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PRELIMINARY RESULTS FROM THE NEW YORK STATE RADON-REDUCTION DEMONSTRATION PROGRAM

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ABSTRACT

This paper presents preliminary results of the current New York State radon-mitigation project which has three broad task areas: demonstrate cost-effective techniques in 16 existing houses, assess previously installed techniques in 14 existing houses, and demonstrate radon resistant construction techniques in 15 new houses. The mitigation strategies demonstrated in the 16 existing houses include: sealing by caulking or parging, sub-slab depressurization with and without interior footing drains, sub-film depressurization, exterior footing-drain depressurization, block wall depressurization, basement pressurization, and radon removal from water using granular activated carbon and/or aeration. Multiple mitigation phases were planned where possible, so as to develop comparative data on the effectiveness of alternative approaches. The mitigation techniques previously installed in the 14 houses included: sealing, heat recovery ventilation, and sub-slab depressurization. Among the radonresistant construction techniques being demonstrated in the 15 new houses

are: a continuous airtight polyethylene film installed over aggregate before the slab is poured to the foundation wall, a continuous layer of surface bonding cement installed around the exterior of the foundation wall and footing, a course of termite blocks installed around the foundation wall, and interior and/or exterior footing drains discharged to daylight or to a sump airtight to the basement and vented to the outside.

This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication.

INTRODUCTION

The current New York State radon-mitigation project has three broad task areas:

- Demonstrate Cost-Effective Techniques in Existing Houses,
- Assess Previously Installed Techniques in Existing Houses, and
- Demonstrate Radon Resistant Construction Techniques in New Houses.

Interim results from each of these task areas are summarized below.

DEMONSTRATE COST-EFFECTIVE TECHNIQUES IN EXISTING HOUSES

Sixteen single-family detached houses were selected for study, eight in Albany and Rensselaer Counties (coded with the prefix AR), and eight along the lower Hudson River valley in Orange and Putnam Counties (coded with the prefix OP). The houses represented an assortment of construction styles. Most were of wood frame construction above grade, although one had full-height (two stories plus basement) masonry walls. Substructure types represented in this study included finished and unfinished basements, crawl spaces, combinations of basements and crawl spaces, and combinations of basements and slab-on-grade houses. Both hollow concrete block and poured foundation walls were found, as well as a variety of heating systems and foundation openings. Initial screening measurements of the houses ranged from 20 to 180 pCi/L.*

Field teams visiting each house performed a series of diagnostic procedures (1,2) including radon grab sampling, vacuum tests of air communication, and blower-door tests. Connectivity beneath slabs, within concrete block walls, and between slabs and concrete block walls was characterized using chemical smoke and tracer gases. Health department measurements of radon concentrations in the water were also noted. The results of these diagnostic tests were then considered before selecting mitigation measures.

Mitigation measures used in this task (3) included sealing soil gas entry routes by caulking or parging; sub-slab depressurization with and without interior footing drains; sub-film depressurization (that is, depressurization under an installed plastic film barrier)· exterior footing drain depressuriza-

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(*) 1 pCi/L = 37 Bq/m^3.

tion; block wall depressurization; basement pressurization; and radon removal from water using granular activated carbon, diffused bubble aeration, and packed tower aeration. Multiple mitigation phases were planned where possible, so as to develop comparative data on the effectiveness of alternative approaches. Table 1 summarizes most of the mitigation techniques installed in these houses, and provides an estimate of the effectiveness of each technique, based primarily on continuous radon monitoring results in the screening measurement location (basement).

The performance of the various mitigation techniques installed in this task may be summarized as follows (refer also to Table 1).

SEALING ENTRY ROUTES

Caulking cracks and openings as a stand-alone mitigation technique was tested in six houses (houses AR-01, AR-09, AR-16, AR-17 AR-20, OP-09). It produced reductions ranging from 2% (house AR-01) to 74% (house AR-20), with the bulk of the reductions above 50%. This is a surprisingly strong showing for caulking alone and may indicate the potential for further reductions if more careful caulking was performed.

Parging of a porous poured concrete foundation wall surface was attempted in only one house (house OP-09), and poroduced a 37% reduction in radon levels.

SUB-SLAB DEPRESSURIZATION

Sub-slab depressurization without sealing was used in eight houses (houses AR-04, AR-05, AR-09, AR-16, AR-17, AR-19, AR-20, OP-01), and produced reductions ranging from 4% (house AR-19 passive sub-slab ventilation) to 95% (house AR-16). The majority of the reductions were in the 90-95% range. Depressurization in houses AR-16 and AR-20 was applied to a sump connected to a complete loop of interior footing drains and resulted in the greatest reductions of the sub-slab depressurization systems (95% and 94%, respectively).

Sub-slab depressurization with sealing was used in six houses (houses AR-16, AR-17, AR-20, OP-09, OP-13, OP-17), and produced reductions ranging from 35% to 93%, with all but one house in the 82%-93% range. The 35% reduction with this approach was seen in house OP-13, in which exterior footing drain depressurization worked dramatically better than sub-slab depressurization.

Sub-slab depressurization at four perimeter suction points was compared to depressurization at a single central suction point in house OP-01. The design, which used four perimeter suction points and a regenerative fan, produced a 47% reduction in radon concentration, while the design which used a centrifugal fan and a single, central suction point produced a 31% reduction. The most effective radon mitigation technique for this house was apparently outside block wall depressurization, which resulted in an 86% reduction, relative to pre-mitigation levels.

SUB-FILM DEPRESSURIZATION

Depressurization beneath an installed barrier was used in one house (OP-05) to treat a rock outcrop which was an identified source of radon. This technique produced an 81% reduction in radon concentrations compared to pre-mitigation levels.

EXTERIOR FOOTING-DRAIN DEPRESSURIZATION

Only one house was treated with exterior footing-drain depressurization (using an existing footing drain around the exterior of the house). This house, OP-13, showed a 35% radon reduction with sealing plus sub-slab depressurization, while sealing and exterior footing drain depressurization showed a 79% reduction.

BLOCK WALL DEPRESSURIZATION

Outside wall depresurization was used in three houses. Reductions of 98% (AR-01, with sealing) and 86% (OP-01, no sealing) were produced in two houses with relatively straightforward installations. House OP-16 was treated with passive wall and active wall depresssurization. Passive ventilation combined with sealing produced reductions of only 28%; active depressurization improved the reductions to 59% (relative to pre-mitigation levels). The critical action for this house appears to have been foaming the block cores above grade. This step, combined with active wall depressurization, resulted in radon reductions of 96% compared to pre-mitigation levels.

Inside wall depressurization was also tested in three split-level houses (on the inside block wall common to the basement and the slab-on-grade). However, in each case, wall depressurization was combined with sub-slab depressurization and so there are no data for inside wall depressurization alone.

BASEMENT PRESSURIZATION

Basement pressurization was used in only two houses, AR-09 and AR-17. For house AR-17, pressurization alone reduced initial radon concentrations by 98%. Also, sealing alone produced a 61% reduction in this house. When combined, the already high radon reduction performance of the pressurization system was not measurably improved with sealing. So far there are no basement pressurization results for house AR-09.

RADON REMOVAL FROM WATER

Water treatment was applied in two houses with high radon levels in the water (house OP-03 with approximately 400,000 pCi/L and house OP-05 with approximately 200,000 pCi/L). Since water was not the only significant radon source in these houses, treatment of the water was not successful enough to be a stand-alone mitigation technique in either installation.

Use of a granular activated charcoal filter reduced initial radon concentrations by 34% in the bathroom of house OP-03. Addition of sub-slab depressurization reduced radon levels by 60% (from 21.9 to 8.8 pCi/L) in the lower level family room. However, the radon decay products captured in the charcoal filter introduced serious gamma radiation problems near the filter which was located in a small utility room next to a frequently used laundry and bathroom. The final system combined diffused bubble aeration, charcoal filtration (after aeration), and sub-slab depressurization for a reduction in the lower level family room of 86% compared to pre-mitigation radon levels. A third method of removing radon from water was also tested temporarily in house OP-03, in which the aeration was provided by air blowing through a packed tower. Two tower lengths were used. Radon concentrations in the water (not in the house) were reduced by more than 99% with the charcoal filter, more than 99.5% with the diffused bubble aeration system, approximately 85% with the packed short tower aeration system, and approximately 92% with the packed tall tower aeration system. Since the radon stripped from the water in aeration systems is vented to the outside, gamma radiation is not a problem (unlike charcoal filter systems where radon and progeny are trapped in the filter medium).

In house OP-15, aeration was not tested independently of sub-film depressurization and wall depressurization. Starting at a pre-mitigation crawl space level of 232 pCi/L, a combined sub-film and wall depressurization system produced a 96% reduction in radon concentrations to 8.5 pCi/L in the crawl space. Addition of a diffused bubble aeration system brought the radon levels to 1 pCi/L on the first floor. (Average reduction of radon in the water was over 99%.) This house had very high initial radon levels. The aeration system produced a significant reduction in living area radon levels, treating a radon source from the water which other techniques did not address.

ASSESS PREVIOUSLY INSTALLED TECHNIQUES IN EXISTING HOUSES

A pioneering infiltration, ventilation, and indoor air quality survey of 60 New York State houses in the Niagara Mohawk Power Corporation service territory was conducted in 1982-83 (4). Fourteen of these houses were discovered with moderately high radon levels. Early in 1984, low-cost radon mitigation techiques were installed and included sealing entry routes, sealing and sub-slab depressurization, isolating and venting unpaved crawl spaces, and installing heat-recovery ventilators (5). These mitigation systems represent some of the earliest systems installed in the United States (not associated with the mining industry) using low-cost common residential construction materials and methods. It was thought useful to return to these installations, inspect the longevity of the various components of the systems, and assess their long-term effectiveness.

Each house was visited in late 1986 and 1987, during which a thorough inspection was made to assess the wear and tear of system components, observe any settling of the house structure that produced new cracks in the foundation walls and floor, and determine if any deliberate or inadvertent changes may have been made by the homeowners that could have contributed to a change in the system's performance. During conversations with the homeowners, an assessment was also made of their satisfaction with the mitigation system. Among the factors discussed were noise, comfort level, and usability of the space. In most houses more detailed diagnostic tests were also performed to assess the effectiveness of the existing radon mitigation system. Among the diagnostic tests were smoke stick tests to determine leaks, air-flow measurements, sub-slab communication tests, and pressure measurements in the suction pipe of sub-slab depressurization systems relative to the inside air. In some houses a tracer gas test was used to check for leaks and/or sub-slab communication. Short-term radon concentrations were measured using grab-samples and charcoal canisters. If parts of the system did not appear to be working satisfactorily, these components were replaced, updated, or redesigned and re-installed. Short-term radon measurements were then repeated using charcoal canisters, followed by long-term radon mreasurements using alpha-track detectors.

The mitigation techniques employed in this task can be divided into three main groups:

- Sealing Entry Routes (houses NM-26 and NM-41, see Table 2),
- Heat-Recovery Ventilation (houses NM-16, NM-19, NM-28, NM-29, NM-51, and NM-56, see Table 3), and
- Sub-Slab Depressurization (houses NM-02, NM-05, NM-12, NM-21, NM-31, and NM-37, see Table 4).

Each of these groups will now be summarized.

SEALING ENTRY ROUTES

The sealing that was performed in houses NM-26 and NM-41 was the simplest and least expensive (about $300 and $400 in 1984) radon mitigation technique with the least effect on the lifestyle of the homeowners. Unfortunately, it probably also had the least effect on radon levels. The decrease in long-term average radon concentrations that may have occurred after sealing in 1984, was overwhelmed by larger radon reductions in the summer of 1987, when windows were left open and by an increase in radon concentrations in the fall of 1987 when windows were closed again (see Table 2, house NM-26). For house NM-41, long-term radon concentrations in the basement did not change from 1984 to 1986. Although the polyurethane caulk used to seal cracks and small openings appeared to be in good condition, there was some shrinkage of the concrete used to cover an unpaved basement floor area and a sump. It appears that the greatest practical problem with this technique is the difficulty in finding <u>all</u> the significant openings in the foundation.

Since year-long average radon levels in the living areas of both houses were moderate, further mitigation is probably not required, except to provide for more natural ventilation during the non-heating season. However, if permanent, dramatic reductions of radon were required, sub-slab depressurization systems in these house would have a high likelihood of success, based on experience with similar houses.

HEAT-RECOVERY VENTILATION

Six houses used heat-recovery ventilators (HRVs) as a method of reducing radon (houses NM-16, NM-19, NM-28, NM-29, NM-51, and NM-56; see Table 3). The HRVs were easy to install by experienced HVAC contractors, with moderate first costs (approximately $1,000 for equipment and labor in 1984), inexpensive to operate (usually less than 70W, operating part-time), provide the expected ventilation rate, required essentially no maintenance, and performed very quietly. Besides reducing radon, other benefits of operating a HRV mentioned by homeowners include the reduction of odors, and the control of humidity levels. However, the reduction of radon was less than expected from calculating the increase in air exchange rate due to the HRV. As with houses that were sealed, this was probably because the variations in radon levels due to environmental changes (including pressure differences and natural ventilation) that overwhelmed the radon reductions due to increased ventilation from the HRV. Attempts to compare results from the two monitoring periods are therefore very difficult in these houses.

Radon reductions in the houses during the heating season were moderate and actually negative in two of the houses (NM-29 and NM-51). In house NM-28, NM-29, NM-51, and NM-56, where summer data are available, reductions of radon were greater in the summer than during the heating season. In houses NM-28 and NM-56, which had the HRVs on full time, radon reduction was more consistent through the different seasons.

Since year-long living-area radon concentrations appear to be below the 4.0 pCi/L action level in these houses, further mitigation will not be done except to provide for more natural ventilation during the non-heating season. In all but one house (house NM-24), further reductions in radon could be achieved, during the heating season, by operating the HRV for a greater fraction of time or full time. (However, there would be an added electrical and thermal energy penalty.) If more dramatic reductions of radon were required, simple sub-slab depressurization systems could be installed in all these houses except houses NM-19 and NM-28. These two houses were over 100 years old and had stone foundation walls which would require extensive sealing before sub-foundation depressurization may be expected to work.

SUB-SLAB DEPRESSURIZATION

Sub-slab deprssurization systems were installed in 6 of the 14 houses (houses NM-02, NM-05, NM-12, NM-21, NM-31, and NM-37, see Table 4). Sealing was also used in most of these houses to maximize the sub-slab depressurization field. The sealing requirements in most of the houses and the need for venting unpaved crawl spaces in two of the houses, meant that (1984) installation costs varied widely; from $150 for the simplest system to $1250 for the most elaborate. These systems provided the greatest potential for reduction of radon. Unfortunately, because of the lack of experience in installing these systems, they were also the most problem prone.

The most serious problem occurred in house NM-05 when the sub-slab depressurization system vent pipe, next to a sideways "S" shaped bend, filled with condensation water because the drain hose became blocked with debris. This completely blocked air movement to the outside. The problem was exacerbated by poor quality caulk used around the connection between the fan and vent pipe. Thus radon drawn from the sump was forced to travel into the basement, through openings between the fan and vent pipe. This increased the radon concentration in the basement beyond the original concentrations before the system was installed. To solve this problem the vent pipe was re-routed to avoid bends that may collect condensation water and reduce air flow.

A second problem, alluded to above, was the poor quality caulk used in two of the six sub-slab depressurization installations (houses NM-05 and NM-21). This caused the leakage of radon into the basement when the openings were on the positive pressure side of the fan relative to the basement. On the negative pressure side of the fan, if openings were large enough, short-circuiting will occur, where basement air is drawn directly into the sub-slab ventilation system, reducing the magnitude of the negative pressure in the suction pipe and reducing the extent of the sub-slab depressurization field. Similar short circuiting will occur if there is inadequate sealing of openings in the basement floor and wall (especially large openings close to the depressurization fan). To overcome this problem, the low-quality butyl caulk was replaced, where possible, by high quality polyurethane caulk which was originally used on four of the six sub-slab depressurization installations and appeared to hold up very well from 1984 to the present (early 1988).

A third problem in the sub-slab depressurization systems was the use of axial fans to provide depressurization. Axial fans are designed to move relatively large quantities of air when there is no static pressure; for example, to vent electrical equipment and machines. The ideal sub-slab depressurization fan, on the other hand, should provide a large static pressure to a large tightly enclosed space (the sub-slab cavity) while venting very little air. Axial fans are therefore not well suited for sub-slab depressurization. They do not induce the large static pressures required, and they do not last as long as they would if operating in free air. In fact, one of the fans failed (in house NM-31) after only 3 years. To solve this problem, all axial fans (except the larger axial fan in house NM-21) were replaced with in-line centrifugal fans which are more suited to conditions of large static pressure.

Outside vent openings also caused problems for two of the sub-slab depressurization installations. The outside vent opening of house NM-37 faced directly into the prevailing winds, and had movable louvers which remained closed when the wind blew. This vent opening was replaced by a screened opening with rain cover. For house NM-21, the outside vent opening consisted of a 6-in. (15 cm) elbow facing downward with no screen. It was discovered that children had placed pieces of wood down the opening, restricting the flow of air. This vent opening was replaced by a screened opening with fixed open louvers.

The sub-slab depressurization systems in this study had fans located inside the house, so that if any openings developed on the positive pressure side of the fan, radon could leak into the house. This happened in house NM-05 after the exhaust pipe was blocked with condensation water (as mentioned above), and radon leakage may have caused problems in house NM-02. Ideally, fans should be installed outside, or as close to the outside as possible; and all inside exhaust pipes should be carefully sealed and checked with smoke sticks and/or tracer gas.

To summarize, sub-slab depressurization systems were by far the most effective systems in consistently reducing radon levels. However, the early systems that were installed in this study, when there was very little experience in this area, developed some problems which, in hindsight, could easily have been avoided. To learn from mistakes, it is most important to perform long-term tests and continually evaluate the effectiveness of radon mitigation systems.

DEMONSTRATE RADON-RESISTANT CONSTRUCTION TECHNIQUES IN NEW HOUSES

In this task (which is less than half completed), radon-resistant construction techniques are to be applied to 15 new houses, with simultaneous monitoring (and previous baseline monitoring) in 5 control houses. Emphasis will be on the development of cost-effective passive methods of radon-resistant construction with potential applicability to building codes (6).

Housing site selection is critical to the success of this task because of the need to presume high radon levels in houses not yet built. Ideally, subdivisions require the following characteristics:

1. Geologic features indicative of high radon availability.
2. Occupied new houses with high radon levels in close proximity to undeveloped homesites.
3. Substructure types representative of standard construction.
4. A high annual rate of construction and sales so that test houses are likely to be occupied during the 1987-88 heating season.
5. A homebuilder/developer interested in participating in the project.

A study of 210 houses by Onondaga County Health Department (7) identified a band of bedrock with high radon levels, which included the following formations: Marcellus shale, Onondaga limestone, Manlius limestone, Camillus formation, and Syracuse formation. Within this band of bedrock, the distribution of radon levels was: 77% above 4 pCi/L, 22% above 20 pCi/L, and 1% above 100 pCi/L. The highest levels were over Onondaga limestone and Marcellus shale.

Based on this information, several housing subdivisions in Onondaga County were identified as possible candidates for this task, situated either on Onondaga limestone or Marcellus shale and where nearby houses had radon levels higher than 20 pCi/L. These sites were visited by a geologist and staff from the New York State Department of Health who collected information on depth of soil to bedrock, bedrock faults. fractures, joints, soil gas radon, soil and bedrock radium, and soil gas permeability. Homebuilders/developers of the subdivisions were also contacted to ascertain interest and information on the rate of construction. This narrowed the potential housing subdivisions to three. At two of these subdivisions, two control houses for each subdivision (four total) were monitored with charcoal canisters. All four houses had basement radon levels above 10 pCi/L. A fifth house that had previously been measured to have basement radon levels between 10 and 20 pCi/L was chosen as the control house in the third subdivision. These control houses are identified as ON-01 and ON-02 from the first subdivision; ON-04 and ON-05 from the second subdivision; and ON-03 from the third subdivision.

Houses ON-06, ON-07, ON-08, ON-10, ON-11, ON-12, and ON-13 were the first houses to be constructed to resist radon entry.

Among the mitigation techniques installed in these hosues were:

° Continous airtight polyethylene film installed over aggregate before slab is poured to foundation wall.

    - Plastic film tears, penetrations, or joints sealed with builder's tape.
    - Plastic film attached to top of footings with bituminous caulk.
    - Perimeter edge of slab tooled and filled with polyurethane caulk.

- Continuous layer of surface bonding cement installed around exterior foundation wall and footing.

- Course of termite blocks installed on top of foundation wall.

- Interior and/or exterior footing drains discharged to daylight or to a sump airtight to the basement and vented to the outside.

Provisions were made to actively vent the interior and/or exterior footing drains, if passive venting is not sufficient to keep radon levels below 4 pCi/L.

Preliminary integrated radon concentrations are available only for houses ON-06, ON-08, ON-09, and ON-10. House ON-09 has radon levels only slightly above EPA guidelines (5.5, 8.0, and 6.7 pCi/L in the basement, 4.4 pCi/L on the first floor, and 4.7 pCi/L on the second floor). The remaining houses monitored so far all have radon levels below the EPA guideline of 4 pCi/L.

CONCLUSIONS

Results from the demonstration of cost-effective techniques in 16 existing houses show: 1) surprisingly large radon reductions (up to 74%) using sealing alone. 2) expectedly large radon reductions (most were 90-95%) using sub-slab suction, 3) a significant radon reduction (86%) using outside wall depressurization in a relatively simple installation, 4) an outstanding radon reduction (98%) using basement pressurization, and 5) a wide range of radon-in-water reductions (85-99.5%) with the four different water treatment systems that were tested.

The assessment of previously installed techniques in 14 existing houses was an evaluation of the long-term effectiveness of sealing, heat recovery ventilation, and sub-slab depressurization. Complete sealing was deemed to be impractical because of the difficulty in finding all of the significant openings in the building sub-structures. Heat recovery ventilators did not achieve the radon reductions projected from calculating projections in the air exchange rate although the systems, were relatively maintenance free. The sub-slab depressurization systems, judged to provide the greatest potential for radon reduction, were observed to be failure prone due to problems originating from poor installation.

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TABLE 1. SUMMARY OF RESULTS FROM DEMONSTRATION OF TECHNIQUES IN EXISTING HOUSES

				INTEGRATED RADON CONCENTRATION (pCi/L)		
HOUSE NUMBER	STYLE	PHASE	MITIGATION TECHNIQUE	BEFORE	AFTER	PERCENT REDUCTION
AR-01	RAISED RANCH	1	SEALING ONLY	17.5	17.1	2
		2	SEALING PLUS OWD*	17.5	0.4	98
AR-04	SPLIT-LEVEL	1	SSD	22.8	13.2	42
		2	SSD PLUS IWD PLUS SEALING	22.8	2.2	90
AR-05	SPLIT-LEVEL	1	SSD	21.3	4.2	80
		2	SSD PLUS IWD	21.3	1.9	91
AR-09	SPLIT-LEVEL	1	SSD	22.5	1.5	93
		2	SSD PLUS IWD PLUS SEALING	22.5	0.4	98
		3	SEALING ONLY	22.5	9.9	56
AR-16	CAPE COD	1	SSD (INTERIOR FOOTING DRAIN)	15.5	0.8	95
		2	SEALING ONLY	15.5	5.7	63
		3	SSD PLUS SEALING	15.5	1.7	89
AR-17	CAPE COD	1	SSD	23.6	2.2	91
		2	BP	23.6	0.5	98
		3	SEALING ONLY	23.6	9.1	61
		4	SSD PLUS SEALING	23.6	1.6	93
		5	BP PLUS SEALING	23.6	0.5	98
AR-19	COLONIAL	1	SSD	30.4	29.1	4
AR-20	RANCH	1	SSD (INTERIOR FOOTING DRAIN)	35.7	2.3	94
		2	SEALING ONLY	35.7	9.3	74
		3	SSD PLUS SEALING	20.6	6.4	82
OP-01	COLONIAL	1	SSD (REGENERATIVE FAN, 4 SUC. PTS)	20.6	11.0	47
		2	SSD (CENTRIFUGAL FAN, 1 SUC. PT)	20.6	14.3	31
		3	OWD	20.6	2.8	86
OP-03	BI-LEVEL	1	CHARCOAL FILTER	37.3	24.8	24
		2	FILTER PLUS SSD PLUS SEALING	21.9	8.8	60
		3	FILTER PLUS SSD PLUS SEALING PLUS AERATION	21.9	3.0	86
OP-05	RANCH	1	SFD	232	44.2	81
		2	SFD PLUS OWD	232	8.5	96
		3	SFD PLUS OWD PLUS AERATION	160.3	1.0	99
OP-09	COLONIAL	1	SEALING (PARGE WALLS, SEAL CRACKS)	23.5	14.7	37
		2	SSD (REGENERATIVE FAN, 4 SUC. PTS)	23.5	3.4	86
OP-13	BI-LEVEL	1	SEALING PLUS EFDD	13.9	2.9	79
		2	SEALING PLUS SSD	13.9	9.1	35
OP-16	RAISED RANCH	1	SEALING PLUS PASSIVE OWD	55.4	40.1	28
		2	SEALING PLUS ACTIVE OWD	55.4	22.7	59
		3	SEALING PLUS ACTIVE OWD PLUS FOAMING	55.4	2.3	96
OP-17	BI-LEVEL	1	SEALING PLUS PASSIVE SSD	37.1	39.3	-6
		2	SEALING PLUS ACTIVE SSD	37.1	3.1	92

*Technique applied first is listed first.

BP = BASEMENT PRESSURIZATION,
EFDD = EXTERIOR FOOTING-DRAIN DEPRESSURIZATION,
IWD = INSIDE WALL DEPRESSURIZATION,
OWD = OUTSIDE WALL DEPRESSURIZATION,
SFD = SUB-FILM DEPRESSURIZATION,
SSD = SUB-SLAB DEPRESSURIZATION (ACTIVE).

TABLE 2. ASSESS PREVIOUSLY INSTALLED TECHNIQUES
SUMMARY OF SEALING RESULTS

HOUSE NUMBER	STYLE	(YR*)	MITIGATION TECHNIQUE	INTEGRATED RADON CONCENTRATION (pCi/L) BEFORE	AFTER	PERCENT REDUCTION
NM-26	SALT BOX	(84)	SEALING, AIR CIRCULATION ADJUSTMENT	6.7	4.1	39
		(SU87)	AS ABOVE	6.7	1.6	76
		(F87)	AS ABOVE	6.7	9.3	-39
NM-41	COLONIAL	(84)	SEALING	4.8	2.6	46
		(86)	AS ABOVE	4.8	2.6	46

TABLE 3. ASSESS PREVIOUSLY INSTALLED TECHNIQUES
SUMMARY OF HEAT-RECOVERY VENTILATION RESULTS

HOUSE NUMBER	STYLE	(YR*)	MITIGATION TECHNIQUE	INTEGRATED RADON CONCENTRATION (pCi/L) BEFORE	AFTER	PERCENT REDUCTION
NM-16	CONTEMPORARY	(84)	80 CFM** WHOLE HOUSE HRV on 1/2 TIME	2.4	2.4	0
		(88)	AS ABOVE	2.4	2.3	4
NM-19	VICTORIAN	(84)	150 CFM BASEMENT HRV ON 1/6 TIME	19.9	12.1	39
		(88)	AS ABOVE	19.9	19.3	3
NM-28	FARM HOUSE	(84)	150 CFM BASEMENT HRV ON FULL TIME	9.3	4.8	48
		(SU87)	AS ABOVE	9.3	2.5	73
		(F87)	AS ABOVE	9.3	5.1	45
		(W88)	AS ABOVE	9.3	6.5	30
NM-29	BI-LEVEL	(84)	150 CFM WHOLE HOUSE HRV ON 1/4 TIME	7.4	2.3	69
		(SU87)	HRV OFF	7.4	0.2	97
		(F87)	HRV ON 1/4 TIME	7.4	7.4	0
		(W88)	AS ABOVE	7.4	12.5	-69
NM-51	UNDERGROUND	(84)	DRAIN SEALING, 150 CFM WHOLE HOUSE HRV CONTROLLED BY RH	1.9	1.0	47
		(SU87)	AS ABOVE	1.9	0.9	53
		(F87)	AS ABOVE	1.9	1.9	0
		(W87)	AS ABOVE	1.9	2.1	-11
NM-56	COLONIAL	(84)	80 CFM BASEMENT HRV ON FULL TIME	4.0	1.9	53
		(SU87)	AS ABOVE	4.0	1.1	73
		(F87)	AS ABOVE	4.0	1.9	53
		(W87)	AS ABOVE	4.0	2.4	40

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*SU= Summer, F= Fall, W = Winter.

** 1 cfm = 0.00047 m^3/s

TABLE 4. ASSESS PREVIOUSLY INSTALLED TECHNIQUES
SUMMARY OF SUB-SLAB DEPRESSURIZATION RESULTS

					INTEGRATED RADON CONCENTRATION (pCi/L)		
HOUSE NUMBER	STYLE	PHASE	(YR)	MITIGATION TECHNIQUE	BEFORE	AFTER	PERCENT REDUCTION
NM-02	BI-LEVEL	1	(84)	SEALING, SSD WITH 20W AXIAL FAN	9.0	3.5	61
		1	(87)	AS ABOVE, LEAK IN VENT PIPE	9.0	7.7	14
		2	(88)	MORE SEALING, SSD WITH 20W CENTRIFUGAL FAN	9.0	1.4	84
NM-05	CONTEMPORARY	1	(84)	SEALING, SSD WITH 20W AXIAL FAN, VENT CRAWL SPACE WITH 20W AXIAL FAN	16.2	3.0	81
		1	(86)	AS ABOVE, SSD VENT BLOCKED WITH CONDENSATION WATER	16.2	23.0	-42
		2	(88)	MORE SEALING, SSD AND CRAWL SPACE VENTING WITH 40W CENTRIFUGAL FAN	16.2	5.4	67
NM-12	COLONIAL	1	(84)	SEALING, SSD WITH 20W AXIAL FAN, VENT CRAWL SPACE	18.3	2.9	84
		1	(86)	AS ABOVE, CRACKS IN SLAB	18.3	4.7	74
		2	(88)	MORE SEALING, SSD WITH 20W CENTRIFUGAL FAN, VENT CRAWL SPACE	18.3	1.8	90
NM-21	COLONIAL	1	(84)	SEALING, SSD WITH 30W AXIAL FAN	49.8	1.4	97
		1	(86)	AS ABOVE	49.8	2.9	94
		2	(88)	MORE SEALING, 30W AXIAL FAN REPLACED	49.8	0.2	100
NM-31	BI-LEVEL	1	(84)	TWO SSD SYSTEMS WITH TWO 20W AXIAL FANS	15.5	1.3	92
		2	(88)	TWO SSD SYSTEMS WITH TWO 20W CENTRIFUGAL FANS	15.5	1.3	92
NM-37	COLONIAL	1	(84)	SEALING, SSD WITH 20W AXIAL FANS	28.3	8.1	71
		1	(87)	AS ABOVE	28.3	11.3	60
		2	(88)	MORE SEALING, SSD WITH 20W CENTRIFUGAL FAN	28.3	2.7	90