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FOLLOW-UP ALPHA-TRACK MONITORING IN 40 EASTERN PENNSYLVANIA HOUSES WITH INDOOR RADON REDUCTION SYSTEMS (WINTER 1988-89)

by

A. G. Scott
A. Robertson

AMERICAN ATCON INC.
1105 North Market Street
P.O. Box 1347
Wilmington, DE 19899

EPA Purchase Orders 9D0645NFFX and 9D1937NASA

EPA Project Officer: D. B. Henschel

Air and Energy Engineering Research Laboratory
Office of Environmental Engineering and Technology Division
U.S. Environmental Protection Agency
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16. ABSTRACT The report gives results of 4-month-long alpha-track detector (ATD) measurements of indoor radon concentrations, completed during the winter of 1988-89 in 38 of 40 houses where radon reduction techniques had been installed 2-4 years previously during an earlier EPA project. The techniques, installed between June 1985 and June 1987, generally involved some form of active soil ventilation: three were air-to-air heat exchangers, and two involved carbon filters to remove radon from well water. The purpose of these measurements was to determine if the radon reduction performance of the systems had degraded compared to previous wintertime radon measurements. Comparison of the current ATD results with those from 1986-87 and 1987-88 indicates that, in the 34 houses where the system was in continuous operation during this measurement period, the radon levels generally compared well with those measured during the previous years. In only two houses did significant, unexplainable increases occur. Two soil ventilation fans failed during the previous year: 5 out of 34 fans have failed to date. One air-to-air heat exchanger has needed repair. The one water treatment unit designed specifically for radon removal is giving 97% removal, whereas the other has degraded to 65%.

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Radon	Ventilation	Stationary Sources	07B	13A
Alpha Particles	Wells	Indoor Air	20H	08I
Monitors	Water	Soil Gas	14G	
Measurement	Fluid Filters			13K
Residential Buildings			13M	

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ABSTRACT

In an earlier study (Reference 1), developmental indoor radon reduction techniques were installed in 40 houses in the Reading Prong region of eastern Pennsylvania. These systems were installed, modified and tested over the period 1985 to 1987. Active soil ventilation was installed in 36 of the houses; 3 had heat recovery ventilators (air-to-air heat exchangers); and 2 installations included carbon adsorption to remove radon from well water. A follow-up study of post-mitigation radon concentrations in these houses was conducted during the winter of 1987-88 (Reference 3), for the purpose of assessing long-term system performance after up to 2 or more years of operation. The present report provides the results of further follow-up radon concentration measurements made during the 1988-89 heating season, to determine how system performance was being maintained after an additional year of operation.

The measurements were made using alpha-track detectors placed in the basement and living area of each house over the 4-month period December 1988 to April 1989. The mitigation systems are most challenged at this time, since cold weather increases the driving forces moving soil gas into the house. Detectors were exposed in pairs at both measurement locations, in order to indicate outliers. In addition to these two pair of 4-month detectors, another pair of detectors (to be exposed for one year) was placed in the main living area of each house, to provide a measurement of the annual average exposure of the occupants; these detectors will be collected in December 1989. In addition to exposing the detectors in pairs, other QA/QC measures included submission of blanks (unexposed detectors), and of spikes (detectors exposed to known radon concentrations in a test chamber) to the Terradex laboratory. The blanks indicated a zero correction by -0.26 pCi/ℓ. Based upon the results from the spikes, the reported radon concentrations were corrected by multiplying by a factor of 1.21. Based upon comparison of the detector pairs, two outliers were found among the detectors used in this project; they did not impact upon the validity of post-mitigation results, because they were observed in houses where the mitigation system did not operate for part of the measurement period, so that valid post-mitigation data from these two houses was not possible anyway.

In the 34 houses where the radon reduction system was in continuous operation during the entire 4-month measurement period, the radon levels measured compared well with those measured during a similar period in the 1986-87 and the 1987-88 heating seasons (or any differences appeared explicable) in all but 2 of the houses. In those two houses, concentrations in the basement had increased by 220 to 360% for no apparent reason. But, overall, there does not appear to be any general degradation in system performance.

In 3 of the 40 houses, the fans on the active soil ventilation systems did not operate during the entire measurement period. In two cases, the fans failed during the measurement period; in the third case, the fan inadvertently became unplugged. In one of the houses having a HRV, the motor driving the HRV fans and rotary heat exchange wheel failed. Two of the 40 houses have discontinued participation in the project.

Of the 34 houses having operating soil ventilation fans, two fans failed during this measurement period, as indicated above. As reported in Reference 3, three other fans had failed before or during the 1987-88 measurement period, but have since been replaced. The failure of the HRV motor is the first reported failure among the 3 HRV installations under this project.

At the 2 houses with charcoal water treatment units, the one unit not specifically designed for radon-in-water showed a continued decrease in radon removal efficiency, continuing a trend observed in Reference 1. But in the second house, having a unit marketed specifically for radon removal, radon removal efficiency has been maintained.

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SECTION 1.

INTRODUCTION

A total of 40 homes in communities on the Reading Prong in eastern Pennsylvania were chosen for demonstration of indoor radon reduction techniques under EPA Contract 68-02-4203. The primary mitigation measures in all but 4 of these houses involved active soil ventilation; of the other 4 houses, 3 houses received air-to-air heat exchangers, and 1 house received just a radon-in-water removal unit. The systems were installed and tested over the period of June 1985 to June 1987. This project was reported in detail in EPA-600/8-88-002 (Reference 1).

Follow-up alpha-track detector (ATD) radon concentration measurements were made in 38 of these 40 demonstration homes over a 3-month period during the winter of 1987-88, in order to assess long-term system performance after up to 2 or more years of operation. The results of these 1987-88 ATD measurements are presented in a previous report (Reference 3). Only 38 of the original houses were measured because one of the houses had been removed from the original site, and the owner of a second house had discontinued participation in the project.

The present report provides the results of further follow-up ATD radon measurements in the remaining 38 demonstration homes over a 4-month period during the 1988-89 heating season, to determine system performance after an additional year of operation. These measurements were conducted under EPA Purchase Orders 9D0645NFFX and 9D1937NASA.

SECTION 2

OBJECTIVES AND APPROACH

The primary goal of the program was to measure the long-term post-mitigation average radon concentration in the demonstration houses with a total measurement error of less than 80 Bq/m^3 (2 pCi/ℓ). To that end, average radon concentrations were measured with Terradex 'Track-Etch' detectors exposed for approximately 4 months during the heating season. The forces that urge radon from the soil into the home are highest during this time, and therefore present the greatest challenge to radon mitigation systems. The original pre-mitigation results obtained by the Pennsylvania Department of Environmental Resources (DER) and the initial post-mitigation measurements were both measured during the winter period. Additional detectors were left in the main living area of each house to obtain a measurement of the annual average exposure when collected in December 1989. Another goal of the program was to observe the durability of the mitigation system hardware, in particular, the continued operation of the mitigation fans.

Quality assurance and control measures were instituted to ensure that the acquired data were of acceptable quality. In particular, unexposed Track-Etch detectors were included as blanks in each set of detectors sent to Terradex for analysis. In addition, a number of detectors were exposed to known concentrations in the radon chamber operated by the U.S. Department of Energy Environmental Measurements Laboratory (EML) in New York. They were sent "blind" for processing by Terradex as a check on both the validity of the manufacturer's calibration and the relative standard deviation of the group. A "zero correction" equivalent to the mean reported concentration of the blanks was subtracted from each ATD result reported by Terradex. A "gain correction" -- defined as the ratio of the known EML exposure to the zero-corrected average of the reported Terradex results on the spiked samples -- was used as a multiplier to further correct the reported concentrations.

As an additional QA/QC measure, detectors were exposed in groups of two at each measurement location to reduce measurement uncertainties and facilitate the identification of outliers. Outliers would be determined when the two detectors at a given location differed from one another by an amount greater than the relative standard deviation. The relative standard deviation for the alpha-track detectors -- which varies depending upon the absolute value of the radon concentration -- is calculated from the extensive prior testing where ATDs were exposed in sets of three (References 1 and 3).

SECTION 3.

PROCEDURES

The demonstration houses were visited during the period of December 12-16, 1988 to install Terradex "Type SF" Track-Etch detectors in accordance with the guidance given in the EPA Measurements Protocol (Reference 2). Typically, detectors were placed in both the main living area and in the basement, hung together in groups of two from an interior wall or ceiling in the living area and a central joist in the basement. A second group of two was hung in each living area for retrieval after one year, in December 1989. Each detector was marked with the installation date and the house identification code. That information, plus the detector numbers and their locations were recorded in a Track-Etch Record Book kept specifically for that purpose. During this visit all soil ventilation fans, and the three air-to-air heat exchangers, were checked and found to be operational.

The houses were visited 4 months later, during April 4-7, 1989, to remove the detectors. The homeowners were interviewed to discover any events that might affect the system performance. A retrieval rate of 100% was achieved and the removal dates logged in the Track-Etch Record Book and written on the detector. Retrieved detectors were placed in pairs into the manufacturer's aluminized-mylar envelopes, which were then sealed by folding and taping in a low-radon atmosphere.

Six unexposed blanks were marked with fictitious house codes, recorded and sealed for "blind" shipment with the house-exposed detectors. Also shipped were eleven similarly-disguised detectors exposed in the EML Radon Chamber: ten exposed to 737 pCi.d/ℓ and one returned unexposed for QA/QC purposes.

On May 19, 1989 -- after waiting to receive the spiked detectors from EML, with the intent to submit the entire batch of detectors to the Terradex lab at the same time -- the house-exposed detectors and the blanks were sent to the manufacturer's laboratory for analysis. The spiked detectors were not received from EML until June 7, because they had been mis-directed in the mail and returned to EML. The spiked detectors were dispatched to Terradex on the following day. Results for all detectors were received from Terradex by June 29, 1989.

For the two houses having water treatment units, water samples were drawn just before and just after the charcoal unit, according to procedures defined by the Pennsylvania DER. These water samples, obtained when the ATDs were deployed in December, were submitted to the DER laboratory for analysis.

SECTION 4.

QA/QC RESULTS

The results from the QA/QC blanks and chamber-exposed detectors are listed in Table 1. The seven blanks show a mean exposure of 29.9 pCi.d/ℓ for a ficticious 116-day exposure period; these blanks thus indicate a need for a zero correction of -0.26 pCi/ℓ (-10 Bq/m^3), i.e., subtraction of 0.26 pCi/ℓ from the individual reported concentrations.

As shown in Table 1, the detectors exposed at EML had known exposures which were 15.5% greater on average than the zero-corrected means of the results reported by Terradex for these spiked detectors. Thus, a gain correction was applied to all of the zero-corrected Terradex results from the house-exposed detectors. The gain correction of 1.21 was calculated, as the ratio of known EML exposure/zero-corrected average Terradex result.

Utilizing the above results, the corrected average results presented in this report were calculated from the average of the reported Terradex results using the equation:

Corrected value (pCi/ℓ) = 1.21 x (Reported value minus 0.26 pCi/ℓ).

This approach is viewed as a first-order correction to the manufacturer's calibration. Since the gain correction of 1.21 was determined based upon a single chamber exposure level (736.6 pCi.day/ℓ), it is not known for certain that this correction is in fact linear. That is, the gain correction might actually be slightly different at different exposure levels. However, it was not practical within the scope of this project to perform a sufficient number of spikes at a sufficient number of exposure levels to accurately define non-linearities in the gain-correction-vs.-exposure-level relationship (second-order and higher effects). Accordingly, the selected exposure level of 736.6 pCi.day/ℓ for the spiked detectors was selected to be within the "typical" range expected for the detectors exposed in the houses (i.e., the range excluding high readings due to fan failures); this level was toward the upper end of this typical range, so that more of the corrections would reflect interpolation to lower exposure levels rather than extrapolation to higher exposure levels.

Two sets of the detectors exposed in groups of two had results which differed from each other by an amount greater than the relative standard deviation, indicating that at least one of the results in each set must be an outlier. In the basement of House 7, the two detectors differed by over 50% (68.0 and 102.6 pCi/ℓ); in the living area of House 31, the measurements varied by over 30% (66.1 and 88.4 pCi/ℓ). It was not possible to definitely identify which of the two results in each case was the outlier. Since the fan had failed in each of these houses part way through the monitoring period, it was not even possible to obtain a clue by comparing these results with previous ATD measurements with the mitigation system operating. However, the question of which one from each pair was the outlier was of no real importance, since neither result was characteristic of an operational mitigation system.

SECTION 5.

MONITORING RESULTS

The reported results for the monitors placed in the demonstration homes are listed in Tables 2A and 3A. The average radon concentration is calculated from the mean reported result for the two monitors by first subtracting 0.26 pCi/ℓ (the zero correction), and then multiplying the result by the gain correction of 1.21. In Tables 2B and 3B, the mean radon concentrations for the previous heating seasons are also shown for comparison.

5.1 Houses With Fans Off During Part of Monitoring Period

Tables 2A and 2B show those homes in which the system did not operate for at least part of the monitoring period. Since system operation was interrupted during the monitoring period in these homes, the 1989 ATD results do not give a fair indication of system performance, and are presented separately for that reason. For completeness, Tables 2A and 2B include the two houses (Houses 1 and 11) that are no longer in the program.

In House 7, where the sub-slab + block wall suction fan failed during the monitoring period, the measured results were 103.1 pCi/ℓ in the basement and 24.2 pCi/ℓ upstairs. These contrast with the results of 4.9 and 3.8 pCi/ℓ achieved in 1988, and 4.1 and 2.8 pCi/ℓ in 1987, when the fan operated throughout the monitoring periods. The fan had been temporarily uplugged during some plumbing work some time after Christmas (i.e., after perhaps 30% of the monitoring period). All attempts to restart the fan after it was plugged back in met with failure. The owner was given assistance to get the fan repaired under warranty.

In House 14, with a block wall suction system, the 1989 averages of 10.8 pCi/ℓ in the basement and 8.0 pCi/ℓ upstairs represent a partial return to pre-mitigation status (36 pCi/ℓ in the basement), and contrast with previous results in 1986, 1987 and 1988 when they were approximately 1 pCi/ℓ. This is consistent with the owner's report that the fan was inadvertently unplugged for an unknown period, as a result of the plug having fallen out of the electrical outlet.

At House 17, radon averages of 8.5 pCi/ℓ in the basement and 4.9 pCi/ℓ in the living area are comparable to previous results, even though there was a period of 15 days during which the heat recovery ventilator was not operating. Since prior data suggest that the HRV was only achieving a limited radon reduction, it is not surprising that failure of the unit during 13% of this monitoring period did not notably affect results. The owner felt that the fan shaft had been bent during adjustments to the HRV, and that this had led to deterioration and eventual seizure of the bearings in the motor which drives both the intake and exhaust fans, and the rotary heat exchange wheel, in this HRV design. The motor, complete with shaft and bearings, was replaced by the vendor, and the system returned to normal operation, in 15 days during this measurement period.

In House 31, the sub-slab suction fan failed in mid-January 1989 (i.e., the system was off for about 70% of the monitoring period). The radon results from this house were 252.7 pCi/ℓ in the basement and 93.3 pCi/ℓ in the living area. These levels reflect a substantial return towards the pre-mitigation average of 485 pCi/ℓ in the basement, and contrast sharply with post-mitigation averages of 2.8 and 8.3 pCi/ℓ in 1988, and 1.8 and 5.7 pCi/ℓ in 1987. The owner was given assistance to have the fan repaired under warranty.

In the houses where the sub-slab suction fans were off for a known, significant portion of the 1987-88 or 1988-89 measurement periods, it is of interest to compare the observed radon concentrations with the originally-measured pre-mitigation values. This comparison would suggest to what extent the radon source term might be being reduced by the operation of the soil ventilation system. That is, if the system fan has been off for, say, 70% of the measurement period, one can calculate what the measured concentration should be if the radon level were being maintained at the previously-measured post-mitigation value during the 30% of the time that the fan is on, and if the level quickly returned to its original pre-mitigation value as soon as the fan went off. If the observed radon level is significantly lower than this calculated value, this result might suggest that the radon is delayed in recovering to its original pre-mitigation level; i.e., that the soil underlying the house is being depleted of radon by the system.

Using this approach, the levels in the basement of House 2 during the 1987-88 measurement period (when the fan was off for 12% of the period) should have been in the vicinity of 50 pCi/ℓ, given the original pre-mitigation value of 413 pCi/ℓ and the post-mitigation value of 3 to 5 pCi/ℓ. By comparison, the value actually measured in the basement during that period was only 5 pCi/ℓ, suggesting essentially no recovery of the sub-slab radon during the approximately 2 weeks that the fan was off. In House 7, where the fan was off during about 70% of the 1988-89 period (and where the original pre-mitigation value was 402 pCi/ℓ), a calculated level of about 280 pCi/ℓ compares with a measured value of 103 pCi/ℓ, suggesting some delay in radon recovery over the approximately 3-month fan-off period. In House 31, where the system was off during 70% of the 1988-89 period, a calculated level of about 340 pCi/ℓ compares with an actually-measured value of 253 pCi/ℓ, again suggesting some delay in recovery, but less of a delay than is apparent in Houses 2 and 7. And in House 15, where the system was off for most of the 1987-88 period, a calculated value of about 18 pCi/ℓ compares with a measured value of 20 pCi/ℓ, suggesting little delay in recovery, within the sensitivity of this measurement.

It is emphasized that these ATD results can give only a rough indication of any delays in radon recovery. The comparisons in the preceding paragraph can be confounded by, e.g., natural variations in source term and radon-entry driving forces from winter to winter, and by uncertainties in the actual pre-mitigation levels (which, for Houses 7, 15 and 31, were determined by several-day Pylon measurements rather than by 3-month ATD measurements). Better measurements of recovery delays could be made through continuous radon measurements after a system has been turned off. However, these results above do give an initial indication that there can be some delay in radon recovery after sub-slab ventilation systems are turned off, but that this delay can vary from house to house; sometimes there is little delay.

5.2 Houses With Fans On Throughout Monitoring

Tables 3A and 3B show the results for those houses where the soil ventilation fan operated for the entire monitoring period, thus providing a fair measure of the mitigation system performance.

An analysis of the data in Table 3B indicates that the mean heating season radon concentration measured in 1989 is similar to that measured last year for almost all homes, indicating no overall degradation in system performance. Of the 34 houses in that table, 16 of them have 1989 ATD results, both in the basement and upstairs, which vary from the 1988 results by less than 1 pCi/ℓ; in 24 of the houses, no one result varies by more than 2 pCi/ℓ from 1988. Considering the variability of radon levels in houses, and the accuracy of the measurement method, this agreement suggests no degradation within our ability to measure. Of the 24 houses in Table 3B which changed by less than 2 pCi/ℓ, the majority (58%) decreased in radon level both in the basement and upstairs; 71% decreased in the basement. (The fact that such a large percentage decreased in concentration could be partially due to the fact that, in 1989, the measurement period extended to early April, thus encompassing an additional 2 weeks of possibly mild weather compared to the 1988 period, which extended only to late March. Also, the 1988/89 winter was reported by the homeowners to have been relatively mild.)

Of the 10 other houses, where either the upstairs or basement levels changed by 2 pCi/ℓ or more: in 3 houses (Houses 4, 15 and 39), levels dropped dramatically in 1989 because the mitigation system had been off for part or all of the 1988 measurement period; in 2 other houses (Houses 10 and 19), levels decreased by about 5 pCi/ℓ for unknown reasons, reflecting the variability of the system and the house dynamics; in 3 other houses (Houses 2, 9 and 22), levels increased by 2.0 to 4.2 pCi/ℓ (an increase of 25 to 32%), either due to system/house dynamics variability, or perhaps due to some limited degradation; and in the final 2 houses (Houses 33 and 40), there was a significant increase in radon levels in the basements (by 220% in House 33, by 360% in House 40), sufficiently large to suggest that some degradation might have occurred.

Of greatest concern are Houses 33 and 40, with the large, unexplained increases in the basement which possibly suggest some degradation. In both these houses, radon upstairs did not increase nearly so dramatically (in fact, in House 33, the upstairs concentration went down). House 33 was a small basement house with poured concrete foundation walls and no adjoining living wing. Suction is drawn by a Kanalflakt T2 fan on a concrete-lined, concrete-bottom sump pit having no drain tiles; holes were drilled through the concrete walls of the pit to provide access to the sub-slab. While communication under the slab has not yet been measured, diagnostic smoke stick testing after installation of the system had suggested that the distribution of the suction under the slab was ambiguous. Thus, one possible explanation for the observed increase is that the system might have been marginal to begin with, and something happened prior to or during this particular measurement period to reduce system effectiveness, increasing radon from 3.5 pCi/ℓ in 1988 to 11.2 pCi/ℓ in 1989. House 40 was a very large basement house with poured concrete walls, having multiple slab pours and extremely poor sub-slab communication. Twenty sub-slab suction pipes penetrate the slab and connect to a single Kanalflakt T2 fan; most of the 20 pipes have soil gas flows of less than 1 cfm (0.5 L/s). Although the system has many suction pipes, it may be marginal due to the very poor communication, and this could be an explanation for the increase in basement concentrations from 1.9 pCi/ℓ in 1988 to 8.8 pCi/ℓ in 1989.

In Houses 2, 9, and 22 -- where 1989 ATD results increased by 2.0 pCi/ℓ or more on one or both levels in comparison with 1988 -- no clear reason for the increases is apparent, and they could reflect the normal combined variability of the mitigation system, the house dynamics, and the measurement accuracy. Houses 2 and 9 are the only two remaining study houses having baseboard duct systems operating to pressurize the block walls and the sub-slab; that both of these houses should have increased by a notable amount when the majority of houses decreased, might be a commentary on the variability or durability the baseboard pressurization approach. In House 2, the increases in radon concentration from 1987 to 1988 to 1989, shown in Table 3B, suggest a consistent trend, possibly a limited continuing degradation in system performance. In House 9, there is not a trend over the 3 years; levels in 1987 were higher than in 1988 and not substantially lower than in 1989, so that the 3 years seem to define a range within which the system normally varies. Both House 2 and House 9 had dramatically-elevated pre-mitigation concentrations, so that a small degradation or a small variation in weather patterns could potentially have a very noticeable effect on indoor radon.

In Houses 4 and 15, where 1988 results were high due to failure of the soil suction fans, 1989 concentrations have returned to original post-mitigation levels following repairs, as shown in Table 3B. In House 39, where the sub-slab suction fan was turned off at times during the 1988 monitoring period, we note a considerable decrease for 1989 -- to 7.5 pCi/ℓ in the basement and 1.8 pCi/ℓ in the living area -- since, this time, the fan operated continuously. The 1989 ATD readings in House 39 are the first representative post-mitigation cold-weather measurements obtained in that house; these readings are notably higher than the short-term Pylon continuous radon monitor results of 2.0 pCi/ℓ measured in the basement in June 1987, during mild weather, immediately after the mitigation system was installed. A level of 7.5 pCi/ℓ represents a 93% radon reduction in basement concentrations by the 3-pipe sub-slab suction system in House 39, a reduction probably limited by the limited sub-slab communication measured under the basement slab.

The baseboard block wall + sub-slab pressurization system in House 2 had also reportedly been turned off for 12 days during the 1988 ATD measurement period (about 12% of the period). Thus, it might be expected that the 1989 results would be lower than the previous year's, since the system reportedly operated the entire time this year. This is particularly true in view of the high pre-mitigation radon concentrations in that house (413 pCi/ℓ); even a 12-day interruption in system operation would have been expected to have dramatically increased the 3- to 4-month ATD result in 1988. However, as shown in Table 3B, 1989 levels in this house are similar to (even slightly higher than) the 1988 values. This unexpected result is consistent with the observation last year that, surprisingly, the 1988 results from House 2 were only slightly higher than had been the 1987 results despite the 12-day interruption in 1988. As discussed previously in Section 5.1, perhaps the "recovery rate" of sub-slab radon is slow enough under House 2 such that 12 days was not sufficient for sub-slab radon concentrations to build back up to their pre-mitigation values, after the soil ventilation system had been depleting the soil gas for 1 to 2 years.

In Reference 3, apparent increases in average concentration at Houses 18 and 25 were observed in 1988 relative to 1987. These increases were attributed to the fact that the 1987 ATD monitoring period had not been initiated until February in House 18 and March in House 25, thus missing two or more months of the coldest weather; the 1988 period, by comparison, had been initiated in December, thus including the traditionally cold months of December, January and February. This suggestion is supported by the 1989 levels; the 1989 ATD measurement period also began in December, and it gave results similar to the 1988 results for these two houses.

In House 10, an apparent continuing degradation in system effectiveness was observed in Reference 3 between 1986 and 1988 (3.3 pCi/ℓ in the basement in 1986, to 9.0 pCi/ℓ in 1987, to 15.2 pCi/ℓ in 1988). This consistent trend toward increasing radon concentrations is halted in 1989, when the basement level (10.4 pCi/ℓ) drops back toward the 1987 value. In retrospect, it would seem that the only deterioration in system performance occurred between 1986 and 1987, and the average of 11.5 pCi/ℓ is probably representative of system performance thereafter.

A number of houses (2, 9, 20, 28 and 32) have radon concentrations upstairs which are greater than the levels in the basement by 1.0 pCi/ℓ or more. Several of these (Houses 9, 20 and 32) have radon levels in well water above 20,000 pCi/ℓ; because most water usage is upstairs, except for the clothes washer, radon in water could be contributing preferentially to airborne concentrations upstairs. The concentration of radon in water at House 28 is not known. Some (Houses 2 and 9) have block fireplace structures which could provide soil gas a direct route upstairs without entering the basement; these two houses also are the only two houses having baseboard-duct block wall pressurization systems. House 20 has an adjoining paved crawl space which may not be being fully treated, so that radon can enter the living area through the crawl space sub-flooring.

The interesting result seen in House 19 in 1987 and 1988 -- where radon levels were very low upstairs (0.6-0.8 pCi/ℓ) despite no apparent radon reduction in the basement (32.0-33.5 pCi/ℓ) -- continues in the 1989 results. Levels are 0.6 pCi/ℓ upstairs and 28.5 pCi/ℓ in the basement. This house has a block wall suction system in the basement. The owner had requested that the EPA not proceed with a sub-slab suction system, which had been the next step planned when the wall suction did not reduce the basement concentrations. The basement is reasonably isolated from the upstairs, since the house has electric baseboard heat upstairs only, and hence there is no circulation from the basement via central forced-air ducts connecting the stories. Perhaps the wall suction is drawing enough air out of the basement through the block walls to depressurize the basement relative to upstairs. Thus, the air and radon in the basement is prevented from flowing upstairs.

The 1989 ATD results in House 28 continue to suggest that the HRV at that house is providing about 80% reduction in the basement, a situation also noted in the discussion of the 1988 results in

Reference 3. This apparent effectiveness is suspect; perhaps the pre-mitigation ATD value is incorrectly high. Short-term (4-day) Pylon continuous measurements made in February 1987 with the HRV on and off, back-to-back, indicated that the unit was giving reductions of 15-45%, not 80%.

Much of the preceding discussion has focussed on the comparison of the 1989 ATD results with the 1988 results, assessing changes over the year. For 30 of the houses, valid measurements (with continuously-operating systems) are available for both 1989 and 1987, permitting a direct comparison of effects over that 2-year period and giving a longer-term measure of performance. In 6 of these 30 houses, the 1989 measurement in either the basement or the upstairs (or both) is greater than the 1987 readings by 2.0 pCi/ℓ or more. One of these houses is House 33, which, as discussed previously, suffered a significant, unexplained degradation between 1988 and 1989; the difference between the 1987 and 1988 readings in this house are sufficiently small such that it is not clear that any real degradation occurred during that first year. In the other 5 houses (Houses 2, 9, 18, 20 and 22), the 1989 levels are greater than the 1987 levels by 2.5 to 3.9 pCi/ℓ. In 3 of these houses (Houses 2, 20 and 22), the 1988 readings fall between the 1987 and 1989 values, suggesting a possible consistent upward trend; however, the differences from year to year are sufficiently small that some of the difference may be due to natural variability, and the apparent trend may simply be coincidental. For the other 2 houses (Houses 9 and 18), 1989 readings are lower than the 1988 measurements; thus, there is no trend, and the 1987, 1988 and 1989 values may simply be defining the range over which radon levels naturally vary. If there were any real degradation in these 2 houses, it must have occurred between 1987 and 1988. As indicated previously, the apparent increase in radon between 1987 and subsequent years in House 18 may be due to the fact that the 1987 ATD measurement in that house did not start until February, thus missing two of the coldest winter months and potentially reducing the measured concentration; there may not have been any real increase in radon levels in this house at all.

SECTION 6.

MECHANICAL SYSTEM RESULTS

The fan failures at Houses 7 and 31 during the 1989 measurement period represent the third and fourth failures to date of the large plastic-body centrifugal fan (Kanalflakt Model T2) installed in most of the demonstration houses on the Reading Prong in Pennsylvania. The fan at House 7 had been unplugged during some household plumbing repairs, could not be restarted after it was plugged in again. While the reason for this failure will not be known until the fan repairs are completed (under warranty), the nature of the failure suggests a capacitor failure. The fan at House 31 ceased to operate in mid-January 1989. Again, the reason for the failure will not be known until the fan is repaired.

The problems experienced in 1988 with the Kanalflakt T2 fans at Houses 4 and 15 were traced to seized and noisy bearings, respectively. Both fans have operated satisfactorily since repairs, and provided 1989 radon averages of approximately 1 pCi/ℓ.

As indicated in Reference 3, a fan also had failed prior to the 1988 measurement period, at House 2. This fan was a Kanalflakt Model W2 metal-bodied unit, mounted horizontally on the foundation wall. This fan had been repaired, by replacing the capacitor, prior to the 1988 measurements.

Thus, of the 34 houses having operating soil ventilation systems, a total of 5 fans have failed over the 2- to 4-year period that these systems have been operating. One of the failures was due to a capacitor problem, and two due to bearing failure, with the cause of the remaining two still to be determined. Four of these fans (the 4 Model T2s) have been operating in suction, and the fifth (House 2, the Model W2) was operating in pressure.

The system breakdown at House 17 represents the first failure for an HRV unit, installed by a local HVAC contractor in three of the demonstration houses. The owner of House 17 reported that the bearings seized on the motor which drives the intake and exhaust fans, and the rotary heat exchange wheel, in this HRV model. He attributed the cause to the fan shaft having been bent by the contractor during adjustments to the original installation, thereby causing an imbalance which resulted in the gradual deterioration of the bearings. The unit was repaired within 15 days after the failure, and is now operating satisfactorily.

It is noted that, for each of these mechanical failures, the problem had been identified (and sometimes corrected) by the homeowner prior to the visit by EPA's contractor. This was true even though these early systems had not been equipped with alarms to alert the homeowner to such failures.

SECTION 7.

WELL WATER TREATMENT

In December 1988, the activated charcoal system installed in House 2 for removal of radon from water was checked for performance by taking samples of water before and after passage through the unit and having them analyzed by the Pennsylvania Department of Environmental Resources (DER). The measured average concentrations in the water before and after the unit were 57,200 and 19,900 pCi/ℓ, respectively, indicating a removal efficiency of 65%. This represents a further deterioration in performance from a high of 95% at installation in August 1986, through approximately 80% at mid-winter 1987, to 65% in December 1988. This deterioration is not altogether surprising, since the charcoal used in this unit was not specially selected for radon removal from water; the unit, purchased from a local vendor in Pennsylvania, had been designed to remove organics from water.

The radon removal efficiency of the charcoal treatment unit at House 30 was also checked during the Track-Etch installation period in December 1988. Water samples taken before and after passage through the charcoal unit were analyzed by the DER. The average radon concentrations in the water before and after the unit were 156,000 and 4,360 pCi/ℓ, respectively, a 97% removal. This removal is comparable to the measured removal efficiency of 99% measured immediately after installation in August 1986, and 95% to 99% during various measurements throughout 1987. There is no degradation in removal efficiency evident with this unit, despite the high input concentration, averaging aproximately 200,000 pCi/ℓ since installation, and despite the high water usage associated with a family with two young children. Perhaps this is attributable to the charcoal, which was specially selected by the vendor in Maine for radon removal from water.

A new well has been drilled at House 30 about 30 ft (10 m) from the old well. Preliminary test results suggest that the dissolved radon concentration is much lower in the new well. The owners intend to draw all of their water from the new well. If radon concentrations are substantially lower in the new well, the charcoal adsorption unit may no longer be required at this site.

SECTION 8.

CONCLUSIONS

For the 34 houses in which the mitigation system was operating as intended during the entire monitoring period, the 1989 ATD results are not greatly different from the comparable post-mitigation measurements made in previous years. Thus, there does not appear to be any general degradation in mitigation system performance with time alone. Only at Houses 33 and 40 does a significant unexplained increase in post-mitigation radon concentration appear to have occurred, and then only in the basement.

Tables 4A and 4B present an overall summary of the 1989 ATD results, indicating the degree of success achieved with the different reduction techniques in terms of reductions to specified residual radon levels, and to specified percentage reductions. Since performance figures in these tables are based on radon concentrations in the basement during the winter, generally the worst-case situation, the performance would undoubtedly be better if one considered the house as a whole for the entire year.

The generally consistent performance of these mitigation systems between 1986/87, 1987/88 and 1988/89 confirm the conclusions drawn in Reference 1:

- radon reductions of 90-99% can be achieved with properly designed active soil ventilation systems;
- heat recovery ventilators can provide moderate radon reductions (usually no greater than 50%);
- carbon adsorption units can remove up to 95-99% of the radon in well water, if the unit is specifically designed for radon removal.

While Tables 4A and 4B are useful in summarizing the large amount of data, the reader must be alert to the factors which have created some of the apparent effects in these tables. For example, the very high percentage reductions quoted are the result of extremely elevated initial pre-mitigation concentrations, frequently well above 100 pCi/ℓ (3,700 Bq/m^3); lower pre-mitigation values would naturally give lower percent reductions. Likewise, the relatively high number of houses still above 4 pCi/ℓ is due, in part, to the high pre-mitigation levels, as well as the relatively poor sub-slab communication that appeared to exist under a number of these houses. In addition, wall ventilation would appear from Table 4B to be a successful method, with 3 out of 4 installations giving greater than 95% reduction; however, pure block wall ventilation is not currently a recommended technique. The high success rate achieved in this program is only apparent, due to the fact that the unsuccessful wall ventilation installations were all converted to some other type of system. The one wall ventilation system that would appear in the tables to be the least successful (20-40 pCi/ℓ residual in the basement, <50% reduction) is House 19, discussed in an earlier section; however, considering the concentrations achieved upstairs in this house (<1 pCi/ℓ, or <37 Bq/m^3), this system can be regarded as successful if the upstairs is the primary living area.

The significant reduction (77%) in airborne radon produced by water treatment alone (House 30), to 3.9 pCi/ℓ (140 Bq/m^3) is due to very high well-water radon concentrations in this house, up to 310 000 pCi/ℓ (11.5 MBq/m^3) by one measurement. Houses with lower initial radon concentrations in the water would have lower air concentrations and correspondingly smaller reductions.

SECTION 9.

REFERENCES

1. Scott A.G., Robertson A. and Findlay W.O., "Installation and Testing of Indoor Radon Reduction Techniques in 40 Eastern Pennsylvania Houses", report prepared for U.S. Environmental Protection Agency by American ATCON, EPA-600/8-88-002 (NTIS PB88-156617), Research Triangle Park, NC, January 1988.

2. U.S. Environmental Protection Agency, "Interim Indoor Radon and Radon Decay Product Measurement Protocols," EPA-520/1-86-04 (NTIS PB86-215258), Washington, D.C., February 1986.

3. Scott A.G. and Robertson A., "Follow-up Alpha-Track Monitoring in 40 Eastern Pennsylvania Houses with Indoor Radon Reduction Systems (Winter 1987-88)", report prepared for U.S. Environmental Protection Agency by American ATCON, EPA-600/8-88-098 (NTIS PB89-110035), Research Triangle Park, NC, September 1988.

TABLE 1. QA/QC RESULTS FOR 1988/1989 DOSIMETER BATCH

IDENTITY	EXPOSURES REPORTED BY TERRADEX (pCi.day/ℓ) INDIVIDUAL DOSIMETERS	MEAN	KNOWN EXPOSURE (pCi.day/ℓ)
BLANKS	15.0, 43.2, 31.6, 31.6, 15.0, 36.3, 36.3	29.9	0.0
SPIKES (EML)	578.7, 626.6, 628.8, 607.0, 687.6, 639.2, 624.0, 698.1, 683.2, 602.2	637.5	736.6

ZERO CORRECTION= -29.9/116 = -0.26 pCi/ℓ

GAIN CORRECTION = 736.6/(637.5-29.9) = 1.21

TABLE 2A. SUMMARY OF MONITORING RESULTS FOR HOUSES WITH MITIGATION FANS OFF DURING AT LEAST PART OF THE MEASUREMENT PERIOD

HOUSE ID #	INDIVIDUAL 1989 TRACK ETCH READINGS (pCi/ℓ)* BASEMENT TE1	TE2	LIVING AREA TE1	TE2	AVERAGE RADON (pCi/ℓ) 1989** B	LA
1	House moved from site					
7	68.0	102.6	20.4	20.0	103.1	24.2
11	Owner no longer participating					
14	9.6	8.8	6.9	6.8	10.8	8.0
17	7.5	7.1	4.7	3.9	8.5	4.9
31	201.0	216.4	66.1	88.4	252.7	93.3

* Individual Track Etch measurements as reported by Terradex, without correction.

** The zero correction of -0.26 pCi/ℓ and then the gain correction of 1.21 were applied in calculating the average of the 1989 Track Etch measurements from the individual readings.

TE1 and TE2 refer to the individual Track Etch detectors in each cluster of two.

B - basement

LA - living area (story above basement).

TABLE 2B. SUMMARY OF RESULTS TO DATE FOR HOUSES WITH MITIGATION FANS OFF DURING AT LEAST PART OF THE 1989 MEASUREMENT PERIOD

			Average Radon Concentration (pCi/ℓ)								
				Post-Mitigation***							
House		Final	Premiti-	1989		1988		1987		1986	
ID#	Type*	Mitigation System	gation**	B	LA	B	LA	B	LA	B	LA
1	1	Wall + sub-slab pressurization (baseboard duct)	146	House moved from site prior to Track Etch measurements							
7	1	Sub-slab + wall suction	(402)	103.1	24.2	4.9	3.8	4.1	2.8	-	-
11	1	Wall + sub-slab suction (baseboard duct over French drain)	49	Owner discontinued participation in project prior to Track Etch measurements							
14	1	Wall suction	36	10.8	8.0	1.1	1.4	0.5	0.7	0.7	0.6
17	1	Heat recovery ventilator	9	8.5	4.9	8.2	6.4	7.6	4.1	-	-
31	1	Sub-slab suction	(485)	252.7	93.3	2.8	8.3	1.8	5.7	-	-

* House Type:
1 = Block basement walls

** Pre-mitigation radon concentrations reported here represent a single Terradex Track Etch alpha-track detector measurement arranged by the Pennsylvania Department of Environmental Resources during a heating season prior to installation of EPA's radon mitigation system. Where it is known that the pre-mitigation ATD was not placed in a representative location, or where the ATD result was clearly not representative of subsequent Pylon measurements made by EPA, the pre-mitigation concentration shown here is the average of at least 48 hours of hourly radon measurements made in the basement during cold weather using a Pylon AB-5 continuous radon monitor. Where Pylon measurements have been used, the pre-mitigation value is shown in parentheses. The Pylon measurements were made during the 1985-87 system installation period (see Reference 1).

*** Post-mitigation radon concentrations reported here represent the average of clusters of two (1989) or three (pre-1989) alpha-track detectors exposed for a 4-month (1989) or a 3-month period (pre-1989) during the winter. 1989 measurements as reported in Table 2A (December 1988 - April 1989). The 1988 measurements were reported in Reference 3 (December 1987-March 1988). The 1987 measurements were reported in Reference 1 (December 1986-March 1987). 1986 results were reported in Reference 1 (December 1985-March 1986). All results corrected for gain correction and zero.

B = Track Etch measurements in basement

LA = Track Etch measurements in living area (story above basement)

TABLE 3A. SUMMARY OF 1989 TRACK ETCH MONITORING RESULTS FOR HOUSES WITH MITIGATION FANS ON THROUGHOUT 1989 MEASUREMENT PERIOD

HOUSE ID #	INDIVIDUAL 1989 TRACK ETCH READINGS (pCi/ℓ)* BASEMENT TE1	BASEMENT TE2	LIVING AREA TE1	LIVING AREA TE2	AVERAGE RADON (pCi/ℓ) 1989** B	LA
2	4.9	4.7	8.0	6.9	5.5	8.7
3	2.8	2.6	1.8	1.8	3.0	1.9
4	1.5	1.0	1.1	1.1	1.2	1.0
5	4.5	4.2	3.8	3.9	5.0	4.4
6	2.6	3.2	2.5	2.4	3.2	2.4
8	2.7	2.6	1.0	1.2	2.9	1.0
9	10.5	10.5	13.6	15.2	12.4	17.1
10	9.0	8.6	7.0	8.2	10.4	8.9
12	1.6	1.5	2.0	1.9	1.6	2.1
13	2.6	2.4	2.6	2.5	2.7	2.8
15	1.4	1.3	1.3	1.3	1.3	1.3
16	4.1	4.3	1.3	1.0	4.8	1.1
18	11.0	10.5	4.6	4.3	12.7	5.1
19	24.5	23.0	0.9	0.6	28.5	0.6
20	7.7	6.5	7.6	8.3	8.3	9.3
21	1.7	1.9	2.0	2.9	1.9	2.7
22	8.3	10.0	3.5	3.6	10.8	4.0
23	2.6	1.9	1.4	1.6	2.4	1.5
24	3.6	4.0	3.3	3.4	4.3	3.7
25	5.9	6.5	4.4	4.8	7.2	5.3
26	0.7	0.8	1.2	1.1	0.6	1.1
27	5.0	4.8	2.2	1.7	5.6	2.1
28	3.0	3.4	4.5	4.4	3.6	5.1
29	2.3	1.7	1.8	2.5	2.1	2.3
30	3.4	3.5	2.0	2.0	3.9	2.1
32	0.7	0.6	2.9	2.9	0.5	3.2
33	9.1	9.9	0.9	0.7	11.2	1.2
34	4.4	4.5	4.8	4.8	5.1	5.5
35	2.3	2.2	1.2	0.9	2.4	1.0
36	0.9	0.9	1.0	0.6	0.8	0.7
37	1.1	0.9	0.9	0.5	0.9	0.5
38	5.8	6.3	5.4	7.2	7.0	7.3
39	6.5	6.4	1.8	1.7	7.5	1.8
40	7.1	7.9	2.2	2.4	8.8	2.5

* Individual Track Etch measurements as reported by Terradex, without correction.

** The zero correction of -0.26 pCi/ℓ and then the gain correction of 1.21 were applied in calculating the average of the 1989 Track Etch measurements from the individual readings.

TE1 and TE2 refer to the individual Track Etch detectors in each cluster of two

B - basement

LA - living area (one story above basement)

TABLE 3B. SUMMARY OF RESULTS TO DATE FOR HOUSES WITH MITIGATION FANS OPERATING THROUGHOUT THE 1989 MEASUREMENT PERIOD

House ID#	Type*	Final System	Average Radon Concentration (pCi/ℓ) Pre-Mitigation**	Post-Mitigation*** 1989 B	1989 LA	1988 B	1988 LA	1987 B	1987 LA	1986 B	1986 LA
2	1	Wall + sub-slab pressurization (baseboard duct) + carbon adsorption on well water	413	5.5	8.7	4.8	6.7[a]	2.6	5.2	-	-
3	1	Wall + sub-slab suction	350	3.0	1.9	3.5	2.3	3.5	2.1	4.4	1.7
4	1	Sub-slab suction	25	1.2	1.0	7.3	3.1[a]	0.7	0.8	-	-
5	1	Wall pressurization	(110)	5.0	4.4	5.0	4.4	4.3	4.3	-	-
6	1	Sub-slab suction	60	3.2	2.7	4.1	3.2	3.3	4.9	-	-
8	1	Wall suction	183	2.9	1.0	3.5	1.5	3.9	1.8	3.1	1.3
9	1	Wall + sub-slab pressurization (baseboard duct)	533	12.4	17.1	10.4	12.9	11.6	14.5	-	-
10	1	Drain tile suction	626	10.4	8.9	15.2	9.9	9.0	6.5	3.3	3.0
12	1	Drain tile suction	(11)	1.6	2.1	2.2	2.2	3.7	2.5	-	-
13	1	Sub-slab suction+ + drain tile suction	64	2.7	2.8	2.6	3.9	2.3	2.0	-	-
15	1	Drain tile suction	(18)	1.3	1.3	19.7	11.0[a]	1.1	1.0	-	-
16	2	Wall suction	395	4.8	1.1	5.7	2.5	5.4	1.7	-	-
18	1	Heat recovery ventilator	12	12.7	5.1	13.5	3.4	8.8	2.1	-	-
19	1	Wall suction	32	28.5	0.6	33.5	0.8	32.0	0.6	-	-
20	2	Sub-slab + wall suction in bsmt; suction under crawl space slab	210	8.3	9.3	6.5	10.0	5.8	9.9	-	-
21	1	Sub-slab suction	172	1.9	2.7	2.0	2.7	3.1	2.6	-	-
22	3	Sub-slab suction (basement + slab)	24	10.8	4.0	8.6	4.4	7.6	2.7	-	-

(continued)

TABLE 3B (continued)

23	3	Sub-slab suction (basement + slab)	98	2.4	1.5	2.6	1.6	-	-	-	-
24	4	Sub-slab suction	66	4.3	3.7	3.6	3.8	4.3	4.6	-	-
25	4	Sub-slab suction	122	7.2	5.3	7.7	6.0	5.4	3.0	-	-
26	1	Drain tile suction	(89)	0.6	1.1	1.1	1.6	2.1	1.5	-	-
27	1	Drain tile suction	21	5.6	2.1	4.0	2.2	3.8	2.2	-	-
28	1	Heat recovery ventilator	21	3.6	5.1	4.1	4.4	2.4	5.3	-	-
29	5	Drain tile suction (interior sump) + suction under crawl space liner	61	2.1	2.3	1.6	2.0	1.9	1.4	-	-
30	1	Carbon adsorption treatment of well water	17	3.9	2.1	4.0	1.6	3.0	1.3	-	-
32	1	Sub-slab suction	(6)	0.5	3.2	1.2	4.4	1.0	3.2	-	-
33	4	Sub-slab suction	82	11.2	0.7	3.5	1.2	2.2	1.1	-	-
34	4	Sub-slab suction	470	5.1	5.5	5.4	5.5	5.5	3.7	-	-
35	4	Sub-slab suction	144	2.4	1.0	1.0	0.9	0.8	0.7	-	-
36	3	Sub-slab suction (basement + slab)	300	0.8	0.7	1.1	1.0	1.6	0.7	-	-
37	3	Sub-slab suction (basement only)	87	0.9	0.5	1.2	0.7	0.6	1.7	-	-
38	1	Sub-slab suction	309	7.0	7.3	8.7	7.2	-	-	-	-
39	1	Sub-slab suction	111	7.5	1.8	46.1	17.5[a]	-	-	-	-
40	4	Sub-slab suction	148	8.8	2.5	1.9	1.2	-	-	-	-

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

(continued)

TABLE 3B (concluded)

** Pre-mitigation radon concentrations reported here represent a single Terradex alpha-track detector measurement arranged by the Pennsylvania Department of Environmental Resources during a heating season prior to installation of EPA's radon mitigation system. Where it is known that the pre-mitigation ATD was not placed in a representative location, or where the ATD result was clearly not representative of subsequent Pylon measurements made by EPA, the pre-mitigation concentration shown here is the average of at least 48 hours of hourly radon measurements made in the basement during cold weather using a Pylon AB-5 continuous radon monitor. Where Pylon measurements have been used, the pre-mitigation value is shown in parentheses. The Pylon measurements were made during the 1985-87 system installation period (see Reference 1).

*** Post-mitigation radon concentrations reported here represent the average of clusters of two or three alpha-track detectors exposed for a 3- to 4-month period during the winter. 1989 measurements as reported in Table 3A (December 1988 - April 1989). 1988 measurements made during the period December 1987 - March 1988 (Reference 3); 1987 measurements generally made during the period December 1986 - March 1987; 1986 measurements generally made during the period December 1985 - March 1986 (see Reference 1). All results corrected for gain correction and zero correction where needed.

[a] A superscript "a" indicates that the ATD measurements in that house during that year are not representative of an operating mitigation system, because the system was off for part or all of the measurement period.

Absence of results for 1986 or 1987 for a given house indicates that: alpha-track measurements were not made in that house that winter; or the radon mitigation system was changed significantly between that winter and the following winter; or the alpha-track measurement was made significantly outside the December - March window due to the system installation schedule.

B = Track Etch measurements in basement

LA = Track Etch measurements in living area (story above basement)

TABLE 4A. OVERALL SUMMARY OF 1989 RESULTS FROM THE HOUSES WHERE MITIGATION FANS OPERATED CONTINUOUSLY DURING THE MEASUREMENT PERIOD.

RESIDUAL RADON CONCENTRATIONS IN BASEMENT DURING WINTER

Mitigation Type	Total No. of Houses Tested	Total No. of houses with indicated residual radon level (pCi/ℓ)			
		≤4	4-10	10-20	20-40
Sub-slab suction	17	9	6	2	0
Wall ventilation	4	1	2	0	1
Sub-slab + wall vent	4	1	2	1	0
Drain tile suction	6	4	1	1	0
Heat recovery vent	2	1	0	1	0
Water treatment	1	1	0	0	0
Totals	34	17	11	5	1

TABLE 4B. OVERALL SUMMARY OF 1989 RESULTS FROM THE HOUSES WHERE MITIGATION FANS OPERATED CONTINUOUSLY DURING THE MEASUREMENT PERIOD.

PERCENTAGE RADON REDUCTIONS IN BASEMENT DURING WINTER

Mitigation Type	Total No. of Houses Tested	Total No. of houses with indicated percentage radon reductions				
		≥95%	90-95%	75-90%	50-75%	≤50%
Sub-slab suction	17	9	6	1	1	0
Wall ventilation	4	3	0	0	0	1
Sub-slab + wall vent	4	4	0	0	0	0
Drain tile suction	6	3	1	1	1	0
Heat recovery vent	2	0	0	1	0	1
Water treatment	1	0	0	1	0	0
Totals	34	19	7	4	2	2

Notes:

1. The radon levels in the basement during winter are generally the worst-case situation. The residual radon concentration would be lower if one considered the house as a whole for an entire year.

2. The figures in Table 4B were obtained by comparing the basement average ATD result from the December 1988-March 1989 measurement period with the pre-mitigation winter-time ATD measurement reported by the Pennsylvania Department of Environmental Resources (both concentrations as shown in Table 3B).