Environmental Health & Engineering, Inc.

Predicted Indoor Radon Concentrations from a Monte Carlo Simulation of 1,000,000 Granite Countertop Purchases

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ABSTRACT

Objective

Previous laboratory and field based research has shown that there is a negligible health risk from radon from granite countertops. We expanded upon this analysis, using a Monte Carlo simulation, to determine the actual probability that installing a granite countertop in a residential home would lead to a meaningful health risk.

Methods

We conducted a Monte Carlo analysis and simulated 1,000,000 granite countertop purchases to obtain a distribution of indoor radon concentrations due to the granite countertops. The analysis considered information on the likelihood that a particular type of stone would be purchased, the size of the countertop installed, the size of the home, and ventilation rate of the home. For each of the 1,000,000 simulations, the predicted indoor radon concentration from each scenario was determined.

Results

The results of the Monte Carlo simulation show that there is an extremely low probability of a granite countertop causing elevated levels of radon in a home.

- 999,513 of the 1,000,000 simulations (99.95%) produced indoor radon concentrations less than the level that is typically found outdoors in the U.S. (0.4 picocuries per liter [pCi/L]).

- The median predicted indoor concentration from granite countertops from these 1,000,000 simulations was 0.0003 pCi/L. This value is 10,000 times lower than the U.S. Environmental Protection Agency (EPA) action level for indoor radon of 4 pCi/L.

- There was only a 1 in 1,000,000 chance of a granite countertop producing a radon concentration of 3.5 pCi/L or greater. This "worst-case" scenario was a result of an improbable scenario that included installing a large countertop (109 ft^2) into a relatively small home (800 ft^2) with an air exchange rate that is typically found in a "tightly" constructed home (0.20 air changes per hour), and where the radon

emission rate was nearly 3 times higher than the highest actual measured emission rate from a full slab of granite.

- The combined probability of developing lung cancer from this "worst-case" scenario is over 1 in 100 million. This is calculated from the Monte Carlo simulation, which showed that the probability of having this extreme scenario exist is 1 in 1,000,000, and then applying EPA's estimate of the risk of developing lung cancer from a 4 pCi/L exposure of 7 in 1,000 for non-smokers. Therefore, the population-level risk of installing a granite countertop installation that leads to 4 pCi/L or greater in the home, and that installation leading to lung cancer, is 7 in 1,000,000,000 (1 in 1,000,000 x 7 in 1,000). For smokers, the population-level risk is 23 in 1,000,000,000.

INTRODUCTION

Radon is a gas that comes from the natural decay of uranium in soil. Radon from soil is present in the outdoor air and can also penetrate into buildings and homes from the surrounding soil, where it can build up into higher concentrations than are found outdoors (EPA, 2007). Because it is so common, radon can be detected in outdoor air and in homes all across the United States. Radon is of concern because it is a known lung carcinogen (i.e., causes lung cancer) (EPA, 2003; NRC 1999). The amount of radon in air is measured in units called picocuries per liter of air, or pCi/L.

Granite countertops were the subject of a media scare in 2008 after a group claimed that radon from granite countertops presented a health risk to homeowners. The claims were quickly shown to be based on faulty science and lacked merit. Because granite is a natural product that is mined from the Earth, it is true that granite can emit low levels of radon gas. This has been known for a long time and is similar to other building products that contain naturally occurring materials that emit radon such as concrete and gypsum (i.e., wallboard or drywall) (Ingersoll,1983; Mustonen, 1984; Chao and Tung, 1999; Petropoulos et al., 2002; Stoulos et al., 2003; Maged and Ashraf, 2005; de Jong et al., 2006; Kobeissi et al., 2008; Ngachin et al., 2008;Sonkawade et al., 2008). However, since many products emit low levels of chemicals and gases the important question to ask is—are these emissions meaningful to health? In the largest study of radon exposure from granite countertops that has been conducted to date, it was shown that radon emissions from granite countertops do not lead to radon concentrations in the home that are as high as those typically found outside, and most often result in concentrations that are well-below outdoor levels and would not even be detectable without specialized equipment (Allen et al., 2010). That study has been peer-reviewed, published in a scientific journal, and the results presented at scientific conferences across the country.

The goal of the research presented in this paper was to calculate the actual probability of an exposure from granite countertops that might lead to a potential health concern. This was done by using a standard statistical modeling technique called Monte Carlo simulation in which we simulated 1,000,000 granite countertop purchases and estimated the indoor radon concentration from the granite countertop for each purchase. The end results are a distribution of potential indoor radon concentrations from granite countertops installed in a distribution of homes that mirror the U.S. housing stock. By simulating so many purchases, we allow for the possibility of a true "worst-case" scenario and, most importantly, determine the probability of that scenario occurring.

METHODS

Monte Carlo Simulation Overview

Monte Carlo simulation refers to a commonly used and widely accepted statistical technique that uses repeated random sampling of multiple variables to yield the distribution of potential outcomes (Cullen and Frey, 1999; Robson and Toscano, 2007). The outcome of our Monte Carlo simulation is the predicted indoor radon concentration in a home due to the full range of potential granite countertop installations.

The predicted indoor radon concentration depends on several factors, including: type of granite purchased, radon emission rate for that type of granite, amount of granite countertop installed, size of the home where the countertop is installed, and ventilation rate of that home. Our Monte Carlo analysis simulated 1,000,000 granite countertop purchases. For each purchase, the simulation picked a value for each of the parameters based on a distribution of possible values and then calculated the predicted indoor radon concentration. This was then repeated 1,000,000 times and the result was the full distribution of expected indoor radon concentrations due to granite countertops. The distributions for each of the input parameters are discussed in the following sections and the results for input parameters based on the Monte Carlo simulation are provided in the Appendix.

Predicted Indoor Radon Concentration

The parameters described in the previous section can be combined to yield a predicted indoor radon concentration for a home, measured in picocuries per liter (pCi/L), using the following formula:

$$\text{Radon Concentration (pCi/L)} = \frac{\text{Radon Emission Rate (pCi/ft}^2\text{/h)} \times \text{Surface Area of Granite (ft}^2\text{)}}{\text{Volume of Home (ft}^3\text{)} \times \text{Ventilation Rate (1/h)} \times 28\ \text{L/ft}^3}$$

Factors that Influence Radon Concentrations

Type of Granite Purchased and Radon Emission Rate

The likelihood of purchasing a particular type of granite (often designated by color) for each simulated purchase was determined based on the percentage of market share for each stone. Market share percentages were calculated by analyzing sales data from 13 of the largest granite suppliers in the U.S. who submitted sales data representing nearly 800,000 countertop sales. For example, our market share analysis showed that the stone color “New Venetian Gold” accounted for 5.4% of sales. Therefore, the probability of selecting this color in each simulated purchase was 0.054.

Previous testing measured the radon emission rate for 124 types, or colors, of granite (Allen et al., 2010; EH&E, 2009; EMSL, 2008). These types accounted for nearly 80% of the types of granite sold, based on the market share analysis. After the color was chosen in each simulated purchase, the corresponding slab-average radon emission rate for that color was determined based on previously published data (Allen et al., 2010; EH&E, 2009; EMSL, 2008). For some colors, multiple slab-average radon emission rates were available and the emission rate data fit a lognormal distribution. Therefore, if this color stone was chosen for a particular simulation, the Monte Carlo analysis chose an emission rate for that stone purchase based on the distribution of possible values.

Amount of Granite Countertop Installed

Sales records from over 10,000 countertop purchases were used to determine the distribution of granite countertop sizes sold for kitchen installations. The database also included over 800 records for countertops purchased for installation in bathrooms. The data indicated that the size ranges fit a lognormal distribution (Table 1).

Table 1 Distribution of Countertop Sizes (ft^2) for Bathroom and Kitchen Countertop Installations						
Room	**n**	**Mean**	**St Dev**	**Median**	**5th Percentile**	**Max**
Bathroom	869	18	12	15	7	103
Kitchen	10,685	49	20	47	21	206

ft^2 square feet
n number
St Dev standard deviation

For each simulated purchase, we assumed that a person purchased both a kitchen and bathroom countertop. The model selected the countertop size for the kitchen and bathroom for each simulated purchase. The total size of the kitchen and bathroom installations were added together to yield the total square footage of installed countertop. Last, the total square footage was multiplied by 2 to account for radon emissions that could occur from the underside of the granite countertops. We limited the lower size range to the 5th percentile value from the sales records (21 ft^2 for kitchen; 7 ft^2 for bathroom), and used the maximum as the upper limit (206 ft^2 for kitchen; 103 ft^2 for bathroom).

Size of Home

We used nationally-representative data from the U.S. Department of Housing and Urban Development (HUD) American Housing Survey (AHS) from 2009 (Table 2) to determine the distribution of home size across the U.S.

Table 2 Distribution of Homes Sizes for Single Detached and Manufactured/Mobile Homes in the U.S. (2009)			
Group	**Size (square footage)**	**87,717**	**Percent of Total**
1	Less than 500	764	0.9%
2	500 to 749	2,303	2.8%
3	750 to 999	5,847	7.1%
4	1,000 to 1,499	20,410	24.8%
5	1,500 to 1,999	20,115	24.4%
6	2,000 to 2,499	14,077	17.1%
7	2,500 to 2,999	7,448	9.0%
8	3,000 to 3,999	7,115	8.6%
9	4,000 or more	4,343	5.3%
	Not reported (includes don't know)	5,295	Not included

A discrete distribution function was used in the Monte Carlo simulation. For each simulated purchase, the model selected a house size group for each granite purchase based on the percentages (i.e., probabilities) listed in Table 2. After the size group was selected, an actual house size was selected from within the size group assuming a uniform distribution within the group. For example, if a simulated purchase selected group 4, the simulation would then select an actual size home ranging from 1,000 to 1,499 ft^2, assuming an equal probability for any value between 1,000 – 1,499 ft^2. The selected house size, measured in square feet, was then multiplied by a ceiling height of 8 feet to yield the volume of the house in cubic feet (ft^3).

Ventilation Rate of Home

We used published ventilation rates from a study of 2,844 U.S. homes to determine the distribution of ventilation rates, in units of air changes per hour (ACH), for residences across the U.S. (Murray and Burmaster, 1995). The data follow a lognormal distribution and show a median ventilation rate of 0.51 ACH. This value is consistent with other reports of typical air exchange rates in U.S. homes (ASHRAE, 2005). The data fit a lognormal distribution in our analysis and we used the 99th and 1st percentiles as the upper and lower limits of the distribution (4.76 and 0.08 ACH, respectively).

RESULTS

The results of the Monte Carlo simulation show that there is an extremely low probability of a granite countertop causing elevated levels of radon in a home. The final distribution of results for the predicted indoor radon concentrations from all 1,000,000 simulations is presented in Figure 1 (log-scale presented in Figure 2). The results show that there is a 1 in 1,000,000 chance of the indoor radon concentration exceeding 3.5 pCi/L.

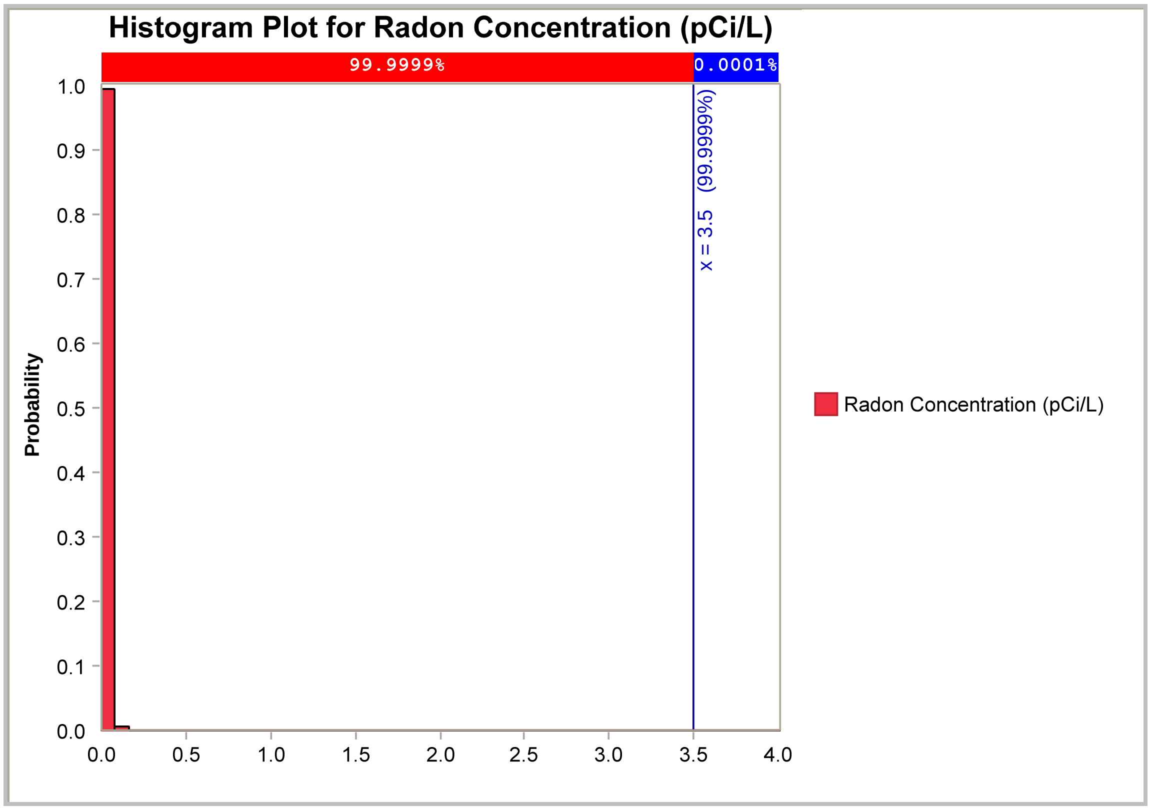


Figure 1

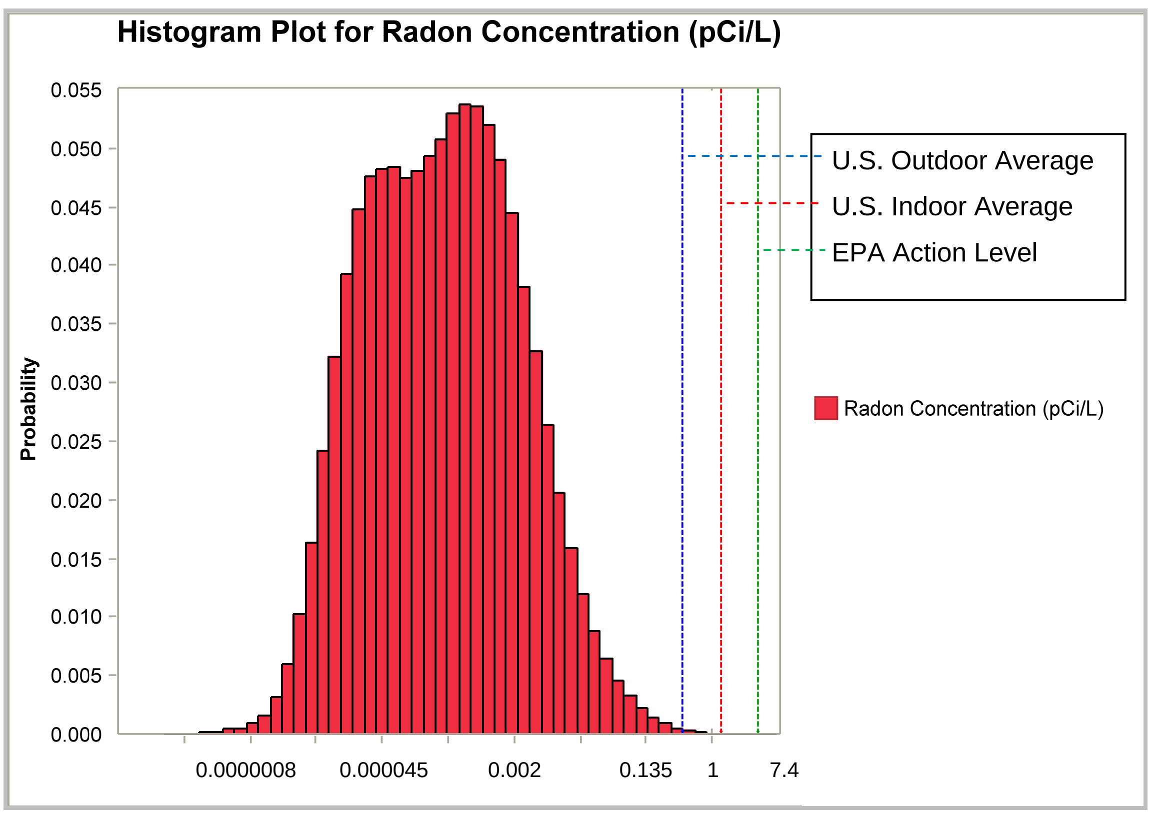


Figure 2

Based on an analysis of the full distribution of predicted indoor radon concentrations, the following observations can be made:

- 999,513 of the 1 million simulations (99.95%) produced indoor radon concentrations less than the level that is typically found outdoors in the U.S. (0.4 pCi/L).

- The median predicted indoor concentration from granite countertops from these 1,000,000 simulations was 0.0003 pCi/L. This value is 10,000 times lower than the EPA action level for indoor radon of 4 pCi/L.

- There was only a 1 in 1,000,000 chance of a granite countertop producing a radon concentration of 3.5 pCi/L or greater. This ”worst-case” scenario was a result of an improbable scenario that included installing a large countertop (109 ft^2) into a relatively small home (800 ft^2) with an air exchange rate that is typically found in a ”tightly” constructed home (0.20 air changes per hour), and where the radon emission rate was nearly 3 times higher than the highest actual measured emission rate from a full slab of granite.

- The combined probability of developing lung cancer from this “worst-case” scenario is over 1 in 100 million. This is calculated from the Monte Carlo simulation, which showed that the probability of having this extreme scenario exist is 1 in 1,000,000, and then applying EPA’s estimate of the risk of developing lung cancer from a 4 pCi/L exposure of 7 in 1,000 for non-smokers. Therefore, the population-level risk of installing a granite countertop installation that leads to 4 pCi/L or greater in the home, and that installation leading to lung cancer, is 7 in 1,000,000,000 (1 in 1,000,000 x 7 in 1,000). For smokers, the population-level risk is 23 in 1,000,000,000.

In the very limited instances where a simulated purchase lead to a predicted indoor radon concentration greater than 1 pCi/L, an examination of the data revealed that this was not only an extremely rare event, but also a result of an implausible scenario. To demonstrate, we extracted the top 10 scenarios that lead to the highest predicted radon concentrations (Table 3). These scenarios each represent a 1 in 1,000,000 chance of occurring. For each of these extreme scenarios, the predicted indoor radon concentration is influenced by one or more unlikely combination of factors:

1) A large countertop installation in a generally small home (in one scenario, the granite countertop accounted for nearly 30% of the total surface area of the home)

and/or

2) An air exchange rate that is fifty percent lower than typically found in what would be considered a tightly constructed home (0.2 air changes per hour)

and/or

3) A radon emission rate from the full granite slab that exceeded the highest actual measurements from granite by a factor of 2 or more.

Table 3 Top 10 of 1,000,000 Scenarios with Highest Predicted Indoor Radon Concentration

Rank	Conc (pCi/L)	Countertop Size (ft^2)	House Size (ft^2)	Percent of Home as Countertop	AER (h^{-1})	Radon Emission Rate (pCi/ft2/hr)
#1 of 1,000,000	3.5	109	814	13%	0.20	595
#2 of 1,000,000	2.4	85	389	22%	0.08	102
#3 of 1,000,000	2.4	121	985	12%	0.11	240
#4 of 1,000,000	2.3	74	492	15%	0.40	702
#5 of 1,000,000	2.3	87	303	29%	0.11	102
#6 of 1,000,000	2.2	99	837	12%	0.11	228
#7 of 1,000,000	2.1	98	3,097	3%	0.10	736
#8 of 1,000,000	1.9	64	1,251	5%	0.09	382
#9 of 1,000,000	1.9	85	1,651	5%	0.09	376
#10 of 1,000,000	1.8	78	890	9%	0.16	371

Conc concentration
pCi/L picocuries per liter
ft^2 square feet
AER air exchange rate
h^{-1} per hour
$pCi/ft^2/hr$ picocuries per square foot per hour

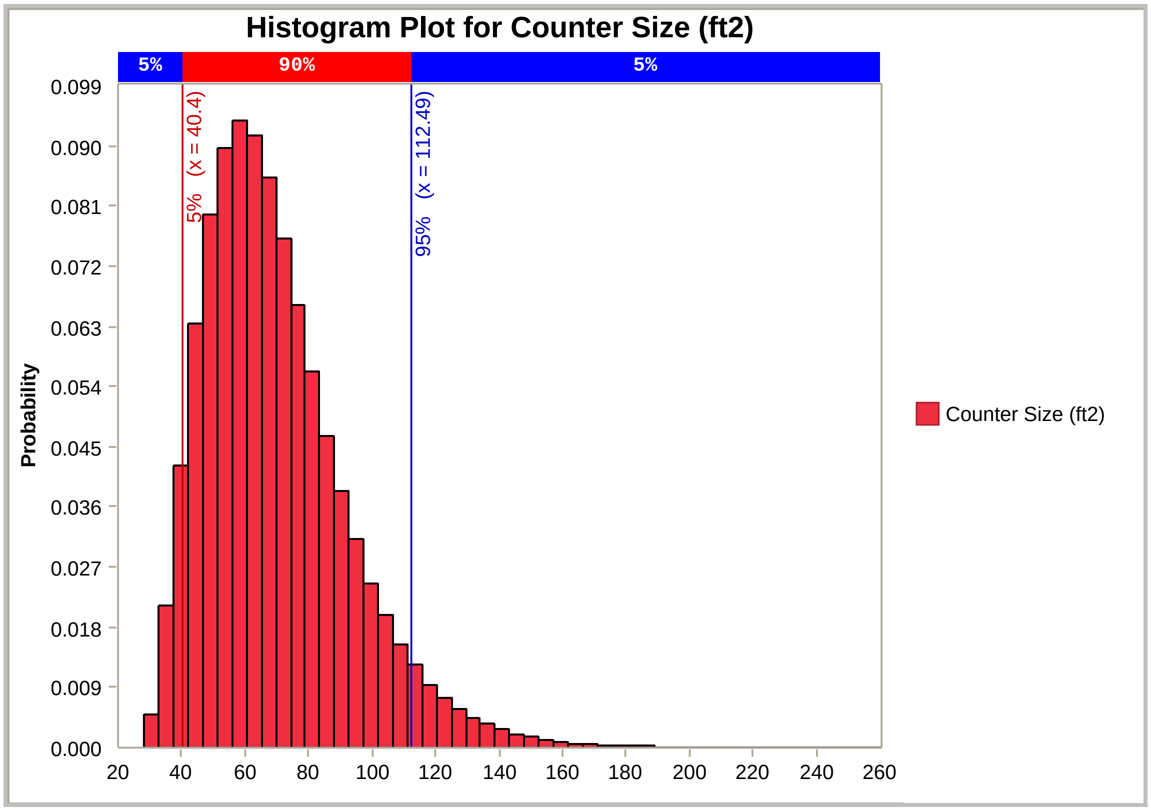
An examination of these “worst case” scenarios demonstrates that these scenarios are not only extremely unlikely to occur in a modeling analysis, but also that they are not likely to occur in the real-world because they are implausible.

Conclusion

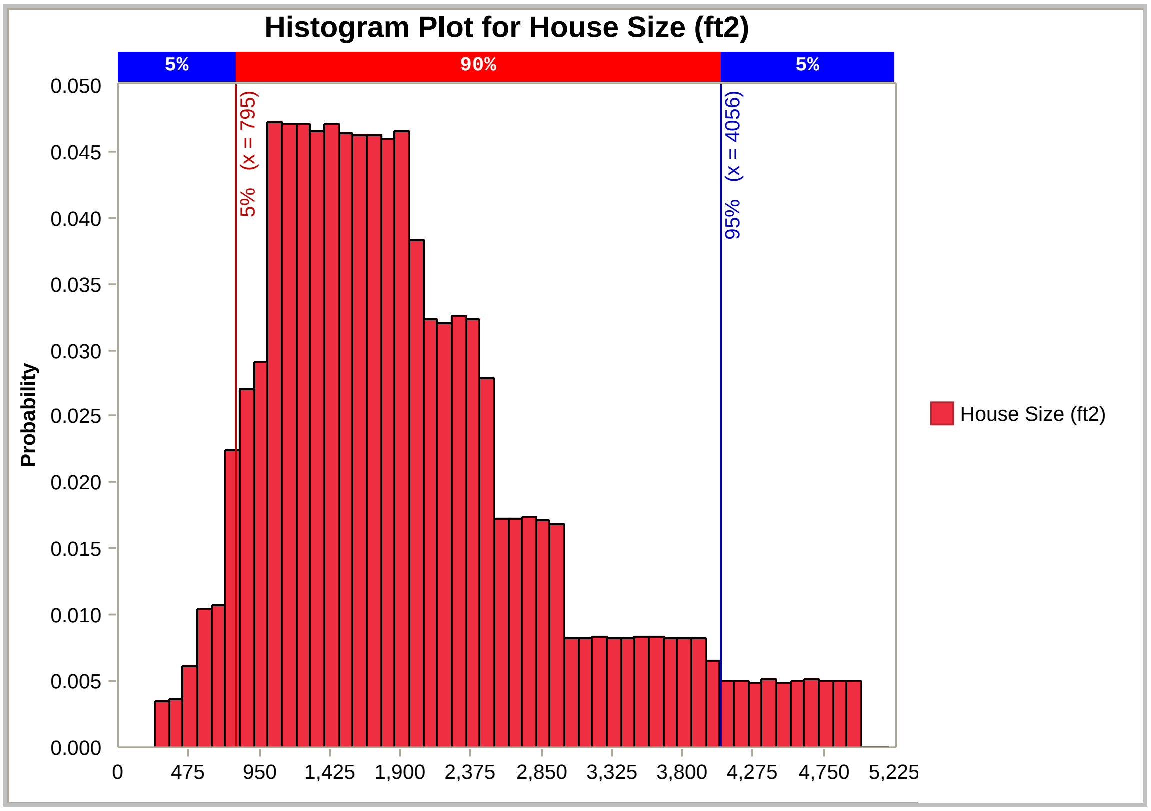
The results of simulating 1,000,000 granite countertop purchases demonstrate that the likelihood of a granite countertop leading to a health effect is extremely remote. These *de minimus* risks would be considered acceptable based on risk limits used by EPA in regulating potential environmental hazards. This research supports evidence previously published in the scientific literature that the health risks of radon exposure from granite countertops is negligible.

APPENDIX—Distribution Results for Key Input Parameters

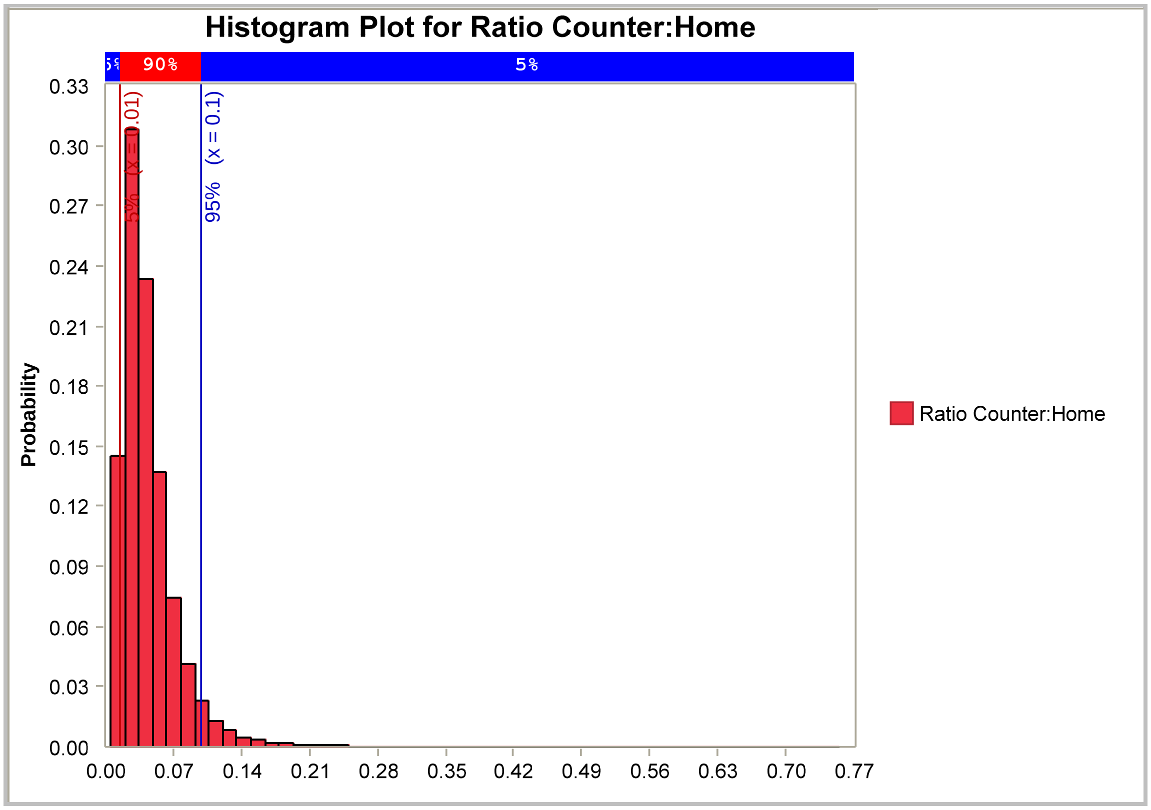
A. Distribution of countertop sizes (ft^2) from Monte Carlo Simulation (effective emitting area used in the analysis was two times the countertop square footage)



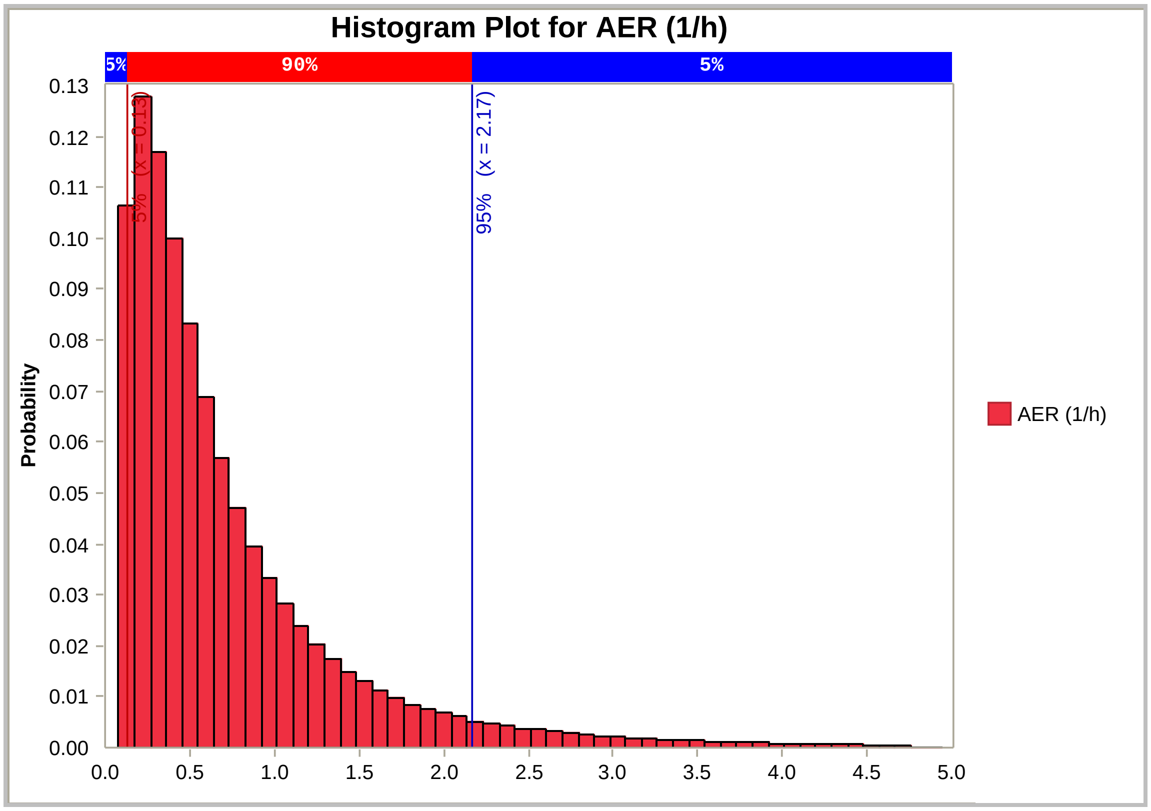
B. Distribution of house size (ft^2) from the Monte Carlo simulation (house size was multiplied by an assumed 8 foot high ceiling to yield a house volume for the calculations)



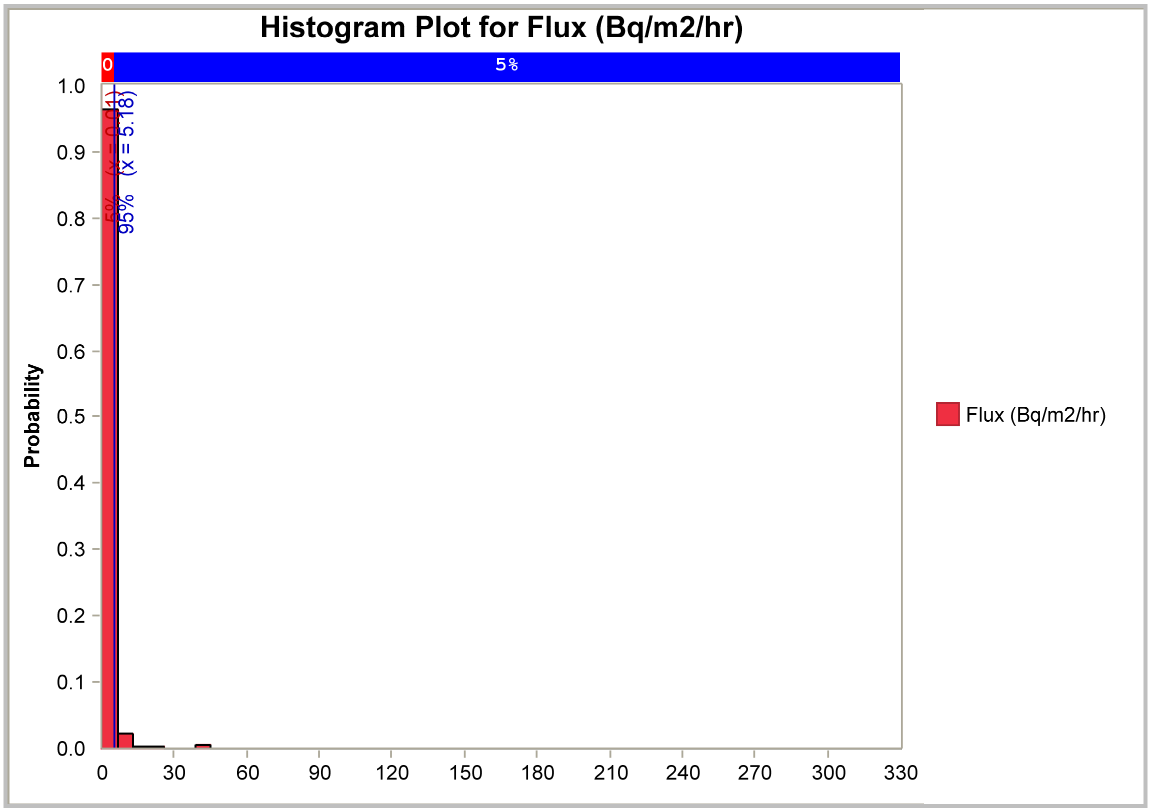
C. Distribution of the ratio of countertop size (ft^2) to house size (ft^2) from the Monte Carlo simulation



D. Distribution of air exchange rates (AER; 1/h) from the Monte Carlo simulation



E. Distribution of radon emission rates, or flux, from the Monte Carlo simulation ($1\ Bq/m^2/h = 27\ pCi/ft^2/h$)



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ENVIRONMENTAL HEALTH & ENGINEERING, INC.

117 Fourth Avenue
Needham, MA 02494
Web: www.eheinc.com

Tel: 800.825.5343
781.247.4300
Fax: 781.247.4305