation system: SUB-SLAB SUCTION	PHASE: FINAL	

HOUSE 39

PENNSYLVANIA DER MEASUREMENTS

Working Level grab samples (Kusnetz)	0.345 WL
Average radon (Terradex)	111 pCi/L
Radon concentration in water	low (municipal water)

1. DESCRIPTION

This one story house with built in garage was built in the late 1960's on a small levelled lot partway up the side of a steeply sloping ridge in the south of Allentown. The walls are covered with aluminum siding. Heating is by electric baseboards in the basement room and electric radiant ceiling units upstairs, where there is an unused fireplace and a wood stove. The wood stove is the main source of heat during of heat during the winter.

Only the rear of the basement is in the ground, and it contains a garage and a laundry room at one end, and a work room at the other. The house front entrance is in the middle of the front basement wall, with stairs to the main floor. The basement walls are of hollow concrete blocks which have been mortared closed at the top. The walls are exposed only in the garage, and are covered by fiberglass insulation battens in wooden framing in the work room, and by wall board in the laundry room. The poured concrete slab is without cracks. The wall/floor joint at the back wall has been caulked with asphaltic sealant and an asphalt coated wooden strip has been installed 50 mm out from the wall to form a channel to divert water leakage to the garage and outside. The slab is penetrated by two hollow floor jacks, a water line and a sewer line. Only the back wall and part of the end wall are below grade.

The owner indicated that there was a plastic barrier below the slab but probably no subslab aggregate.

2. ACTION

2.1. PHASE 3

As this house had hollow concrete block walls below grade on two sides only and the slab built directly on bedrock the mitigation method chosen for demonstration was subslab ventilation. The aim was to demonstrate that basements with hollow block subgrade walls and poor subslab permeability could be treated with suction points placed close to the walls and with high suction fans.

In May 1987, premitigation testing of the sub-slab permeability was conducted using a vacuum cleaner to suck on holes drilled through the slab. The extent and strength of the suction induced at nearby holes was investigated using a smoke pencil and pressure measurements. Communication between holes was not detectable except at one location at the rear of the house, where a suction of 13 Pa was measured at one hole when a suction of 13 000 Pa was applied to a hole 2.5 m away. Probes found a mixture of clay and rock beneath the floor.

Radon concentrations in air samples taken from the drilled holes were 2 000 and 10 000 pCi/L by the garage (rear) wall, 2 400 pCi/L near the rear work room wall, 1 400 by the front work room wall, 1 300 pCi/L by the front laundry room wall, and 380 from an opening by the water meter. Basement air concentrations over a four day period varied between 1 and 63 pCi/L and averaged 24 pCi/L. The low concentrations were associated with the garage door being open for much of the day.

A three point sub-slab ventilation system with two access points close to the garage wall, and one near the centre of the below-grade part of the end wall was installed. The rear wall footing was much wider than normal and required the floor exhaust points be at least 450 mm from the wall. Poor water drainage was noted at each entry point. Soil and pieces of broken bedrock were removed from each hole and replaced by clean crushed rock. Four-inch PVC pipe was used throughout the system and suction was provided by a large plastic bodied centrifugal fan connected through the end wall.

Suction in the pipes was 300 Pa. Pipe flows were; garage wall 0.9 L/s at 3 200 pCi/L, work room wall 0.8 L/s at 3 800 pCi/L, and end wall 14 L/s at 16 pCi/L. Night time radon concentrations in the basement were reduced from 50 pCi/L before the fan was turned on, to a maximum of 9 pCi/L on the first night that the fan ran, and then remained below between 0.5 and 3 pCi/L for the next two days.

Alpha Track detectors were installed in the basement and the upstairs living room in June 1987 to measure the long term radon concentration.

3. OTHER MEASUREMENTS

Indoor radiation fields ranged from 7 to 11 uR/h, averaging 9 uR/h. On the surrounding site the field ranged from 9 to 18 uR/h.

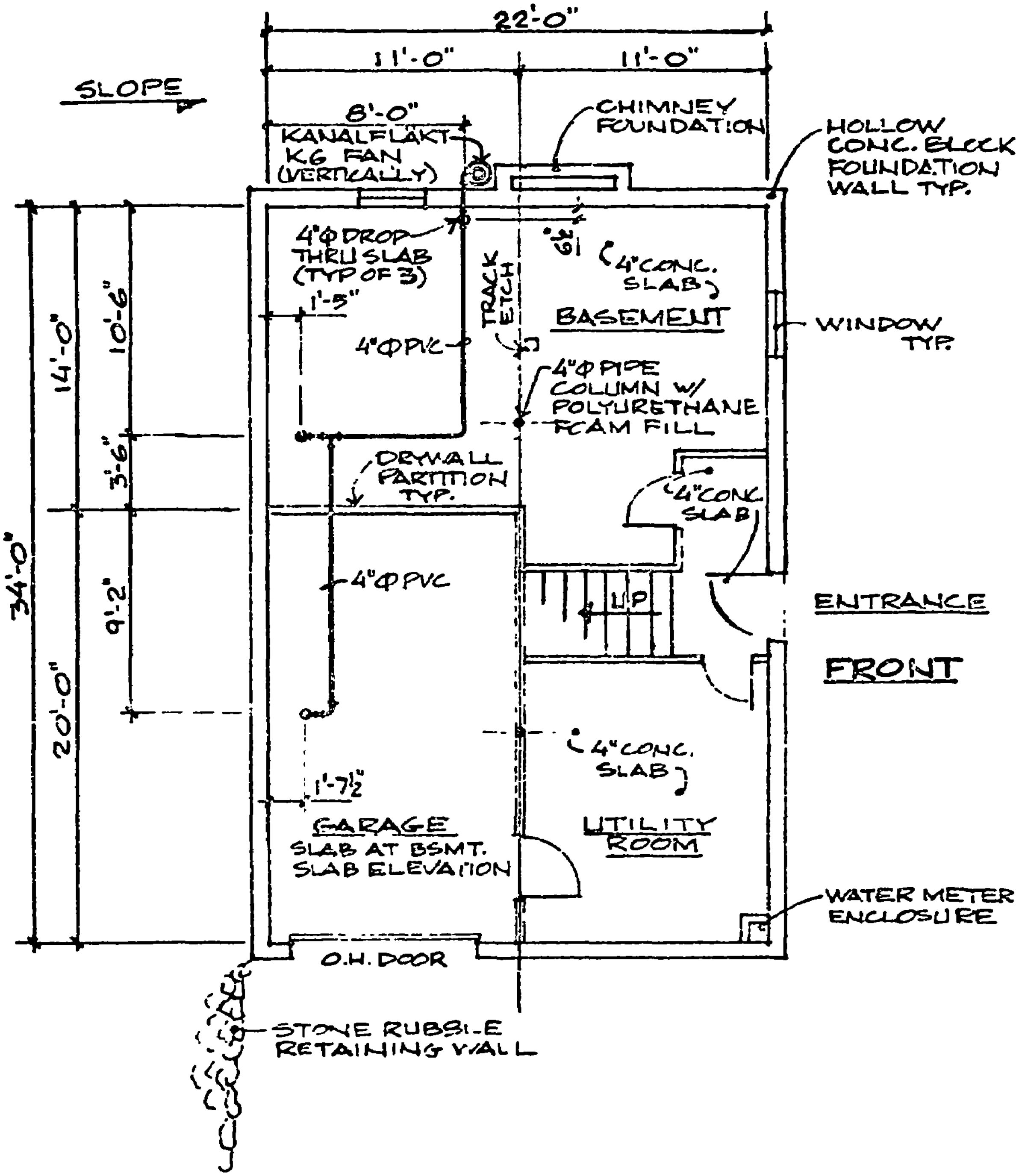
MEASUREMENTS SUMMARY FOR HOUSE 39

PYLON AB-5 HOURLY MONITORING

PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	MEAN	COMMENTS
3	Premitigation	05/87	Survey	1-63	21	over 1 days
3	Sub-slab ventilation 150 L/s	06/87	Without fan	0-50		Over 20 hrs work in progress
	centrifugal fan		Fan on	0- 9	2	over 66 hrs

SYSTEM MEASUREMENTS FOR HOUSE 39

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
3	Premitigation testing	05/87			19 000	Hole A- rear wall garage
					10 000	Hole B- rear wall garage
					2 400	Hole C rear wall workroom
					1 400	Hole D front wall workroom
					1 300	Hole E front wall laundry
					380	Hole F front wall water meter
	13 000 Pa suction at test hole		0	some flow		A-B
			0	some flow		C-D
			13	some flow		C-B
			0	no flow		E-A
			0	some flow		E-D
			0	some flow		E-F
3	Sub-slab ventilation; 150 L/s centrifugal fan	06/87	325	0.9	3 200	Riser 1 rear wall garage
			275	0.8	3 800	Riser 2 -rear wall workroom
			275	11	16	Riser 3- rear wall workroom
			325	16	460	at fan
					8	workroom air



LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
FOUNDATION PLAN	Date: 6/16/87	39
Mitigation system: SUB-SLAB SUCTION	PHASE: FINAL	

HOUSE 40

PENNSYLVANIA DER MEASUREMENTS

Working Level grab samples (Kusnetz)	1.15 WL
Average radon (Terradex)	148 pCi/L
Radon concentration in water	low (municipal water)

1. DESCRIPTION

This very large two story detached house with attached garage was built in the early 1960's on a level site at the top of a ridge to the north of Easton. The front wall and one end wall is sheathed in brick, with cedar shakes elsewhere.

The house is heated by electric radiant heaters in the ceiling and two fireplaces which are back-to-back on the first floor, supported by a large concrete block structure in the centre of the basement. Air conditioning is by small window units.

The basement is unfinished with walls and floor of poured concrete, and is divided into four rooms by concrete block internal walls. There is an external entrance into one room used as a work room. The floor was poured separately in each room, and there are construction joints at each doorway. There are no other visible cracks in the walls or slabs. The steel jacks which support the suspended floor are hollow and penetrate the basement floor slab. There is a large wall/floor shrinkage gap around the perimeter of the slabs. The owner reported that the builder had told him that there was no crushed rock beneath the basement floor.

2. ACTION

2.1. PHASE 3

As this house was very large, 230 m² of basement, and was probably built on low permeability bedrock without any intervening crushed rock plenum, the mitigation method chosen for demonstration at this site was sub-slab ventilation.

In May 1987, premitigation testing was conducted using a vacuum cleaner to suck on holes drilled through the slab while investigating the extent and strength of suction at nearby holes and openings with a smoke pencil and pressure measurements. An industrial 1/2 inch hammer drill with a 3/8 inch bit was used to drill through the floor slabs. Each hole took several minutes to drill, as the bit frequently struck hard pieces of aggregate that took a long time to drill through.

No communication could be measured between the holes. No airflow was produced down several holes even when 13 000 Pa suction was applied to a hole less than 1 m away. Probes showed that the slab had been poured directly on low permeability soil and broken bedrock. Sounding with a metal bar showed that the floor was in poor contact with the soil near the perimeter walls, and smoke was drawn very slowly down two holes there.

Air samples drawn from the interior of the hollow block walls showed radon concentrations ranging from 32 to 240 pCi/L. The basement air radon concentration was in the region of 10 pCi/L at the time and for 3 days monitoring ranged from 22 to 209 pCi/L averaging 113 pCi/L. Air samples from three holes drilled in the floor slab gave radon concentrations of 3 700 pCi/L in the end room, 5 500 pCi/L in the front room, and 10 300 pCi/L in the workroom. Although the walls were routes of radon entry, the low radon concentrations found there in comparison to those beneath the floor, suggested that they were not major ones.

To check that the wall/floor joint was a route of entry, despite the very low sub-slab permeability, twelve enclosures were placed over wall/floor joints. The radon concentrations in the enclosures after 24 hours were; end room 770, 2 400 pCi/L on external walls; front room 1 900, 1 400 pCi/L on external walls, and 2 100, 1 000, 240 pCi/L on internal block walls; rear room 900, 250 pCi/L on internal block walls; work room 1 800, 7 400 on external walls and 570 pCi/L on an internal block wall. The radon concentration in the basement air was 100 pCi/L. There was no correlation between the size of the wall/floor joint and the radon concentration in the enclosure. A number of the enclosures had radon concentrations that were a large fraction of the sub-slab soil gas concentrations, so the wall/floor joint was a probable entry routes.

The sub-slab permeability test gave no guidance for the system design, except that one fan would probably be sufficient to handle all the air that could be extracted from the sub-slab space, so the standard design was used with exhaust points located near the outside walls and near internal concrete block walls with a nominal separation of 4 m. This lead to a twenty-point sub-slab ventilation system, which was installed in the basement over a six day period in June 1987.

A large plastic bodied centrifugal fan installed in a window well at the end wall provided suction to a 6 inch duct which split into two parallel 6 inch ducts which ran through the front and rear basement rooms and into the work room. Four pipes for the end room came off the main duct, and eight pipes ran from each duct after the split. The 125 mm diameter holes for the exhaust pipes were made with a coring drill. The low permeability of the sub-slab fill was confirmed, for the drill cooling water did not drain down the hole, and extracted soil contained a great deal of clay. To increase the effective permeability, the soil and broken bedrock were removed as far under the slab as possible and replaced by clean crushed stone. The hollow steel house jacks were drilled and filled with expanding foam to increase the airtightness of the floor.

While the workmen installed the system, the external basement door was open all the working day. Radon concentrations in the basement varied from 10 to 50 pCi/L under these conditions, and rose to as high as 133 pCi/L when work was finished and the door closed at night. When the system fan was turned on radon concentrations dropped, ranging from 2 to 4 pCi/L, and averaging 3 pCi/L.

System testing found that the suction in the exhaust pipes was almost constant, ranging from 250 to 275 Pa, with the higher suctions in the pipes nearer the fan. Flows in the pipes were very low, all in the region of 0.3 L/s. Only one pipe had a flow 1 L/s or more. The total flow to the fan was only 24 L/s, confirming the low permeability of the sub-slab material. Radon concentrations in the pipes varied widely. Along the end wall of the house, radon concentrations were 830, 730 pCi/L, along the rear wall they were 9 000, 22 000, 6 200, 290, 1 500, 340 pCi/L, along the garage wall 1 600, 3 100 pCi/L, and along the front wall 1 300, 5 700, 1 800, 1 900, 4 100 pCi/L. Radon concentrations in pipes near the internal block walls and chimney structure were lower, at 200, 1 700, 160, 29, and 270 pCi/L.

The pipes with the highest radon concentrations were not in the areas where the enclosures had high radon concentrations, but were close to the area of the basement where the radiation level was 50% higher than normal. The higher radiation is probably caused by localised zone in the bedrock of higher uranium content, and this in turn would also give higher radon concentrations in soil gas.

Alpha Track dosimeters were installed upstairs and in the basement in June 1987 to measure the long term average radon concentration.

3. OTHER MEASUREMENTS

Indoor gamma radiation ranged from 6 to 10 uR/h, averaging 8 uR/h. There was a hot spot of 16 uR/h about 3 m in diameter in the basement end room. Gamma radiation over the site varied from 9 to 11 uR/h, averaging 10 uR/h.

MEASUREMENTS SUMMARY FOR HOUSE 40

PYLON AB-5 HOURLY MONITORING

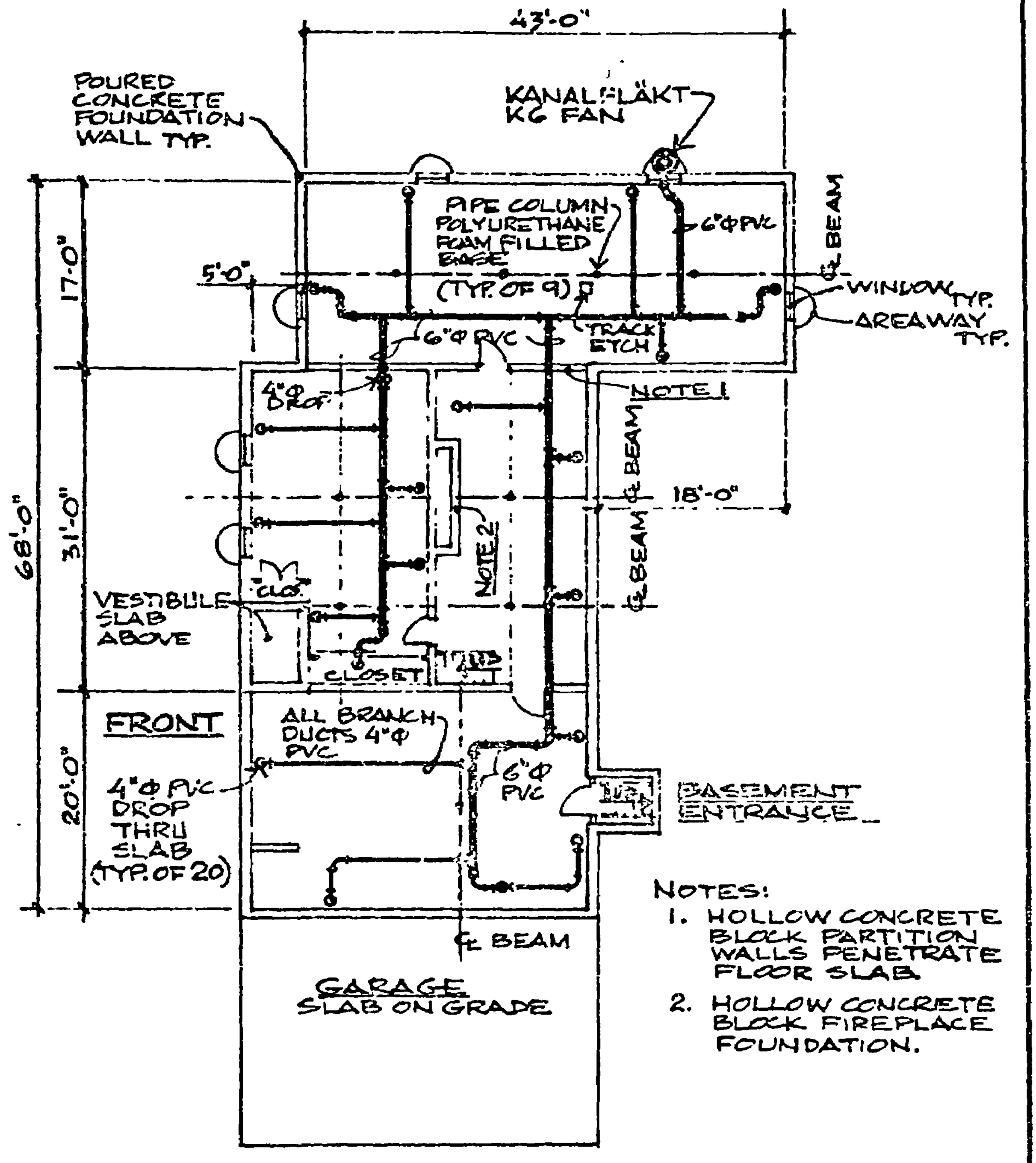
PHASE	MITIGATION SYSTEM	TEST DATE	STATUS DURING TEST	RADON (pCi/L) RANGE	MEAN	COMMENTS
3	Premitigation	05/87	Survey	22-209	113	over 69 hrs.
3	Sub-slab ventilation	06/87	Work in progress no fan	10-133	52	over 70 hrs cellar door open
		06/87	Fan on	2- 4	3	over 57 hrs

SYSTEM MEASUREMENTS FOR HOUSE 40

3	Premitigation testing	05/87	0	0	For all combinations of slab holes 13 000 Pa applied

SYSTEM MEASUREMENTS FOR HOUSE 10 (CONT.)

PHASE	MITIGATION SYSTEM	DATE	SYSTEM MEASUREMENTS PRESSURE Pa	FLOW (L/s)	RADON (pCi/L)	COMMENTS
3	Sub-slab ventilation	06/87	210	0.1	830	*i end wall external
			250	0.3	9 900	*2 rear wall external
			250	0.2	22 000	*3 rear wall external
			250	0.3	4 400	*4 front wall external
			250	0.1	730	*5 end wall external
			265	1	270	*6 cross wall internal
			265	0.2	1 900	*7 front wall external
			265	0.2	1 800	*8 front wall external
			275	0.2	5 700	*9 front wall external
			275	0.2	160	*10 cross wall internal
			275	0.3	1 700	*11 central wall internal
			275	0.5	29	*12 central wall internal
			275	0.3	200	*13 central wall internal
			275	0.4	6 200	*14 rear wall external
			275	0.2	290	*15 rear wall external
			275	0.3	1 500	*16 rear wall external
			275	0.1	340	*17 rear wall external
			265	0.2	1 600	*18 garage wall external
			275	0.5	3 400	*19 garage wall external
			275	0.2	1 300	*20 front wall external
			275	21		at fan
	Riser					



LOW COST REDUCTION OF INDOOR RADON		HOUSE NUMBER
FOUNDATION PLAN	Date: 6/13/87	40
Mitigation system: SUB-SLAB SUCTION	PHASE: FINAL	