Radon Testing of Various Countertop Materials
Final Report

by

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Introduction

Natural stone countertops are becoming popular in modern kitchens because they look pleasant and inviting. Among the natural stones, granites are the most popular because granite is the most durable, it is chip and scratch resistant, and it only requires resealing about once a year. However, certain consumer protection groups have raised concerns over granite countertops because of their radon emission potential. It is, therefore, imperative to design a test to give a realistic account of this radon emission potential; and based on the results of the tests; draw a conclusion as to whether this concern is realistic.

Characteristics of Countertop Pieces

The sample pieces have the following characteristics. The popularity of these countertops is indicated by the survey at the shop in ranking order with the number in parenthesis as their # 1 sale. For the 13 sample sets we have received for testing, they should represent about 95% of the granite countertops currently on market.

- 6 x6 inches with upper side polished as countertop being marketed
- The lower side and vertical sides are not polished
- 4 pieces each sample
- Dakota mahogany: 3 cm thick; all the others 2 cm thick
- Inadequate packing resulted in damaging of corners and scratching of upper surfaces

1.   New Venetian Gold (20)
2.   Uba Tuba (18)
3.   Santa Cecilia (18)
4.   Tropic Brown (12)
5.   Absolute Black (9)
6.   Tan Brown (6)
7.   Crema Bourdeaux (5)
8.   Baltic Brown (5)
9.   Giallo Veneziano (4)
10.   China Black
11.   Yellow Star
12.   Dakota Mahogany

Geology of Radon

Radon has three natural occurring nuclides, ^{222}Rn, ^{219}Rn, and ^{220}Rn, which are derived in a series of decay from ^{238}U, ^{235}U, and ^{232}Th, respectively. The respective half-lives are 3.8235 days, 3.96 seconds, and 55.6 seconds. The respective parent radium species of these radon species are ^{226}Ra, 223Ra, and ^{224}Ra. Radon is the heaviest natural occurring gas. It is chemically inert and capable of dissolving in water in large quantities. Being longer in half-life, ^{222}Rn generated from minerals in soil may enter pore fluids and migrate a significant distance from the site of generation along certain conduits into the basement of our house. A small fraction may even migrate into the atmosphere through diffusion and advection before undergoing radioactive decay. This type of radon, ^{222}Rn, is the only kind of natural occurring isotope species that is capable of migrating into our house and general health concerns.

Uranium is a natural occurring radioactive element. It can decay through a series of daughter products and form radium. Each radium atom or ^{226}Ra decays by ejecting from its nucleus an alpha particle composed of two neutrons and two protons. As the alpha particle is ejected, the newly formed radon atom recoils in the opposite direction, just as a high-powered rifle recoils when a bullet is fired. Alpha recoil is the most important factor affecting the release of radon from mineral grains.

The location of the radium atom in the mineral grain (how close it is to the surface of the grain) and the direction of the recoil of the radon atom (whether it is toward the surface or the interior of the grain) determine whether or not the newly formed radon atom enters the pore space between mineral grains. If a radium atom is deep within a big grain, then regardless of the direction of recoil, it will not free the radon from the grain, and the radon atom will remain embedded in the mineral. Even when a radium atom is near the surface of a grain, the recoil will send the radon atom deeper into the mineral if the direction of recoil is toward the grain's core. However, the recoil of some radon atoms near the surface of a grain is directed toward the grain's surface. When this happens, the newly formed radon leaves the mineral and enters the pore space between the grains or the fractures in the rocks. Radon atoms move in pore space or fracture with ease and efficiency and may have a chance to escape into the surrounding air.

Light-colored volcanic rocks, granites, dark shales, sedimentary rocks that contain phosphate and metamorphic rocks derived from these rocks have higher than normal but variable uranium contents. Some of these rocks, if they are compact, durable and possess intrinsic beautiful stone patterns, are cut, polished and used as granite countertops in common households. However, for a compact rock with no internal porosity and fractures, like a granite countertop, only radium atoms in the very surface layer of countertop have a chance to generate radon atoms that escape quickly into the air of the nearby environment. Radon atoms in pore spaces and fractures are of minimal concern in the case of granite countertops. The very surface layer includes the polished upper, the unpolished lower and the sides of the countertop. The situation can change if granite is crushed. The drastic increase in surface area can be a health risk for indoor users (Ranjbar and Barghordar, 2006). Alternatively, if the crushed granite is used to make other building materials, radon emanation can also be a health concern (Al-Jarallah, 2001; Xinwei et al., 2006).

The uranium content in the rocks that manufactured into the countertop is variable. The type and characteristics of constituent minerals is also variable. The emanation ratio can be quite variable (Sasaki, T., Gunji, Y., and Okuda, T., 2004) as affected by the distribution of the radium parent, the degree of polishing, and the physical conditions of emanation. The best way of evaluating the emanation potential of these granite countertops is, therefore, to be determined experimentally.

Mineralogy and Petrology

The polished side of the countertop sections is examined under 40x magnification. Small uraniferous zircon, and titanite crystals are invisible at this magnification level but some of the uranium containing apatite are visible as inclusions in biotite. Biotite and the trace minerals included in biotite are places where uranium concentrate and, therefore, the major source of radon. The images of tropic brown and Baltic brown are not very clear because the surfaces were somewhat scratched during shipping. The dimensions of the images are approximately 3x2 inches (7.6x5.1 cm).
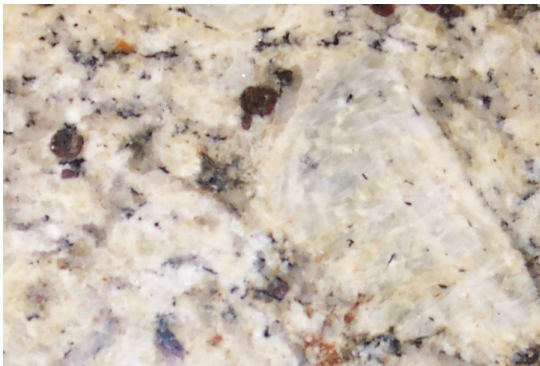
1. Gallo ornamental

Orthoclase is white and quartz is colorless. The dark brown mineral is biotite.

2. Santa Cecilia

Colorless quartz and slight pink colored orthoclase form the base of the pattern. Biotite crystals are in clusters and darker. Equidimensional almandine garnet, brown in color, occurs at places.

3. New Venetian gold

Light colored quartz, orthoclase, brownish almandine, and darker biotite form the base of the pattern. Orthoclase and quartz clusters up to 7x4 cm in area (right side) occur at places.

4. Yellow star
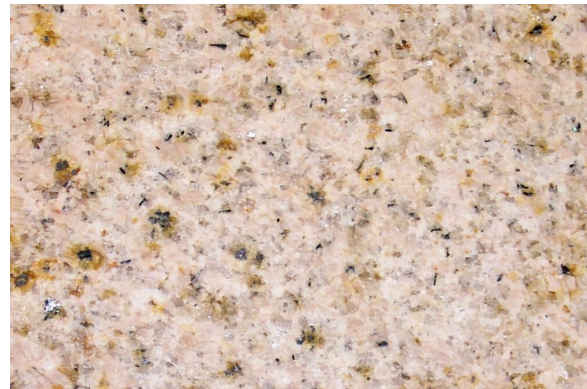
Slight pink colored orthoclase and colorless quartz and dark colored biotite form the base of the pattern. Brownish stain spots from iron oxidation (left and upper side) are seen at places.

5. Gallo Venetian
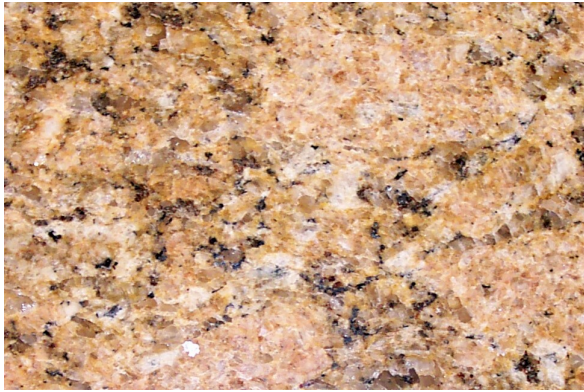
Othoclase is flesh colored. Biotite is the only dark mineral. Brown apatite inclusions inside biotite are visible at 40x magnification.

6. Crema Bourdeaux
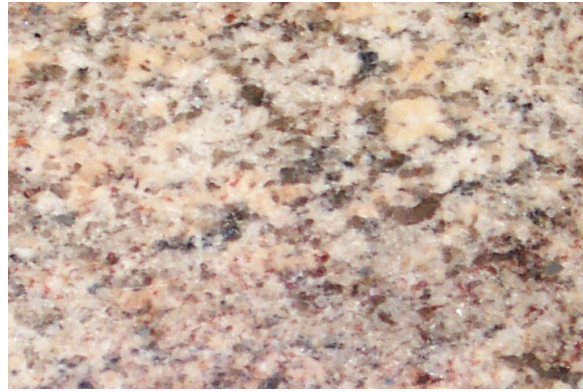
Most of the crystals are between 1 and 5 mm typical of granite. Larger crystals varying between 5 and 12 mm are found at places. Orthoclase is flesh colored and quartz is clear. Quartz crystals are highly fractured and cleavages of orthoclase crystals are highly developed. Biotite is the only dark mineral.

7. Baltic brown
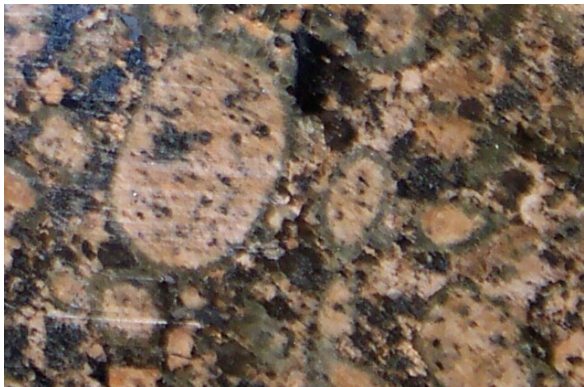
Granite with circular clusters (orbicules) varying between 1x1 cm to 3x5 cm. Orbicules are composed of interlocked quartz and orthoclase crystals (granophyes) and zoned with an outer dark ring. Matrix is much darker than orbicules. Crystals in matrix varying between 1 and 10 mm.

8. Tropic brown

Equigranular texture with crystals varying between 5 and 10 mm. Orthoclase is much more abundant than quartz. Biotite is the only dark mineral.

9. Tan brown

The rock contains flesh colored orthoclase and white plagioclase with dark colored biotite. It is not a granite, but monzonite by petrological classification.

10. Darkota mahogany (3 cm thick)

Equigranular texture with crystals varying between 1 and 8 mm. Flesh colored orthoclase is decorated with clear quartz and clusters of darker biotite.

11. Uba Tuba

The rock contains white plagioclase and dark colored augite. It should be considered gabbro by petrological classification.

12. China black

The rock contains very fine grained white plagioclase, dark colored augite, and yellowish green olivine. Crystals are generally smaller than 1 mm. It is basalt by petrological classification.

13. Absolute black

Equigranular pyroxene and olivine crystals are found inside a network of long plagioclase crystals (ophitic texture). The texture is typical for an igneous rock known as diabase.

Radon Release Study

Radon measuring unit, pCi/L, used experimentally and by the US Environmental Protection Agency and Bq/ m^3, and Bq/m^2 that is employed in certain literatures.

- pCi/L= picocuries per liter of air
- Ci = 3.7 x 10^{10} disintegration/second
- pCi = 0.037 disintegration/second
- 1pCi/L=37 Bq/m^3
- Bq/m^2= Bq/m^3/m or radon flux/unit area

Countertop pieces 6x6 inches are placed inside a 5 gallon (19,000 cm^3) polyethylene container with a screw cap on top. Birch dowel rods, with a 1/8 inch diameter, are used if more than one piece of stone is placed inside. An electronic radon monitor that gives pCi/L reading at hourly basis is placed on top of the stone pieces for an instantaneous reading. The build-up of radon activity inside the emanation container follows the well known equation

$$A_t = A_o(1-e^{-\lambda t})$$

where λ is the decay constant of ^{222}Rn or 0.1813 day^{-1}, and A_o and A_t are initial and final values of the radon activities. And t represents the elapsed time. At least four half-lives or 3.8235 daysx4=15.3 days for each set of countertop pieces is required to get a satisfactory measurement of the radon emission of that particular countertop sample. Counting started at 3:30 pm, 2/5/2008 without delay as we have received the shipment. The sample pieces that represent the top side of the countertop are polished and thus has the lowest radon flux when comparing with the bottom and vertical sides. The radon flux of these sides is expected to be higher because of surface roughness.

Our experimental approach is similar to that utilized by Al-Jarallah (2001) and Chao et al. (1997) but should be superior when compared to the method used by Kitto and Green (2005). They

utilize a flux chamber loaded with an electret or a charged Teflon disc to detect radon flux. The smaller volume of the chamber, 960 mL and also the smaller surface area measuring 182 cm^2 may be more sensitive to the natural of polish of the surface and mineral heterogenity of the sample rather than an average radon emanation of the stones.

The actual monitoring results of these 13 countertops are listed in table 1. Only Yellow Star and Crema Bourdeaux are followed for additional time to observe the relationship between radon counts and the surface area. Other sets of stone should have similar liner relationship by reasoning as presented in figure 3. Deviation of the data points from the regressed line is believed to relate to damaged corners and variations in polish among the surfaces. Figure 1 and 2 shows the growth of radon activities of Crema Bourdeaux and Yellow Star inside the container. The nature of growth with time is what has been described by the formula $A_t = A_o(1-e^{-\lambda t})$ as presented earlier. The radon counts at the maximum growth at the end of the second up to the fourth week after counting start are reported in table 1.

Table 1. Radon levels of granite countertop pieces.

| Sample	Counting Start	Counts (pCi/L)			
		4 pieces	3 pieces	2 pieces	1 piece
Yellow Star	2/5/2008 15:30	24	19	12	7
Gallo Ornamental	2/5/2008 15:30	2		1	
Santa Cecilia	2/5/2008 15:30	1			
New Venetian Gold	2/5/2008 15:30	1			
Gallo Veneziano	2/13/2008 11:00	1			
Crema Bordeaux	2/29/2008 09:30	292	196	152	54
Baltic Brown	3/1/2008 11:00	42			
Tropic Brown	3/1/2008 11:00	47			
Darkota Mahogany	3/1/2008 11:00	20			
Tan Brown	3/24/2008 11:30	3			
Uba Tuba	3/24/2008 11:30	1			
China Black	3/24/2008 11:30	1			
Absolute Black	4/3/2008 10:00	1			
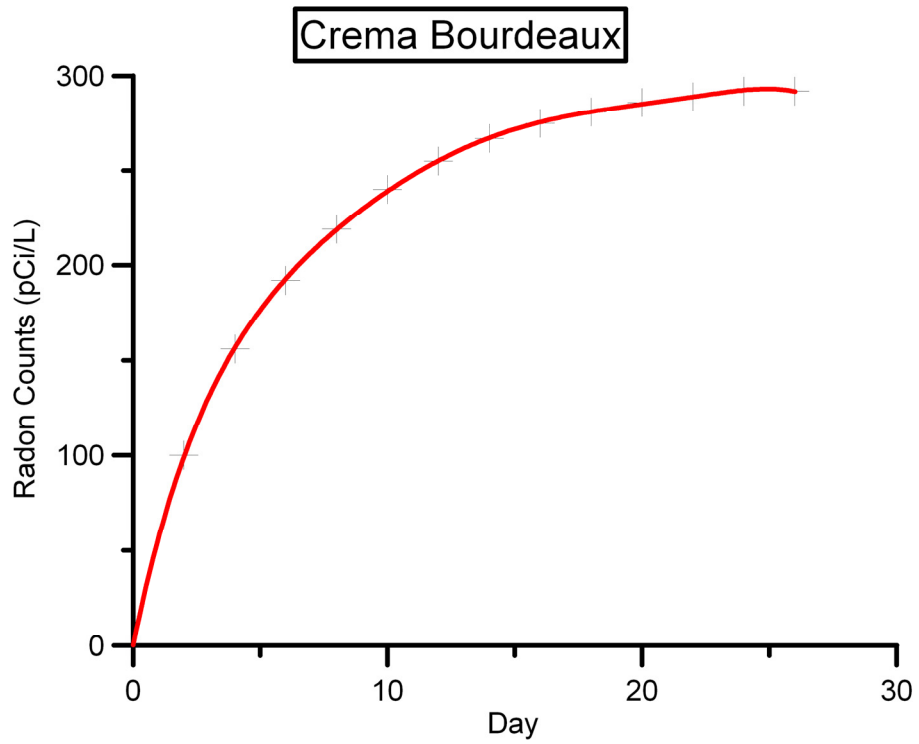
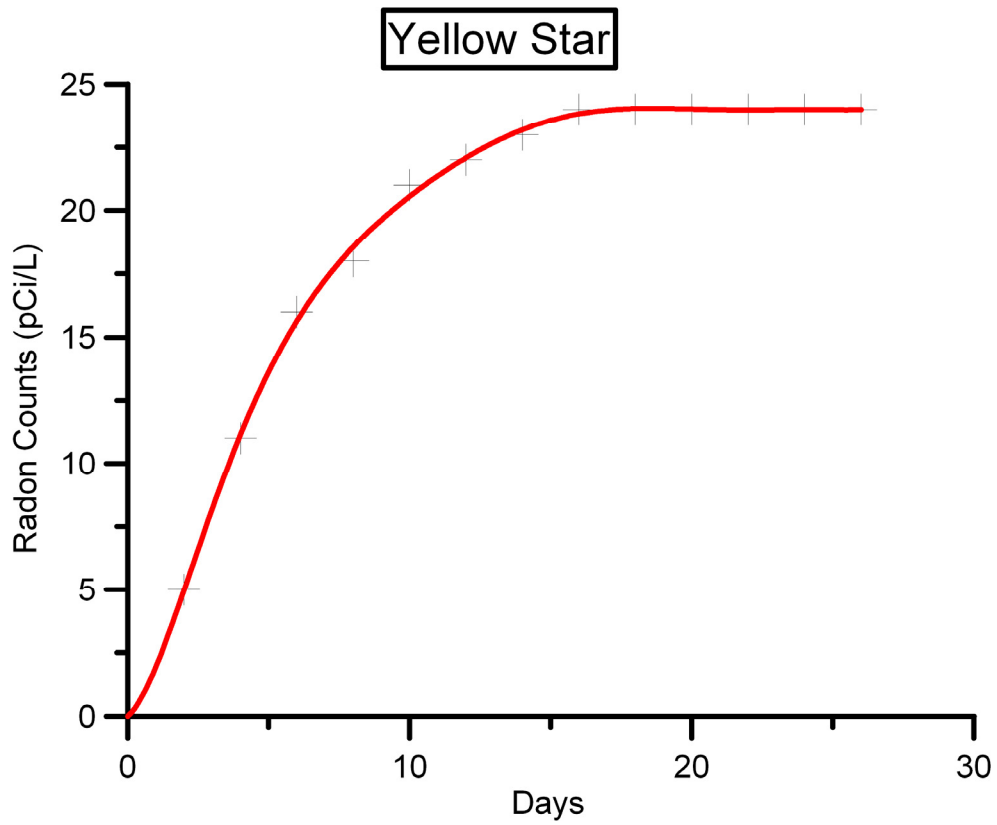Figure 1. Growth curve of radon counts of all four Crema Bourdeaux pieces inside the container

Figure 2. Growth curve of radon counts of all four Yellow star pieces inside the container

Surface Area Extrapolation

(y-axis) Radon Counts (pCi/L)
Crema Bourdeaux
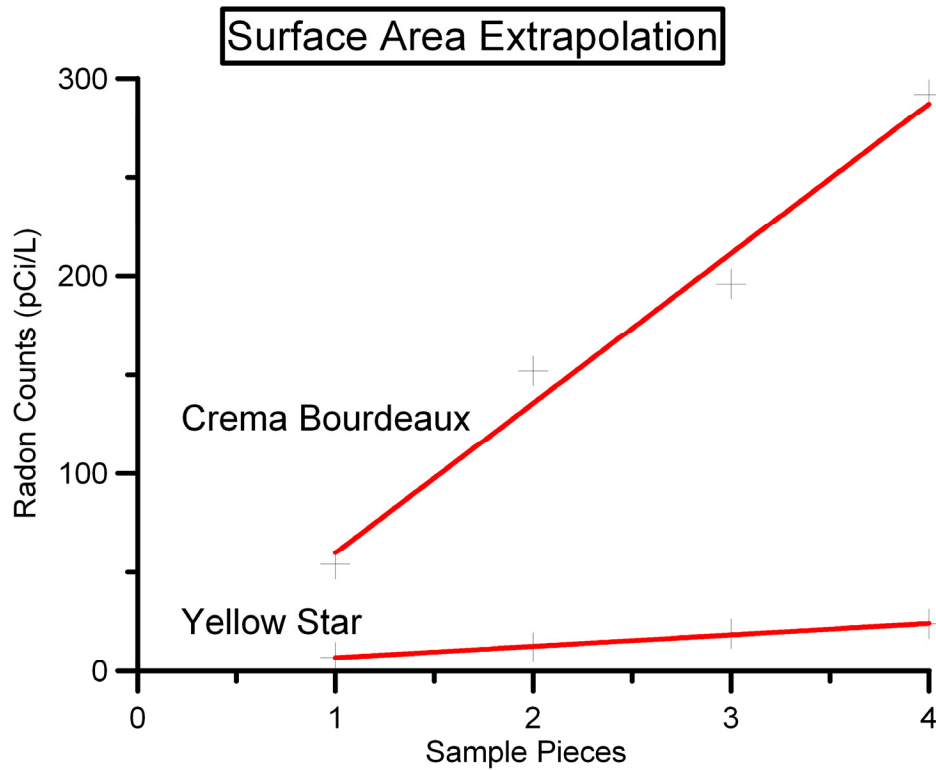Yellow Star
(x-axis) Sample Pieces

Figure 3. Relationship between radon counts at the maximum equilibrium values and surface area as represented by sample pieces of Crema Bourdeaux and Yellow Star.

Addition to House Radon Level

Radon moving through soil pore spaces and rock fractures near the surface of the earth usually escapes into the atmosphere. Where a house is present, however, soil air often flows toward its foundation due to differences in air pressure between the soil and the house, the presence of openings in the foundation of the house, and increases in permeability around the basement due to construction related disturbances. Most houses draw less than one percent of their indoor air from the soil; the remainder comes from outdoor air, which is generally quite low in radon. Radon can also enter home through their water systems if ground water has high radon level due to the high uranium content in the underlying rocks.

The air volume of a regular house of 2000 ft^2 with a normal 8 ft ceiling height, the volume is 16,000 ft^3. The volume of our counting container is 0.67 ft^3. The multiplication or air dilution factor is 24000. Assume that the average size of a granite countertop in a regular house is 13x2 ft or has a total surface area of approximately 54 ft^2. The surface areas of 4 pieces of 6x6 inches stone with a 2 cm thickness is 2.5 ft^2. Then the amplification factor is 22. If the thickness is 3 cm such as that of Dakota mahogany, then the surface area becomes 2.8 ft^2 and the amplification factor becomes 19. The addition of radon level to the house with a granite countertop as indicated can then be calculated. Radon counts added to the house equals to the radon in measuring container at equilibrium (estimated equilibration time varies from two to four weeks) multiplies by 22 or 19 and then divides by 24000. In the worst case as represented by Crema Bourdeaux at equilibrium is

$$292 \text{ pCi/Lx}22 \div 24000 = 0.27 \text{ pCi/L}.$$

The study did not account for routine ventilation or air exchanges in a typical home, which would dilute the concentration of radon gas. Normal air change rate/hour (ACH) for a regular house related to heating or cooling is about 6 ACH. Normal rate of infiltration, or outside air comes in, is about 0.25. The actual radon dilution factor can be much bigger than what is calculated. Radon from granite countertop can, therefore, only add a very small amount to the house when it is not used such as during the period of vacation. Radon from countertops cannot exceed the maximum equilibrium level because ^{222}Rn decays quickly with a half-life of 3.8235 days. Radon infiltration from the basement of the house, however, can continue to increase. Specific radon emanation measurements of residential premises can only be performed when the air exchange rate, indoor and outdoor radon levels, and ventilation model are also carefully followed (Tung et al., 2004).

Recommended Action Level

The US EPA suggests a 90 days long-term test. A long-term test will give you a reading that is more likely to tell you your home's year-round average radon level than a quick short-term test. "Alpha track" and "electret" detectors are commonly used for this type of testing. The lung cancer risk levels for smokers and non-smokers are given in table 2 and 3 for comparison.

Table 2. Radon risk level if you smoke

Radon Level	If 1,000 people who smoked were exposed to this level over a lifetime*...	The risk of cancer from radon exposure compares to**...	WHAT TO DO: Stop smoking and...
20 pCi/L	About 260 people could get lung cancer	250 times the risk of drowning	Fix your home
10 pCi/L	About 150 people could get lung cancer	200 times the risk of dying in a home fire	Fix your home
8 pCi/L	About 120 people could get lung cancer	30 times the risk of dying in a fall	Fix your home
4 pCi/L	About 62 people could get lung cancer	5 times the risk of dying in a car crash	Fix your home
2 pCi/L	About 32 people could get lung cancer	6 times the risk of dying from poison	Consider fixing between 2 and 4 pCi/L
1.3 pCi/L	About 20 people could get lung cancer	(Average indoor radon level)	(Reducing radon levels below 2 pCi/L is difficult.)
0.4 pCi/L	About 3 people could get lung cancer	(Average outdoor radon level)	
Note: If you are a former smoker, your risk may be lower. * Lifetime risk of lung cancer deaths from EPA Assessment of Risks from Radon in Homes (EPA 402-R-03-003). ** Comparison data calculated using the Centers for Disease Control and Prevention's 1999-2001 National Center for Injury Prevention and Control Reports.			

Table 3. Radon risk if you've never smoked

Radon Level	If 1,000 people who never smoked were exposed to this level over a lifetime*...	The risk of cancer from radon exposure compares to**...	WHAT TO DO:
20 pCi/L	About 36 people could get lung cancer	35 times the risk of drowning	Fix your home
10 pCi/L	About 18 people could get lung cancer	20 times the risk of dying in a home fire	Fix your home
8 pCi/L	About 15 people could get lung cancer	4 times the risk of dying in a fall	Fix your home
4 pCi/L	About 7 people could get lung cancer	The risk of dying in a car crash	Fix your home
2 pCi/L	About 4 person could get lung cancer	The risk of dying from poison	Consider fixing between 2 and 4 pCi/L
1.3 pCi/L	About 2 people could get lung cancer	(Average indoor radon level)	(Reducing radon levels below
0.4 pCi/L		(Average outdoor radon level)	2 pCi/L is difficult.)

Note: If you are a former smoker, your risk may be higher.
* Lifetime risk of lung cancer deaths from EPA Assessment of Risks from Radon in Homes (EPA 402-R-03-003).
** Comparison data calculated using the Centers for Disease Control and Prevention's 1999-2001 National Center for Injury Prevention and Control Reports.

Conclusion

The testing procedures for radon emanation of granite countertops are designed for normal use of these stones only as countertops. Adapting the 4pCi/L action level as recommended by US EPA as a reference and the house is not in active use, Crema Bourdeaux countertop raises less than 7% of this action level. The second and the third highest radon count stone Tropic Brown and Baltic Brown can add only approximately 1% of this action level. All the other countertops adds only insignificant amount of radon to the house. If normal air exchange rate is applied or the house is actively used, then the radon addition should be much smaller.

The main source of radon emitted from granite countertop is from trace minerals found inside the brown or black minerals known as biotite because of their uranium content. The radon emanation from other minerals in the countertops such as orthoclase and quartz are negligible. If proper resealing is applied once a year or at other frequencies recommended by the industry, the radon emanation can further be reduced.

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Qualification in Geology and Radon Testing

Dr. Chyi is currently a professor of Geology and Civil Engineering. He is a fellow of the Geological Society of America and Society of Economic Geologists. Dr. Chyi has served on the University of Akron Radiation Safety Committee from 1984 to 2005, and chaired from 1988-1992, 1994-2000, and 2002-2005. Other than regular geology courses, he also taught nuclear geology and radon geochemistry.

Dr. Chyi has been engaged in radiochemical analysis since 1966. In addition to his geology background, he also has worked in the Department of Chemistry, University of Kentucky from 1972-1974, and the Division of Applied Physics, Argonne National Laboratory in the summer of 1979. He engaged in aggregate application research recently with the Department of Civil Engineering, The University of Akron. He has engaged in soil gas radon research for earthquake forecast with National Taiwan University since 2000.

Education
1964   B.Sc. (geology), National Taiwan University, Taipei, Taiwan
1968   M.Sc. (geology), McMaster University, Hamilton, Ontario, Canada
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