False negatives

A different analytical approach utilizes the empirical data collected in this study and the hypergeometric distribution. Instead of determining the percent of samples needed to achieve 95% confidence (Table 11), the percent sampled was fixed and the confidence level determined. Setting 95% confidence in Table 11 is equivalent to capping the errors at 5%. Instead of using the most difficult case to detect (Table 11), that is where a building only has one unit ≥ 4pCi/L, the data collected in this study is now used.

For each of the percentages sampled, the probability that the sample did not include any units ≥4 pCi/L was, at most, the percentage of units that are not sampled. For example, for 90% sampling, the error is 10%, at most. (This is under the assumption that there is one unit ≥4 pCi/L in the building). In this case, the maximum error is the percentage of un-sampled units.

Table 12. The number of units to test using various sampling percentages

Number of ground contact units	10% sampling	25% sampling	50% sampling	75% sampling	90% sampling
5	1	2	3	4	5
6	1	2	3	5	6
7	1	2	4	6	7
8	1	2	4	6	8
9	1	3	5	7	9
10	1	3	5	8	9
11	2	3	6	9	10
12	2	3	6	9	11
13	2	4	7	10	12
14	2	4	7	11	13
15	2	4	8	12	14
16	2	4	8	12	15
17	2	5	9	13	16
18	2	5	9	14	17
19	2	5	10	15	18
20	2	5	10	15	18
21	3	6	11	16	19
22	3	6	11	17	20
23	3	6	12	18	21
24	3	6	12	18	22
25	3	7	13	19	23
26	3	7	13	20	24
27	3	7	14	21	25
28	3	7	14	21	26
29	3	8	15	22	27
30	3	8	15	23	27

For the buildings in the study database with at least one positive unit, 27% had **only** one unit ≥4 pCi/L. These buildings therefore had the maximum error probability, which is the proportion of un-sampled units. The more units ≥4 pCi/L in a building, the lower the error probability.

The number of units sampled was determined by multiplying the percent sampled by the number of units in the building. If this result was not an integer, then the number was rounded up. For example, for 75% sampling of a building with 5 ground contact units, 4 units must be sampled because 75% of 5 is 3.75.

Table 13 presents the average error probabilities under the different sampling percentages. These estimates can be thought of as false-negative probabilities. The probability for each building is based on the number of units ≥4 pCi/L and the hypergeometric distribution. Appendix C presents the Monte Carlo bootstrap 95% confidence intervals for the average probabilities.

A similar analysis has been presented previously (Neri 2019). But that analysis presented sample size estimates to be 95% certain that less than 6.7% (the U.S. average) and 33.3% (for states with high radon levels) of units in the building had radon ≥4 pCi/L.

In buildings with all units below 4 pCi/L, one will make the right decision with testing any percentage of units, by definition. In buildings with at least one unit ≥4 pCi/L, one wants to ensure that the probability that sampling identifies at least one unit with elevated radon is high. This means that the false negative rate must be low.

Table 13. Average probability (%) of partial sampling missing a unit in a building with ≥4 pCi/L using various sampling percentages.

Number of ground contact units	Number of buildings	10% sampled	25% sampled	50% sampled	75% sampled	90% sampled
05-06	45	58	34	19	4.7	0.0
07-08	71	55	36	15	4.6	0.0
09-10	40	65	39	24	8.5	3.8
11-12	37	52	41	21	8.1	2.8
13-14	14	51	35	20	7.4	2.2
15-16	20	47	32	15	5.0	1.3
17-18	15	59	39	21	8.1	1.9
19-20	12	69	46	23	8.9	2.6
21-26	22	52	34	18	6.7	2.3
All	276	58%	38%	19%	6.5%	1.7%

Ground contact units only. Includes building with at least one unit ≥4 pCi/L. Note that for 90% sampling all units are tested for buildings with 9 or fewer units.

The calculation only included buildings with at least one unit ≥4 pCi/L so it was not sensitive to the prevalence of buildings with ≥4 pCi/L versus buildings containing all units below 4 pCi/L. The probability largely depends on the number of units ≥4 pCi/L in a building among the buildings with at least one unit ≥4 pCi/L. For the remainder of this section, the focus will be on buildings with a maximum of 26 ground contact units.

As shown in Table 13, the overall average false-negative probability was 19% for 50% sampling, 6.5% for 75% sampling, and 1.7% for 90% sampling. The error for an individual building could be as high as the proportion of un-sampled units.

<u>*Total error*</u>

Another way to examine sampling errors is to estimate the probability that a wrong decision is reached with partial sampling (Table 14). Specifically, this table shows the probability that testing results are all below 4 pCi/L and the building had at least one unit ≥4 pCi/L. These probabilities are found by multiplying the aforementioned false negative probabilities by the proportion of buildings with at least one unit ≥4 pCi/L. In this analysis, the total probability is 7.6% for 50% sampling, 2.5% for 75% sampling, and 0.6% for 90% sampling.

Table 14. Probability (%) of an incorrect decision with various sampling percentages.

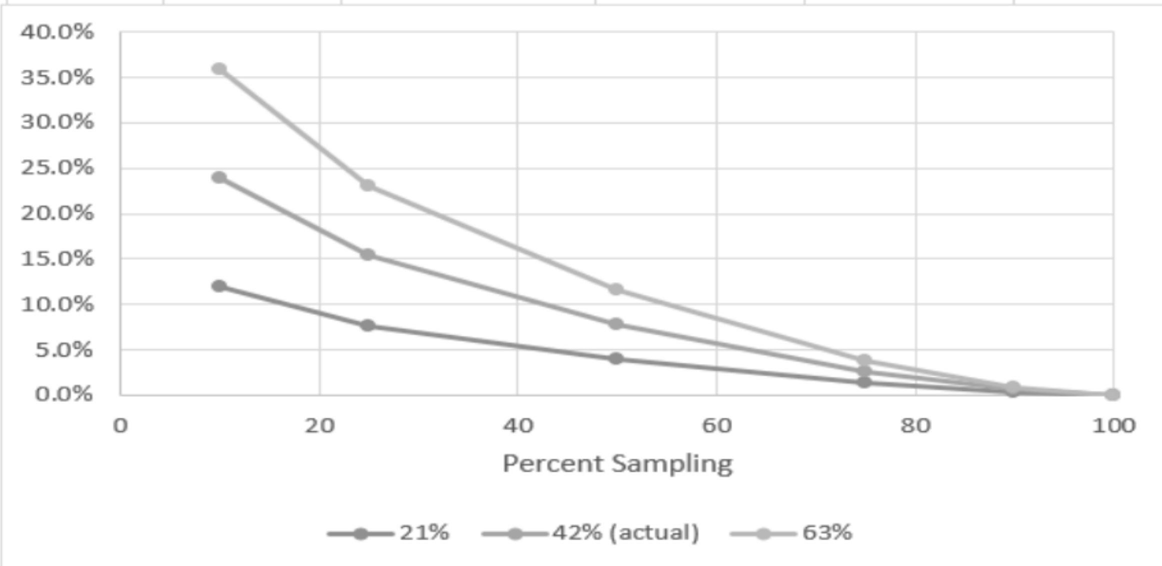
Number of ground contact units	10% sampled	25% sampled	50% sampled	75% sampled	90% sampled
05-06	21	13	7.3	1.7	0.0
07-08	22	14	6.0	1.9	0.0
09-10	26	15	8.7	3.0	1.3
11-12	19	15	7.6	3.0	1.0
13-14	20	14	8.1	3.0	0.9
15-16	22	15	7.1	2.3	0.6
17-18	30	20	11	4.3	1.0
19-20	33	22	11	4.3	1.2
21-26	34	22	11	3.8	1.2
Total	23%	15%	7.6%	2.5%	0.6%

Note that for 90% sampling all units are tested for buildings with 9 or fewer units.

These probabilities were very sensitive to the percent of buildings with any units ≥4 pCi/L. With a population of buildings that had a higher percent of buildings with any units ≥4 pCi/L, the total error could be calculated by multiplying the false negative rate in this study by the believed prevalence in the population of interest and the total error would be greater.

A sensitivity analysis was conducted to assess how the total error probability would change if the percent of buildings with any units ≥4pCi/L were 50% lower or 50% higher than the 42% observed (Figure 6). The total error stayed very low for 75% and 90% sampling.

Figure 6. Total error probability by percent sampling and percent of buildings with any radon ≥4 pCi/L (21%, 42% or 63%).



<u>*Reliability and measurement error*</u>

Sampling within units, buildings, and properties show the results were consistent and reliable but to varying degrees.

Observational error (or measurement error) is the difference between a measured value of a quantity and its true value. Measurement error itself is hard to interpret. Instead, the reliability ratio was examined. The reliability ratio shows overall consistency of a measure and ranges from 0 to 1, where 1 is perfect reliability.

Reliability can be defined operationally as the degree of correlation between two measurements taken in the same housing unit. In the radon context, it is the percent of the total variance in log-radon levels that is explained by the unit, or in other words, the percent of the total variances that is not explained by within-unit variability.

Model #1 – Reliability sampling within a dwelling unit

The dataset had 932 units with duplicate radon measurements (i.e., two radon measurements in the same unit) from 295 buildings on 138 properties. The reliability ratio for replicates within a unit was 0.95, which is very high. The reliability is a function of the total variability in log radon (1.30) and the measurement error variability (or within-unit variability) (0.06). Of the 133 side-by-side duplicate samples with one detector ≥4 pCi/L, only 16 detectors had the duplicate <4 pCi/L.

Model #2 – Reliability of sampling within in a building

This model estimated the reliability in sampling different units within a building. When <100% sampling of ground contact units is conducted, this model shows how sensitive the results are to the selection of units for sampling. Radon measurements from 7892 units in 687 buildings on 152 properties were included. Results found the reliability ratio for different units within a building was 0.73, which shows that sampling within a building was fairly consistent. The reliability is a function of the total variability in log radon (1.37) and the within-building variability (0.37).

Model #3 – Reliability of sampling within a property

This model estimated the reliability in sampling different buildings within a given multifamily property. Results allow the determination of the strength of the association of radon in different buildings on the same property. The model only included properties with more than one building sampled and included 7037 radon measurements (units) from 645 buildings on 110 properties. The reliability ratio for different buildings within a property was 0.65, which shows that sampling results within a property was still fairly consistent and a reliable predictor about two-thirds of the time. The total variability in log radon is 1.43 and the within-property variability is 0.5. The reliability is a function of the total variability in log radon (1.43) and the within property variability (0.50). Table M2-1 (in *EARTH Statistical Tables* file) presents the variability estimates for the models.

Selection of a Testing Plan

For multifamily housing, any radon testing plan must address three key factors: health, feasibility, and cost. In some cases, testing less than 100% of units is necessary because it may not be feasible to test all units on all floors. But in the case of testing multifamily buildings for radon, this barrier does not exist, since ground-contact units are much more likely to have elevated radon levels than units on upper floors. The vast majority of multifamily buildings in the US have 20 or fewer ground-contact units.

The data collected for this study demonstrates that radon measurement professionals are testing 100% of ground contact units as part of their work, and it is feasible to do so.

Given that it is feasible to test 100% of ground contact units, what are the benefits and trade-offs of a sampling plan? The main benefit of sampling fewer than all ground-contact dwellings is avoided costs for devices, laboratory analysis, and labor. A fair estimate of this savings would be $50 per dwelling not sampled. However, any decision to use less than 100% sampling will mean that some positive units could be missed. Missing units with elevated radon means that buildings will not be mitigated (but should be), and residents will be exposed to elevated radon and incur an increased risk for developing lung cancer.

On the cost side, EPA estimates that the lifetime risk of lung-cancer death for dwellings with an average radon level of 5 pCi/L is approximately 30 out of 1000 residents. Assuming two residents per home, then the lifetime risk is 60 lung cancer deaths per 1000 homes with an average radon level of 5 pCi/L (AAFP 2018). Based on the estimates below (Radon Risk Analysis), the cost per person with lung cancer is at least $280,000, so the cost per home is at least $16,800. Any dwelling that is missed by less than 100% sampling and is not mitigated has a cost of $16,800.

Can the savings be so great from testing as to accept this cost? Consider a 90% sampling plan. Such a plan would only be applied to buildings with 10 or more ground contact units. Because such a plan calls for rounding up to the next whole integer, 90% sampling in a building with 9 ground contact units (8.1) would result in all 9 units being tested. In this case, 90% sampling is the same as 100% sampling.

But for larger buildings with 10 or more ground contact units, the study found there were about 5,000 total ground contact units in the 300 buildings assessed. Sampling 90% would mean 500 units were not tested for a savings of $25,000 (10% x 5,000 x $50). Table 14 reports that for these 300 buildings, about 1% (3 units) with elevated radon would be missed. Therefore, the savings is about $8,333 per unit with elevated radon missed by employing a 90% sampling plan, while the cost is over $16,800 per unit.

This leads us to conclude that 100% sampling is an appropriate plan for multifamily radon testing.

Radon Risk Analysis

In 1999 the National Academies of Science (NAS) conducted a review of the medical literature to determine the potential health risk to the population exposed to radon concentrations at the concentrations found in dwellings. The National Research Council, the operating arm of the NAS, convened the Biological Effects of Ionizing Radiation (BEIR-VI) committee which found (NRC 1999) that studies on the development of radon related lung cancer were sufficient to derive valid risk estimates. The committee's central risk estimates of 15,400 to 21,800 radon-related lung cancer deaths per year in the US are in common use today.

The approach described by the BEIR-VI committee was applied to determine the reduction in lung-cancer risk associated with detection and mitigation of the 1693 units that contained radon levels ≥4 pCi/L in the study database. Estimates of radiological dose and risk of lung cancer were determined for the occupants of units which would not have measured had less than 100% testing (and subsequent mitigation) protocols been applied. These calculations to determine the added risk for radon-related cancer utilize the most current effective dose conversion factors regarding internal exposure to radon for occupants of housing units containing levels above the EPA action of 4 pCi/L.

Several factors were combined to develop the estimate of additional dose, including equilibrium ratio, occupancy factors, and dose conversion factors. Measurements of radon gas are related to the presence of short-lived radon progeny that dose lung cells using an equilibrium ratio (ER). Measured ER values in home indoor environments are generally near 0.4, depending primarily on ventilation conditions (Porstendorfer 1994).

Traditionally, radon progeny concentration is expressed as working level (WL) or approximately 100 pCi/L. WL can be related to equilibrium equivalent radon concentration (radon in secular equilibrium with its short-lived progeny) using Equation 1.

$$WL = ER * Rn\ level\ (pCi/L) * 1\ WL/100\ pCi/L \qquad \text{(Eq. 1)}$$

The exposure quantity is expressed as a dose quantity using dose conversion coefficients. Radon exposure can be expressed in working level months (WLM), as the cumulative exposure of 1 WL for 170 hr, a conventional definition of an occupational month based on 730 hours in a month.

The annual radon exposure is defined by Equation 2. The home occupancy factor for a year (0.7) was determined by using EPA *Exposure Factors Handbook* value of 16.4 h indoors at home per day (EPA 1997). It was also assumed that a person spends 350 d/y at home. For example, a person living for one year in a unit with 4 pCi/L, and assuming 70% occupancy and 0.4 equilibrium factor, receives about 0.6 WLM of exposure.

$$WLM/year = WL * Occ.Fact. * 12\ mo./yr * (730\ hrs/mo\ /\ 170\ hrs/mo) \qquad \text{(Eq. 2)}$$

Finally, a series of assumptions and models serve to convert exposure to dose. The International Commission on Radiological Protection (ICRP) derived an estimated excess lifetime lung tumor risk coefficient of $5x10^{-4}$ per WLM. This value is identical to the UNSCEAR (2008) estimate of $5x10^{-4}$ per WLM for human underground miner data and similar to the BEIR-VI (NRC 1999) estimate of $5.3x10^{-4}$ per WLM for the lifetime excess risk.

$$\text{Lung cancer cases/year} = \text{WLM/yr-person} * \text{cases/WLM} * 2\ \text{person/unit} * \text{units} \qquad \text{(Eq. 3)}$$

Using Eq. 3 and the calculated additional radiological dose, these models provide an estimate of the additional annual lung-cancer cases based on the increased risk for the occupants of units that may not have been measured (and mitigated) had less than 100% testing protocols been applied. It must be noted that several variables are considered when developing risk estimates due to radon exposure. Fluctuations in estimating the cumulative indoor radon progeny exposure relate to both spatial and temporal variation, time spent indoors, and conversion coefficients.

The models estimate that, for the 1163 units with indoor radon measurements >4 pCi/L, the detection and mitigation of those radon levels to 4 pCi/L would remove 712 WLM each year. Using the risk coefficient of $5x10^{-4}$ lung-cancer cases per WLM, mitigation of the units to 4 pCi/L would remove 7-8 lung cancer cases over a decade. In reality, radon mitigations of these 1163 units to below 2 pCi/L, would remove 1050 WLM and save an estimated 11 lives per decade. There are 25 million units in more than half a million multifamily properties with five or more units in the US (RHFS 2018).

The cost of a lung cancer case has been estimated in several ways. Mariotto (2010) estimated the lung cancer prevalence at 457,000 cases in 2020, with each case of medical treatment at a cost of $68,000-80,000 USD. Lost earnings for each lung cancer case are $210,000 (Bradley, 2008). In medical expenses and lost earnings alone, the cost of a single lung cancer case is $278,000-290,000, and therefore the cost of the 11 cases avoided ranges from $3 to $3.2 million.

Conclusions

A summary of nearly 8000 radon measurements in multifamily buildings quantified the probability of missing a ground contact unit containing radon using current partial-testing protocols of 10-25% in some federally assisted housing. Based on measurement data for building sizes of 5-20 ground contact units, the testing proportion that is necessary to assure the absence of units with elevated radon was determined for various sampling percentages. For buildings of 5-26 ground contact units, protocols of 10% and 25% of ground-contact units failed to identify an average of 47-69% and 34-46%, respectively, of the buildings with any ground contact units with radon ≥4 pCi/L. To achieve 95% confidence that no units in the building have radon ≥ 4pCi/L in buildings up to 20 units, 100% sampling is required. For the vast majority of multifamily building sizes, all ground floor units in multifamily buildings should be tested for radon.

APPENDIX A

Data Reporting Template

An Excel spreadsheet contained the columns below as a single row. Measurement professionals submitted completed spreadsheets.

Unit	Result	Test Type	Corner/End Unit	Entry Opens to Outside	Location	Location Other Description	Room Use Description	Start Date

End Date	Device Used	Device Manufacturer	Vents	Vent Status	Address	City	State	Zip

EPA Zone	Mitigation	Stories	HVAC	Subsidized Property	Lender-Initiated	Loan Type	Notes

APPENDIX B
Quality Control Summary

Summary of Quality Assurance Procedures for the EARTH Study

Detailed Quality Assurance requirements were provided in the Quality Assurance Plan dated Feb 26, 2018. In brief, they included the following:

1. All devices and laboratories used to measure the radon concentrations in multifamily buildings were to be approved for use by the National Radon Proficiency Program or the National Radon Safety Board and personnel deploying the samplers were certified by the National Radon Proficiency Program, and/or the National Radon Safety Board.
2. At least 5% blank samples and 10% duplicate samples were to be collected.
3. No more than 5% of data were to be missing or otherwise unusable.
4. All measurement equipment was to be calibrated at least annually.
5. All (100%) of the ground contact units were required to be tested as required by the ANSI-AARST MAMF standard, proficiency program certification, and state certifications (if applicable).

An Excel-worksheet template was used to import data from measurement professional's computer files, minimizing the potential for input errors. The template spreadsheet had embedded cell formulae to evaluate input values. Some columns and formulae were 'locked' to assure proper data were entered and evaluated.
Two levels of review were completed: One by the Field Operations Manager and the second by the study statistician.
The results of the QA procedures for this study are as follows:

- All devices, laboratories, and field testing personnel met the appropriate credential and calibration requirements.
- Of the 12,700 units potentially eligible for inclusion in the study database, 7,892 units were ultimately included following data cleaning. This exceeded the study goal of obtaining 7,000 units.

There were 932 duplicate samples collected exceeding the target of 10%. All but one of the results that were above 4 pCi/L were within the tolerance limit of ± 25%, exceeding the study goal. There were 6 other sets of duplicates that were outside the tolerance limits, but these were all well below 4 pCi/L, exceeding the study goal.

- 567 blank samples were collected, which exceeded the target of 5%. Over 98% of these had radon levels below 0.3 pCi/L, demonstrating no contamination.
- More than 95% of all buildings included in the final analysis dataset had 100% of ground contact units tested. In a few cases (less than 2%), not all ground-contact units could be accessed for testing or the results were determined to be invalid because they were outside tolerance limits.

This study and its large dataset met or exceeded the established quality assurance requirements.

APPENDIX C

Data Statistics

The following are statistical analyses in addition to those in Results and Discussion above.

Some notable associations between geometric mean radon under selected testing and housing characteristics are discussed below.

Assisted Living: Among the multifamily properties for which data were provided, 43% were assisted living facilities. The geometric mean radon level for 3,380 assisted living units was 1.35 pCi/L, which is 15% lower than the level in units in non-assisted living properties. The possible causes of this differential, such as resident control of HVAC, variations in site selection criteria, and operational or staffing considerations, may deserve further study.

Number of units		Geometric Means			Significance
Not Assisted Living	Assisted Living	Not Assisted Living	Assisted Living	Ratio: Not assisted to Assisted	p-value
4,512	3,380	1.35	1.17	1.15	<.001*

* A statistically significant difference

Unit Location: Data for the location of the unit within the ground contact footprint were available for nearly half of the buildings. Units located at the corner or end of buildings, which comprise 20% of ground-contact units, had a geometric mean radon level higher than units with adjacent units on at least two sides. This pattern is confirmed by the reality that an end unit will pull radon from a larger ground area than one inside the footprint.

Number of units		Geometric Means			Significance
Not Corner or End	Corner or End	Not Corner End	Corner or End	Ratio: Not corner or end to corner-end	p-value
2,849	760	1.09	1.35	0.81	<.001 *

* A statistically significant difference

Housing Subsidy: Information regarding the presence or absence of a federal subsidy (such as public housing, voucher, or project based assistance) is known for approximately 20% of the units. The units with some form of subsidy had a geometric mean radon level of 1.08 pCi/L, which was 26% lower than the geometric mean for unsubsidized units (1.46 pCi/L), suggesting that a subsidy may provide some degree of protection.

Number of units		Geometric Means			Significance
No Subsidy	Subsidized	No Subsidy	Subsidized	Ratio: No subsidy to subsidized	p-value
773	876	1.46	1.08	1.36	<.001*

* A statistically significant difference

HVAC System: For nearly 25% of units, data were provided for the type of HVAC system. The geometric mean radon level was higher in units with forced air systems supplying both heating and cooling than those with heating only (by 50%) and non-forced air systems (by 30%). The p-value from the test that at least one pair of the three group GMs are different is less than 0.001, indicating that at least one pair are different. Geometric mean radon in units with forced air with heating and cooling are significantly higher than buildings with forced air with heating only ($p<0.001$) and units with other HVAC systems ($p<0.001$). Geometric mean radon in units with 'other HVAC systems' (e.g., electric) are not significantly different than units with 'only forced air with heating' ($p=0.123$). Both systems are more prevalent in northern climates which contained a low percentage of units ≥4 pCi/L (Table 9) and thus lower geometric means.

Groups compared		Number of units		Geometric Means			Significance
First group	Second group	First group	Second group	First group	Second group	Ratio: First to Second	p-value
Forced Air (heating and cooling)	Forced Air (heating only)	1,522	148	1.33	0.86	1.54	<.001*
Forced Air (heating and cooling)	Other	1,522	190	1.33	1.02	1.30	<.001*
Forced Air (heating only)	Other	148	190	0.86	1.02	0.85	0.123

* A statistically significant difference

Multiple Test Dates: Only 5% of the units were in buildings with multiple test dates. The geometric mean radon level was significantly higher in units with multiple test dates than buildings with only one test date ($p<0.001$).

Number		Geometric Means		Significance
One Test Date	Two or More Test Dates	One Test Date	Two or More Test Dates	p-value
7,466	426	1.2(1.2-1.3)	1.8 (1.7-2.0)	<.001*

* A statistically significant difference

Lender Involvement: Most testing was lender-initiated (84%). The geometric mean radon level was significantly higher in HUD/FHA loans than other types of loans (p=0.045). Geometric mean radon levels for the lender transactions were measurably lower than the properties for which the testing initiation factor was unknown.

Lender involvement	Number of units	Percent of units	Geometric mean (95% CI) (pCi/L)	Percent ≥4 pCi/L
Unknown	1,284	16.3	1.8(1.7-1.9)	15.6
Yes, for HUD/FHA loan	6,314	80.0	1.2(1.2-1.2)	14.9
Yes, for another kind of loan	294	3.7	1.0(0.9-1.2)	7.5

Other notable radon analyses

1) For units with radon <4 pCi/L, determine if there is a difference in the unit geometric mean radon level between buildings where all units were <4 pCi/L and those where at least one unit was ≥4 pCi/L.

Any unit in building ≥4 pCi/L	Number of ground contact units	GM radon (pCi/L)	95% Confidence interval for GM
No	4,202	0.82	0.73 - 0.91
Yes	2,527	1.35	1.21 - 1.51
	6,729		

Ground contact units only

A mixed model that controlled for the correlations between units in the same building and property was used to test this analysis. The model only included units with radon <4 pCi/L. A fixed effect for any positive units in the building is included in the model. The model was used to test whether radon levels were different in units located in buildings with any units ≥4pCi/L than in buildings with all units <4 pCi/L.

Units in buildings with at least one unit ≥4 pCi/L had significantly higher GM radon than units in buildings with no elevated radon (1.35 versus 0.82 pCi/L; p<0.001). The presence of a positive unit serves as an indicator for greater risk in such buildings. The variance parameters are presented in Table P1-2 of the EARTH Statistical Tables file

2) In units with radon <4 pCi/L, determine if there is an association between their geometric mean radon level and the percent of units with radon ≥4 pCi/L in the building. (Table P1-2 in EARTH Statistical Tables file)

A mixed model that controlled for the correlations between units in the same building and property was used to test this analysis. The model only includes units with radon <4 pCi/L. A fixed effect for the percentage of positive units in the building is included in the model. The model is used to test whether radon levels were higher as the percent of positive units in the building increased.

There was a statistically significant association between the GM of the units and the percentage of units with radon ≥4 pCi/L ($p<0.001$). Each increase of 10% in the percent of buildings with radon ≥4 pCi/L was associated with a 13% increase in the GM of units. The variance parameters are presented in Table P1-2 (in *EARTH Statistical Tables* file).

3) Bivariate analysis

Results of an analyses to determine whether GM radon levels are different for selected testing and housing characteristics by unit are presented in Table B1-1 (in *EARTH Statistical Tables* file).

Evaluation is based on analysis of variance (ANOVA) models for each testing and housing condition considered. Unknown responses are excluded. The overall p-value is the observed significant level from the statistical test that at least one pair of group comparisons are different. The group p-value is the observed significance level from the test that the first and second groups are different. If there are only two groups for the variable, then the two p-values are equal. For example, if the only responses are yes and no (like assisted living) then the only comparison is yes versus no and the two p-values area identical.

The more comparisons that are made between groups, the more likely that erroneous decisions are made. The Bonferroni adjustment of the group p-values was used to adjust the threshold p-values for significance. So instead of comparing each group comparison p-value to the selected significance p-value of 0.05, we use 0.05 divided by the number of pairs of group comparisons. Comparisons that are statistically significant at that adjusted p-value level are marked with "*".

For example, consider "assisted living" in Table B1-1. The Table shows that:

- The first group is Assisted Living = Yes, the GM is 1.35
- The second group is Assisted Living = No, the GM is 1.17
- The column labeled "Overall p-value(1)" is from the test that at least one pair of the first and second group comparisons is different
- The first group over second group GM is 1.15. In other words, the assisted living GM is 15% higher than the non-assisted living group. There is only one comparison so p-value threshold for significance is 0.05 and the comparison is statistically significant.

Table B1-1 includes all comparisons between responses for a variable. For example, for the "Building American Climate zone" there are 5 possible zones (COLD, HOT-DRY, HOT-HUMID, MARINE and MIXED-HUMID). This means that there 10 zone comparisons. Table B1-1 shows that

- The GM for COLD BA climate zone is 1.14 pCi/L
- The GM for HOT-DRY BA climate zone is 2.28 pCi/L

- The column labeled "Overall p-value(1)" is from the test that at least one of the ten pairs of the first and second group comparisons is different. P<0.001 so there is at least one pair is significantly different.
- The first group over second group GM is 0.5. In other words, the COLD GM is 50% that or the HOT-DRY GM. This is a statistically significant difference between the two GMs because the p-value is less than 0.005 (0.05/10).

4) Determine if there is a difference between buildings with a positive on upper floors and buildings without a positive on upper floors.

Radon measurements on an upper floor were taken in 257 buildings. Seven percent (18) of those buildings had upper floor measurements ≥4 pCi/L. These would be reduced following remediation of the building due to elevated radon in ground-contact units.

Table H1-1 describes differences in ground contact units and buildings by the presence or absence of radon ≥4 pCi/L in any **upper floor** units. All radon metrics were much higher in buildings where a unit on an upper floor was ≥4 pCi/L.

Table H1-1. Mean ground-contact unit radon levels and percent ground-contact units with radon level ≥4 pCi/L for buildings with or without any upper floor units with radon level ≥4 pCi/L.

Upper floor radon ≥4pCi/L	**Number of buildings**	**Percent of buildings with at least one ground contact unit ≥4pCi/L**	**Ground contact units**			
			Number of units	**Arithmetic mean**	**95% Confidence interval**	**Percent ≥4 pCi/L**
Y	18	94.4	250	7.35	6.13 - 8.57	50.8
N	239	45.6	2745	2.22	2.12 - 2.32	13.8

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