A COMPARISON OF INDOOR RADON CONCENTRATIONS BETWEEN PRECONSTRUCTION AND POST-CONSTRUCTION MITIGATED SINGLE FAMILY DWELLINGS

by: **James F. Burkhart, Physics Department, University of Colorado at Colorado Springs Colorado Springs, CO 80933**

Douglas L. Kladder, Residential Service Network, Inc., 525 E. Fountain Colorado Springs, CO 80903

ABSTRACT

We have done a detailed study comparing indoor radon concentrations among single family dwellings in Colorado Springs that were mitigated prior to the completion of construction and similar buildings that were mitigated after construction. There appears to be evidence which indicates that "preconstruction" mitigation is more effective at lowering indoor radon concentrations than "post-construction" mitigation.

A total of 102 owners of single family dwellings, in two different areas within the city, agreed to participate in the study. Thirty-nine homes formed the preconstruction mitigation category (with 14 of these homes having only passive systems), 24 had been mitigated after construction and the final 39, chosen as a control group, had never been mitigated but shared similar soil and surficial geological features with the mitigated homes (including distance to nearby faults). Eighty nine homeowners successfully completed the test. All of theses houses were tested over the same 48-hour period, under closed-house conditions, thereby controlling the variables of weather and, to some extent, occupants' usage.

By analyzing the data obtained, we can conclude that there is a statistically significant difference in post-mitigation indoor radon concentrations (as measured by simultaneous charcoal screening tests) between the preconstruction and the post-construction mitigated homes. The preconstruction category exhibited the lower radon average, although both mitigation categories had averages below 4.0 pCi/L. Such a conclusion could have an impact on current mitigation practices, especially as they pertain to new housing construction.

Esthetics, installation costs and operating costs of the two mitigation techniques (pre and post-construction) are also discussed herein.

INTRODUCTION

The purpose of this study is to assess the relative effectiveness of radon reduction methods in residential structures when they are utilized after the home is constructed as opposed to when the home is mitigated prior to the completion of construction. It is hoped that the results discussed herein will provide information for the building industry and those agencies which assist it in developing approaches to mitigating new and existing homes.

This study was conceived by the authors when it was noted that data collected from post-mitigation testing over the last three years were giving the indication that post-construction mitigation provided similar results to mitigations performed prior to the completion of construction. However, such a conclusion was difficult to make due to varying environmental conditions which affected test results. Consequently, this study was designed to remove many of the typical testing variables by testing all subject homes simultaneously and on the same floor. As will be seen later, the hypothesis that active mitigation, whether performed during or after construction, had essentially the same results proved to be <u>incorrect</u> based upon the total data obtained.

The study was conducted concurrently within two different areas of Colorado Springs, Colorado, which we refer to as Area 1 and Area 2. The two study areas offer a unique opportunity for comparison since they are both infill subdivisions where a significant number of homes have no radon mitigation system at all (Category 1). These unmitigated homes serve as a basis for reference as to what a mitigated home might have been if no radon reduction techniques had been used. Furthermore, these same areas had a relatively large number of homes that had been mitigated with active systems (i.e., operating fans installed) after construction (Category 2) and prior to the completion of construction (Category 3). A fourth category was necessary to distinguish between these homes mitigated during construction using active systems and homes using only caulking, membranes or sub-slab ventilation without fans. In this region, these latter homes are called "radon ready" by the authors. We designated these radon ready houses as category 4.

Homeowner participation was voluntary and solicited on a neighborhood-wide basis through the two appropriate homeowner's associations, therefore no preselection of mitigation techniques occurred. However, subsequent interviews with participants indicated that all mitigated homes with active systems (Categories 2 and 3) employed sub-slab or sub-membrane depressurization techniques as the primary mitigation method. No attempt has been made to determine relative ventilation rates within test homes.

Homes in Area 1 were all within a half mile radius while homes in Area 2 were within a one-quarter mile radius. The homes in both areas were custom homes, ranging in size from 3,000 to 4,000 square feet of livable area. Most homes had finished walk-out basements.

The number of homes initially participating in this study fell into the four categories as noted in Table 1 below. The numbers in the brackets, on this same chart, show the number of participants who conducted the charcoal canister test correctly and who were subsequently used as our data base.

TABLE 1. NUMBER OF HOMES PARTICIPATING IN THE STUDY

Category	Area 1	Area 2	Total
1 Homes never mitigated	26 (22)	13 (13)	39 (35)
2 Homes mitigated after construction	12 (12)	12 (11)	24 (23)
3 Homes mitigated during construction	19 (15)	6 (4)	25 (19)
4 Homes made "radon-ready" for future mitigation	10 (8)	4 (4)	14 (12)

GEOLOGY OF THE TEST AREAS

A previous study (1) had already shown correlations between certain characteristics of the soils and geology of these two areas and the indoor radon concentrations as measured by screening tests. Specifically, elevated radon concentrations are predicted for these two areas because of low shrink-swell potential (indicating very little clays), and relatively high permeability of the soil as determined from the Soil Conservation Service County Soil Surveys (2). The surficial geology of both areas is made up of rock derived from the Pikes Peak batholith (3) which is known to contain 5.0 ppm of uranium (4). Finally, Area 2 is known to be relatively close to a major fault system. This fact is believed to contribute to enhanced radon transport.

A more precise breakdown of the above characteristics for each of the two areas is as follows:

Area 1 soil has a low shrink-swell potential with a permeability of 2 to 6 inches of water per hour. The surficial geology is a Dawson Arkose with some Verdos alluvium (both dervived from the Pikes Peak granite). The average distance of these homes to a major fault is 2.8 km.

Area 2 soil has a low shrink-swell potential, also, with a permeability of 6 to 20 inches of water per hour. The surficial geology is Rocky Flats alluvium (which is also derived from the Pikes Peak granite). The average distance of these houses from a major fault is .75 km.

Ignoring house construction details completely, the above characteristics would lead one to predict elevated radon in homes in both areas and the higher permeability and closer distance to a fault in Area 2 would suggest even higher radon levels in those homes. These predictions will be seen to be verified when the actual measurements are discussed in the Statistics section, below.

TESTING METHODOLOGY

Radon Measurements Laboratory, housed at the University of Colorado-Colorado Springs, is a primary lab for the evaluation of radon concentrations using the 48 hour, four-inch, open faced charcoal canister. These canisters are of typical design with approximately 70 grams of 8 X 16 mesh Calgon charcoal encased in a four-inch diameter canister, one-and-five-sixteenths inches high, covered with a 30-50 % open-mesh retainer screen. The laboratory has analyzed over 8,000 canisters over the last three years.

Canisters are read using a three inch by three inch NaI(Tl) crystal housed within a commercial lead shield. A 1,024 channel MCA is used to look at the three most intense lead-214 and one bismuth-214 photopeak lying between 220 and 692 KeV. The minimum detectable activity (MDA) at the 3 σ level was calculated to be 0.13 pCi/l for canisters measured 3 hours after closing and slightly higher for the balance of the canisters.

The usual quality assurance procedures were in place during this testing period with 100 % of the blanks being identified and duplicates above 4.0 pCi/l all within the 10 % precision expected. The 2 σ error was 0.17 pCi/l at 1.0 pCi/l and 0.4 pCi/l at 30 pCi/l. This low error was maintained by measuring all the canisters (after equilibrating) the same day the test concluded.

The canisters were delivered to the participants by the authors along with a detailed instruction sheet. The instruction sheet augmented prior phone conversations and further oral instructions at the time the canisters were delivered. The tests were all to begin on the morning of December 17th and conclude on the morning of December 19th, 1990. The canisters were placed in an open area in the basement (in most cases, the family room), 30 inches off of the floor in the center of the room. The canisters were sealed by the homeowner and placed outside for pick-up by the authors. Non-compliance with the instructions, or failure to perform the test, led to 13 of the original 102 participants being dropped from the subsequent data base. This gave us an 87 % compliance with the fairly stringent test requirements.

THE WEATHER DURING THE TESTING PERIOD

Since all of the homes were tested during the same time period and the distance between the two test areas is only a few kilometers, the weather was identical for all houses. It is probably safe to assume, therefore, that pressure differentials brought on by outside temperatures, wind, surface conditions (i.e.; frozen soils) and atmospheric disturbances were also similar.

Nonetheless, it is instructive to review the climatological data for that 48 hour period because the weather conditions were clearly such as to promote an honest screening test by discouraging surreptitious ventilation. Table 2 below shows the weather data from the morning of December 17th through the morning of December 19th. Not shown on this table is the fact that the winds were gusty for a short time on the morning of the 18th, with a peak gust of 48 mph from the northwest.

TABLE 2. CLIMATALOGICAL DATA FOR THE TEST PERIOD

Date	temp (high and low)		pressure	winds	precipitation
Dec 17	30°F	17°F	29.78 ↓	8.2mph	light snow
Dec 18	49°F	17°F	29.62 →	10.8mph	none
Dec 19	27°F	21°F	29.60 →	8.0mph	light snow

STATISTICS

This section is in two parts. First, the raw data will be presented in histogram form for each area separately and then both areas combined. Second, the results of the t-tests (testing the means of two populations to see if the populations are the same or different) will be given after each histogram.

RAW DATA IN HISTOGRAM FORM

Figure 1 below compares the indoor radon concentrations as measured during the testing period in Area 1 with the number of houses having a particular radon concentration. The black bars refer to those houses which were never mitigated (Category 1) and the bars with hash marks within them refer to houses which have passive systems only (Category 4), the so-called "radon ready" homes.

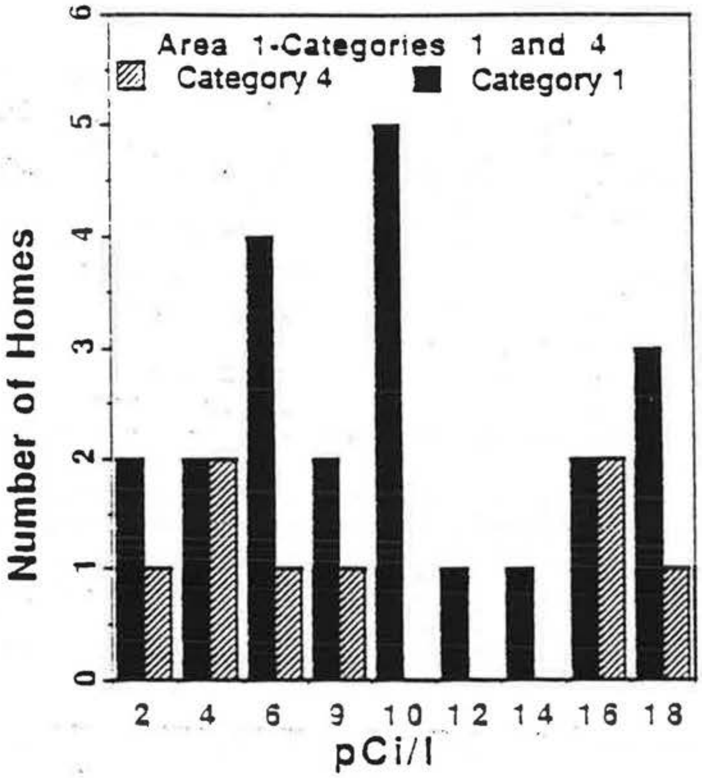

Figure 1. Radon in homes in Area 1, Categories 1 and 4

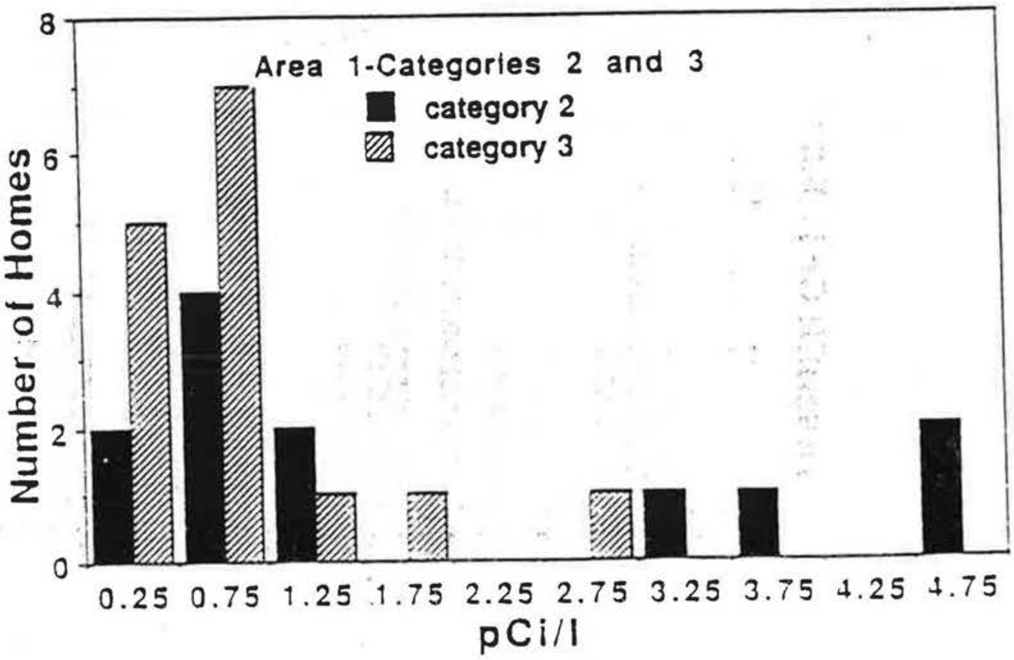

Figure 2. Radon in homes in Area 1, Categories 2 and 3

Figure 2 above makes the same comparison between number of houses and radon concentrations in Area 1 only using houses mitigated after construction (Category 2) and houses mitigated during construction (Category 3).

Comparing Category 1 and Category 4, in Area 1, and using the null hypothesis that the two categories represented the same population, a t-test was performed. The t-test, with a t value of .017, tells us that the two categories are indistinguishable. It would appear that "radon ready" houses have the same radon as unmitigated houses. The statistics are given in Table 3.

Comparing Category 2 and Category 3, in Area 1, and using the null hypothesis that the two categories represented the same population, a single tailed t-test, with a t value of 2.416 indicates that the two populations are indeed different at the 95% confidence level with the houses mitigated during construction (category 3) having the lower radon mean. The statistics are summarized in Table 3

Figure 3 below compares the indoor radon concentrations as measured during the testing period in Area 2 with the number of houses having a particular radon concentration. The black bars refer to those houses which were never mitigated (Category 1) while the bars with hash marks within them refer to houses which have passive systems only (Category 4).

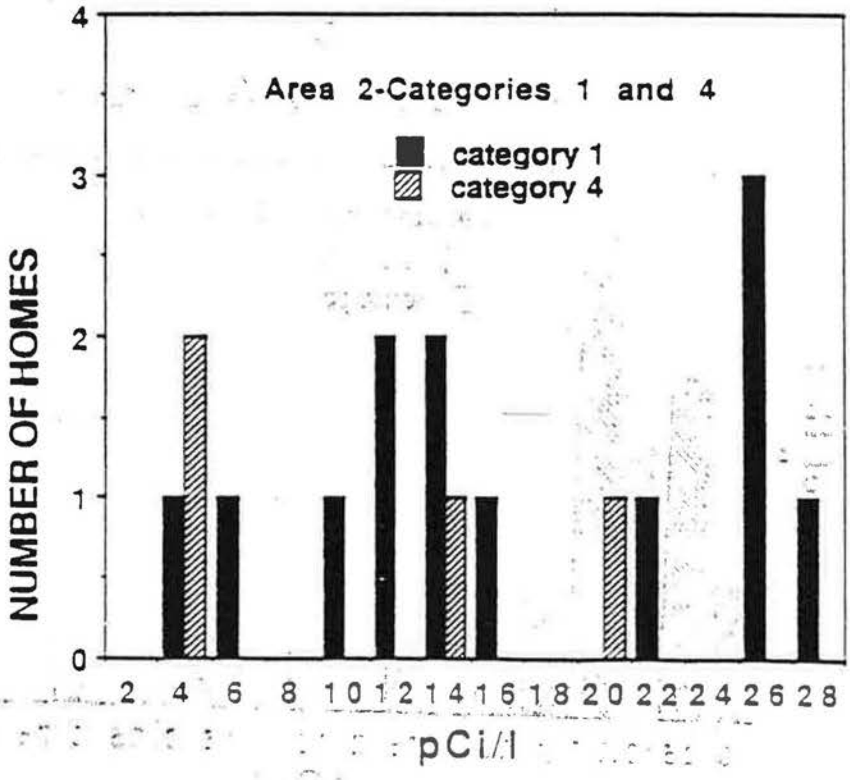

Figure 3. Radon in homes in Area 2, Categories 1 and 4

Figure 4 compares the indoor radon concentrations in Area 2 with the number of homes at a particular radon concentration. Here, the black bars refer to homes mitigated after construction (Category 2) while the hash mark bars refer to homes mitigated during construction (category 3).

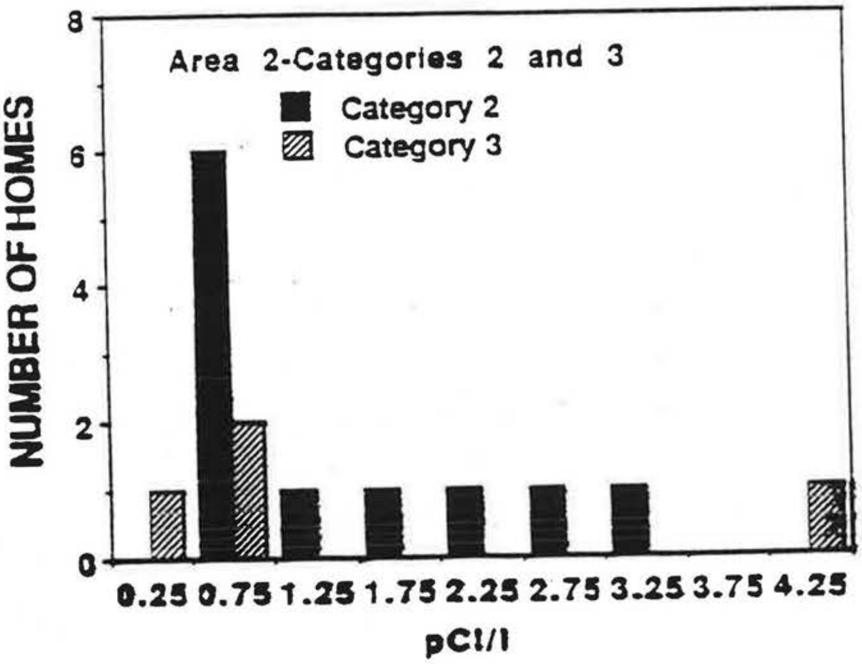

Figure 4. Radon in homes in Area 2, Categories 2 and 3

Comparing Category 1 and Category 4, in Area 2, and using the null hypothesis that the two categories represented the same population, a one-tail t-distribution, with a t value of 1.304, seems to confirm the null hypothesis. That is, as in Area 1, "radon ready" homes have the same average radon as do unmitigated homes. The statistics are shown later in Table 4.

Comparing Category 2 and Category 3, in Area 2, and using the null hypothesis that the two categories represented the same population, a one-tail t-test, with a t value of .091, seems to confirm the null hypothesis. That is, homes mitigated during construction have the same average radon as do homes mitigated after construction. It should be mentioned that the small number of homes (only 4) in category 3 make this conclusion far from certain, although statistically justified. The statistics are shown later in Table 4.

Finally, the data from the two areas is combined, thereby making any conclusions more general and, because of the larger numbers involved, more convincing. We begin by showing a histogram of the combined data, Categories 1 and 4 in figure 5.

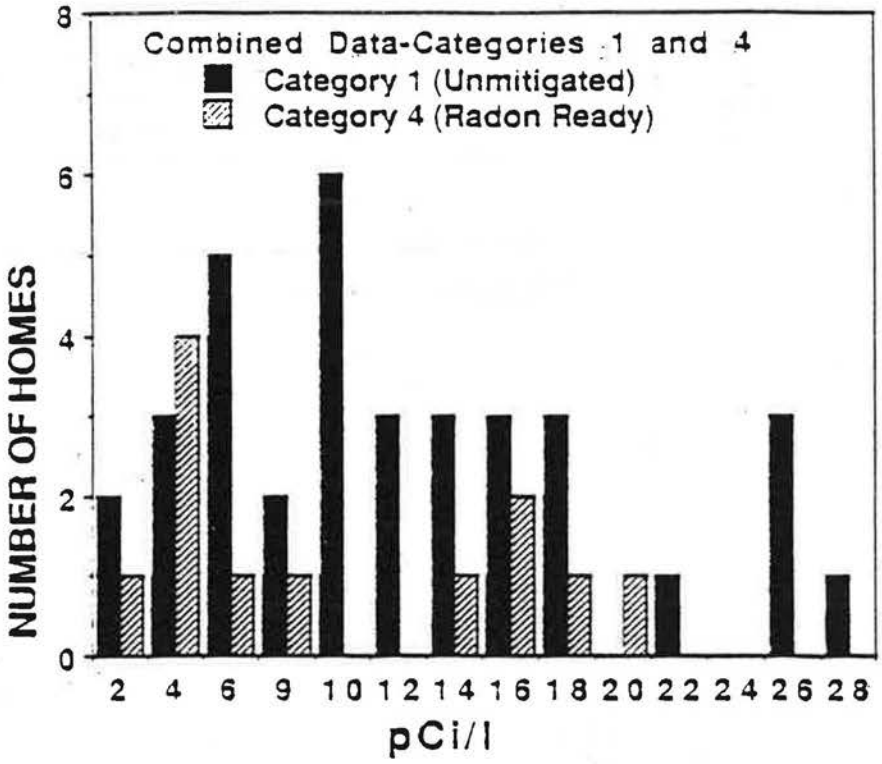

Figure 5. Radon in all the homes combined, Categories 1 and 4

When we combine all the data from both areas, we can also compare radon levels in homes which were mitigated during construction (Category 3) and homes mitigated after construction (Category 2). This comparison is given below in figure 6.

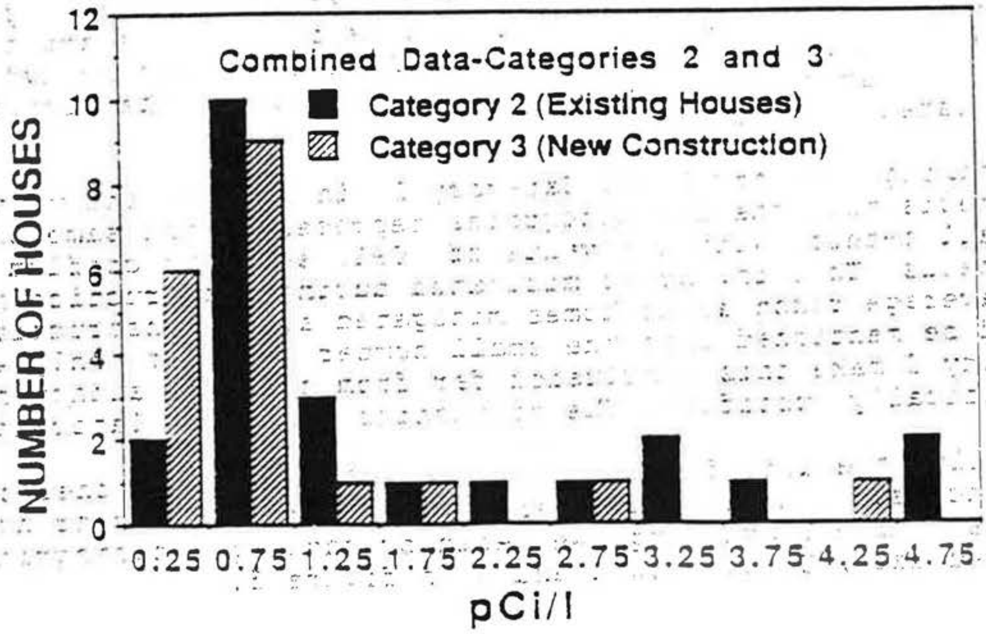

Figure 6. Radon in all the homes combined, Categories 2 and 3

Comparing unmitigated homes (Category 1) with "radon ready" homes (Category 4) in the combined data, and using the null hypothesis that the two categories really represent the same population, a single tailed t-test with a t value of .987 seems to confirm the null hypothesis. At this point, it seems safe to say that "radon ready" homes are no better at reducing radon concentrations than are unmitigated homes. The statistics are shown in Table 5.

A last comparison is now made. This is comparing houses mitigated during construction (Category 3) with houses mitigated after construction (Category 2) with all data combined. Again, the null hypothesis is that the two categories will represent populations with similar averages and standard deviations, i.e.; that it makes no difference in indoor radon levels if a house is mitigated during or after construction. This time, it is probably safe to reject the null hypothesis because a single tailed t-test indicates that the two are separate populations at the 98% confidence level, with a t value of 2.059. The statistics are shown in Table 5.

To show the effectiveness of the radon prevention measures in the three mitigation categories, a final histogram is presented. Figure 7 compares the average of each of the categories when all of the data is combined.

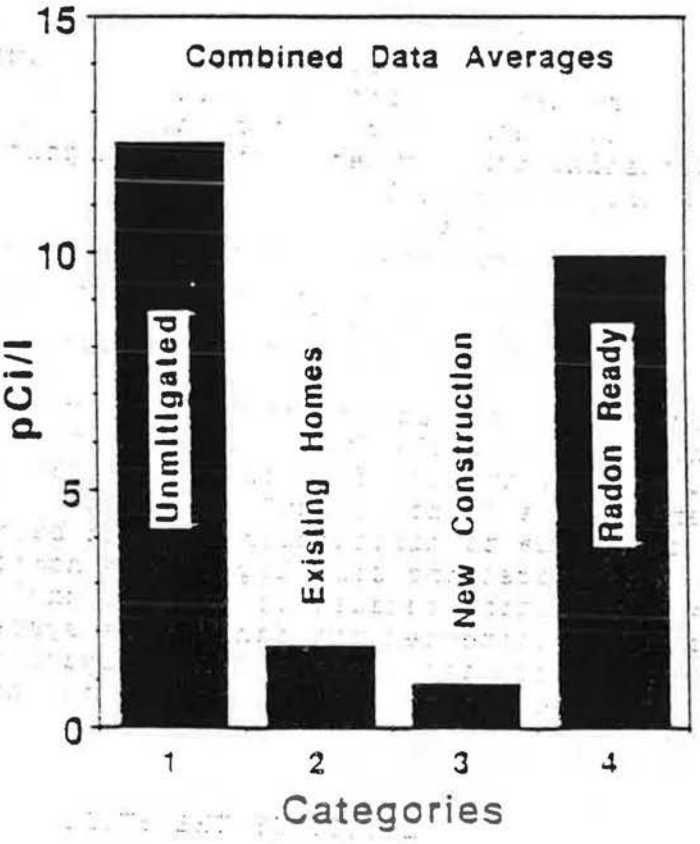

Figure 7. Average radon in all homes combined, broken down by category

DATA REVIEW

After receiving the questionnaires and the exposed canisters, the authors found several conflicting comments regarding descriptions of the type of system installed. Consequently, a combination of participant interviews, site visits and construction files were reviewed to verify which category each house really belonged within. All mitigated houses were reviewed in this manner which yielded some additional insights for this study:

1) Several new home owners were under the impression that adequate systems had been installed in their homes by the builders. Some of these systems turned out to be only barrier techniques (sealing or sub-concrete polyethylene). Perhaps more notable were homes that had sub-slab perforate piping systems that were stubbed up in the basement (most were sealed and one was open into the home). As an interesting note, this survey was the first time some of the homes were tested after occupation. For the purpose of the study, these homes were moved into Category 4 with Category 3 retaining only active sub-structure depressurization systems.

2) Two homes had utilized a sub-concrete mesh system where all of the rest of the survey utilized foundation drains or a combination of foundation drain and interior piping approaches for negative field propagation. These two homes were more than twice the mean of the other existing homes. Inspection of these homes indicated that the problem was not necessarily with the membrane, but rather with the installation. Fans were installed inside with extensive positive side piping. Non-standard fittings were utilized, which discharged beneath windows and near dryer vent openings. As the purpose of the study was to distinguish between during- and post-construction techniques as they are actually being installed, these two houses were maintained in the Area 2 data pool. The balance of the mitigated properties were carried out by the same RCPP listed contractor. Although it is not the purpose of this paper to distinguish between installers, it reinforces the need for proper training of those involved in radon mitigation.

3) Some homes which had active mitigation systems installed, after construction, had inoperable fans. These homes were moved to Category 4 since the authors felt that they represented a passively vented system as in a "radon ready" approach. At this time, no attempt has been made to distinguish between barrier versus passive systems. As an interesting side light, one homeowner insisted that her system was operating because it was not unplugged. She was only convinced when she inspected the fan. This system was installed three years ago before the present EPA mitigation guidelines requiring certain operating indicators for the homeowners were developed (5).

RESULTS OF THE STUDY

What follows is a discussion of each area separately, culminating in a discussion of both areas combined. However, it should be kept in mind that because of the smaller data base of Area 2, conclusions based upon this smaller data base may prove to be less convincing.

RESULTS FROM AREA 1

A comparison of the mean radon levels listed in Table 3 clearly indicates that mitigation during or after construction had beneficial effects. In fact, the means of both Categories 2 and 3 were well below the current EPA guideline of 4.0 pCi/L. As these were screening measurements taken at the lowest living area, current approaches would recommend no further action by the homeowner (6).

TABLE 3. RADON LEVEL MEANS AND STANDARD DEVIATIONS FROM AREA 1

Category	Description	Number	Mean	Standard Deviation
1	Unmitigated	22	9.8	5.26
2	Post-construction mitigation	12	1.94	1.72
3	During construction mitigation	15	0.78	0.64
4	Radon ready	8	9.77	6.63

Homes that were mitigated during construction with active sub-slab systems (Category 3) outperformed those active systems that were installed after construction (Category 2). This conclusion is based on a one-tail t-distribution at the 95% confidence level.

Homes that were built with radon ready systems or had passively vented systems showed statistically no benefit over homes that had no mitigation work done.

RESULTS FROM AREA 2

As was seen in Area 1 using unmitigated houses as reference (Category 1), mitigation which occurred during or after construction showed significant beneficial reductions. Additionally, both the mean of Categories 2 and 3 were well below the current screen action level of 4.0 pCi/L (Table 4).

TABLE 4. RADON LEVEL MEANS AND STANDARD DEVIATIONS FROM AREA 2

Category	Description	Number	Mean	Standard Deviation
1	Unmitigated	13	16.57	± 8.39
2	Post-construction mitigation	11	1.43	0.86
3	During construction mitigation	4	1.49	1.74
4	Radon ready	4	10.27	8.71

Homes that were mitigated during construction with active systems (Category 3) did not show a statistical difference from those homes that were mitigated after construction (Category 2). This result is certainly different from that obtained in Area 1. This may be due to the smaller sample volume and the effect of the non-mitigation guideline homes. One might also speculate that the higher soil porosity in Area 2 allows equal propagation of a sub-slab negative pressure field regardless of the use of a perimeter drain system (Category 2) or a perimeter drain system plus a sub-slab pipe network (Category 3).

Although the mean of radon ready homes (Category 4) in Area 2 was lower than non-mitigated homes (Category 1), no statistical difference can be demonstrated. Therefore, the conclusion for Area 2 is the same as for Area 1 in that no reduction benefit was seen on radon ready installations.

RESULTS FROM BOTH AREAS COMBINED

In order to better answer the question that served as the hypothesis for this paper, both data sets were combined. This approach can be justified due to similarity of home construction, unmitigated levels and soil type. The only difference noted, however, was slightly different soil porosity. The comments made above regarding unmitigated homes (Category 1) with respect to mitigated homes (Categories 2, 3 and 4) remain the same when the data is combined. That is, any active mitigation system is beneficial and no benefit was derived from radon ready homes (See Table 5 below).

TABLE 5. RADON LEVEL MEANS AND STANDARD DEVIATIONS FROM BOTH AREAS

Category	Description	Number	Mean	Standard Deviation
1	Unmitigated	35	12.32	± 7.28
2	Post-construction mitigation	23	1.70	1.37
3	During construction mitigation	19	0.93	0.96
4	Radon ready	12	9.94	6.98

When all data is combined, including the anomalies mentioned earlier, one can determine statistically that systems installed during construction (Category 3) outperformed systems installed after construction (Category 2). Categories 2 and 3 are two distinctly different populations as verified by the one-tail t-test at the 98% confidence level.

IMPLICATIONS OF RESULTS

It is interesting to note that the existing homes that were mitigated after construction (Category 2) had a mean screening result of 1.70 pCi/L ± 1.40. Although this is at a level below the current EPA action level of 4.0 pCi/L, it is right at contemplated values for the new proposed guideline of 2.0 pCi/L. (Ref 7). Although it is reasonable to assume upper floors of these homes would be at lower concentrations of radon, it should be noted that due to terrain and architectural plans, many of these lower level floors contain family rooms and bedrooms. The adoption of 2.0 pCi/L guideline for living areas may be difficult to consistently achieve with mitigation techniques observed in this study.

Similarly, the homes that had active mitigation system installed during construction exhibited a mean result of 0.93 pCi/L ± 0.96. Within one standard deviation all of these Category 3 homes would exhibit screening levels beneath both the existing guideline of 4.0 pCi/L and the proposed guideline of 2.0 pCi/L.

The overall mean of new homes constructed with active systems (Category 3, mean 0.93) would lend partial credence to the (Option 1) prescriptive approach proposed in the draft model standards for new buildings. (Ref 8). However, the approach of not requiring, or not emphasizing post-occupancy testing may result in not identifying improper installations, as this study did. This may, on the other hand, speak to proper education of installers and the extension of the RCPP program to home builders as well as specialty radon mitigation sub-constractors.

The inability to distinguish between "radon ready" systems (Category 4) and non-mitigated homes reinforces the need for testing within 30 days of occupancy for a non-activated radon ready home. This is referred to as Option 2 of the Draft Model Standards for New Buildings. Furthermore, the results of Category 3 indicate the ability to reduce levels to below 2.0 pCi/L once the radon ready system is made active by addition of a fan. It would be prudent to emphasize testing after actuation of the system fan for the same reasons as indicated above.

Homeowners' understanding of proper system operation was inadequate in some cases. Interviews with participants indicated little information was passed on from previous homeowners or building contractors. This comment is more pertinent with respect to homes which were constructed with radon ready systems. In this case, some homeowners felt that a complete system had been installed. This can be dealt with either in a regulatory manner or perhaps a greater emphasis can be placed on the present Radon Contractor's Proficiency Program and particularly the Mitigation Guidelines (5).

The data made available from this study will, with further evaluation, offer opportunities to assess differences between finer points of mitigation installations. A more detailed review of homes in Categories 2 and 3 that fell outside the standard deviation of the mean can be made to assess these installation differences. A comparison of individual results to soil porosity and soil gas measurements can also be made in order to assist in developing a predictive model, at least for this geological area.

Furthermore, a more detailed review of Category 4 homes needs to be made to determine which radon ready approaches may offer the most cost effective benefit.

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