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Evaluation of percentage-based radon testing requirements for federally funded multi-family housing projects

Antonio Neri
Preventive Medicine Residency and Fellowship, Population Health Workforce Branch, Division of Scientific Education and Professional Development, Centers for Surveillance, Epidemiology and Laboratory Support, Centers for Disease Control and Prevention, Atlanta, Georgia

Abstract

Radon is a leading cause of lung cancer. Recommendations for radon testing in multi-family housing focus on testing a percentage of all units. There is considerable variability among recommendations as well as their implementation. I used the hypergeometric distribution to determine the probability of identifying one or more units with radon at or above 4.0 pCi/L for two prevalences (1:15, the U.S. average) and 1:3 (for states with many homes with radon ≥4.0 pCi/L) using two approaches. First, the distribution was used to evaluate the probability of finding one or more units with radon at or above 4.0 pCi/L when: (1) testing 10% or 25% of a range of ground-floor units; or (2) testing a varying percentage of units in 10-, 20-, or 30- ground-floor unit buildings. Second, the method was used to determine the number of units to be tested to identify one or more units with radon at or above 4.0 pCi/L with 95% probability, given a range of total ground-floor units. Analyses identified that testing 10% or 25% of ground-floor units had low probability of identifying at least one unit with radon at or above 4.0 pCi/L, especially at low prevalence. At low prevalence (1:15), at least 10 units need to be tested in structures with 20 or fewer total units; at high prevalence (1:3), at least 5 units need to be tested in units with structures having 10 or fewer units to achieve 95% probability of identifying at least one unit with radon at or above 4.0 pCi/L. These findings indicate that recommendations for radon testing in multi-family housing may be improved by applying a well-established and more rigorous statistical approach than percentage-based testing to more accurately characterize exposure to radon in multifamily housing units, which could improve lung cancer prevention efforts.

CONTACT Antonio Neri ANeri@cdc.gov Centers for Disease Control and Prevention, 1600 Clifton Rd. MS V24-5, Atlanta, GA 30329.

Disclaimer
The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention (CDC).

Conflicts of Interest
This research was an effort to address questions about radon testing posed by public, private, and academic partners working to identify and control radon exposure. The author has interacted with members of the American Association of Radon Scientists and Technologists (AARST), a professional membership organization, as a part of his work in this field on this and other research. AARST sponsored a portion of Dr. Neri's travel to attend the Annual International Radon Symposium and Trade Show to present his research in 2015. He has not received any funding from AARST directly for any of his radon-related research.

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Keywords

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Introduction

Radon is a colorless, odorless gas that is a radioactive decay product of uranium and is well established as one of the leading causes of lung cancer.[1–3] Testing using passive or active radon measurement devices is the only way to determine radon concentrations and subsequent risk to human health.[4] The Environmental Protection Agency has estimated the average indoor radon level by county in the U.S. to help homeowners and occupants determine the risk of radon exposure above the action level.[5] It is estimated that more than 36% of the U.S. population lives in rental housing, but a higher percentage (~40%) of families who are at or below the federal poverty level live in multi-family housing.[6,7] In addition, it is estimated that 69% of an individual's time is spent in their residence, indicating a potentially extensive duration of exposure to indoor air contaminants.[8] It is important that testing procedures accurately assess the risk for radon exposure in residential buildings to prevent exposure to this known carcinogen. Two agencies have radon testing recommendations for multi-family housing. These recommendations and their interpretation vary considerably, and following one over another may result in differences in identifying risk of exposure to a substantial proportion of the U.S.

One radon testing recommendation comes from the U.S. Department of Housing and Urban Development's (HUD) Federal Housing Administration (FHA).[9] This program has provided mortgage insurance to over 34 million properties since 1934 and is the largest mortgage insurer in the world. Since 2013, HUD has required that applications for mortgage insurance for multi-family buildings include proof of radon testing.[9] Radon testing for FHA-supported mortgages must be in accordance with the protocol developed by the American National Standards Institute (ANSI) and American Association of Radon Scientists and Technologists (AARST) in 2016 (also known as ANSI-AARST Measurement, Air, Multifamily (ANSI-AARST MAMF)).[10] While ANSI-AARST MAMF 2016 calls for testing 100% of ground floor units and 10% testing on upper floors, the 2013 HUD recommendations only require testing at least 25% of ground-floor units in each building on a property. According to the HUD and ANSI-AARST protocol, if any unit has a radon test at or above 4.0 pCi/L, the owners are required to mitigate the radon in the structure.[9,10] In addition, since 2006, the U.S. government-sponsored Federal National Mortgage Association and Federal Home Loan Mortgage Corporation (also known as Fannie Mae and Freddie Mac) require radon testing of multi-family housing. These recommendations state that owners are required to test "*a minimum of 10 percent of the units, or one unit per building* [of] … *units on the lowest habitable floor*." These recommendations also state that "*all elevated radon results require further testing and, in addition, the consultant must indicate* [to Freddie Mac] *the cost of potential remediation*."[11]

However, radon professionals have indicated that individuals testing multi-family housing for radon may interpret these recommendations differently, and one state health department has reported confusion from inquirers about the recommendations.[12] The variety of radon testing recommendations and varying application indicate a need to evaluate the effectiveness of using percentage-based testing recommendations to more accurately identify radon in multifamily housing.

Previous work by HUD has developed guidance regarding the minimum number of units to test for lead-based paint in multi-family housing which can inform the evaluation of percentage-based testing for radon.[13] The hypergeometric distribution has been used in the HUD lead-based paint testing guidance for multi-family housing to determine the probability of detecting a specific characteristic (e.g., a unit with lead-based paint) when sampling units at random, without replacement. This method calculates the probability of finding at least one unit with a given characteristic given that a certain number of units are tested.

The HUD lead-based paint recommendation establishes the minimum number of units to be tested in order to determine with 95% probability that the tester will identify at least one unit with lead-based paint assuming a given prevalence of units with lead-based paint. Similarly, this approach can be applied to determine the probability of identifying at least one unit with radon at or above 4.0 pCi/L if one tests a certain number of units. The hypergeometric distribution can be used to help develop guidance for how many units need to be tested assuming a certain number of units will have radon at or above 4.0 pCi/L to determine with 95% probability that at least one unit with radon at or above 4.0 pCi/L will be identified in a given sample.

This article describes an evaluation of percentage-based radon testing recommendations for multi-family housing using the established hypergeometric distribution methodology. In addition, this paper explores alternatives to percentage-based testing to improve the specificity of radon testing in multi-family housing.

Methods

The hypergeometric distribution was used, as previously described by HUD, to evaluate the probability of identifying at least one unit with radon at or above 4.0 pCi/L (referenced hereafter as “high radon”) in a given number of units available to be tested.[13] The key inputs needed for the hypergeometric distribution are the prevalence of units with high radon and the total number of units available to be tested. Because of the paucity of published information about the prevalence of units with high radon in multi-family housing, two prevalence rates were used as inputs for single family homes in the U.S.: (1) the EPA-reported average radon concentrations (1 in 15 homes as high radon, hereafter listed as 1:15); and (2) the EPA-reported prevalence in areas with elevated radon concentrations (1 in 3 homes as high radon, hereafter listed as 1:3).[4]

Two approaches were taken to assess percentage-based radon testing recommendations using a prevalence of either 1:15 units or 1:3 units with high radon. The first approach determined the probability of identifying at least one ground-floor unit with high radon over a range of 10–100 units, when testing 10% or 25% of all ground-floor units. The second approach evaluated three scenarios with a total of 10, 20, or 30 ground-floor units over a range of percentage of total units tested. Finally, the minimum number of units to test over a range of total ground-floor units was determined in order to find at least one unit with high radon with 95% probability. All analyses were done in the open-source R statistical package (Version 3.0.2, R Foundation for Statistical Computing, Vienna, Austria).

The following assumptions were made for this analysis.

1. Identification of one unit as high radon would result in either further testing of all units or installation of a radon mitigation system for the structure.
2. Percentage-based recommendations would be applied individually to each structure that shares a common footing, basement, or crawlspace on the property as these would presumably have approximately the same potential for radon intrusion into the livable spaces.
3. The percentage-based guidance being evaluated and recommendations generated by our analyses applied solely to habitable units on the level closest to the ground, as limited published information indicates that these units have higher radon levels than the units above.[14–16]
4. Radon prevalence in multi-family units approximated that in single-family homes.
5. Radon concentrations in each unit of a multifamily housing complex were unrelated.

Results

Figure 1 depicts probability of detection as a function of total ground floor units available for testing for each percentage-based testing approach. As anticipated, the probability of identifying at least one unit with high radon (≥4.0 pCi/L) was higher for all assessments in situations with greater prevalence of high-radon units (1:3) vs. low prevalence (1:15). The probability of identifying at least one unit with high radon was less than 60% for structures with less than 10 ground-floor units for either prevalence when testing 10% of all ground floor units. If the testing scheme used only a random selection of 10% of all ground-floor units, the number of ground-floor units had to be greater than 35 at the higher (1:3) prevalence rate of radon and had to be 85 units at lower (1:15) prevalence in order to have 95% probability of identifying at least one with a high radon level. If the testing scheme used a random selection of 25% of all ground floor units, the number of ground floor units available for testing had to be greater than 20 at high prevalence rates of radon and greater than 100 at low prevalence of radon in order to have 95% probability of identifying at least one with a high radon level.

Figure 2 illustrates the probability of identifying one or more units as high radon as a function of testing a fixed percent of units (X-axis) in structures that have 10, 20, and 30 ground-floor units. In order to identify at least one unit with high radon in a structure with 95% probability, one would need to test more than 95% of all ground-floor units in a structure with 10 ground-floor units (essentially all 10 units), 75% of all ground-floor units in a structure with 20 ground-floor units (test 15 units), and 75% in a structure with 30 ground-floor units (test 23 units) if the true radon prevalence is at the low (1:15) level. At the higher prevalence (1:3) one would need to test 55% in a structure with 10 ground-floor units (test 6 units), 35% in a structure with 20 ground-floor units (test 7 units), and 25% in a structure with 30 ground-floor units (test 8 units) to achieve 95% probability of identifying at least one unit with radon levels at or above 4.0 pCi/L.

The minimum number of units that would need to be tested by unit size for both prevalence assumptions in order to obtain 95% probability of identifying at least one unit with a high radon is listed in Table 1. At the lower prevalence rate (1:15), in a structure with 20 ground-floor units or fewer, a minimum of 10 units would need to be tested to achieve a 95% chance of identifying at least one unit with high radon. At the higher prevalence rate (1:3), in a structure with 10 or fewer units, a minimum of five units would need to be tested to achieve the same goal.

Discussion

This analysis indicates that the current recommendations for percentage-based testing likely do not accurately identify the risk for radon exposure in multi-family housing. Specifically, testing 10% or 25% of all ground-floor units results in a generally low probability of identifying units with radon levels at or above 4.0 pCi/L in structures with fewer than 30 ground-floor units where radon prevalence is high and fewer than 100 units where radon prevalence is average. In addition, these results indicate that any approach based upon testing a percentage of units will have marked variability in the probability of identifying units with radon above the current EPA action level (4.0 pCi/L). Finally, the hypergeometric distribution can be used to calculate the number of units that would need to be tested to achieve 95% probability of identifying at least one unit with radon at or above 4.0 pCi/L for a range of units.

These results indicate that the current percentage-based testing approaches may incorrectly classify some multi-family housing units as free from radon risk based on too few samples. The potential for inaccurate classification of a property as not having radon could result in occupants being unknowingly exposed to radon levels above the EPA action level and could place occupants at greater risk of developing radon-induced lung cancer. This study indicates that a potential solution to this would be to apply the methodology used to develop the HUD lead-based paint testing recommendations for multi-family units to more accurately identify radon exposure risks and prevent lung cancer.

The HUD FHA and Fannie Mae/Freddie Mac mortgage insurance programs are the largest in the world and their policies carry substantial impact. In 2014, HUD’s Federal Housing Authority program insured 192 mortgages for multi-family rental housing totaling $2.9 billion.[17] In 2017 alone, Fannie Mae/ Freddie Mac insured more than $280 billion in loans to multi-family housing projects.[18] Because these insurance programs have radon recommendations, many of the buildings purchased may be tested for radon. A revision to the policies of these and other lenders of funds for multi-family housing to a more robust statistical approach than percentage-based testing would improve the accuracy of radon testing and affect more than 100 million people living in multi-family housing in the U.S. Decreasing exposure to radon through improved testing in such a substantial proportion of the U.S. population has potential to prevent a portion of the more than 21,000 cases of radon-related lung cancer each year.

The approach applied here has a number of limitations that need to be addressed in further research. Most importantly, this conservative approach assumes there is no correlation between the radon test results in one multi-family unit when compared to another within the same structure. Although little information exists about this correlation, Antignani et al.[19] indicated a 25–48% coefficient of variation between radon concentrations in adjacent rooms of an office building on the first and ground floor, respectively. As an indicator that radon concentrations in adjacent units may be correlated, a few recent studies have noted some correlation between fine particulate matter and airborne nicotine levels in smoker-occupied apartments vs. adjacent non-smoker apartments or hallways.[20,21] Should there be correlation between radon levels in adjacent apartments, it may be that fewer units than indicated here would need to be tested in order to achieve 95% probability of identifying at least one unit with radon at or above 4.0 pCi/L (i.e., the estimates provided by this analysis may be conservative, resulting in more testing than necessary). Future analyses should evaluate correlations in radon concentrations between units in the same building and how it relates to both existing multi-family housing as well as new construction in the U.S. Second, in the absence of thorough testing information in multi-family housing an assumption was made that the prevalence of units at or above 4.0 pCi/L in multi-family housing is approximately the same as that in single-family housing. As multi-family buildings have a host of different construction and building ventilation issues vs. single-family homes, this may not be the case and more research is needed to better evaluate these differences. Finally, applying these recommendations to actual test results would help validate the theoretical approach.

Conclusions and recommendations

While this analysis has provided an additional method to determine how many units in a multi-family building need to be tested for radon, much work remains to be done to clarify or improve existing radon testing recommendations. Additionally, guidance is needed for what units to test (i.e., ground floor units versus units on higher-level floors), what to do if multiple separate structures exist on the property (i.e., is testing one structure sufficient), what to do with a radon test result that is at or above 4.0 pCi/L (i.e., further testing, and if so how much and where, or mitigation, and if so, which units/structures), and cost-effectiveness analyses specific to multi-family housing. In addition, further analyses may be necessary to estimate the impact of more accurate radon testing using the hypergeometric distribution approach evaluated here if it were to be implemented in institutions that fund a substantial proportion of multi-family housing in the U.S. These analyses provide a starting point for a discussion to improve radon testing in multi-family housing to ensure better public health protection.

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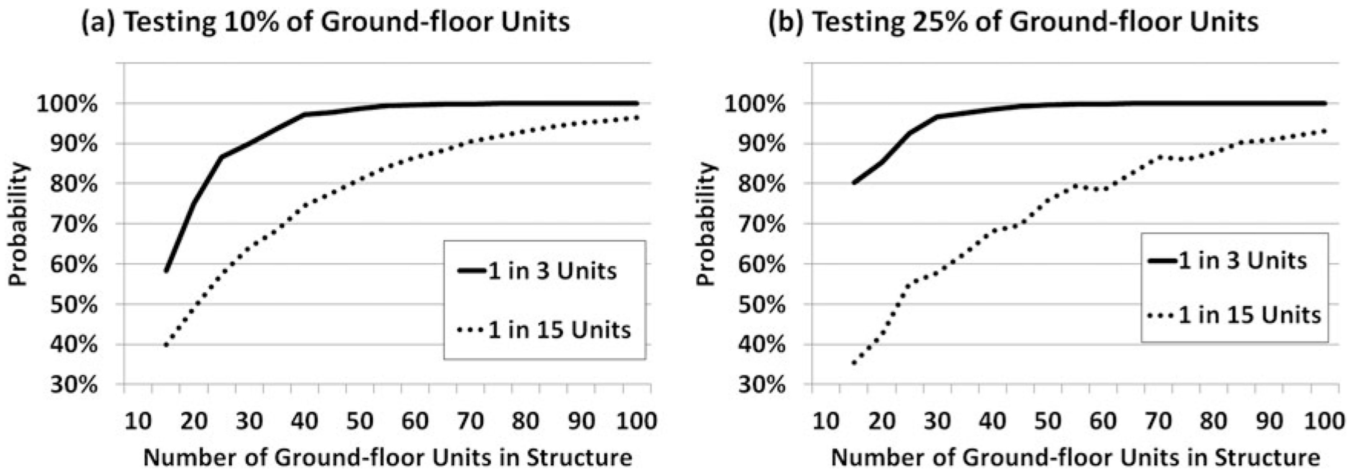

Figure 1.
Probability of identifying one or more units with radon at or above 4.0 pCi/L as a function of total ground floor units when testing (a) 10% and (b) 25% of all ground floor units at radon prevalence of 1:3 (solid line) and 1:15 (dashed line).

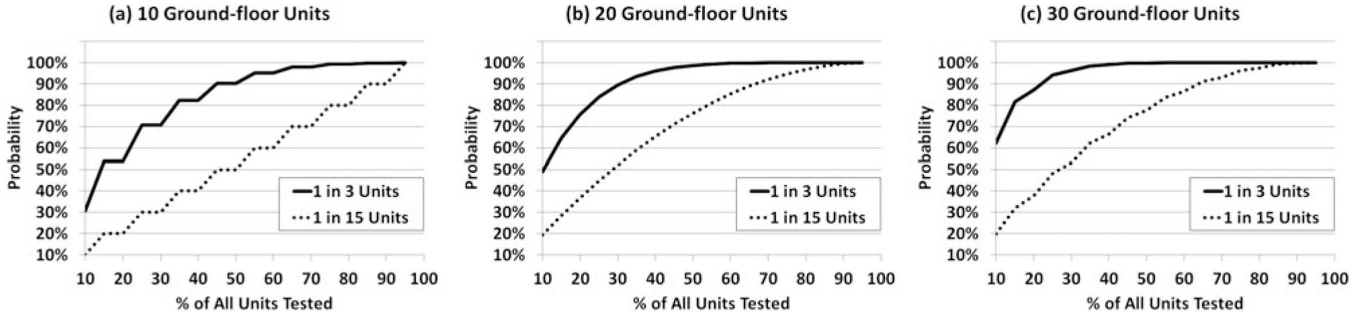

Figure 2.

Probability of identifying one or more units with radon at or above 4.0 pCi/L as a function of testing a range of percent of units in structures with (a) 10-, (b) 20-, or (c) 30- ground floor units at radon prevalence rate of both 1:3 (solid line) and 1:15 (dashed line).

Table 1.

Minimum number of units needed to be tested by total number of ground floor units in order to achieve 95% probability of finding one or more unit with radon at or above 4.0 pCi/L at radon prevalence of 1:3 and 1:15.

Total Number of Ground-floor Units	Prevalence 1:3 Number to Test	Prevalence 1:15 Number to Test
10	5	10
15	6	10
20	7	10
25	7	12
30	8	14
35	8	15
40	8	17
45	9	19
50	9	19
55	9	20
60	9	22
65	9	22
70	9	23
75	9	25
80	9	25
85	9	25
90	10	27
95	10	27
100	10	27