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RESOLVING THE RADON PROBLEM IN CLINTON, NEW JERSEY, HOUSES

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Significantly elevated radon concentrations were found in several adjacent houses in Clinton, New Jersey. The United States Environmental Protection Agency screened 56 of the houses and selected 10 for demonstration of radon-reduction techniques. Each of the 10 houses received an intensive radon diagnostic evaluation before a house-specific radon reduction plan was developed. Depressurization effects caused by temperature differentials and the operation of mechanical equipment were quantified. Before and after radon reduction plans were implemented, radon concentrations were determined by charcoal canisters and continuous radon monitors. A variety of sealing and subslab depressurization techniques were applied to the 10 houses. Radon concentrations were reduced by over 95% in all 10 houses. The cost of applying radon reduction techniques ranged from $1500 to $8500 per house. House construction characteristics were described which contributed to the high cost of radon reduction. In summary, the 10-house radon reduction demonstration in Clinton, New Jersey was successful in showing homeowners with similar house types some effective ways of reducing radon concentrations.

INTRODUCTION

In March 1986, the New Jersey Department of Environmental Protection (DEP) reported to the United States Environmental Protection Agency (EPA) that significantly elevated radon concentrations had been measured in a single-family dwelling in Clinton, New Jersey. Within 24 hours, EPA's Air and Energy Engineering Research Laboratory personnel were in the house in Clinton where radon had been discovered. They were making measurements, diagnosing potential radon entry routes, and developing a radon-reduction strategy for the house. Because the radon concentrations observed in this house far exceeded any residential radon measurements previously made in New Jersey, the New Jersey DEP conducted a general radon survey involving all interested Clinton homeowners. Charcoal canisters were distributed to the homeowners; the radon concentrations measured in 103 houses are summarized in Table 1. Due to the alarmingly high radon concentrations observed in many of the Clinton houses, the New Jersey DEP requested EPA's assistance in developing methods to reduce radon concentrations in the houses.

In April 1986, screening visits were made in 56 homes in Clinton with the intent of selecting 10 homes where radon-reduction techniques could be demonstrated. A list of evaluation criteria based on a combination of factors relating to information that could be gleaned from the study and the relative environmental hazard to current homeowners was developed. Evaluation criteria used in selecting the 10 houses included in the radon-reduction project were: (1) the ability to identify and access the radon source in the house; (2) the ability to reduce radon concentrations with few potential complicating sources (e.g., fireplaces/chimneys); (3) elevated radon concentrations based on the prior New Jersey DEP survey; (4) house substructures; (5) homeowner cooperation; (6) worker access to the house; (7) smokers in the house; (8) young children in the house; and (9) the amount of time occupants spend in the house. Table 2 summarizes the housing styles that characterized the Clin-

Table 1. Clinton radon levels.

Concentration Bq/m^3*	No. of Houses	% of Sample
>76,000	2	1.9
38,000–76,000	3	2.9
19,000–38,000	13	12.6
9500–19,000	17	16.5
4700–9500	17	16.5
2400–4700	12	11.7
1200–2400	12	11.7
600–1200	14	13.6
300–600	5	4.9
150–300	6	5.8
<150	2	1.9
	103	

*1 Bq/m^3 = 0.027 pCi/L

ton radon screening area and identifies the different house types that were ultimately selected to be part of the radon-reduction demonstration. Table 3 shows by floor plan the distribution of the houses selected for the demonstration study.

RADON-REDUCTION TECHNIQUES

To provide maximum protection to the homeowners whose houses had been selected and to workers in the houses, all of the houses were opened to the maximum extent possible, and fans were used in the houses to produce good ventilation. This was possible due to spring and summer outdoor temperatures, which caused minimum discomfort to the homeowner. Each of the 10 houses received a detailed radon diagnostic evaluation before a house-specific radon-reduction plan was developed. These evaluations included assessments of aggregate beneath the concrete slab floors, the presence of drain tiles surrounding the interior and exterior of the houses, cracks and penetrations in the floors and subgrade walls, and the presence of large thermal bypasses that could exaggerate cold weather basement depressurization.

Basement depressurization effects

In the majority of houses, differential air pressure between basement air and outside air was measured. Temperature-driven stack effects and mechanical equipment effects were isolated, and the induced pressure differences were measured. Pressure difference measurements for two houses are listed in Table 4 (Osborne et al. 1987).

House-specific radon-reduction techniques applied

The four split-level houses included in the study were each a combination of block—wall basement and slab-on-grade substructures with a common wall. The slab-on-grade section of these houses had forced-warm-air heating ducts beneath the slab. These ducts were not tightly sealed at the joints, and some of the ducts had clearly settled in the soil, leaving a large gap between the register and the duct. A smoke pencil easily demonstrated the potential entry of soil gases from around the outside of the ducts and into the house via the heating registers.

The major solution to the radon problem for the slab-on-grade portion of the split-level houses was to seal the slab just below the registers with concrete and route new heating ducts into the attic. A plastic pipe with an in-line fan was then connected to the

Table 2. Clinton housing styles.

House Type	No.	No. Selected	No. Over 38,000 Bq/m^{3}*
Bi-level	56	3	0
Split=Level	27	4	3
Two=Story (full basement)	9	1	1
Two=Story (slab)	5	1	1
Miscellaneous (different builder)	30	1	1
	127**	10	6

*1 Bq/m^3 = 0.027 pCi/L
**Of the 127 houses in the screening area only 103 participated in the New Jersey survey of radon levels and only 56 of these houses were included in the screening effort.

abandoned heating ducts, creating suction in the ducts and surrounding sub-slab area. In addition, two of the four split-level houses also had their floor/wall perimeter cracks sealed.

The basements of these houses were found to have several inches of crushed stone beneath the slab and both interior and exterior, below-slab drain tiles. Subslab suction was the radon-reduction technique applied. This was achieved by inserting plastic pipe with in-line fans through openings created in the concrete slab in two houses and through existing sump holes that were later sealed in the other two houses. All of these subslab systems were vented to the outside through the roof. Major accessible cracks and penetrations in the floors and walls were also sealed (U.S. EPA 1986a).

The three bilevel houses, often referred to as split foyers or raised ranches, had completely finished living space on the lower level. The slab floor of the lower level was typically 0 to 100 cm (0 to 3 ft.) below grade. Two different approaches were tried for the three houses. In the first house, subslab suction

Table 3. Distribution of houses selected for the demonstration.

Construction Design (substructure)	House No.
Split-Level (combination slab-on-grade and block basement)	C8A C1A C4A C5A
Bilevel (slab-below-grade)	C9B C2B C6B
Two-Story (slab-on-grade and block basement)	C3C C10D
Other (combination slab-on-grade and dirt crawl space)	C7E

Table 4. Pressure difference measurements for two houses.

House C5A	Pressure Change
House closed; outside temp. = 17°C(62°F), inside temp. = 19°C (67°F)	0 Pa
Dryer + bath fan on	1 Pa
Furnace + dryer + bath fan on	2 Pa
Furnace + dryer + bath fan on inside temp. = 27°C (80°F)	3-4 Pa
House C6B	
House closed; outside temp. = 17°C (62°F), inside temp. = 18°C (64°F)	0 Pa
Furnace on, inside temp. = 34°C (93°F)	4 Pa
Furnace on + attic hatch opened inside temp. = 34°C (93°F)	5-6 Pa

Note: In general it was found that:

- Dryers and bathroom fans resulted in a 1 Pa or less negative pressure on a basement.
- Furnaces in the 0.1055 x 0.1266 GJ (100,000 to 120,000 Btu/hr) range put 2-3 Pa negative pressure on a basement.
- Differential temperatures of 11 to 16°C (20 to 30°F) resulted in 1-3 Pa negative pressure on a basement.
- To reduce a negative pressure of 3-4 Pa to 0 Pa requires 0.65 0.93 m^2 (7-10 ft^2) of window area to be opened to the outdoors.

was attempted with little success due to the lack of sufficient aggregate beneath the slab. As a second phase of radon-reduction, the floor/wall perimeter crack was enlarged and a backer-rod spacer placed in the crack before a tight polyurethane seal was used to cover the crack. This also left a channel beneath the backer rod around the perimeter of the house that was connected to a plastic pipe with an in-line fan. This technique permitted perimeter suction on the floor/wall crack, which was exhausted through the roof.

The other two bilevel houses were subjected to a different radon-reduction approach because of the difficult job encountered in the first bilevel when trying to enlarge the floor/wall crack. These two houses had their floor/wall cracks sealed, but the primary radon-reduction technique was applied from the exterior of the houses. Along one side of the two houses, a trench was dug to the level of the first hollow core foundation block. Three different penetrations were made in blocks along this wall. Two penetrations, made at the corners of the side wall, entered the void space in the foundation blocks on the front and rear walls. These penetrations permitted block-wall suction on the front, side, and rear walls. In the center of the side wall, a penetration was made through the block and into the loose backfill soil near the floor/wall crack beneath the house floor slab. By tying all three penetrations along the side wall into a common vertical plastic vent pipe equipped with an in-line fan, suction could be applied simultaneously to three walls and the subslab.

The two-story basement house had a much larger basement space than the split-level houses, requiring two subslab suction points at opposite ends of the basement. The two suction systems were not ducted together; each had its own fan. Basic sealing of cracks and floor and wall penetrations was performed.

The two-story slab-on-grade house was the house in Clinton where radon was first discovered. This house presented a special problem because it had subslab heating ducts similar to the slab portion of the split-level houses. Unfortunately, since the house was two-story, new heating ducts had to be routed through the available space between floor joists in the ceiling of the first floor. This was both difficult and expensive, since it required resurfacing some of the walls and ceiling. Again, the original heating ducts were used for subslab suction, similar to the split-level houses. In addition, due to the high radon levels in this house, a perimeter floor-crack suction system (similar to the first bilevel house) was used.

A different type of split-level house built by another contractor was the tenth house to receive radon-reduction treatment. This house was a combination slab-on-grade and crawl space with a common wall. The slab-on-grade portion of the house received an exterior wall suction treatment similar to the previous two bilevel houses; however, only one penetration point was used to apply suction to one side wall and the rear wall. The open soil in the crawl space of this house was covered by a fiber mat. On top of the mat, a network of perforated PVC pipe was completely covered by 10 mil (254 μm) polyethylene plastic. The plastic was held in place and sealed at the edges by wooden furring strips. The PVC pipe was connected to an in-line fan and vented to the outdoors.

Cost of radon-reduction

Table 5 (U.S. EPA 1987) shows the cost to install radon-reduction techniques in each house. The original goal of spending, on average, only $2500 per house (based on earlier radon-reduction efforts in Boyertown, Pennsylvania) was exceeded primarily because of the high cost associated with applying radon-reduction techniques to house C3C. This house had essentially no subslab aggregate, and the soil beneath the slab had subsided to 2.5-10 cm (1-4 in.) below the slab. Depressurizing the soil was complicated by the existence of this air space.

Poor subslab aggregate was also a contributing factor in raising the cost of radon-reduction in other houses. In house C6B little aggregate was found, and airflow from the central hole punched in the slab was only partially successful. In addition, house C6B had an incomplete foundation in a small crawl space accessed through the back of a closet. Radon concentrations in the crawl space were found to be elevated, and repair of the foundation was necessary.

A major cause for the elevated average radon-reduction cost was the use of a novel method of perimeter suction in houses C3C and C6B (the second-highest-cost house). This technique required the labor-intensive work of cleaning out the perimeter crack, filling it with backer rod (a compressible plastic foam), sealing with pourable polyurethane, and ventilating the perimeter wall. The cost of this method was excessive; therefore, other houses, specifically C9B and C2B, had their radon levels reduced by another method.

The cost of radon-reduction per house dropped as the project progressed. Houses C1A, C3C, and C6B were the first three houses where radon-reduction techniques were applied. All subsequent houses showed a lower cost for radon-reduction than did these three. The radon-reduction plan employed in house C1A for $3300 was virtually repeated in houses C8A, C5A, and 4A at reductions of $500 or more per house.

House C10D was originally projected to be one of the least costly radon-reduction demonstrations. Simple sump hole suction and good sealing of openings and cracks in the basement slab were recommended. When the work was completed, monitoring indicated that the radon concentration was still excessive. Measurement of pressure differences between room air and subslab air in the basement showed that suction did not extend to the far end of the basement. A second subslab suction system was installed to achieve good suction across the entire slab. When monitoring showed that radon levels in the basement had doubled after installation of the second fan, an intensive diagnostic examination of the basement revealed that: (1) a tiny fan leak was allowing radon-rich, subslab air into the basement, and (2) the fan exhaust on the outside of the house had been placed at ground level, allowing radon-rich air to leak back into the basement. When these two problems were remedied, basement air radon was significantly reduced.

PRE- AND POST-RADON-REDUCTION MEASUREMENTS

Before and after the radon-reduction plans were implemented, radon concentrations were determined by charcoal canisters and continuous radon monitors (Brennan and Osborne 1987). These measurements were made in the lowest livable area of the house and according to published EPA guidelines (U.S. EPA 1986b). The early charcoal canister data were obtained by the New Jersey DEP before the warmer spring weather reduced the cold weather stack effect. Unfortunately, the pre-radon-reduction continuous monitor data were collected during warmer weather when radon concentrations were lower. Therefore, the pre- and post-radon-reduction data reported in Table 6 are only charcoal canister data. These are the only data

Table 5. Radon-reduction installation cost (1986 U.S. dollars).

House Code	Radon Reduction Methods	Labor*	Materials	Heating System**	Electrical	Total
C1A	o Sump-hole suction o Sealed sub-slab duct suction o Sealed perimeter crack o Supplied makeup air to furnace	2,460	200	490	150	3,300
C4A	o Sealed perimeter crack o Sump hole suction o Sealed sub-slab duct suction o Supplied makeup air to furnace	1,560	300	490	120	2,470
C8A	o Interior sub-slab suction o Sealed perimeter crack o Sealed sub-slab duct suction	1,150	150	490	140	1,930
C5A	o Sealed perimeter crack o Supplied makeup air to furnace o Interior sub-slab suction	1,700	400	490	150	2,740
C9B	o Exterior sub-slab suction o Sealed perimeter crack	1,040	400	----	400	1,840
C2B	o Sealed perimeter crack o Exterior sub-slab suction	1,250	400	---	220	1,870
C6B	o Perimeter suction o Sub-slab suction	3,000	1,000	170	360	4,530
C3C	o Perimeter suction o Interior sub-slab suction o Sealed sub-slab duct suction o Supplied makeup air to furnace	6,650	400	1,310	140	8,500
C10D	o Sump hole suction o Interior sub-slab suction	2,860	150	---	170	3,180
C7E	o Interior sub-slab suction o Ventilation and isolation of crawl space	900	400	---	200	1,500
		22,570	3,800	3,440	2,050	31,860

* This is only installation cost (diagnostic costs not included).

** Rerouting ducts and addition of dilution air.

Table 6. Clinton radon reduction results.

House Code	Concentration, Bq/m^3* 4/86	12/86	Reduction, %	House Type
C1A	83,000	150	99.8	
C4A	56,000	150	99.7	split-level (block basement/slab)
C8A	29,000	110	99.6	
C5A	24,000	185	99.2	
C9B	15,000	590	96.1	
C2B	26,000	220	99.2	bilevel (slab partly below grade)
C6B	37,000	440	98.8	
C3C	44,000	220	99.5	Two story (slab)
C10D	50,000	300	99.4	Two story (block basement + crawl)
C7E	16,000	260	98.4	split level (crawl space/slab)

*1 Bq/m^3 = 0.027 pCi/L

available that compare cold weather concentrations before and after radon-reduction.

DISCUSSION

The 10-house radon-reduction demonstration in Clinton, New Jersey was successful in showing homeowners with similar house types some effective ways of reducing radon concentrations. During the 10-house study in Clinton, five homeowner meetings were held to explain the techniques used to reduce radon concentrations and to elaborate on which approaches were working and which were not as effective or cost effective. To assist homeowners with different floor plans, 20 house-specific radon-reduction plans were developed for other houses in the Clinton area. These plans, along with the plans used in the 10-house project, were made available at no cost to Clinton residents.

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