FIELD TEST AND DEMONSTRATION OF RADON PREVENTION TECHNIQUES IN NEW HOMES

FINAL REPORT

Prepared for

U.S. Environmental Protection Agency
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Jersey Central Power and Light
Morristown, New Jersey

by

NAHB Research Center
400 Prince George's Boulevard
Upper Marlboro, MD 20772-8731

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TABLE OF CONTENTS

TABLE OF CONTENTS
(continued)

1.0 INTRODUCTION

Radon awareness is increasing due to widespread publicity on the extent of radon exposure in the United States, coupled with reports in the scientific literature on potential health risks (BE-88, IC-87). The State of New Jersey and the U.S. Environmental Protection Agency (EPA) have been particularly concerned about radon reduction techniques for new construction. Their concerns are shared by members of the building community.

This mutual concern resulted in a joint venture between the New Jersey Builders Association (NJBA), EPA, the New Jersey Department of Community Affairs, the Jersey Central Power and Light Company, and the NAHB Research Center (Research Center) to demonstrate radon reduction techniques in new homes. Representatives of these groups, along with radon experts from industry and academia, formed the New Jersey Builders Radon Advisory Group (NJBRAG) to provide oversight to the project. The demonstration was carried out by the Research Center in cooperation with participating builder members of NJBA.

2.0 OBJECTIVES

The purpose of the project was to demonstrate cost-effective radon reduction techniques in new homes in "radon prone" areas of New Jersey. Three main objectives were:

1. To determine the practical limitations of selected radon reduction techniques under field conditions;
2. To determine builder's costs for the various techniques; and
3. To the extent possible, to determine the effectiveness of selected radon reduction techniques.

3.0 PROJECT SCOPE

The project was organized into four tasks as summarized below:

3.1 Establishment of a New Jersey Builders Radon Advisory Group

The NJBRAG was established to provide overall guidance to the project. The responsibilities of this group included reviewing radon prevention techniques recommended for the demonstration homes, and assisting in developing the selection criteria and testing requirements for the demonstration homes.

3.2 Design of Generic Radon Reduction Systems

The Research Center in cooperation with NJBRAG developed generic guidelines for radon-resistant construction (see Appendix A). The guidelines stressed cost-effective measures, use of materials familiar to the builder, and minimal changes to the existing building design. These measures were integrated into the demonstration homes as they become available.

3.3 Field Implementation and Monitoring

This task included recruitment and selection of participating builders, construction of test homes, development of a Quality Assurance plan for critical measurements, and monitoring of indoor radon levels. Potential builders for the project were contacted by phone and through mailings by NJBA and the Research Center. Screening criteria were as follows:

- The builder should be building a variety of house types;
- The soil radon concentration at each site should be greater than 200 pCi/l; and
- The site should demonstrate radon flux out of the soil.

3.4 Documentation and Technical Transfer

Compliance with specifications, costs and performance of the radon reduction measures were evaluated under this task. Results were consolidated into a set of recommendations that could serve as a guideline for builders and/or for development of appropriate building code provisions.

4.0 PROJECT SCHEDULE

The original project schedule was divided into two phases over a 38 month period. The first phase was to closely monitor the construction of an initial set of homes built to the generic specifications, and to conduct short- and long-term indoor radon tests on these homes. A more detailed set of specifications would then be developed for construction of homes in the second phase.

After several initial tests of Phase I homes, many of the home owners and builders were reluctant to wait for results of the planned long-term confirmatory tests before proceeding with additional mitigation. This problem and others cited below forced a revision to the work plan and schedule. The result was deletion of the first phase and all short-term testing from the program. This was designed to permit the project team to gather most of the desired data within the original 38 month time frame, although the number of homes involved had to be reduced.

5.0 RECRUITMENT OF BUILDERS

Recruitment efforts included mass-mailings of an information sheet with NJBA's monthly newsletter, direct contacts by the Research Center using NAHB mailing lists of New Jersey builders, program announcements in three issues of NJBA's Dimension magazine, and special programs at the 1988 and 1989 NJBA annual convention. In addition, builders were solicited at five different radon seminars conducted throughout New Jersey by Research Center staff. In all, an estimated 8,000 contacts were made.

Twenty eight sites representing nearly 400 homes were identified through the recruitment process and visited to perform soil screening tests. Of the sites visited, 24 were selected for participation in the project. Although the number of homes at these sites far exceeded the original objectives for the project, many builders left the program or did not finish the number of homes they had planned. In several cases, they never even broke ground. As a result, only 22 homes were finished in time for long-term indoor radon measurements. Reasons given by builders for dropping out or not joining the project were as follows:

- Liability. In many cases, potential candidates were reluctant to participate on the advice of legal council. In one case the builder, after entering the program and participating in a plan review and soil tests, suddenly withdrew after discussing the project with his attorney. This in spite of the fact that the builder uses subslab depressurization in all of his homes as a marketing tool. However, he does not conduct follow-up test as required in this program and the attorney felt that this would unnecessarily increase the builder's liability.

- Market Conditions. Shortly after the project was initiated, the housing market in New Jersey began a steady decline, forcing builders to postpone starts and in several cases abandon plans to build homes altogether. In one situation, a large volume builder suddenly reversed a decision to participate on the advice of his marketing staff, who believed that involvement in the project could discourage potential sales.

- Legislation. About the time the project started, New Jersey passed a law requiring that any radon measurement results be reported to the state and that they become, in effect, a part of the homes permanent record. Since builder confidentiality could not be assured under this law, several of the builders withdrew from the project.

- High Radon Levels. At one site, the builder withdrew from the project after the initial measurements revealed high indoor radon levels. Although this builder had written a radon guarantee into his sales contract, he feared the project would be avoided by buyers if word of the elevated radon levels spread. The builder opted to mitigate the homes on his own and withdraw from the project.

- Involvement of Homeowners. Several builders declined to participate due to the intended use of long-term measurements requiring participation of homeowners. In other cases, actions of the homeowners invalidated the results of the radon tests.

6.0 DEMONSTRATION HOMES

Participation agreements were developed for builders and homeowners. A copy of each of these agreements is shown in Appendix B. In addition, a Quality Assurance (QA) plan was developed and submitted to EPA following review by NJBRAG (QA-88). Finally, a Building Characteristics Data Sheet was developed and used to document details on each home (Appendix C).

Seven builders representing 11 different sites throughout New Jersey eventually finished homes for the study. Forty-nine homes were identified for construction and follow-up testing, but only 22 homes were completed in time. Numbers were assigned to each of the original 49 homes in consecutive order, as shown in Table 1 in Section 7.0. The nonconsecutive numbering of homes in this section is due to the homes that were not completed in time for radon measurements. The homes completed by each builder are described in this section.

6.1 Builder No. 1

This builder in Morris County had planned on building four homes during the summer and fall of 1988. Only one of the homes was completed during the project. Soil test results varied at the site, from just under 300 pCi/l to over 2600 pCi/l.

Construction:

House #1 is a 3900 square foot, two-story house with a 2250 square foot full basement and an attached 1200 square foot three car garage on a slab. Concrete block foundation walls have a solid top and bottom course. The exterior of foundation walls is covered with parging and a bituminous coating. A drainage system runs around the base of the foundation on the exterior. The concrete slab floor was placed over an eight-inch layer of gravel under a polyethylene vapor barrier. All floor and wall joints and openings were caulked, including two cracks in the finished floor slab. A six-inch PVC passive vent stack was installed within the fireplace chase. An axial fan was mounted in an inclined portion of the stack between the basement floor slab and the fireplace chase (at a 30° angle to the floor). The fan was activated after a three day charcoal test showed basement levels above 4.0 pCi/l. Long-term alpha track detectors (ATD) were placed in the home immediately after the fan was activated.

Costs:

The builder provided the following estimate of costs for radon resistant construction:

Four inches of additional aggregate (4 inch typical)	$200.00
Tooling and Caulking	100.00
Vent Stack	75.00
Fan Installation	75.00
TOTAL	$450.00

Discussion:

This builder found the recommended strategies for radon-resistent construction relatively easy to incorporate into his home. One practical limitation of installing the passive stack in the fireplace chase was the necessity to locate the fan inside the living space.

6.2 Builder No. 2

This builder's site was located in Somerset County, New Jersey. Two homes were planned, however the second home was not completed in time to be included in the program. Soil radon levels ranged from 64 pCi/l to 341 pCi/l.

Construction:

House #5 is a 5500 square foot, two story home with a walk-out basement and an attached garage. The basement slab area is approximately 3000 square foot and was cast tight to the foundation walls. The concrete slab floor was placed over four inches of aggregate covered by a six-mil polyethylene vapor barrier. The vapor barrier was not installed continuous to the exterior walls, did not overlap at some joints, and was not repaired where over-cut at penetrations. The concrete block foundation walls have a solid top and bottom course. The exterior of the foundation walls is parged and covered with a bituminous coating. Penetrations in the floors and walls, and all concrete joints, are caulked. Both interior and exterior perimeter foundation drains were installed, and are interconnected. The exterior perimeter drain flows by gravity to daylight, the interior drain flows to a covered sump. A four inch PVC vent stack runs from the sump to the attic, where it is terminated and capped.

Costs:

The builder's estimated costs for radon mitigation are as follows:

6" of aggregate under basement floor slab	$150.00
6 mil. polyethylene vapor barrier	70.00
Caulk wall and floor penetrations and seal joints	50.00
Interior PVC perimeter drain	50.00
4" PVC vent pipe from the sump through roof	50.00
TOTAL	$370.00

Discussion:

This house was unoccupied during indoor radon testing. The HVAC system was operating, but at a reduced level. No major problems with the recommended radon-resistant features were noted by the builder.

6.3 Builder No. 3

This builder was planning to build 26 homes at two sites in Warren County, New Jersey. Only six of these were completed in time for indoor measurements to be conducted. With one exception, soil radon levels were above 900 pCi/l, with a high of 4543 pCi/l.

Construction:

All homes at theses sites have full basements. The living areas range from 3150 square foot to 3350 square foot with foundation areas ranging from 1150 square foot to 1350 square foot. Private wells provide potable water to the homes. All foundation walls are poured concrete with a bituminous coating applied to the exterior. All wall penetrations and floor-wall joints are grouted and/or caulked. A polyethylene vapor barrier was placed over four to six inches of aggregate prior to casting the slabs. The barriers were not taped at laps or penetrations, and often stopped short of the slab edges. The concrete floor slabs were cast tight against the foundation walls. Additional radon-resistant features vary in different homes, with some employing only passive sealing and/or a passive stack, and others using active subslab depressurization. Specific measures used in the six completed homes are as follows:

House #17 has a passive system consisting of a four-inch PVC vent stack installed from the subslab aggregate through the roof.

House #18 has an active system consisting of a four-inch vent stack installed from the subslab aggregate up through the roof above the garage, with an axial fan located in the basement.

House #19 has a passive system consisting of a 4-inch vent stack installed after completion of the house by running it along the foundation wall between the garage and house, then up through the roof.

House #22 has a passive vent stack consisting of a four-inch pipe installed from the subslab aggregate up through the garage roof. The home owners subsequently installed an axial fan in the stack approximately 10 weeks into the long-term monitoring period.

House #24 has a rough-in for a subslab depressurization system consisting of a four-inch vent stack capped in the attic. A grid of PVC pipes under the floor slab is connected to the stack.

House #31 has a passive system consisting of a six-inch PVC vent stack installed from the subslab aggregate up through the garage roof.

Costs:

Radon mitigation costs for the homes at these sites varied with the measures used. The builder provided the following estimated costs of features used in different homes.

6 mil. polyethylene vapor barrier	$100.00
Caulk and/or seal all penetrations in floors and walls	50.00
4" PVC vent stack & perimeter foundation drain	200.00
Grid subslab pipe system	150.00
In-line axial fan	100.00
TOTAL	$600.00

Discussion:

This builder offered a radon warranty in his sales contract that required him to activate a subslab depressurization system if indoor radon levels exceeded 4 pCi/l. In a number of cases, the system was activated based on short-term test results. Home owners were frequently reluctant to wait for confirmation from long-term tests. Long-term tests were re-started after systems were activated. After several cases of home owners or the builder modifying the homes, a decision was made to eliminate the short-term tests, thus permitting the long-term measurements to be conducted without being invalidated by modifications to the homes.

Limitations at this site were generally related to quality control. For example, joints in slabs were caulked in some homes, but not in others. In one case, a fan was installed in the basement rather than outside the living space. Most of the vent stacks were installed with bends and horizontal runs to avoid structural members.

6.4 Builder No. 4

This builder had two sites in the program. The first, located in Morris County, is a single-home site in a small subdivision. Soil radon levels were just under 2000 pCi/l. Long-term ATDs placed in the basement of this home were discarded by the home owners, leaving only the first floor ATD available for analysis.

Six homes were planned for the second site, which is located in Sussex County. Soil radon levels ranged from 975 to 2,915 pCi/l. Only two homes were completed in time for indoor testing, and the radon detectors could not be retrieved from either of these. One home owner moved abroad and left no forwarding address, and the buyers removed the detectors from the other home before they could be informed of the program.

Construction:

House #32 at the first site is a two-story home on an 880 square foot basement foundation with an attached garage. Foundation walls are concrete masonry with solid top units, and parged on the exterior. The concrete slab floor was cast tight to pipes and to exterior walls. A small crack subsequently opened around the perimeter walls. A polyethylene vapor barrier and four inches of aggregate were used under the slab. A section of four-inch PVC pipe was installed to extend from the aggregate through the basement slab, and was capped in the basement.

House #33 and House #34 on the second site had identical first floors and basements. The foundation consists of a 625 square foot basement, and an 875 square foot slab-on grade that includes a family room, laundry room, and an attached garage. One home has three bedrooms and two baths on the second floor. The other home has four bedrooms and two baths on the second floor. The foundation walls of each home are concrete masonry with solid top units. The exterior of the foundation walls on the first home is parged and sprayed with a bituminous coating. A polyethylene waterproofing barrier was used on the exterior of the second home. The concrete slab in each home was cast tight to exterior walls and to pipes protruding through the slab.

Identical radon mitigation features were used in each of these two homes including a nominal four inches of aggregate under the basement slab covered with a polyethylene vapor barrier, and a short section of four inch pipe inserted into the aggregate and capped just above the slab. A four-inch perforated pipe runs along approximately 1/2 the inside perimeter of the slab-on-grade section of the home. The perforated pipe is connected to a short section of non-perforated four-inch pipe that is inserted through the foundation wall into the basement, where it is capped for later connection to the basement mitigation system. There were no sumps in either home at the beginning of the monitoring period. Several months later the builder added a sump to the first home after water problems developed. No special precautions were taken to seal the sump lid.

Costs:

This builder estimated that costs for radon-resistant features were similar at each home, as follows:

Aggregate	$350.00
Caulking	50.00
Vapor barrier	30.00
Air tight sump cover	50.00*
Subslab piping and stack	200.00
TOTAL	$680.00

*was not used in the homes

Discussion:

There were no major limitations with the radon-resistant measures used at these sites.

6.5 Builder No. 5

This builder had three construction sites in Sussex County, NJ. The first is a development of 23 single-family homes, the second includes two single-home sites, and the third is a single-home site. Soil radon levels were generally greater than 500 pCi/l at all three sites.

Construction:

In all, seven homes were completed in time for long-term testing. All of these homes are two stories with several variations of foundation. The builder placed six-inches of aggregate and a vapor barrier under all slabs. A rough-in was installed for a subslab depressurization system consisting of a three-inch pipe extending from the subslab aggregate to just above the slab. The following information was gathered for each house:

House #39 is a model home with a basement and an attached garage. The foundation walls are concrete block with a solid top course, and are parged and covered with a bituminous coating on the exterior. A rough-in for subslab depressurization was installed in the basement consisting of a 3-inch pipe from the subslab aggregate to just above the slab. The pipe was not capped.

There are frequent small floor cracks in the basement floor, an opening in the basement wall around a drain line, and an open sump.

House #40 has an 896 square foot basement, connected to a 286 square foot crawl space under a family room, and an attached garage. The foundation walls are concrete block with a solid top course, and are parged and covered with a bituminous coating on the exterior. The crawl space vents directly into the basement through a 24" by 32" access opening. There are no other vents in the crawl space. A rough-in for subslab depressurization was installed in the basement consisting of a 3-inch pipe from the subslab aggregate to just above the slab. The pipe was not capped.

House #41 has a 1200 square foot basement and an attached garage. A rough-in for subslab depressurization was originally included in this home. This was upgraded by the resident who extended the rough-in out through the band joist. The resident also fabricated a wooden cover for an open sump.

House #42 and House #43 have 1,200 square foot basements with attached garages. Basement construction is the same as previous homes, except that there are no sumps in these houses. A three-inch rough-in for a vent stack was installed through the slab and terminated in the basement. The vent was not capped.

House #44 is a two-story home with a 1,900 square foot basement and an attached garage. It has 3,800 square foot of living space. The basement walls are concrete block with a solid top course, parged and covered with a bituminous coating on the exterior. A six inch layer of aggregate was used under the slab. A 3-inch PVC rough-in for a vent was installed but was covered over when the slab was cast.

House #45 is a 3,400 square foot, two-story home with a 1,900 square foot basement and an attached garage. The basement is open to a small crawl space that has a rough concrete floor. The basement walls are concrete block with a solid top course, parged and covered with a bituminous coating on the exterior. The voids of the block wall separating the basement and the crawl space are exposed at the opening to the crawl space. Six inches of aggregate were used under the slab, and a three-inch PVC vent stack is stubbed out from the aggregate into the basement. The vent was not capped.

Costs:

The builder estimates that he averages an extra $150 in costs for radon control in each house. This cost is for PVC pipe, plastic sheeting over the stone, and the labor to install these. The builder normally places 4" - 6" of stone under his slabs. Houses with a sump cost an additional $50 for an air-tight sump lid.

Discussion:

Several problems were encountered with this test site. First, the builder was issued a stop work order (unrelated to radon or this project) just after the project started, and several planned homes were not built in time to be included in the project. During the stop work period the builder was not able to dedicate the effort needed to complete houses satisfactorily. Radon stacks were not capped properly, and final sealing of sump lids was not completed.

6.6 Builder No. 6

This site consists of a development of 21 single-family homes on 8000 square foot lots in Somerset County, New Jersey. Soil radon levels ranged from a low of about 300 pCi/l to over 1,700 pCi/l. Only three homes were completed during this study. All three homes have two stories and are being used as sales models. Two have slab-on-grade foundations; one has a full basement. Long-term ATDs were placed in each home, however none were found in the first slab-on-grade home, and only one of the two ATDs were found in each of the other homes.

Construction:

House #46 is a 1,370 square foot home with a slab-on-grade foundation. Four inches of aggregate and a polyethylene barrier were placed under the concrete slab, which was cast against a felt strip along the wall. Wire mesh (6 x 6 #10) was used in the slab. The polyethylene barrier was overlapped six inches at joints and was installed flush to the walls. A cross pattern of 3-inch

PVC pipe was placed in the subslab aggregate and connected to a 3-inch PVC vent stack that extended up through the roof. There are no floor drains or sump.

House #47 is on a 1,416 square foot slab-on-grade foundation. Other than the larger size, it is identical to house number 46.

House #48 has a 1,786 square foot basement, a 480 square foot garage slab, and a 280 square foot slab-on-grade family room. The basement walls are concrete block with a solid top course and a bituminous-based coating on the exterior. Wall and floor slab cracks developed after construction. The basement has a sump with an air tight lid, although the lid was improperly installed. A four-inch pipe runs from the sump lid to the band joist. A felt strip was used between the slab and walls. The felt extends 1/4-inch to 1/2-inch above the slab. No attempt was made to further seal the slab/wall joint. The building sewer penetrates the wall four feet above the floor slab. An eight inch hole in the wall was left open.

Costs:

The builder estimates that he spends an extra $350 on each house for radon control. This includes the pipe, a polyethylene barrier, an air tight sump, roof work for the stack, and all labor.

Discussion:

All three homes are models with non-typical occupancy. The site superintendent was not overly concerned with the importance of quality control in the installation of the radon features. Follow-through on sealing of openings was poor. Felt expansion strips used between the wall and slab in the basement are the standard practice for this builder. Both the builder and the local inspector prefer this practice and are not anxious to change. These strips make caulking impractical.

6.7 Builder No. 7

This builder is constructing four single-family homes in Morris County, New Jersey. Only one was completed in time for indoor measurements. Soil gas radon levels measured approximately 800 pCi/l.

Construction:

House #49 is a 3,140 square foot home with a combination basement and crawlspace foundation. Foundation walls are poured concrete with a bituminous coating and rigid insulation on the exterior. There is a sump hole in the basement with an air tight cover. The builder used a four-inch piping grid under the slab as a collection system. The grid is connected to a three-inch passive stack vented through the roof. There are four inches of aggregate and a polyethylene barrier under the slab. The crawl space is open to the basement on the north end of the house with a three foot square access opening.

Costs:

This builder pays a subcontractor $900 per house to install the piping system under the slab and up through the roof, and to caulk and seal the foundation. The builder spends another $50 upgrading his sump lids.

Discussion:

There were several cracks in the basement slab which were not sealed. Utility penetrations through the basement wall were not sealed. The floor/wall joint was not caulked, and the airtight sump lid was not installed correctly. The polyethylene barrier was overlapped six inches at seams but was not taped. The barrier was not fit tightly against the wall or taped at penetrations in the slab.

7.0 RESULTS

7.1 Radon Measurements

Soil gas radon levels and permeability were measured at each site using methods described by Rogers (RO-87). Typically, a measurement was taken prior to construction at a depth of 36 inches. Measurements were taken in the vicinity of the home's foundation. In some cases, the builder did not know which lots would be built first, and an attempt was made to obtain representative soil measurements throughout the site, rather than taking one measurement per lot. Results of soil gas measurements at the seven sites where homes were completed are shown in Table 1.

TABLE 1

RESULTS OF HOUSES STUDIED

House	Soil Radon	Soil Permeability	One Year Indoor Radon Level Location	pCi/l	Sealing Code	Mitigation Code	Cost
1	N/A	N/A	Basement 1st Floor	12.0/9.4 3.5	3	4	$450
2	2355	9.1×10^{-8}	House not completed in time for this study				
3	2342	2.7×10^{-12}	House not completed in time for this study				
4	256	3.5×10^{-11}	House not completed in time for this study				
5	64	1.8×10^{-11}	Basement 1st Floor	4.7/5.1 *	2	1	$370
6	341	1.2×10^{-10}	House not completed in time for this study				
7	4543	1.2×10^{-11}	House not completed in time for this study				
8	2320	3.2×10^{-10}	House not completed in time for this study				
9	1803	4.1×10^{-10}	House not completed in time for this study				
10	186	1.5×10^{-10}	House not completed in time for this study				
11	973	8.1×10^{-11}	House not completed in time for this study				
12	965	3.1×10^{-12}	House not completed in time for this study				
13	2847	5.7×10^{-11}	House not completed in time for this study				
14	942	1.5×10^{-10}	House not completed in time for this study				
15	1580	1.8×10^{-10}	House not completed in time for this study				
16	2026	1.2×10^{-10}	House not completed in time for this study				
17	1754	2.6×10^{-6}	Basement 1st Floor	17.0 2.3	2	3	$500
18	1686	2.1×10^{-10}	Basement 1st Floor	13.0 5.9	2	4	$500

Notes:

Sealing Codes: 1=Major Openings, 2=Minor Openings/Cracks, 3=Sealed Tightly

Mitigation Codes: 1=Stub Out for Future Use, 2=Passive Stack Through Wall, 3=Passive Stack Through Roof, 4=Active Stack with Fan

* = Detectors could not be retrieved or were destroyed or discarded by occupants.
N/A = Soil radon levels could not be determined due to low permeability.
Dual indoor radon measurements indicate duplicates.

TABLE 1

RESULTS OF HOUSES STUDIED
(continued)

House	Soil Radon	Soil Permeability	One Year Indoor Radon Level Location	pCi/l	Sealing Code	Mitigation Code	Cost
19	1414	2.1×10^{-6}	Basement 1st Floor	7.6 3.1	2	3	S500
20	2079	2.4×10^{-10}	House not completed in time for this study				
21	2322	5.5×10^{-11}	House not completed in time for this study				
22	1373	2.6×10^{-10}	Basement 1st Floor	10.0 1.1	2	4	S600
23	2703	1.4×10^{-10}	House not completed in time for this study				
24	N/A	2.7×10^{-12}	Basement 1st Floor	3.6/4.3 1.1	3	3	S500
25	3503	2.5×10^{-11}	House not completed in time for this study				
26	214	3.2×10^{-11}	House not completed in time for this study				
27	1364	4.7×10^{-11}	House not completed in time for this study				
28	1533	3.0×10^{-13}	House not completed in time for this study				
29	1382	1.5×10^{-11}	House not completed in time for this study				
30	2623	1.5×10^{-12}	House not completed in time for this study				
31	1374	4.6×10^{-11}	Basement 1st Floor	5.0 1.4/1.8	2	3	S500
32	1979	1.4×10^{-12}	First Floor Basement	0.9 *	1	1	S680
33	2032	2.8×10^{-13}	First Floor Basement	* *	2	1	S680
34	2915	8.9×10^{-12}	First Floor Basement	* *			

Notes:

Sealing Codes: 1=Major Openings, 2=Minor Openings/Cracks, 3=Sealed Tightly

Mitigation Codes: 1=Stub Out for Future Use, 2=Passive Stack Through Wall, 3=Passive Stack Through Roof, 4=Active Stack with Fan

* = Detectors could not be retrieved or were destroyed or discarded by occupants.
N/A = Soil radon levels could not be determined due to low permeability.
Dual indoor radon measurements indicate duplicates.

TABLE 1

RESULTS OF HOUSES STUDIED
(continued)

House	Soil Radon	Soil Permeability	One Year Indoor Radon Level Location	pCi/l	Sealing Code	Mitigation Code	Cost
35	975	1.5×10^{-11}	House not completed in time for this study.				
36	2445	2.6×10^{-10}	House not completed in time for this study.				
37	1295	1.3×10^{-10}	House not completed in time for this study.				
38	N/A	N/A	House not completed in time for this study.				
39	3,197	4.5×10^{-8}	Basement 1st Floor	10.0 4.6	1	1	$200
40	683	2.2×10^{-7}	Basement 1st Floor	9/8.5 2.1	1	1	$150
41	N/A	N/A	Basement 1st Floor	22.0 11.0	1	2	$200
42	N/A	N/A	Basement 1st Floor	19 8.3	1	1	$150
43	549	4.3×10^{-8}	Basement 1st Floor	9.7 4.0	1	1	$150
44	137	2.6×10^{-9}	Basement 1st Floor	18/9.5 2.4	2	1	$150
45	576	1.1×10^{-7}	Basement 1st Floor	8.8 4.9	1	1	$150
46	289	7.9×10^{-7}	1st Floor 2nd Floor	* *	2	3	$350
47	1161	1.5×10^{-8}	1st Floor 2nd Floor	0.7 *	2	3	$350
48	1704	1.4×10^{-10}	Basement 1st Floor	21.0 *	1	2	$350
49	798	1.1×10^{-9}	Basement 1st Floor	3.4/2.5 1.4	1	3	$950

Notes:

Sealing Codes: 1=Major Openings, 2=Minor Openings/Cracks, 3=Sealed Tightly

Mitigation Codes: 1=Stub Out for Future Use, 2=Passive Stack Through Wall, 3=Passive Stack Through Roof, 4=Active Stack with Fan

* = Detectors could not be retrieved or were destroyed or discarded by occupants.
N/A = Soil radon levels could not be determined due to low permeability.
Dual indoor radon measurements indicate duplicates.

Long-term indoor radon levels in completed homes were measured using alpha track detectors (ATD) as indicated in Table 1.

7.2 Quality of Measurements

All radon detectors were deployed and handled in accordance with the approved Quality Assurance Plan for critical measurements (QA-88). Five percent of ATDs from each shipment were returned unexposed to the laboratory. Background varied considerably, ranging from 0.1 pCi/l to as high as 6.1 pCi/l. Most of the blanks were reported with unacceptable background levels. Although the blanks were stored in the same location for nearly identical periods, there was no degree of consistency or other explanation for the unacceptable background levels.

Duplicate devices were deployed for 10 percent of all indoor measurements. Many of the duplicates were discarded by home owners and were not available for analysis. However, those that were available showed poor precision, differing by as much as 100 percent. The project schedule did not permit retesting of homes.

7.3 Cost of Radon Reduction Measures

Costs of various construction measures associated with radon reduction obtained from participating builders are shown in Table 1. These represent direct costs to the builder, and do not include indirect costs and mark-ups. Final consumer costs may be up to 50 percent higher.

In general, the cost of caulking and sealing to reduce major entry routes added $50 (simple caulking) to $300 (extensive sealing) to conventional construction costs for a basement area of about 1,500 square feet. The additional installed cost of a 6-mil polyethylene barrier ranged from $0 where this is standard practice, to $300 where there is a large increase in labor due to longer curing times for concrete.

A passive subslab vent system consisting of 3" PVC increased costs from $50 to $200. In some areas, subslab aggregate is not typically used in residential construction and would be considered an extra cost in a radon mitigation system. Costs of aggregate for the study homes ranged from $150 to $350 depending on the depth of the layer, foundation size, and availability of aggregate.

Initial costs for active subslab depressurization systems are equivalent to those for a passive system plus the cost of a fan and wiring to power the system. Fan costs provided by two builders in the study were $75 and $100 not including labor. A secondary cost associated with an active system is the energy consumption of the fan. Others have estimated this cost to be roughly $30 per year (EP-88).

Since builder costs vary considerably according to their circumstances, their costs should not be compared or evaluated statistically without a significant sample. The following sections contain estimated costs from the study homes with costs obtained using conventional estimating tools (ME-88). These provide a more standardized method for examining costs.

7.3.1 Slab-on-Grade Foundations

The general procedure for reducing entry routes for slab-on-grade construction includes installing a soil gas barrier under the slab, and caulking of wall/floor joints, pipe openings and other penetrations. Tooling and caulking costs can be highly variable. In areas where subslab aggregate and a vapor barrier is already used for moisture control, the added cost for radon mitigation can be very low. Table 2 provides a cost breakdown for typical slab-on-grade radon-resistant construction measures.

7.3.2 Basements

Costs to reduce radon entry routes into basements are generally equivalent to the cost of sealing a slab-on-grade plus the cost of sealing the exterior walls and the cost of an air tight cover if a sump is used. Concrete masonry units generally require parging and a bituminous coating for "water proofing". However, parging may be replaced with a covering of polyethylene or other suitable barrier on the exterior. Depending on local practice, a polyethylene barrier on masonry walls may actually decrease costs if used in place of the parging typically applied to masonry walls. See Table 3 for a cost breakdown of basement construction.

TABLE 2

Slab-On-Grade
Typical 1,200 Square foot Slab

CONSTRUCTION FEATURE	COSTS/SQ. FT.	TYPICAL COST
Sealing		
6 mil polyethylene*	.08	$100
tool & caulk slab	.04 - .065	50 - 80
Typical Range		$ 50 - $ 420
Subslab depressurization		
Stone 4-6"*	.22 - .33	$270 - 400
3" pipe to roof		80 - 130
fan**		170 - 300
Typical Range		$ 80 - $ 830
TOTAL COST RANGE		$130 - $1,010

* Item may be included in new construction, not necessarily related to radon. Cost not included in low estimate of range.

** Optional items. Cost not included in low end of range.

TABLE 3

Basements
Typical 1,200 Square foot Slab

CONSTRUCTION FEATURE	COST/SQ. FT.	TYPICAL COST
Sealing		
6 mil polyethylene slab*	.08	$100
6 mil polyethylene wall*	.08	80
tool & caulk slab	.04 - .065	50 - 80
sump cover**		50 - 60
Typical Range		$ 50 - $ 320
Subslab depressurization		
Stone 4-6"*	.22 - .33	$270 - 400
3" pipe to roof		80 - 130
fan**		170 - 300
Typical Range		$ 80 - $ 830
TOTAL COST RANGE		$130 - $1,150

* Item may be included in new construction, not necessarily related to radon. Cost not included in low estimate of range.

** Optional items. Cost not included in low end of range. Quotes for specialty sump covers were obtained from commercial suppliers.

7.3.3 Crawl Space

None of the builders in the program used crawl space ventilation as a mitigation technique. The incremental cost to minimize radon entry routes into a crawl space depends to a large extent on the location of duct work and prevailing local moisture control strategies. In many areas a vapor barrier is a standard moisture control feature and does not add to costs. Re-routing ductwork to prevent radon entry through return air ducts may increase initial installation costs depending on the house design. Sealing duct work and openings in the floor is generally a more practical approach. See Table 4 for a cost breakdown of crawl space construction.

TABLE 4

Crawl Space
Typical 1,200 Square foot Crawl Space

CONSTRUCTION FEATURE	COST/SQ. FT.	TYPICAL COST
Sealing		
6 mil polyethylene*	.03 - .06	$ 40 - 70
seal ducts and floor		30 - 50
Typical Range		$ 30 - $ 120
Sub-membrane Ventilation**		430 - 1,100
Winter ventilation of crawlspace**		
protection of pipes from freezing, insulate ducts		$ 50 - 200
Typical Range		$ 0 - $1,300
TOTAL COST RANGE		$ 30 - $1,420

* Item may be included in new construction, not necessarily related to radon. Cost not included in low estimate of range.

** Optional items. Cost not included in low end of range.

7.4 Effectiveness

Conclusions from this study on the effectiveness of construction techniques on indoor radon are limited for several reasons. First, it is not feasible at this time to determine what indoor radon levels would be if no special measures were taken. Second, the measurements results provided by the radon laboratory were not very precise (see Section 6.2). Finally, the limited number of homes with indoor measurement results and the variations between mitigation techniques do not provide sufficient basis for statistical evaluation of the results. Despite these limitations, several observations are worth noting.

Subslab depressurization systems in two homes (house 1 and 22) where the system was activated based on short-term radon measurements did not have the impact on radon levels that was expected. Although radon levels in the "lowest living level" (first floor) were reduced to 3.5 pCi/l and 1 pCi/l for the homes, the basement levels were above 9 pCi/l in each home. This suggests that more investigation is necessary to determine the limitations of current mitigation technology.

Of the homes that were completed, there are only four that actually finished the program as it was designed, (i.e. they met the basic conditions of having soil tests results, being built in general conformance with the recommended techniques, and successfully completing the year long indoor measurement period). These homes include house numbers 17, 18, 19, and 31.

House 17, 19, and 31 have passive stacks running from the subslab aggregate up through the roof. Soil gas radon levels were 1754, 1414, and 1374 pCi/l, respectively, for house 17, 19, and 31. In each home, first floor radon levels were below the EPA active level of 4 pCi/l, but all of the basement readings exceeded 4 pCi/l. There were no major openings in the homes' foundations, and although the program schedule did not permit follow-up, it is believed that radon levels could easily be lowered below the action level if the systems are activated.

House 18 has an active subslab depressurization system. Soil gas radon levels were 1868 pCi/l. Indoor radon levels were 13.0 and 5.9 pCi/l in the basement and first floor, respectively. There is no definitive explanation for failure of the active system to lower radon levels below the action level. One possibility is that the aggregate was contaminated in some spots, preventing a sufficient pressure field from developing at points remote from the stack. No further investigation or diagnostic work was performed.

Several homes with elevated indoor radon levels were built on sites that had low soil gas radon levels or low permeability soils that prohibited obtaining a soil gas sample (e.g. house 1, 44). Conversely, some homes on soils with high soil gas levels did not have the high indoor radon levels that might be expected (e.g. house 32, 39). This suggests that a great deal of work may be necessary before it will be possible to correlate soil test results with radon in homes.

8.0 CONCLUSIONS AND RECOMMENDATIONS

8.1 Practical Limitations with Recommended Construction Details

One of the objectives of this project was to identify difficulties encountered during installation of various radon reduction measures under field conditions. The following limitations have been observed:

- A four inch vent stack is not practical in most homes without constructing a 2"x6" wall or a special chase to conceal the stack in living spaces. It is recommended that the minimum size be reduced to three inches. This should have little or no effect on either passive or active performance of the system, and would permit installation in a standard 2"x4" wall.

- Complete sealing of entry routes with under-slab soil gas barriers is not realistic. Polyethylene is difficult to tape and can easily be punctured during concrete placement. Others (AS-91, NA-89) have suggested that the primary function of the barrier is to minimize contamination of the aggregate by the cement. The barrier may also reduce some pressure-driven flow by bridging cracks. Therefore, it is still recommended that a barrier be installed to reduce potential entry points, but it needs to be recognized that a perfect barrier is not practical. In addition, some redundancy can be provided by caulking cracks, joints and other openings in the floor slab.

- Routing the vent stack as directly as possible to the attic has presented problems for some home designs. There were several examples where placement in an interior wall without horizontal runs between floors was difficult since interior walls do not always line up from floor to floor. Further, it is considered desirable to terminate the stack on the rear of the roof to hide it from the street, and a horizontal run is often needed to accomplish this. An active system with a fan in the vent should have no difficulty in operating with such offsets.

- Tooling of concrete joints for caulking presented a problem for most builders since it requires an extra step in the concrete finishing process. The opportunity to tool the slab is easily missed if the concrete sets up too quickly, or too slowly (finishing a slab with a polyethylene barrier may last well into the night). In most cases, the slab was poured tight against the wall with no caulking.

- Quality control was one of the most deficient aspects of the recommended construction measures. Many of the details for caulking and sealing entry routes were overlooked, primarily because builders and their site superintendents are not sufficiently familiar with radon-resistant construction techniques. In other cases, it simply was a low priority item with the laborers or tradesmen.

8.2 Costs for Radon-Resistant Measures

Available data indicates a wide range in the cost of radon reduction practices. Total system costs may range from a few hundred to several thousand dollars over conventional practice. The primary factors include regional economics, the type of foundation, and variations in radon-resistant construction techniques. In any case, as more and more homes are fitted with radon reduction systems, and closer standardization of construction practices occurs, it is expected that costs will decrease. In the meantime, a learning period will be necessary for designers, builders, and tradesmen to incorporate radon mitigation into the construction process.

Finally, it should be noted that many components of radon reduction systems do not add to the price of homes, since these items are also standard practice in "non-radon" construction.

Examples of items that are standard in some areas, but are considered to add extra cost to a home in other areas include subslab aggregate and vapor barriers, and waterproofing (polyethylene) on exterior foundation walls.

8.3 Recommendations for New Construction

At the start of this program, heavy emphasis was placed on minimizing entry routes. Others have suggested that the variability in radon reductions achievable by sealing entry routes limits its applicability as a radon mitigation strategy (AS-91, EP-88, LB-86). The questionable benefits of sealing suggests that too much emphasis has been placed on this method. A more appropriate approach may be to include features for a future subslab depressurization system, and to limit sealing to major entry routes that could compromise an active system. Other research confirms that sealing major entry routes in combination with subslab depressurization is one of the most effective radon mitigation strategies (EP-88, LB-86, SR-90). Based on this premise, the following radon-resistant features are recommended for slab-on-grade and basement homes built in New Jersey.

- All slabs should be constructed over a nominal four-inch layer of aggregate or other permeable material.

- A polyethylene or equivalent barrier should be placed over the aggregate to keep the aggregate from being contaminated as the slab is cast (NA-89, AS-91).

- Significant entry routes through the slab and below-grade walls should be sealed. Examples include penetrations around utilities, sump pits, tops of hollow walls, and floor drains. Standard waterproofing and/or dampproofing should be adequate on exterior walls.

- Provide for a future subslab depressurization system by installing a minimum three inch vent pipe from the subslab aggregate up through the roof, or provide a short section of pipe extending from the aggregate to just above the slab, sealed with an air-tight cap so that it can be extended later if needed. Other suitable methods for connecting the vent pipe to the subslab aggregate may also be acceptable.

9.0 REFERENCES

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10. LB-86, "Radon and Remedial Action in Spokane River Valley Residences", 1986, B.H. Turk et al., Lawrence Berkeley Laboratory, Berkeley, CA.
11. SR-90, "Engineering Design Criteria for Sub-Slab Depressurization Systems in Low Permeability Soils", 1990, Charles Fowler et al., Southern Research Institute, Birmingham, AL.

APPENDIX A

CONSTRUCTION TECHNIQUES FOR NEW HOMES IN RADON-PRONE AREAS OF NEW JERSEY

CONSTRUCTION TECHNIQUES FOR NEW HOMES IN RADON-PRONE AREAS OF NEW JERSEY

Prepared for:

New Jersey Building Radon Advisory Group

Prepared by:

NAHB National Research Center
400 Prince Georges Center Boulevard
Upper Marlboro, MD 20772-8731

November 1987
(Revised May 1988)

CONSTRUCTION TECHNIQUES FOR NEW HOMES IN RADON-PRONE AREAS OF NEW JERSEY

1.0 INTRODUCTION

Presented in the following pages are suggested methods for reducing or preventing radon in new homes, as well as procedures for site selection and monitoring of test and control homes in radon-prone areas of New Jersey.

The NAHB National Research Center (NAHB/NRC) makes no guarantee as to the effectiveness of these methods. The methods are based on EPA recommendations, research results of others, and practical building considerations. They were developed for radon-prone areas of New Jersey, with emphasis placed on local building practice, and apply only to homes participating in the project being conducted by NAHB/NRC and the New Jersey Home Builders Association (NJ HBA).

Three basic foundation types are addressed: basements, including poured concrete and block walls; slabs-on-grade, including conventional and monolithic slabs; and crawlspaces. A base-line prevention system is suggested for each foundation type. These systems include provisions that would enable advanced systems to be fitted at a later date, if required. Details are also suggested for the advanced systems.

2.0 BASE-LINE SYSTEMS

The "base-line" system, designed to seal entry routes and provide a air/gas barrier around the foundation, is presented in Figures I-A, I-B, I-C, II and III. The objective of the base-line system is to prevent, as much as possible, radon from entering the home.

Techniques for poured concrete basements are relatively straight forward and require very little change from conventional practice. Details include a polyethylene vapor barrier under the slab sealed firmly to the inside of each wall; polyethylene film or equivalent barrier adhered to exterior walls; and a drainage system to relieve hydrostatic pressure. A clean, uniformly-graded stone base (minimum 4", #57 stone) is also included with the base-line recommendations. The stone base, required by most building codes and generally considered good building practice, is actually provided to accommodate the advanced systems discussed in Section 3.0. However, it is most cost effective if installed before the slab is poured.

Crawlspace foundations are treated similar to basements with one exception. The floor of the crawlspace is covered with a barrier applied directly over the soil and held in place by a 2" layer of sand, or by pouring a 1" or thicker concrete mud slab over the vapor barrier. Slab-on-grade foundations are treated the same as basement floors with a polyethylene barrier and a stone base beneath the slab.

Developing details for masonry block construction presented a more difficult task, due to a local practice of providing an interior perimeter drain (french drain) at the wall-slab interface. Research and experience in other damp regions of the United States and Canada indicate that dry, block-wall basements can be routinely constructed without an interior perimeter drain. Generally, the methods suggested for radon control are equally effective for waterproofing. In any case, quality control is an absolute necessity to insure the effectiveness of the methods suggested for base-line radon control. As an alternative, builders may consider installing a similar type of perimeter "drain" for block walls. However, this drain should differ from the currently used drain in that it should not completely penetrate the slab. Builders should check local codes and warranty programs before installing this type of drain.

3.0 ADVANCED SYSTEMS

Advanced radon reduction systems apply to homes in which base-line techniques prove insufficient. A 4" base of #57 stone will be installed under slab floors of all test homes in anticipation of the possible need for subslab ventilation. Each test home will also be fitted with an advanced subslab ventilation system capable of being easily disengaged. This will allow for testing of the base-line system as well as the incremental value of the advanced system.

A passive subslab ventilation system, as shown in Figure IV, will be installed in all homes with a slab-on-grade or basement foundation. The system will initially be made inoperative by installing a clean-out approximately 6" above the slab and plugging the stack with a balloon-type plug. In addition, provisions will be made for installation of an in-line fan at a later date should the passive system prove insufficient. (See Figure IV.)

Advanced radon reduction methods for crawlspace foundations will rely primarily on increased exterior venting. This is illustrated in Figure III.

4.0 SITE SELECTION

Candidate sites will be reviewed by the NAHB/NRC staff to determine compliance with selection criteria. Primary consideration will be given to sites located in areas where known radon problems exist. Foundation details and building schedule will also be a consideration.

A soil test will be conducted at candidate sites to determine soil gas radon concentration and soil permeability. Generally, sites with radon gas concentrations above 200 pico Curies per liter (pCi/l) will be considered suitable. However, sites slightly below this level that exhibit high soil permeability will also be considered.

An agreement will be signed with the participating builder to permit testing on homes by NAHB/NRC technicians. Prospective home buyers will also be asked to sign a similar agreement.

5.0 TEST HOMES

Testing will proceed immediately after construction of test homes. All testing will be conducted by placing monitoring devices at the lowest level of the home, and if possible, on the floor level immediately above the lowest level.

An initial short-term test will be conducted on all homes to determine radon levels prior to connection of the passive system. Homes with radon levels below 4 pCi/l will be monitored for one year without connecting the passive system. Homes with initial levels above 4 pCi/l will be connected to the passive stack and monitored for the same one-year period.

Test data will be reviewed at the end of the one year period to determine if further action is necessary. Homes with average annual levels above 4 pCi/l will then be upgraded to the next level (i.e., a base-line system will be upgraded to a passive stack or a fan will be installed on the passive systems). Test homes with upgraded systems will be monitored for an additional one-year period.

6.0 CONTROL HOMES

Approximately one home for each five test homes will be selected as a control home. Ideally, control and test homes will be of similar type construction, located in the same subdivision or area, and on similar soil types.

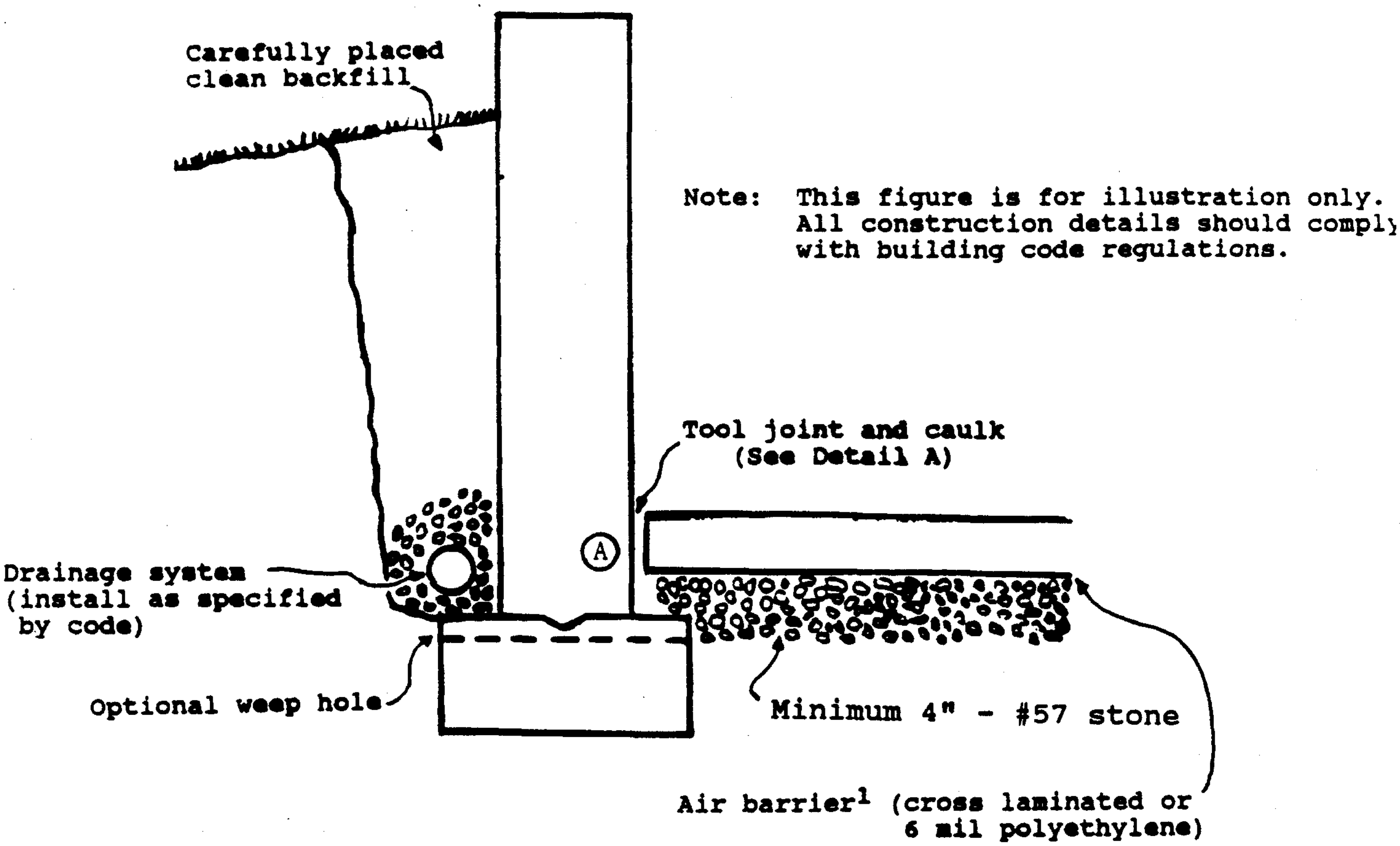
Monitoring of control homes will follow a procedure parallel to that discussed above for test homes. Initially, a short-term test will be conducted on each control home. This will be followed by long-term testing for a two-year period. Placement of test devices will be as specified for test homes.

Test results of control homes will be reported to property owners. Mitigation of control homes with elevated levels will not be undertaken as part of this project. Responsibility for reducing levels in control homes rests with the property owner. However, an effort will be made to provide home owners with suggestions for reducing levels.

7.0 SYSTEM COSTS

One of the primary objectives of this project is to develop cost-effective methods to reduce or prevent accumulation of indoor radon. Estimates will be obtained from participating builders to determine the incremental cost of the radon reduction/prevention systems in comparison to a conventional home with no provisions for radon reduction. A data base will then be developed to estimate the installed cost of all systems. The data base will contain costs for both the base-line systems and the advanced systems.

Figure I-A. Poured-Concrete Basement Wall



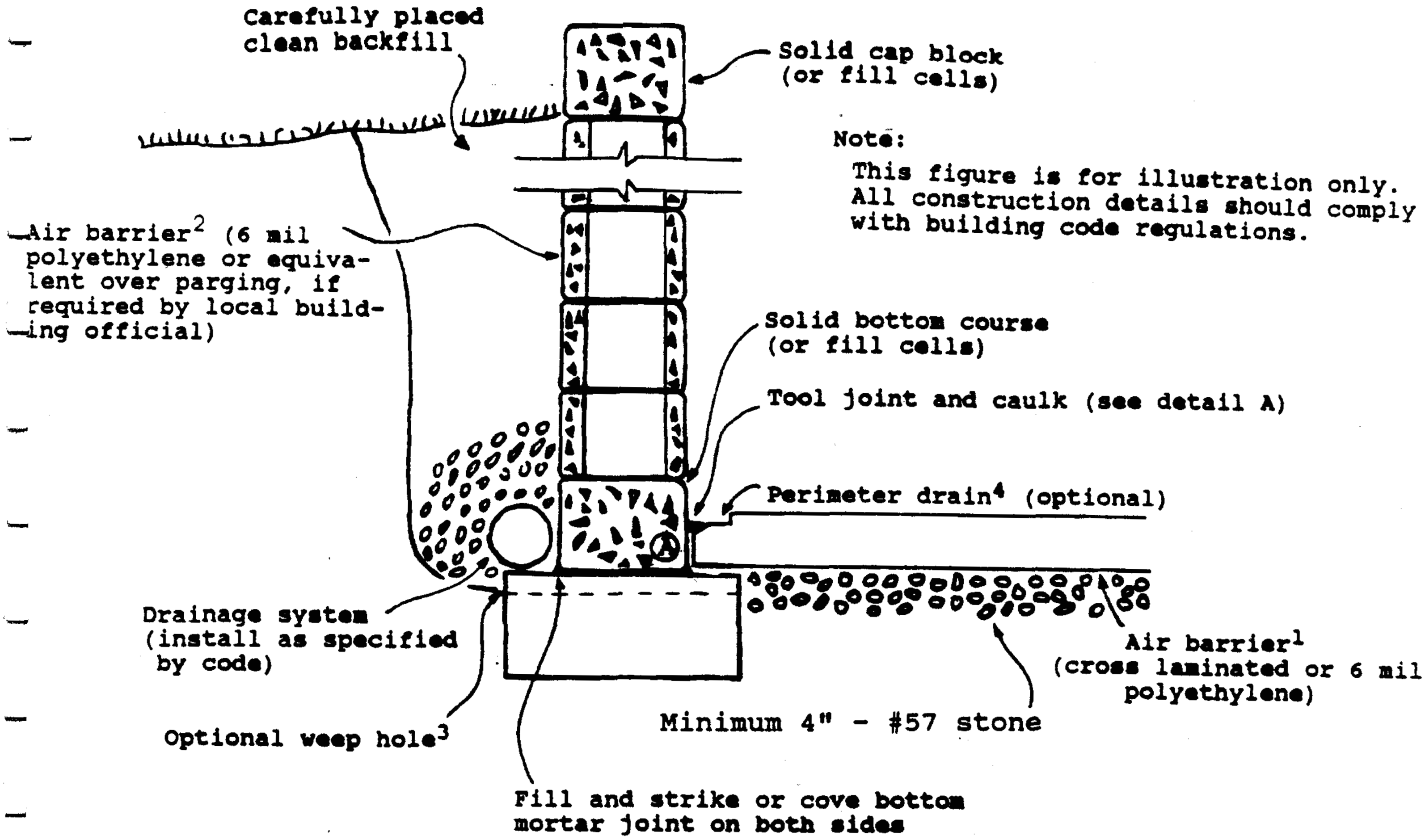
NOTES:

1. Install a continuous barrier under the slab, attached to the wall with an approved adhesive at point A. Seal all penetrations and joints with contractors tape (3M-8086 or equivalent) or urethane foam.

2. Apply a continuous wall barrier extending from the top of the footing to finished grade and secured to the wall with an adhesive or as specified in the CABO OTFDC or the New Jersey State Uniform Construction Code. Seal all penetrations and joints.

3. Seal all sump pits with airtight covers to prevent entry of soil gas.

Figure I-B. Masonry Basement Wall



NOTES:

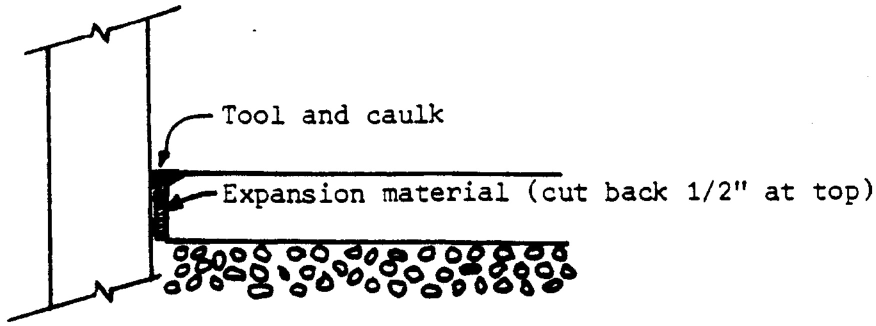
1. Install a continuous barrier under the slab, attached to the wall with an approved adhesive at point A. Seal all penetrations and joints with contractors tape (3M-8086 or equivalent) or urethane foam.

2. Apply a continuous wall barrier extending from the top of the footing to finished grade and secured to the wall with an adhesive or as specified in the CABO OTFDC or the New Jersey State Uniform Construction Code. Seal all penetrations and joints.

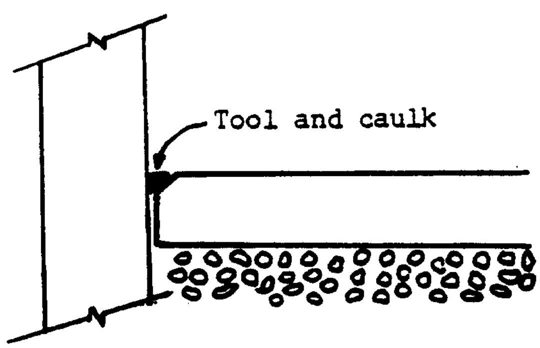
3. The sealing method is independent of the drainage system. However, weep holes installed between the underslab area and exterior footing drains should be recessed into the footing.

4. Optional perimeter drain should flow to an airtight sump and empty through a floor drain designed to prevent escape of gas (Dranjer sump model or equivalent). Seal all sump pits with airtight covers to prevent entry of soil gas.

Figure I-C.

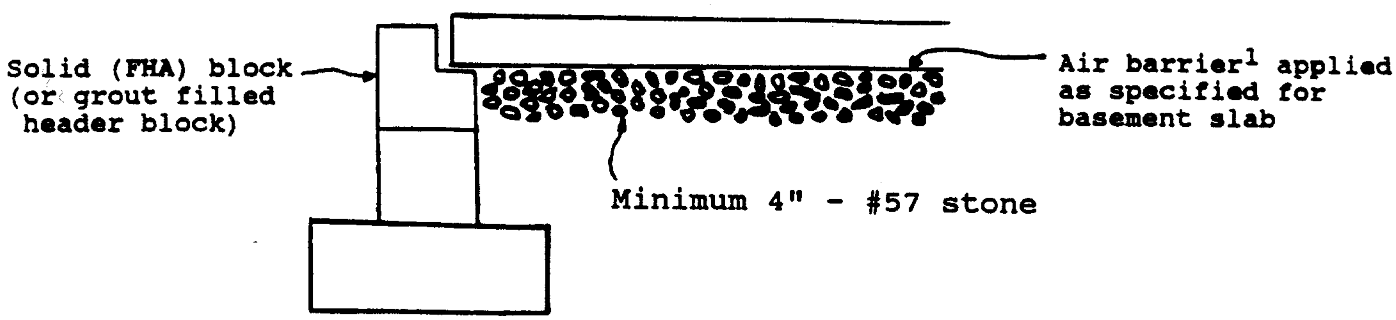


Detail "A"

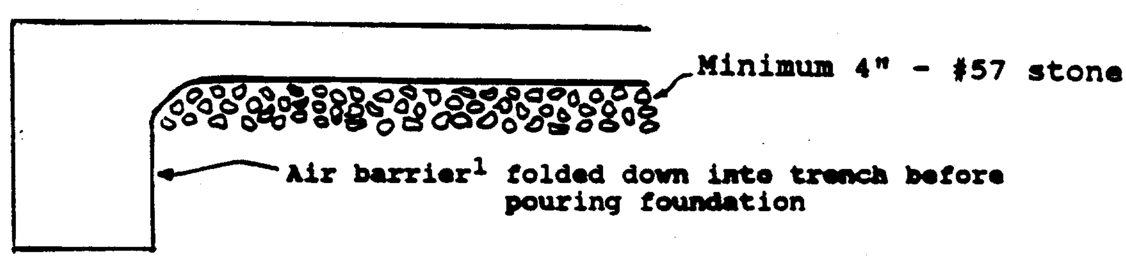


Alternate Detail "A"

Figure II. Slab-On-Grade



A. Conventional



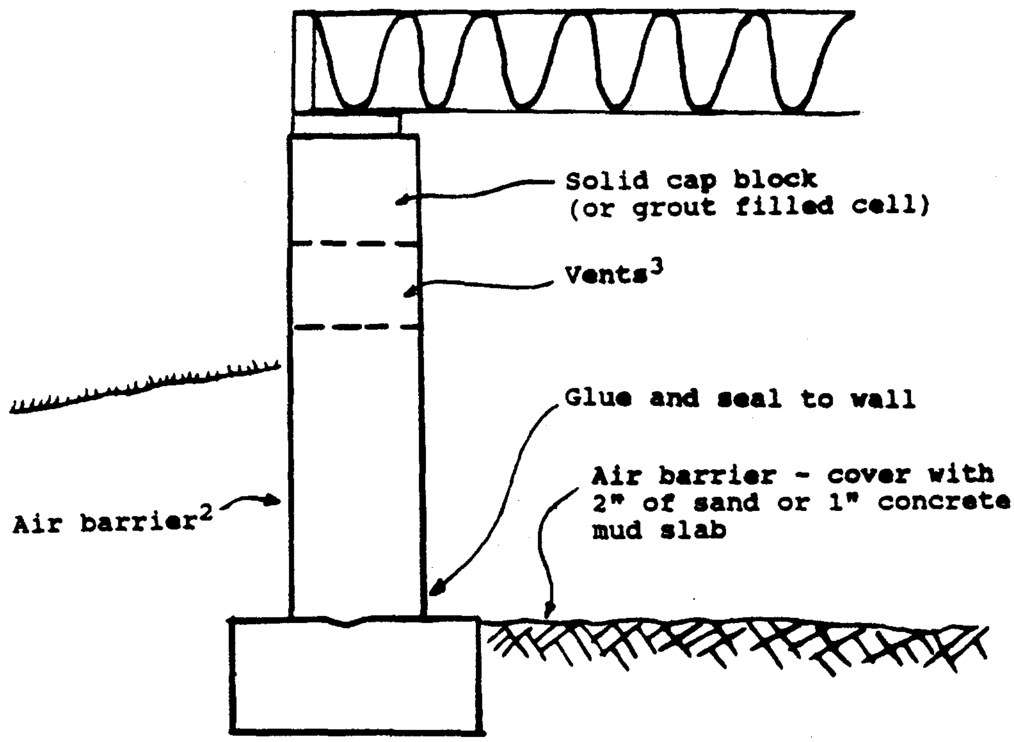
B. Monolithic

NOTES:

1. Seal all penetrations and joints with contractors tape (3M-8086 or equivalent) or urethane foam.

Figure III. Crawlspace[1]

Note: This figure is for illustration only. All construction details should comply with building code regulations.



NOTES:

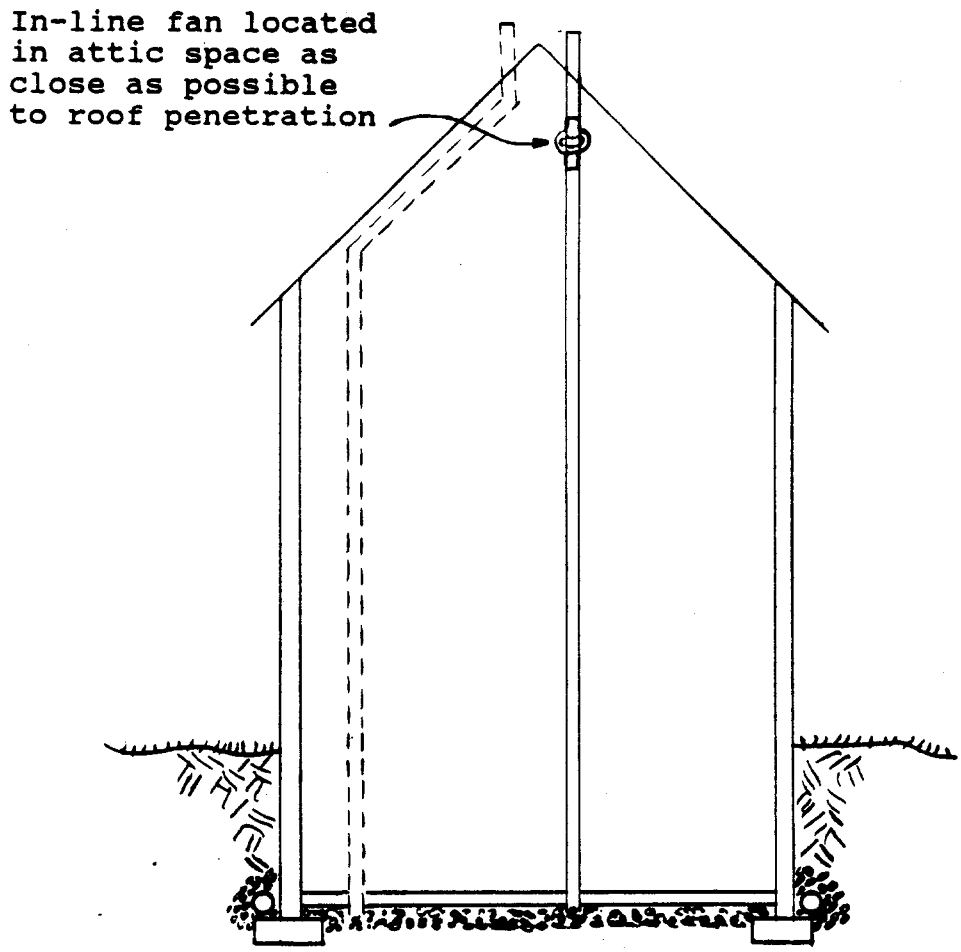
1. Sealing method applies to block or poured concrete walls.

2. Cross laminated or 6-mil polyethylene applied as for basement wall construction.

3. Provide one quarter of vent area to face in each direction. Vents may be placed on three sides if positioned as close as possible to building corners. Minimum aggregate vent area should not be less than 1/150 of total square foot of crawlspace floor area.

4. Minimize ducts in crawlspace. If ducts must run through crawlspace, wrap and seal each duct.

Figure IV. Advanced Reduction Techniques
(Subslab Ventilation)



NOTES:

The stack:

a) should run vertically without change of direction from the slab to the roof.
b) may change direction, but should not be inclined greater than 45 degrees from vertical.
c) should be located in an interior wall.
d) should terminate in the gravel and not bottom out on the soil.
e) may terminate in an interior drain tile or sump crock providing all penetrations are sealed.
f) should be caulked at the slab penetration.
g) should extend above the peak.
h) may require a wind induction hood.

APPENDIX B

PARTICIPATION AGREEMENTS

TESTING AND MONITORING AGREEMENT
BETWEEN
NAHB NATIONAL RESEARCH CENTER
AND

____
BUILDER'S NAME

The undersigned, as a duly authorized representative of ____________________ (hereinafter called the
Builder's Name
"Builder"), hereby enters into this Agreement with the NAHB National Research Center (Research Center) and consents to provisions in the following Articles:

Article 1

The Builder agrees to install radon reduction techniques in accordance with the construction details and schedule in the accompanying document, *Construction Techniques for New Homes in Radon Prone Areas of New Jersey*. All costs for materials and labor relating in any manner to the installation of these techniques will be borne by the Builder.

Representatives of the Research Center will be granted access to the site to monitor construction, and subsequent access to homes for the purpose of installation and removal of testing devices in accordance with the schedule and methods in the previously cited document.

Article 2

Indoor radon test results of unoccupied homes will remain confidential and will be provided to the Builder. Tests of occupied homes shall remain confidential and will be provided to the Builder. The home owner will be instructed to contact the Builder to receive a copy of the test results.

Article 3

The Builder agrees to release the Research Center from any and all liability, and to indemnify the Research Center against any and all losses, claims, liabilities, or damages from third parties, relating in any way to the Research Center's involvement in the radon project, including any personal injuries or property damages.

The Research Center does not warrant the effectiveness of the radon reduction techniques. The Builder and subsequent assignees expressly waive any and all claims against the Research Center of any type, expressed or implied.

NAHB NATIONAL RESEARCH CENTER	BUILDER
____________________ AUTHORIZED SIGNATURE	____________________ AUTHORIZED SIGNATURE
____________________ TITLE	____________________ TITLE
____________________ DATE	____________________ DATE

Builder Form A - June 13, 1989

PARTICIPATION AGREEMENT
FOR
HOMEOWNERS IN
THE RADON RESISTANT
CONSTRUCTION EVALUATION STUDY

The NAHB National Research Center (Research Center) and the New Jersey Home Builders Association (NJHBA) are conducting a research project for the New Jersey Department of Community Affairs and the U.S. Environmental Protection Agency (EPA) to evaluate radon reduction techniques in new homes. It is necessary to conduct long-term monitoring of test homes in order to gauge the effectiveness of these techniques. Testing consists of placing small radon detectors in the home at two locations, one in the basement or lowest level in the house and one on the level directly above. The test devices are relatively small (pill bottle size) and will not interfere with day-to-day use of the areas being tested. Participants will be asked to mail the detectors after one year from the start of the test. A representative from the Research Center may need to arrange brief access into your residence prior to testing.

Your home has been selected to evaluate the radon resistant construction techniques that were included by your builder. This does not imply that your home has or would have had unacceptable levels of radon. The EPA has indicated that some homes in the United States experience elevated levels of radon gas, a naturally-occurring phenomenon which, according to EPA, results from the gas rising up through and escaping from the soil. This phenomenon can occur in any home, regardless of the type of home or who builds it.

Your builder claims no expertise in the measurement or reduction of radon gas levels in homes, nor do their representatives provide any advice to homeowners as to unacceptable levels or possible health hazards of the gas. However, in EPA Publication OPA-86-005, *Radon Reduction Methods: A Homeowner's Guide*, EPA has identified several methods of reducing the level of radon gas in homes, one of which is called a sub-slab ventilation system. EPA advises that this may be an effective method of reducing radon gas levels in a home. This publication is available without charge from EPA. You may wish to contact EPA to receive a copy of this publication and others which EPA has made available concerning radon.

If you decide to measure the level of radon gas in your home, and if your test detects an elevated level, you may wish to take steps to reduce the level detected. One step you may wish to take is to install or have installed a small ventilation fan as recommended by EPA to vent gas from beneath the slab. Your builder has prepared your home for the future addition of a fan assisted sub-slab ventilation system if needed. You may wish to contact EPA or the New Jersey Department of Environmental Protection for further information on whether to install a fan and on the choice of a fan. Upon request, the Research Center will furnish you with sample specifications for such a fan system. Home owners should be aware that the New Jersey Radon Disclosure Law (NJSA26: 2D-73) requires radon test results be disclosed to prospective buyers at the time a contract of sale is entered into.

(over)

Your builder and the Research Center makes no warranty of any kind, express or implied, regarding the level of radon gas in any home before or after the activation of a sub-slab ventilation system. Your builder and the Research Center assume no responsibility for the operation, maintenance or effectiveness of sub-slab ventilation systems or any other devices or methods intended for the reduction of radon gas levels.

- I/we the undersigned, hereby agree to participate in the Radon Resistant Construction Evaluation Study as described above.

- I/we waive our right of confidentiality to permit disclosure of the test data to your builder. Radon test results can be obtained from your builder. Confidentiality will be maintained in the project report.

- I/we agree that the Research Center and the Builder are not responsible for reducing levels of radon in my/our home.

- I/we indicate by my/our signature(s) below that we are the lawful owners of the property at the address below.

HOMEOWNER'S SIGNATURE ______________________ DATE ____________

CO-OWNER'S SIGNATURE ______________________ DATE ____________

ADDRESS ______________________ PHONE NUMBER ____________

RESEARCH CENTER ACKNOWLEDGEMENT ______________________ DATE ____________

APPENDIX C

BUILDING CHARACTERISTICS DATA SHEET

BUILDING CHARACTERISTICS & TEST DATA

New Jersey Radon Demonstration Project

SITE LOCATION: ____________________

LOT NUMBER:_____ STORIES: ______

Part 1 - Building Characteristics

Type of Foundation:

Basement [] Slab-on-Grade [] Crawl Space []

Combination [] (Describe) ____________________________

____

Foundation Size: __________

Type of HVAC System: ____

____

Type of Foundation Wall:

A. Block []
Solid top course [] Solid bottom course []

B. Poured Concrete []

C. Not Applicable []

Type of Foundation Wall Coating:

none [] polyethylene [] parge & bituminous []

bituminous only [] other [] (describe) ______________________

____

Sump Hole Description:

None Used [] open lid [] air-tight lid []

Slab Description:

4"-6" of stone under slab [] barrier under slab []

reinforcing in slab [] joints and penetrations caulked []

Comments on slab:

Description of Radon Stack:

Type & Location of Axial Fan:

Location & Size of Foundation Vents (crawl space only):

Miscellaneous Comments:

Part 2 - Test Data

A. Soil Tests

Radon Screening Test: __________ pCi/l   Permeability: ___________

Date of test: ________

B. Indoor Tests (short-term)

Charcoal: _____ pCi/l Test Dates _______________ Location _______

Charcoal: _____ pCi/l Test Dates _______________ Location _______

Conditions of test: ____

____

C. Indoor Tests (long-term, set 1)

ATD: _____ pCi/l Test Dates _______________ Location _______

ATD: _____ pCi/l Test Dates _______________ Location _______

Conditions of test: ____

____

D. Indoor Tests (long-term, set 2)

ATD: _____ pCi/l Test Dates _______________ Location _______

ATD: _____ pCi/l Test Dates _______________ Location _______

Conditions of test: ____

____