THE RED BOX, A DEVICE TO ASSESS THE POTENTIAL FOR ELEVATED INDOOR RADON

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INTRODUCTION

How many times have you, as a radon tester, been asked to evaluate a vacant property? The owner wants to know if he will have a radon problem in a house before it is built. We know this is not a reasonable question. The level of indoor radon within a building depends greatly on how the building interacts with the ground beneath it. This depends on the number and magnitude of infiltration routes and the pressures, positive and negative, generated in the building. So, the level of radon in a building also depends on how the building is used, the timing of heating and cooling relative to the ambient conditions. We try to eliminate some of the variables by making measurements in closed house conditions. If it is possible, I try to coordinate with the occupants to do the test when they are out of town. This will simplify things, but it does make the test unrealistic. After all, we are trying to protect the habitants from exposure to radon.

In a basic sense, the owner of the property has a reasonable question: Are the uranium levels in the soil high enough to cause a problem? As I have spoken previously, this is pertinent in Santa Barbara County because our soils are bimodal with respect to uranium concentration, and therefore the homes are bimodal with respect to indoor radon concentrations (1). This is because of the Rincon Shale geological formation which has outcropping along the Pacific Plate in California from Los Angeles County in the south through Ventura, Santa Barbara, and San Luis Obispo Counties to Monterey County in the north. Because of biological activity in the shallow sea when this formation was created, the Rincon Shale has significantly elevated uranium content. The Rincon Shale has a radium content of about 25 ppm eU (equivalent uranium). Other soils along the populated coast of California that we have measured have radium content of less than 1.2 ppm eU (2) The California Department of Health Services has made several surveys of indoor radon. They find more than 70% of the homes on the Rincon Shale with levels above 4 pCi/L, but only about 2% of homes off the Rincon have radon levels above this standard (3).

So, even though the property owner is probably ignorant about the reasons for indoor radon problems, in our area he is asking a reasonable question. For us, the answer is simple. The builder should check a geologic map. If the property is an outcropping of Rincon Shale, then the building should be built with “radon ready” construction techniques. Otherwise, use normal building standards.

In this paper I will describe a simple device which models the interaction of a residential house with the soil and may allow a preconstruction radon estimate. Some preliminary data using the device will be presented. Finally, I will suggest some protocols for using the device and some ideas about interpreting the measurements.

SOIL ASSAY

Once upon a time they did teach a soil assay technique as part of the EPA training (4). The scheme involved digging a small hole and placing a radon detector in the hole and then covering it with a glass or metal (gas impermeable) covering. The hole was filled and then a marker was added to remember where the device was planted. A day later the device was unearthed and evaluated. A problem was that the permeability of the soil had been changed. If two different measurements were made side-by-side, duplicate style, the measurements could be very different. Since the exposure of the device is sensitive to the conditions of gas flow in the soil, there were lurking variables. The training people made strenuous cautions that the measurement had limited value. Soon, soil-testing procedures were simply discouraged.

A problem with using these methods to predict the indoor radon level is that they ignored the permeability of the soil which is being radically changed by digging the hole. Professor Don Carlisle of UCLA had a procedure for estimating the permeability of the soil. He had a wine-barrel ring which he would lay on bare ground. He would then pour a known quantity of water into the ring and time how long it would take the liquid to be absorbed into the earth. It was from Don that I learned that Rincon soils had relatively high permeability. Don also had a procedure for hammering a tempered-steel probe one meter into the soil and then extracting a sample of soil gas directly. The radioactivity of the gas was assayed using a Thompson scintillation chamber. Years ago, at a meeting, Don reported measuring over 10,000 pCi/L in Rincon-derived soils (5).

There is also a method to assay the radium level in soil. This has been done at the Radioanalytical Facility of Cal Poly SLO (San Luis Obispo). The procedure uses small aluminum canisters just like the ones that contain charcoal. An amount of soil (100-200 grams) is weighed and the can is sealed. The gamma emissions from radon daughters are measured, just as we do for radon. Since we count the polonium gammas not the radium itself, we need to age the soil for a few half-lives of radon (two weeks is sufficient). The samples have slow rates of emission so long count times may be required for good statistics (2).

THE NEW DEVICE

My idea is to use commonly available equipment to physically model the main components and factors related to the accumulation of radon in a building. Buildings exist because of our need for shelter from the elements: wind, rain and cold. The building shell limits air exchange with the ambient and allows us to create a comfortable indoor environment: mainly, a pleasing warm temperature with respect to outside. The building shell is modeled using a standard 32-gallon red trash can. The can is inverted to collect the emanations from the earth as a house would. Figure 1 on the next page shows the main parts of the model.

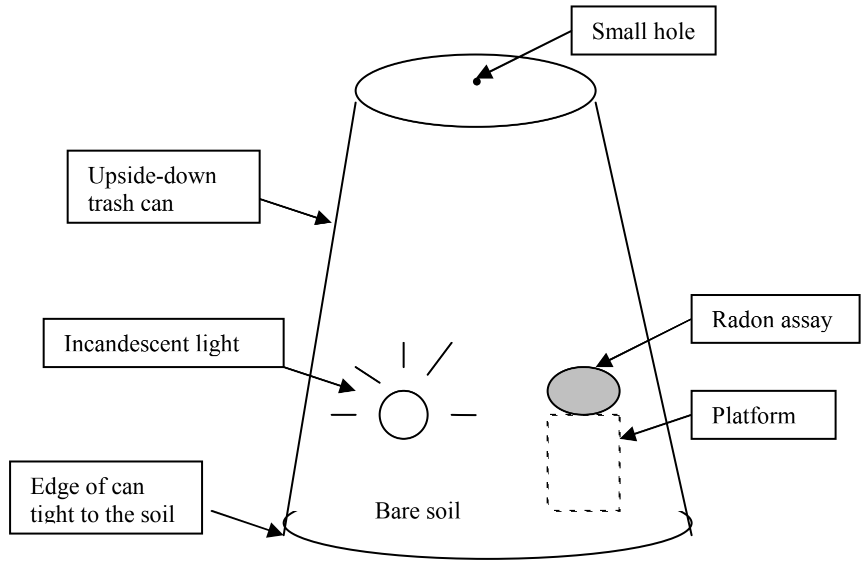

Figure 1. Schematic of soil-gas-house model, the "Red Box."

The stack (or chimney) effect is responsible for creating pressure differences that draw cool air from the soil into the house, and expel warm air either through intentional holes (like a chimney) or inadvertently through ceiling cracks. This effect is the main cause for radon buildup. The model includes the two main pieces of the stack effect. First, the air within the garbage can is warmed using an incandescent light. A 75-watt bulb causes a ~15ºF temperature difference between inside and outside. Second, the leaking of the warm air is allowed through a cylindrical hole drilled in the bottom of the can. (Note: since the can is upside-down, these holes represent leaks in the ceiling.) Figure 2 below shows the profile of the temperatures over a day.

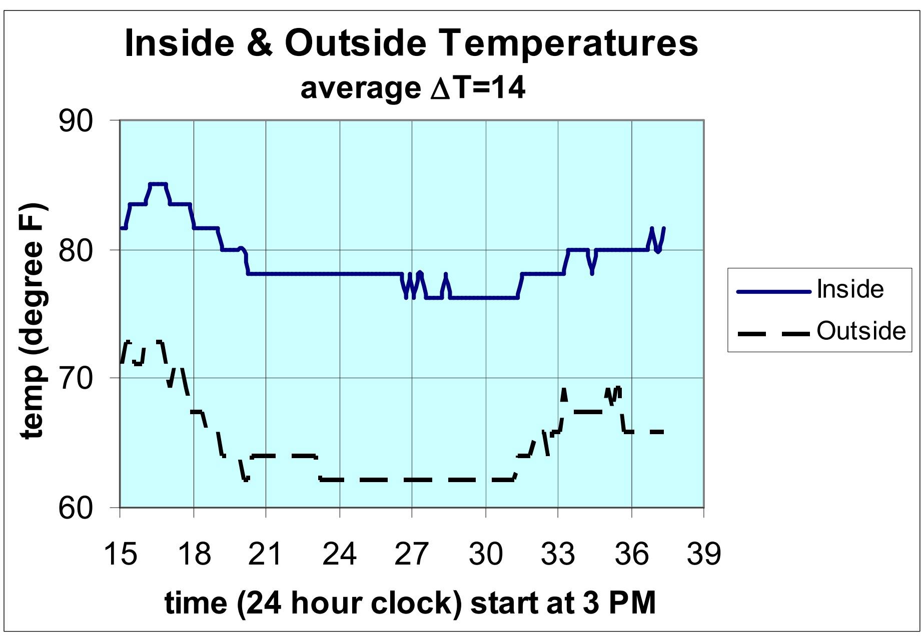

Figure 2. Temperatures in and out of the Red Box.

An important detail is connecting the can to the ground. There will always be leakage of the ambient air into the can around the edge of the can. This reduces the negative pressure that the device can exert on the soil and, thus, uncertainty in estimating the potential of this soil for indoor radon. Even if the can is tight on flat ground, this region has the shortest path for air to travel, from outside to inside and, thus, the smallest amount of radon buildup in a parcel of air moving through the soil. We will return to this in discussing the scaling of the model. To minimize the leakage the following steps are taken: (1) Find an area of flat ground big enough for the can; (2) Trace around the circumference of the can edge; (3) Lift the can, and push the dirt outward around the trace; (4) Return the can to the indention so formed; (5) Moisten the brim of soil and push inward to seal the boundary of the can. As the soil dries, it may pull away from the edge of the can. If this happens, the soil should be pushed back to the edge.

RADON MEASUREMENTS

In the schematic a platform with a radon assay (detector) on top is shown. The platform is a storage basket that has been turned upside-down and allows the detector to be raised a little away from the soil. In my case, the height was about one foot. The radon detector can be any reliable detector. I have tried both the Air-Chek and the Pro-Lab devices and they are satisfactory. They both require four days of exposure. There is a Catch-22 with these devices used in this configuration. When you close the Red Box, the interior radon concentrations are the same as ambient and, therefore, have negligible radon. I haven’t figured out a way to close the box up for 12 hours and then open the detection devices as we do in home testing. And it does take about 6 hours for the radon levels to climb to an equilibrium level. Because of this, a continuous monitor is preferable. I use the *femto*-TECH RS410F survey device for most of my work.

One cute aspect of configuration shown: The *femto*-TECH has an LCD readout on the Sharp calculator face. The small hole in the top of the device makes a pin-hole camera. It works by wave diffraction to produce a magnified, in-focus image of the objects in the Red Box. So you can look in read the radon level for a some time after the box has been closed. (The *femto* eventually turns off the display to save energy.) You can also see the details of the incandescent light, bugs crawling, etc.

The soil-gas testing device was put through its shake-down next to my house in Santa Barbara, California. Even though we do have the uranium rich Rincon Formation in Santa Barbara, my house is not on an outcropping of this formation. I have tested my home numerous times in the last ten years. The 24-hour average is a very consistent 1.4 pCi/L. My house has a raised foundation and the crawlspace is ventilated with numerous passive vents. The dining room does average a little higher (about 1.8 pCi/L) because there is an external patio which obstructs the vents for the crawlspace in that vicinity. The radon level in my house changes very little throughout the year, although it does get a little higher during the rainy season (up to 2.0 pCi/L). Radon levels in the crawlspace are a relatively constant 3.8 pCi/L.

The radon levels in the Red Box are also quite consistent. In standard operating mode, 75-watt light, the 24-hour average level is a consistent 30 pCi/L. This is approximately 20 times the concentration found in the house. There are two things about these results which I found surprising: (1) The radon concentration had a large magnitude. I have made outside measurements before. The recorded levels are consistent with the background from adsorbed radon daughters, essentially nothing (<0.3 pCi/L). I expected to find only a modest amount of radon in the can, a few pCi/L. (2) The radon concentration was rather consistent. Each day it would progress through a similar time profile.

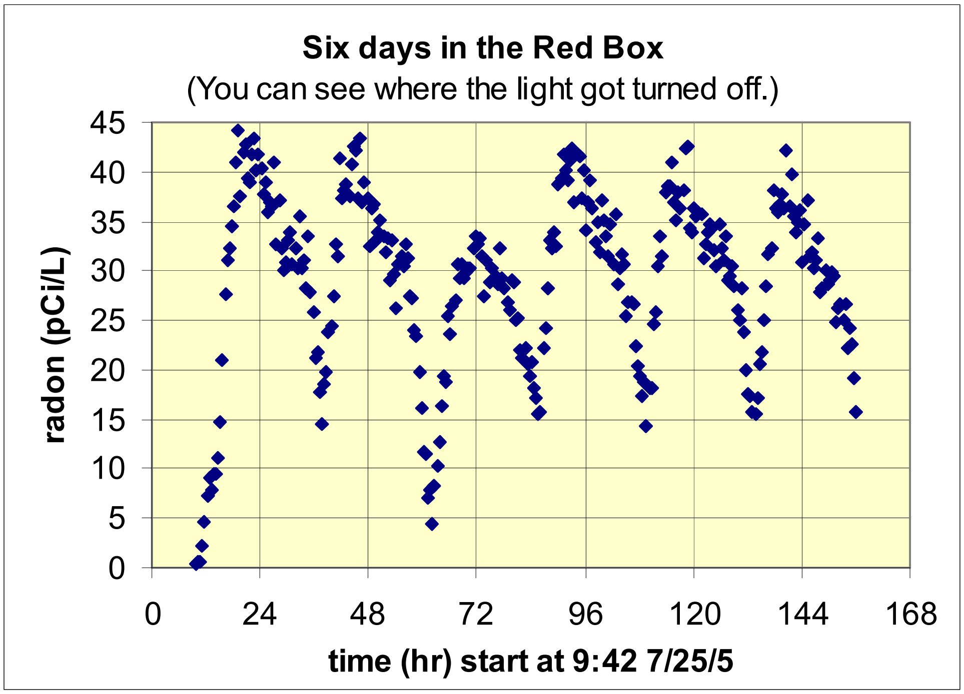

Figure 3. Radon concentrations in the Red Box each half hour for 6 days at the end of July. On the third day the light was turned off reducing the peak radon level.

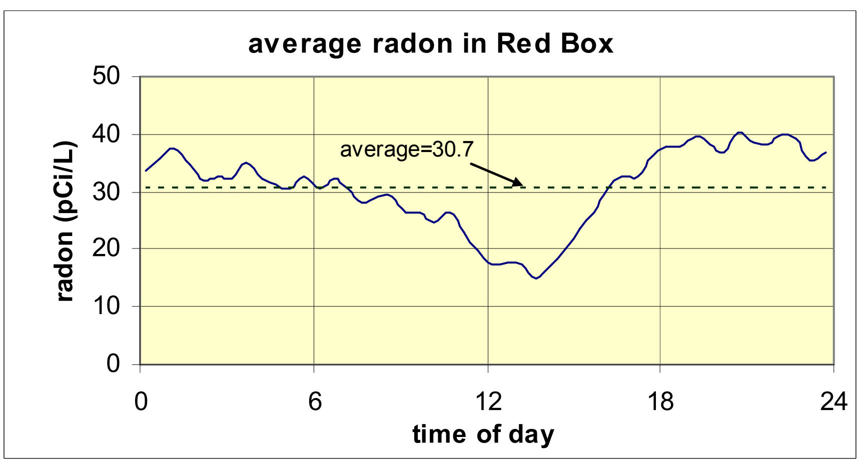

Figure 4. This profile is from the data of Figure 3. The average of the last three days is smoothed. A shadow begins to cool the system at about 1400 each day

PRESSURE MEASUREMENTS

The model was outfitted with two holes for pressure measurements; one 2" from the top; and the other 6" above the bottom. (I had hopped to obtain top-to-bottom pressure differences to show the stack effect.) The holes had irrigation nozzles punched through them to allow the connection of a tube for a standard micromanometer. My manometer is calibrated each year when I teach indoor air at UC Irvine. I cross check its reading with the Cushman & Wakefield people in measuring the pressure drop across air filters. The micromanometer reads minimum pressure differences of 0.001" water column (WC) = 4 pascals and it is continually fluctuating because of its sensitivity. I was not able, however, to get a good pressure reading in the can. At first I convinced myself that there was a 0.005" WC produced in the can by the heat from the light, but frankly, I am not sure.

Then I tried pumping up the can using a sports-ball pump with a needle inflator. This showed that my configuration was not air tight. When the can was pumped the air pressure would momentarily increase, but it would decay away to negligible levels quickly. I could just as easily cause pressure fluctuations by pushing the sides of the can. The can is flexible and pushing to reduce the volume would cause a bounce of internal air pressure, but a higher pressure would not persist that I could consistently measure.

I tried standard methods for observing air flow through the ventilation holes. First, I used a smoke gun, as used to find leaks. I could not discern any movement of air through the holes. Second, I tried covering the holes with soap solution to see if any pressure difference would cause a bubble to form. This also proved to be fruitless. I could get a bubble to form by putting the solution on the hole and then turning the light on. Heating the air in the can does cause the air in the can to expand. That part of physics was confirmed, but the can does not hold a pressure.

An extremely sensitive procedure for evaluating the air-exchange in a chamber is by using a CO_2 detector. If there is no source or sink of a trace pollutant in a chamber, but there is a uniform concentration C_0 at some time (designated t=0), then the concentration will fall off according to the equation

$$C(t) = C_A + \left(C_0 - C_A\right)e^{-At}$$

where C_A is the concentration of the pollutant in the ambient (outside) air. The pollutant is assumed to have always a uniform concentration in the can. To use this equation to evaluate the air exchange rate in our can, we use place a chip of dry ice in the can with a CO2 detector with a data logger. Our can has a volume of 32 gallons (which is ~116 liters or 0.116 m^3). Even a single chip of dry ice (a few cm^3) will create a concentration of more than 3000 ppm in less than 10 minutes as it sublimes. It takes about one hour for the chip to completely sublime and after this time there are no sources or sinks within the can. The concentration falls off extremely slowly and, at the high levels, the CO2 detector does not respond linearly according to the manufacturer Gaztect (6). I needed to wait for 12 hours before the CO2 level had decreased to levels where the detector was designed to operate. The CO2 concentration was about 2400 ppm at 8:30 and about 1900 at 11:30 am. Rearranging the above equation,

$$\ln\left[C(t) - C_A\right] = \ln\left(C_0 - C_A\right) - At$$

a linear relation is shown. The detector indicated that the ambient CO2 was 362 ppm, and this gives the air exchange rate of 0.12 air changes per hour (ACH). Figure 5 shows the data.

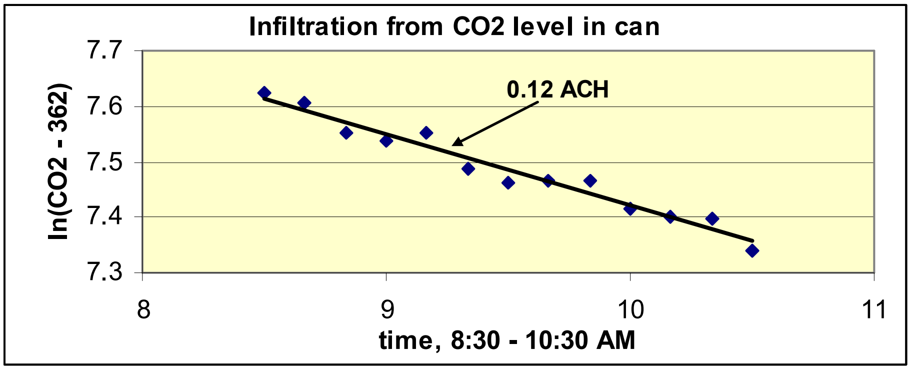

Figure 5. The air-exchange rate is equal to the slope of natural logarithm of carbon dioxide level minus the ambient level.

This means that about 14 liters of air are going into and out of the can each hour. It may be a little more since I did a blank measurement and found that the CO2 would creep up slowly, about the same as it is falling above. So the air exchange rate may be twice as large. I believe that, because of the negligible pressures, the exchange is due to diffusion.

The reasons for radon in the can at high concentrations are not complete at this point. The low pressure is consistent with the low air-exchange rates, but where is all the radon coming from? If the configuration is too leaky to support a negative pressure and draw in radon, how does it rise to the relatively high levels observed? There will need to be more analyses.

COMPARISON

In the following Table, a comparison of the dimensions of house vs. a trash can.

Parameter	Model (can)	House range
Circumference (m)	1.6	30-40
Surface area (m^2)	0.2	100-150
Volume (m^3)	0.116	300-400
Temp Diff (ºF), ΔT	15	5 – 20 (or more)
Air Exchange per hr., A	0.12	0.5 – 2
Timescale (hr,), 1/A	8	0.5 – 2
Average Radon Level (pCi/L)	30	1.5

Table. Comparison of dimensions of model and house.

The device is tighter (lower air exchange) and has smaller dimensions. It is exposed to the bare soil, so it magnifies the indoor concentration of radon significantly.

CONCLUSION

It is fairly easy and inexpensive to build a device for measuring the radon flux from a bare area of soil. The radon concentration measured in this device is 20 times that measured in an adjacent house. If this ratio should be validated with further measurements, then it would mean that, if the model results exceed 80 pCi/L, the house should be build with “radon ready” construction techniques. This assumes the standard 4 pCi/L average level required for further action. It also means that the building itself should be evaluated once it is build if this level exceeds 40 pCi/L

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