RADON – THE TRUTH?

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Radon – A Brief Discussion

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Prelude

A large portion of the general population is under the misconception that the frequently published risks associated with radon are well accepted scientific facts. In reality, the vast majority of well designed studies do not support policy or positions that exposures to indoor radon pose a significant threat to health, and indeed, the majority of those studies indicate that, at concentrations typically seen in homes, as the level of radon increases, the risk of lung cancer goes down, not up. The following section is a brief discussion of how radon occurs and the science-based risks associated with radon exposure.

In a separate discussion, we have also reviewed some of the commonly cited literature and you can read those reviews by clicking, here. At the end of this discussion, there are links to a two-hour lecture on radon in four parts.

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Radon Occurrence

Throughout the entire Earth, the naturally occurring element uranium is found in at least trace amounts. This element is naturally radioactive and with time, the uranium decays into several other elements (called "daughters"), one at a time. Each time a transformation into a new element takes place, the atom is said to undergo "decay". During each decay, energy is released from the atom. The released energy is collectively given the term "ionizing radiation" and the atom is said to exhibit "radioactivity". The list of subsequent daughter products is known as the “decay chain.”

Along this decay chain, one of the elements that is produced is the naturally occurring material called radon. Radon is unique from the other uranium decay products because it is a gas and as a gas, it is capable of migrating from the location of the original uranium atom into the surrounding soil gas. Worldwide, an average of about two radon atoms are emitted from every square centimeter of soil everywhere on the Earth every second of every day1. It is for that reason that virtually every house on the planet always has had radon, and will always have radon occurring in the home. Humans have been breathing radon gas since the dawn of Man.

Radon and Health

When radon decays, it too produces a “decay chain, with its own daughters. During its decay, it releases a "large" atomic alpha particle and the atom is transmuted into polonium. An alpha particle is essentially an helium atom stripped of its electrons. It is at this point that the real hazards associated with radon are encountered. For it is not the radon which is responsible for the health problems, but rather the short lived radon daughters (SLRDs) and their decay products, such as the alpha particles. The radon may be thought of merely a source and a vehicle for the SLRDs.

There are several different kinds (isotopes) of naturally occurring radon. Typically, when we speak of radon, we are speaking of radon 222 which has an half life of 3.8 days. This means that if a volume of radon is sealed into a container and left on its own, half of the radon will decay into SLRDs and be gone in four days. After eight days, only 25% of the original will remain and after 12 days just 12.5% of the original ... and so forth, until, after an appropriate time, just a few atoms remain. However, because of a peculiar trick of physics, proving that God has a sense of humor, the last radon atom may never decay and there exists a finite probability that it could last indefinitely...

Once the radon atom decays, it subsequently undergoes four rapid decays starting with polonium 218 which decays into lead 214, which decays into bismuth 214, which decays into polonium 214. Each of these daughters has a half life of less than 30 minutes (the polonium 214 has a half life of only 0.00016 seconds). Furthermore, the daughters are electrically charged. The SLRDs are measured in units called Working Levels (WL). The significance of these units will be discussed later.

During each decay, at least one of three types of ionizing radiation are emitted by the SLRDs: alpha, beta and gamma. The alpha particle is easily stopped by a single piece of paper or layer of clothing. The fact that it is easily stopped speaks to the issue of its "linear energy transfer" (or LET). Since the alpha particle is large and easily stopped, the alpha particle transfers virtually all of its energy to the material which has stopped the particle. Beta particles have less probability of being stopped and impart less energy into the stopping material. The gamma radiation is similar to X-rays and has an even lower probability of being stopped.

Since the radon is airborne, these daughters have a high probability of being airborne. If the daughters are inside the lung when they decay, the lining of the lung wall becomes the stopping material. Since the alveolar cells of the lung wall do not have a significant protective coating, an alpha particle can collide with the live cell, imparting an enormous amount of energy to the cell, possibly disrupting the DNA within the cell. If the body’s DNA repair mechanisms fail, the cell may encode improper information or may “dedifferentiate;” this is the interaction which is thought to initiate the cancers associated with the SLRDs.

When a daughter is airborne, it has an electrical charge associated with it and it has an higher probability to adhere to other airborne particulates and dust. When the daughters adhere to airborne particulates, it is said to be "attached." An inhaled attached daughter has only about a 3% chance of adhering to the lung lining. An inhaled unattached daughter, on the other hand, has a 50% chance of striking and adhering to the lung wall1; increasing the chances of a an alpha particle/cell collision. Ironically, where dust levels are high, the risks from elevated radon are lower than in dust free areas with the same radon level. It is for this reason, home-based air filters may remove the attached SLRD from the breathable air, but ironically increase the risk associated with newly introduced SLRDs (that sounds contradictory at first, but give it some thought).

Airborne SLRDs are constantly becoming attached to a walls, tables, chairs, carpets and other non-respirable objects. When this occurs, it is said the SLRDs "plate-out." Plate-out effectively removes the SLRD from inhalation exposure and thereby reduces the hazard (and risk) associated with a specific radon concentration without reducing the radon itself. This phenomena is the basis of one of the lesser known "radon" reduction techniques.

Radon and Risk

Industrial Hygienists, in general, are engaged in protection of humans against the harmful effects of ionizing (and nonionizing radiation). The specialized field of managing ionizing radiation is known as “Health Physics” and the job of the Health Physicist is to manage the beneficial use of ionizing radiation while protecting workers and the public from potential hazards. Although political organizations (such as the US EPA) publish a variety of statements of elevated risk, to date there are no scientific studies that have ever actually shown that radon gas, as typically seen in houses, increases the risk of cancer. To be clear: There are NO valid studies that have conclusively demonstrated that typical residential exposures to radon increase the risk of cancer at all. In fact, all of the valid studies performed thus far show one of two things: 1) No risk and/or 2) a decreasing risk of cancer. This view is reflected in a position statement issued by the Health Physics Society, the premier Health Physics organization in the US. According to the position statement issued by the Health Physics Society1a, for doses below 100 mSv (10 rem)

“…risks of health effects are either too small to be observed or are non-existent."

In a May, 2016 revision 1b the HPS reiterates that:

Substantial and convincing scientific data show evidence of health effects following high-dose exposures (many multiples of natural background). However, below levels of about 100 mSv above background from all sources combined, the observed radiation effects in people are not statistically different from zero.

So, just how hazardous is radon? Well, the above referenced document notes that the average US annual equivalent dose from natural background radiation is only about 3 mSv.

We have to remember that there are degrees of exposure, ranging from massive doses seen in miners who also inhale other contaminants, to minimal, negligible doses seen in residential scenarios. The “hazard” (risk) is incumbent on the dose received, and the duration of the received dose, not on some absolute “harm” associated with the radioactive gas at any dose. Elevated levels of radon (and thus the SLRDs) are unquestionably a significant health hazard, but similarly, we simply do not see those kinds of elevated levels in homes, and at concentrations of radon seen in residences, there appears to be no elevated risk (and many studies show the risk of cancer is actually is lower in an house with a little radon than in an house with “no” radon.)

So the question really is not “Is radon dangerous” but rather, how “high” is "elevated"? Further, is the total accumulative life-time dose or the dose rate more important? Recent studies are answering these questions and demonstrating that radon in residential settings is not nearly the cause for alarm originally proffered by politically motivated governmental agencies or financially motivated radon testing and mitigation practitioners.

In the EPA and National Research Council (NRC) risk estimates, the units of exposure are Working Level Months (WLM). One Working Level is defined as any combination of short lived daughters in one liter of air which will ultimately release 1.3E5 MeV (million electron volts) of alpha by decay through polonium 214. Therefore a known concentration of radon has a specific “potential alpha energy concentration” (called the PAEC).

A somewhat more simple version (although less precise) is that a Working Level is a measurement of SLRDs which are in equilibrium with 100 pico Curies per liter of air (pCi/l); in this context, one pCi/l is not equal to one pCi/l in a house. That is a radon concentration expressed in pCi/l derived from WLs in risk estimates are not the same as radon concentrations expressed in pCi/l when measured by a home inspector or other “radon mitigation” service.

Equilibrium is said to have been reached when the maximum concentration of SLRDs has been reached. The ratio of the activity of the SLRDs to the activity of the radon gas is called the Equilibration Ratio (ER). Equilibrium usually occurs in about three to four hours. When an individual receives a dose of one WL in 170 hours (a miner's month), the exposure then becomes called a “working level month” or WLM.

The EPA guidelines for measuring radon were aimed primarily at homeowners (and cannot actually measure radon exposures), and therefore, a more simple version of WLs was needed to communicate radon concentrations to the general public. Therefore, the EPA invented a new unit of measurement and rather complicated the radon issue by using existing units, but applying different meanings to those units.

The EPA evaluated actual ERs between radon gas and SLRDs. By actually measuring the radon gas (which is very difficult, expensive and never done by residential radon measurement services), one can derive the PAEC, an upper limit for the SLRDs. Typically, ERs range from 0.3 to 0.7 2. An ER of exactly 1.0 is never seen because: 1) radon daughters are removed from buildings at different rates; 2) some SLRDs will plate-out while the radon remains airborne; and 3) newly infiltrated radon has not yet decayed.

The EPA arbitrarily decided that an ER of 0.5 represented what it felt would be a typical ER for a home and this became the basis upon which the EPA "pCi/l" was derived (which is why the EPA "pCi/l" cannot necessarily be compared with real pCi/l units). Although this selection has been heavily criticized by many scientists and in some journals such as the Journal of the American Industrial Hygiene Association, the ER of 0.5 is still used by the radon mitigation industry. Therefore, assuming an ER of 0.5, one WL is equal to about 200 pCi/l and not 100 as previously referenced.

Therefore, one begins to see the games that can be played by adjusting the numbers, but keeping the units of expressing the concentrations the same. This "numbers game" is at the heart of EPA risk models.

An unusually low ER in a home (say 0.3) would indicate a particularly dusty area (such as would be found in a home by a dirt road, for example) or a home that burned candles; an high ER (say 0.7) may indicate a particularly still area, an area filtered by a filtration system or particularly "dead" areas such as those rooms found in basements or storerooms.

The ultrafine particle faction of indoor air will significantly alter the ER, and indoor ultrafine particle concentrations are typically much higher in urban areas than suburban areas.

In one study 3, upon which the US EPA heavily relies, evidence involving miners indicated that at levels as low as 80 WLM, the risk of death from lung cancer was very high and the risk increased to 50% chance of death from lung cancer at even higher levels. In that study, the lowest measured exposure was 80 WLM. In fact, in that very important study, the EPA didn't actually measure a very large percentage of the exposed population or miners to determine what their exposure actually was. Instead the EPA states 4

Exposure in the U.S. cohort is poorly known; cumulative WLM (CWLM) are calculated from measured radon levels for only 10.3 percent of the miners...and guesswork is used for about 53.6 percent of the miners.

Guesswork? Let’s look at that again….

Exposure in the U.S. cohort is poorly known; cumulative WLM (CWLM) are calculated from measured radon levels for only 10.3 percent of the miners...and guesswork is used for about 53.6 percent of the miners.

That’s right, “guesswork” formed the basis of the majority of the estimates. The “numbers game” gets messier and messier. If one is allowed to use guesswork without challenge, where could this lead?

It is well known and an absolute, unquestioned scientific fact that the risk associated with SLRDs is a complex relationship with dose. However, in the model used by the EPA, the relationship between the dose from radon and the risk of dying from cancer was mathematically forced to follow a linear relationship up to a certain level (even though there was no scientific evidence that the linear model was valid). Furthermore, it is well known (but poorly understood why) at even higher levels of radon, (or more precisely SLRDs) the risk of death begins to actually decrease again4. The model6 was issued in 1988 by the National Research Council and is called the BEIR IV report. BEIR is an acronym for "Biological Effects of Ionizing Radiation".

In fact, the linear model has long been known to be invalid26, and the EPA has long recognized that the linear model is invalid, but decided to use it anyway. In their 2003 risk estimates 27

The BEIR VI committee adopted the linear no-threshold assumption based on our current understanding of the mechanisms of radon-induced lung cancer, but recognized that this understanding is incomplete and that therefore the evidence for this assumption is not conclusive.

In fact, the linear model is not based on “current understanding of the mechanisms of radon-induced lung cancer,” rather it is based on a voluntary adoption of a philosophical position that is traditionally used in risk estimation where there is no evidence of harm at the doses received.

Indeed, in the previously referenced position statement by the Health Physics Society, the authors explicitly state that qualitative assessments should NOT be made (since no risk is observed when this is done), and that, instead, a subjective philosophically-based risk assessment should be made exclusively based on the assumption of a linear model.

The assumed model has never been shown to be correct, and is scientifically accepted as incorrect. The Health Physics Society at the University of Michigan made the following observation: 28

There is, however, substantial scientific evidence that this model is an oversimplification of the dose-response relationship and results in an overestimation of health risks in the low dose range.

The statement continues with:

Radiogenic health effects (primarily cancer) are observed in humans only at doses in excess of 10 rem delivered at high dose rates. Below this dose, estimation of adverse health effects is speculative. Risk estimates that are used to predict health effect in exposed individuals or populations are based on epidemiological studies of well-defined populations (e. g. the Japanese survivors of the atomic bombings in 1945 and medical patients) exposed to relatively high doses delivered at high dose rates. Epidemiological studies have not demonstrated adverse health effects in individuals exposed to small doses (less the 10 rem) delivered in a period of many years.

This position is repeated throughout legitimate science, including US Governmental Laboratories such as the University of California, Lawrence Berkley National Laboratory which concluded: 27b

Despite being widely accepted as a guideline in setting standards for protecting public health, the linearity hypothesis is not firmly established as an expression of scientific knowledge.

Therein lies the crux of the “controversy:” On one side of the controversy are political lobbyists who want to show a risk to help out the multi-billion dollar radon testing and mitigation industry arbitrarily using invalid risk models, and on the other side of the “controversy” we have scientists saying “There is no evidence of risk.”

The EPA, being a political organization, ignored the science behind the biological effects and used an unsupported assumption that the health effects from the radon could be extrapolated in a linear fashion from the lowest radon concentration in the study (2,720,000 pCi/l-hour) to those levels found in homes. This linear "dose-response" assumption was made even though there was considerable uncertainty for the validity of the extrapolation at lower levels of SLRDs.

The lowest radon concentration in the BEIR IV study (2,720,000 pCi/l-hour) was typically received by the miners over a five year period 7. Yet the EPA and NRC take this five year exposure and spread it out over the course of 70 years, and assume that an individual will spend 18 hours per day in their home, 365 days per year for 70 years. They also assume the “home” is situated in an underground mine, and that the occupants smoke cigarettes in their underground home.

This equates to an accumulative radon concentration of about 6 pCi/l in the home. It is not known, at this time, if it is valid to assume that only the accumulative dose, rather than the dose rate is the sole factor for determining risk. In its model, the EPA, eliminated the "dose-rate-effectiveness factor" from the quality factor which is usually attributed for alpha particles.

Although it is a generally held industrial hygiene principal, that fractionation of the dose over a long period of time lessens the overall effect, this concept is not always accepted for carcinogens (tumor initiators), such as ionizing radiation. For carcinogens, fractionation of the dose may actually increase the overall risk 8.

The NRC understood the limitations of the study and concluded 9...

In summary, a number of sources of uncertainty may substantially affect the committee's risk projections; the magnitude of uncertainty associated with each of these sources cannot readily be quantified. Accordingly, the *committee acknowledges that the total uncertainty in its risk projections is large.*

A later study 10 (referred to as the Cohen Study), which is one of the largest studies, incorporated about 33% of the counties in the U.S. and looked at the issue of the linear, no-threshold dose-risk relationship used by the EPA. In this study, a least squares linear regression of lung cancer rates vs. mean radon levels gave a negative correlation between death and exposure levels. In other words, the higher the radon level in the county, the lower the death rate from lung cancer was for the community. The result was not due to questionable interpretation of shaky statistics; each of the studies showed a negative correlation with slopes of not less than seven standard deviations (and sometimes greater than 10 standard deviations) greater than zero.

This study, known as an "ecological" epidemiological study, looks at relationships between exposure groups and mortality rates. Ecological epidemiological studies carry less weight than studies based on individuals where the actual exposures are known and the study cohort is compared to an unexposed group. In an ecological study, the person who dies may not have been the person who was exposed to the insult. Additionally, ecological studies tend to be more susceptible to confounders. Nevertheless, the author of the Cohen Study maintained that in a study on linear no-threshold relationships, this limitation is not considered to be applicable since the mortality rate depends directly on the average exposure.

Several other independent studies also looked at mortality rates vs. mean radon concentrations and have found similar negative correlations.

Indeed, buried deep within the US EPA documents, and worded in a very complex way, the EPA recognizes that as residential radon concentrations go up, the cancer rates go down. However, the casual reader, thumbing through the EPA risk discussion, would not likely recognize this admission since the EPA made the statement in a purposely very convoluted and confusing manner wherein they state:

Unlike what was found with the more limited BEIR IV and ICRP analyses, the BEIR VI committee was able to conclude that the ERR per WLM increased with decreasing exposure rate or with increasing exposure duration (holding cumulative exposure constant).

We begin to see that the “numbers game” works best when we use language and syntax that no rational member of the general public can actually understand.

At least five U.S. State sponsored projects have performed similar ecological epidemiological studies; four have concluded that low levels of radon, such as those found in the average home, are not harmful (show a negative correlation) and the sixth study indicated a very slight (less than one standard deviation) positive slope, indicating some risk at low level.

Epidemiological studies in other radiological settings have similarly observed evidence contrary to fear-based public health policies. For example, an epidemiological study was conducted for a total of 95,673 workers in combined nuclear industry facilities (Hanford, Oak Ridge, and Rocky Flats, three for sites in the UK, and one in Canada).

60% of the workers, whose radiological exposures were very well defined, received doses greater than 10 mSv (1 rem). The comprehensive results for all cancers taken together showed a very slight decrease in cancer rate with increasing dose. As with all studies, statistical issues can be raised, regarding the results, however, unquestionably was the fact that even at these doses, a clear-cut unambiguous risk was not observed, and the risk appeared to decrease with increasing dose, or decreasing dose rate.

In a US Government Publication 11concerning radon, the following statement is made:

Currently there is very little information about...the health effects associated with exposures to radon at levels believed to be commonly encountered by the public. The only human data available for predicting the risks to the public are studies examining the health effects of exposure to radon and its progeny in underground miners. This information would be *appropriate for predicting the risks to the public if everyone was a miner, everyone lived in mines, and a large fraction of the general population smoked cigarettes.*

Clearly, then, the models used for the estimation of risk are inappropriate since the average American, Canadian, or Western European is not a miner, we do not live in mines, and we do not have similar exposures. The same document then goes on to state:

Depending on the set of assumptions used, the estimated values for lung cancer rates from environmental exposure to radon currently range from quite small to as large as 25% of the total annual lung cancer deaths in the United States.

Ongoing studies that employ more realistic models fail to find any evidence that the risk of death from cancer induced by residential radon exposure is even noteworthy. Furthermore, in modern science, it has been generally assumed that virtually all effects of ionizing radiation result in detrimental effects. However, over the past decades, reports in scientific literature seem to suggest that that low-dose ionizing radiation is not only a harmless agent but often has a beneficial or “hormetic” effect.

The same uncertainties plague chronic-exposure risk assessments for other forms of low level radiation; and the concept of ALARA (As Low As Reasonably Achievable) is used to control those forms of radiation. The definition of ALARA is found in the United States Code of Federal Regulations, 12 and is essentially defined as follows:

A policy of reducing personal and environmental radiation exposures to the lowest level commensurate with sound economics, available technology, and good operating procedures.

EPA Guidelines and Regulations

When the EPA established its radon exposure levels, it actually was attempting to establish limits on the Working Level of the SLRDs. The "real" EPA guideline is 0.02 WL; assuming an ER of 0.5 (which, as we have already seen, is a made-up figure), this would equate to 4 pCi/l of radon. However, an ER of 0.5 may not be appropriate for all buildings.

As mentioned above, the EPA selection of the 0.02 WL limit was not based on health effects or other risk assessment models but rather on a general agreement that 0.02 WL was the lowest technically feasible level of reduction.

The EPA guideline is not law in the U.S., it pertains only to residential homes, and does not carry force of law (although it is a de facto standard upon which litigation may be supported). It is merely one political group's recommended level of reduction. The EPA does not have mandatory limits for radon for other types of buildings and does not prohibit levels of radon in excess of the 4 pCi/l threshold.

As already mentioned, the EPA homeowner’s guidelines for measuring “radon” do not actually measure radon at all. An Industrial Hygienist or an Health Physicist would be laughed into obscurity if they used the EPA guidelines to perform actual human radiation exposure studies. This is because the EPA measurement guidelines have an extremely low confidence level in being able to actually determine a useable exposure value.

Individuals wishing to retain their EPA accreditation in the Radon Contractor Proficiency Program must comply with the EPA's politically derived position on radon (facts and good science notwithstanding), or face forced removal from the program by the EPA. Providing factual discussions on risk are not viewed by the EPA in a favorable light.

During an international scientific gathering, an internationally recognized health physicist was presenting his data that showed that lung cancer rates went down with increasing radon concentrations. The work was funded by the US EPA. A violent shouting match ensued when a U.S. EPA representative began throwing wads of paper at the scientist shouting “We didn’t authorize you to say that!!”

In fact, as already discussed, the data being presented by the scientist was exactly the same data now admitted in the 2003 EPA risk estimates. But the scientist wasn't presenting the findings in appropriate confusing language – and he wasn't playing the required "numbers game."

Radon Entry into Buildings

Most soil gas reaching the surface is quickly diluted by the surrounding air. In the event that a structure is built in or on top of the soil, the dilution of the radon does not take place as quickly, and the radon in the structure may accumulate.

Several factors govern the extent of how much radon will enter a building. The single most important factor is the local geology and surrounding soils. The immediate precursor to most radon gas is radium. (A very small contributor to the radon concentration is radon 226, also called thoron. The contribution of thoron is generally insignificant and will be ignored in this discussion).

The existence of even a small deposit of radium under a building will greatly influence the concentration of radon gas within the building. Micro geological formations such as local disturbances during construction, micro faults and rock out-croppings can significantly alter the radon concentration at the surface. An example of the extreme variability of radon was seen in one study 13 where one soil gas sample contained 250 pCi/l and a second sample taken at 10 meters distance contained 86,000 pCi/l. "Normal" indoor levels in the U.S 14 are typically about 1 pCi/l (using the EPA pCi/l, not the real pCi/l) which is 10 times greater than the outdoor concentrations of about 0.15 pCi/l.

When a building is constructed, pressure differentials between the interior of the building and the exterior of the building are inadvertently created, especially when there is a significant temperature difference between the interior of the building and the outdoors. This pressure differential, delta P (DP) is mostly due to a phenomenon known as the "Stack Effect". The building mimics an exhaust stack and is under negative pressure with regard to the surrounding environment including the atmosphere and the soil gas below the slab. Typically, the DP is greater toward the bottom portion of the building and is equalized near the top of the building.

To satisfy the negative pressure in the building, the net air movement toward the bottom of the building is from the outside of the building to the inside of the building. It has been estimated 14that as much as 20% of this infiltration comes from below ground level. This 20% infiltration accounts for between 80% and 90% of the total radon which enters the building.

In the early days of radon investigations, it was assumed that drafty houses would have less radon than "tight" houses. Additionally, it was assumed that houses with high exchange rates would have lower radon concentrations than houses with few air changes per hour. Contrary to expectations, studies performed thus far show that there is no correlation between "tightness" of a building and the radon concentration 15,16. Very low radon concentrations are commonly seen in very tight buildings and high levels are often seen in the leakiest of houses.

Therefore, the second most important factor in radon entry into buildings is the DP. Several studies have shown that a very strong correlation between DP and radon concentration exists. All things being equal, the greater the pressure differential, the higher the radon level.

Since most commercial buildings fitted with industrial heating, ventilation and air conditioning (HVAC) systems are designed to keep the structure at positive pressure, excessive radon levels in commercial buildings in the U.S. are rare even in "high radon" areas. Typically, the most successful radon reduction techniques are those which address the driving forces of the pressure differential.

Weather can also effect the DP. Generally speaking, when the outside air is cold and the interior of the building is warm, the DP is greater. When the wind blows, the DP is greater. Additionally, when the water table rises, such as following a recent rain, the soil gas pressure rises, increasing the DP. Other meteorological factors such as snow cover can also effect the radon concentrations in a building by creating a "cap" under which the radon can accumulate.

In the U.S., Britain and Sweden, the majority of the radon which enters a building is from the presence of radon in the soil gas. However, there are two other significant sources of radon- well water and building materials. For structures, which are serviced by well water, a significant contribution of indoor radon can be from the radon in well water. Worldwide 16a, the average concentration of radon in surface water is about 10 pCi/l. In the U.S., the average private well-water contains about 750 pCi/l. Levels exceeding 20,000 pCi/l are not uncommon and this author has seen references to levels exceeding 1.6 million pCi/l (0.16 µCi/l).

Due to radon's very high Henry's Law Constant, radon will quickly evolve from water when it is aspirated or exposed to the air. For this reason, processed city water is rarely seen as a contributing factor to the overall radon concentration in a building, since essentially all the radon has left the water in the predistribution processing. However, in well water, the water is not subject to the chlorination and aspiration processes and can be a significant contributor to the building's burden of radon. It is commonly quoted that a water radon concentration of between 6,000 and 10,000 pCi/l will increase the airborne radon concentration in a building by 1 pCi/l.

In a few isolated cases, decorative stone and other building materials have also been identified as being the single largest significant contributors to indoor radon concentrations. The building construction material called "granite" is usually a similar material called granodiorite. The granodiorite has been shown in some cases to be the sole source of radon in a structure. However, no studies have ever demonstrated that the radon contributed by these materials pose an health hazard.

ANALYSIS TECHNIQUES

The most common question we receive is “My radon level was measured at ___.___. How reliable is the number?”

It is important to begin by saying that none of the devices used in home inspection or real estate transactions actually measure radon. Each if the devices used by home inspectors and “radon consultants” measures some particular aspect associated with radon and then, using various assumptions and mathematical machinations, a “radon equivalent” number is generated. The protocols were not designed to be used to estimate annual human exposures to radon, and cannot, with validity or confidence produce radon exposure estimates.

The number reported during a short term test has a very low probability of actually representing the annual radon concentration in the home, and has virtually no utility in estimating the actual human exposure to radon or its SLRDs. Long term testing has a lower sampling error, but depending on the method, similarly cannot be used to estimate human exposures.

The interday and intraday variability of airborne concentrations of airborne contaminants exhibits a geometric standard deviation of between 1.2 and 2.5 GSD.16b. This means that a single short term reading is virtually incapable of estimating the true annual radon concentration. The uncertainty for attempting to extrapolate the yearly radon concentration from a three to seven day sample, such as that probably used for the vast majority of “radon tests” is huge: about +/- 90% (at the 90% confidence level).16c.

The error is due to the large fluctuations seen in radon concentrations at any point in time. The result of a “radon test” can change dramatically when any of the following parameters change:

A cycling air conditioner goes on or off

A cycling forced air furnace goes on (or off)

Barometric pressure fluctuations

Differences in indoor to outdoor temperatures

External doors in the structure are opened or closed

Internal doors in the structure are opened or closed

Macro-airborne particle changes (such as dust from a dirt road)

Phases of the moon

Recent rain

Relative humidity

Snow cover

Soil porosity at the time of the test

Solar loading on the structure

The amount of radon exposed in the underlying soil

Time of day

Time of year

Ultrafine airborne particle loading (such as burning a candle)

Water table levels

Wind direction changes

Wind speeds change

Windows in the structure are opened or closed

As such, the short term “radon” measurements have a huge error associated with them in extrapolating the long term concentrations. Depending on the type of device used by the home inspector, the result may only integrate the last 12 hours of a multiple day test.

To illustrate the sampling error of the short-term methods employed today let’s imagine a single family, single structure two storey home with a partial dug-out basement, on city water, and with a forced air heating system.

Imagine our home has an actual “true” annual radon concentration of 47 pCi/l. Now, let’s hire an home inspector to randomly test the property 21 times over the course of the year. The inspector produces 21 separate “lab reports” with the following results (expressed in pCi/l):

20

6

89

75

3

90

16

45

22

87

69

9

91

11

12

56

7

45

22

5

If we now analyze the validity of the results, we find that there is no statistically significant difference between the results of the tests. That is, each of the test results are “valid” and are all within the upper and lower 95% confidence intervals for the short term method employed. Therefore, based on the short term method used in real estate transactions, an house with a yearly “radon” concentration of say 47 pCi/l (as that given above) can give a reading of anywhere between 91 pCi/l and 2 pCi/l and still be "correct."

(We purposely selected 47 pCi/l since that allows us to illustrate the variance without the use of decimal points. For example, if the house contained 4.7 pCi/L, the range of readings would be from 0.2 to 9.1; but as explained below, the number to the right of the decimal point is meaningless.)

Since the number to the left of the decimal lacks confidence, how could the number to the right of the decimal have meaning? Imagine an agricultural inspector was asked to estimate the annual average weight of cows in a barn by measuring the cows over a three day period using the same precision as “radon” methodologies. Although during the three day period, there were 100 cows, the rancher moves cattle in and out, some of the cows are calves whose weight will increase rapidly over the next few months, and some are full grown, some are dairy and some are breeders, etc. But using the “radon method” of estimation, inspector reports that the annual average weight of the cows was EXACTLY 125,234.2392 pounds.

The inspector simply has no chance of being correct with such precision. Since the number to the left of the decimal point has low precision, to try to pretend that ANY number to the right of the decimal has any meaning is nonsense. At best, and with valid confidence and precision, one could estimate the annual weight of the cows as follows “You have about 60 tons of cows.”

And so it is with radon readings. When we hear someone describe their “average” radon concentration as some value followed by a decimal point and another value, (such as “five POINT two “) it is meaningless. When someone has a reading of, say, 5.2 pCi/l it means just one thing: The actual yearly average radon concentration in the house is probably somewhere between 0.01 pCi/l and twenty pCi/l.

The methods used cannot, with confidence, distinguish an annual exposure concentration of 91 pCi/l from a reading of 2 pCi/l let alone a reading of say 3.6 versus 4.2 pCi/l This misplaced trust in magical laboratory reports is what we call the “CSI” effect.

Charcoal Canisters

The charcoal canister (CC) method of radon concentration estimation is the most widely used method of screening. Like virtually all other "radon measurement devices" the CC method does not actually measure radon but rather it measures the gamma radiation associated with the SLRDs. Several assumptions as to relative humidity, equilibration ratio, transient peaks and others are then incorporated in the final analysis.

There are several advantages of using the CC method. They are relatively cheap, usually costing about $25.00 to $40.00 The placement of charcoal canisters need no special training. Although the sampling error associated with the CC is very high, the analytical precision associated with the CC is very good. The charcoal canisters are inconspicuous, which allows for undisturbed sampling; and they are fast; sample periods can be a little as three days and results can be obtained within three or four hours.

There are some disadvantages associated with the CC as well. The uncertainty for attempting to extrapolate the yearly radon concentration from a five to seven day sample is huge: about +/- 90% (at the 90% confidence level) 17. For this reason, a single CC reading (or indeed several) cannot be used to estimate the annual radon exposure in a house. Also, charcoal canisters are susceptible to humidity changes. Often, the analyzing laboratory will assume a standard percent relative humidity and use that in their calculations.

The CCs are erroneously thought to integrate the radon concentration over the sample period (usually three to five days), but this is not quite true. The CC will bias the results to reflect the last 10 to 12 hours of sample time. Therefore, if during the last 12 hours of sampling time a rain storm has occurred, or the outside temperature has dropped or the wind was particularly strong, then it is likely that the results will be biased high. If on the other hand, the day was calm, unusually dry and warm, the results may be biased low.

Alpha-Track Monitors

Alpha-track monitors are typically small cylindrical containers (about 5 cm high) which contain a piece of plastic film. The opening to the cylinder is often covered with a dust cover. Filtered alpha-track devices always bias the results high.

During the decay of the radon and its SLRDs, the alpha radiation strikes the film and creates microscopic areas of damage which mark the path of the alpha particle. These paths are referred to as "alpha-tracks". After a period of not less than one month (shorter if the radon is particularly high), the film is removed and etched with a solvent to enhance the tracks and the tracks are optically counted under a microscope (there are some automated counting devises). The number of alpha tracks is a function of the radon concentration.

The advantages for alpha-track include simplicity, cost and inconspicuousity. They are slightly more expensive than the charcoal canisters. The alpha-tracks are as easy to use as charcoal canisters and are small and unobtrusive. They are not affected by either temperature or humidity.

Alpha-tracks can be used for long periods of time, integrating the exposure over that time. Typically, they are set for a period of three months to one year.

One disadvantage of the alpha-track method is the fact that they are slow. Generally, they should be exposed for periods not less than one month. Also, the analysis is more subjective than that of charcoal canisters. A +/- 50% uncertainty must be applied to a three month alpha-track measurement (at the 90% confidence level) when extrapolating the mean annual concentration.

Some studies 18 have shown that in using the alpha-track principal some materials may be capable of "remembering" their alpha exposure over the course of several decades. One method uses the glass found in windows, picture frames, and even old spectacles from a building's occupant. A long term decay product of radon is lead-210 which in turn decays to polonium 210. The polonium 210 becomes embedded in the glass via recoil processes and can be analyzed using alpha spectroscopy. The method provides an excellent opportunity to evaluate what the historical radon concentration of the building has been.

Continuous Working Level Meters (CWLMs)

In a CWLM, air is drawn through a filter which traps and retains the SLRDs but allows the radon to pass. The alpha from the SLRDs is counted in a preselected energy window (typically 2 to 8 MeV) over a specified period of time. The counts are automatically converted to WL by means of a calibration factor.

The advantages of the method include the ability to determine the actual extent of the true hazard; i.e. the SLRDs. The method can evaluate the efficacy of mitigation techniques which aim at reducing the SLRDs but do not address radon gas. Sources of radon such as showers, floor drains, sumps et cetera can be determined using CWLM. The results are relatively quick, and are obtained on-site without need for laboratory analysis allowing for real-time monitoring of SLRDs.

Some of the disadvantages include the high initial cost of the instrument or rental fees. The instruments are not simple black-boxes and require the use of a trained operator and the instruments need to be site calibrated.

MITIGATION TECHNIQUES

Mitigation techniques are divided mostly into three groups: 1) those that address reduction of radon gas; 2) those that address the reduction of SLRDs; and 3) those that address the DP.

The average 19 radon gas reduction, as of 1989, from mitigation techniques is 70%. However, it is more practical to speak of absolute reductions rather than per cent reductions. For example, it is easy to get a 98% reduction when reducing the radon in a building from 500 pCi/l to 10 pCi/l but it is extremely difficult to get a 20% reduction when attempting to reduce the radon from 5 pCi/l to 4 pCi/l.

The life time effectiveness of the mitigation techniques is still under review.

Ventilation

Ventilation as a radon reduction technique usually addresses reduction of the radon gas rather than the DP, because usually when a contractor is referring to ventilation, they are referring to ventilation of a crawl space, not a living area. When this is the case, the radon contractor usually refers to "isolation and ventilation". The Building Official's Code Agency recommends 1 square foot (865 cm2) of passive vent per every 150 square feet (14 m2) of floor space with vents within 6 feet (1.8 m) of each corner.

Passive ventilation of a working or living area is typically considered to be an inappropriate technique for buildings in temperate climates because of the difficulty of maintaining comfort zone temperatures during the winter months. An additional problem with passive ventilation is that one does not have good control of the ventilation. A window may be open one minute until someone else feels cold and closes the window.

Additionally, it has been shown 20 that if other than the very lowest level of the building is passively ventilated (say by opening a window) then winds blowing through the building can create a venturi effect and actually increase the radon concentration. As discussed earlier, there is no correlation between air changes per hour and radon concentration, but there is a strong correlation between DP and radon concentration.

Passive ventilation of some heating cellars where the pipes are insulated and the room contains a sump may be a viable option. Ventilation systems designed for radon reduction are often fitted with heat recovery devices to help reduce the loss of heated air to the outside. Passive ventilation is obviously cheap, and easy but it has met with rather checkered results. It is most appropriate for small buildings with very low levels of radon.

Active ventilation, on the other hand, is usually in the form of HVAC systems and are not specifically designed as radon reduction systems. Nonetheless, because the HVAC systems are designed to maintain the building at slightly positive pressure, they address the DP issue. By maintaining a slight positive pressure, HVAC systems overcome the negative pressures of the stack effect and prevent radon from entering a building. The system should be capable of maintaining a positive pressure of at least 0.02 inches of water column (5 Pa) above the ambient pressure.

Filtration Devices

Filtration devices address the SLRDs without addressing the radon problem or the DP problem. Filtration devices circulate the room air through a filter which scrubs out the SLRDs.

On the surface, this type of technique appears to be an excellent solution, however, the filters will also remove the airborne particulates (ultrafine particles, dust, pollen, etc.) thus increasing the ratio of unattached daughters and actually increasing the bronchial radiological dose21. As mentioned earlier, the unattached daughters have a much higher probability of adhering to the lining of the lung wall. Therefore, the sole use of filtration devices is not considered to be an appropriate mitigation technique.

Air Movement Device: Ceiling Fans

This type of a system addresses neither the DP problem nor the radon entry problem, but rather the SLRDs themselves.

Unlike a filtration device, a ceiling fan does not remove the desirable airborne particulates but rather encourages the plate-out of the SLRDs. Since this type of technique can be installed by the homeowner (as a rather attractive addition to a living room or dining room), radon contractors do not have an incentive to disclose this technique to the general public.

Remarkably good reductions (as high as 95%) of SLRDs have been achieved 22 by simply placing a "Casablanca" type ceiling fan in a room. The fan should be capable of complete air movement within the room. Where the desired reduction is on the order of 50%, the ceiling fan alone can correct most of the problems.

Where a reduction of 80% or better is needed, the a ceiling fan in conjunction with a positive-ion generator may correct the problem. The ceiling fan/positive-ion generator combination has been tested in the U.S., Denmark, Finland and Canada 22 with similarly excellent results. The reduction in SLRDs has been consistently as high as 95% and where bronchial doses have been measured 22, the reduction in bronchial dose has been as high as 87%.

The positive ion generator should not be confused with an electrostatic precipitator (ESP). Using an ESP could result in the removal of airborne particulates and an increase in unattached daughters. Also, negative ion generators have been shown to be less effective than the positive ion generators 22. While the fan speed is not critical, the fan should be placed in the center of the room and be large enough to effectively move the air in the room.

A disadvantage to this type of reduction technique is that post-mitigation monitoring would have to involve a continuous working level monitor, instead of the charcoal canisters. Nonetheless, the savings achieved by the technique over some other mitigation methods would nearly off-set the cost of purchasing such an instrument (not to mention renting one).

Another disadvantage to this technique is that it can be readily turned off if not properly installed. The fan and the positive ion generator should be wired such that it cannot be deactivated by unauthorized personnel. The system should be labeled as a "radon reduction" system and allowed to run continuously.

Sealing Floor and Foundation Wall Cracks

Since some 90% of the radon 23 comes from sub-slab infiltration, one of the earliest mitigation techniques involved simply sealing floor and foundation wall cracks to prevent entry. The advantages of this method are its relative ease and low cost.

The disadvantages of the technique include its poor record of success, its limitation to only unfinished basements and the fact that it does not address DP, or SLRDs.

It has been shown that where high levels of radon are present, sealing alone is a very poor mitigation technique. However, sealing of floor and foundation wall cracks is often a necessary supplement to sub-slab depressurization (this will be discussed below).

When such sealing is required, the crack needs to be properly routed out first and then sealed back in with an appropriate material, such as backer-rod and foam.

Where high levels of radon are present, this technique is not recommend as a sole corrective action.

Positive Pressure

In some mitigation cases, the technique was to positively pressurize the basement. This technique has a poor record of success because it involves upsetting the normal use of the basement. It has a potential ability to blow out pilot lights and can be noisy. It is no longer generally considered to be an acceptable mitigation technique.

Sub-slab Depressurization (SSD)

Approximately 90% of the reduction techniques used in the U.S. today are SSD 24.

The idea of SSD is to address the driving force of the radon entry; the DP between the slab and soil gas. Instead of increasing the pressures within the building, SSD reduces the soil gas pressure below the slab. This author has measured in-house/sub-slab pressure differentials of as high as 89 Pa.

The SSD technique involves penetrating the slab with a 7cm to 20cm inside diameter PVC pipe and running the pipe up through the structure and exhausting to above the roof line. A centrifugal fan capable of developing high static pressure is mounted at the exhaust (outside the shell of the structure) to depressurize the slab. The fan should be capable of maintaining a pressure of at least 5Pa below the highest DP recorded or expected.

In some cases, 25 a passive turbine has been used with encouraging results. The driving force for the depressurization is the stack effect and a wind driven turbine at the exhaust.

SSD has a proven track record of achieving 80% to 90% reduction in radon gas levels in favorable structures. SSD works best when the soil type is a sand or a loam. Additionally, the slab should be in good condition; slab cracks and expansion joints will limit the extent of the pressure field. If the slab is damaged or the soil has a high clay content, then SSD can still be used by inserting more and more collection pipes in the slab to extend the pressure field.

Prior to SSD, soil communication tests should be performed. Pilot holes are drilled into the slab and a vacuum cleaner is used to create a negative pressure field below grade. The DP is measured at each of the pilot holes. If the DP at each of the holes is acceptable (5 Pa or greater) then only one hole is needed. If the DP at any one of the pilot holes is less than 5 Pa, then that hole should be enlarged and incorporated as a collection point. Typically, one collection point is needed for every 65 m2.

SSD works well for recessed floating slabs, slab-on-grade and floating slab-on-grade structures.

The are several important variations on the SSD theme. The first is perimeter drain depressurization whereby the pressure field is created using the existing exterior perimeter footing drain.

Block wall depressurization is used when the foundation wall consists of hollow block construction on a poured concrete footer. The foundation wall is penetrated with PVC piping and suction is applied to the wall. Prior to block wall depressurization, a block wall communication test should be performed to ensure uniformity in the depressurization. The block wall communication test is similar to the soil communication test. Doors, fire walls and other anomalies will disrupt the pressure field within the wall and require additional collection points. The block wall may be depressurized from the interior of the building or the exterior of the building.

In addition to the block wall depressurization technique, the same concept may be used for stem wall depressurization. Baseboard depressurization may be appropriate where there is a french drain present. Sumps may be used to depressurize the sub-slab soil.

Another important variation is the membrane suction technique used in crawl spaces. Since the earthen floor in the crawl space is incapable of allowing for an extended pressure field to develop, an impermeable membrane is placed over the entire floor of the crawl space. In some studies and case histories, the membrane is anchored to the floor using furring strips, and in other cases, the membrane is simply allowed to rest on the earthen floor.

Once the membrane is in place, a suction point is cut into the membrane roughly in the central portion and the soil gas is evacuated in the normal fashion.

One of the disadvantages of the SSD type systems is the cost. The initial cost of the installation is higher than most other techniques. The operating costs and the maintenance costs are also higher. The system can become noisy, prompting complaints from the building occupants and even prompting the occupants to deactivate the system.

The radon levels at the exhaust can be quite high and care must be taken to ensure that the radon is not reintrained back into the building shell.

Some contractors have experienced water vapor build-up from improperly installed systems. As the water vapor is extracted from the soil gas beneath the slab, it can condense within the pipes of the system. When this happens, the fan may be incapable of overcoming the back pressure and the pressure field below grade is disrupted. In some cases, the water vapor has condensed in the fan housing causing fan failure. The system must be designed to ensure that water build-up can safety be drained back into the slab, or to the out-of-doors.

The systems need to be installed with elaborate control panels which indicate the total pressure on both sides of the fan. Alarms are recommended to alert the building occupant in the event of fan failure, unacceptably high static pressure in the up-stream side of the fan or other problems which may develop.

If the SSD type systems are installed improperly, they can greatly increase the overall radon concentration in the building. Common faults include:

1) Placing the fan in the shell of the structure; if the fan leaks the radon is exhausted into the building.

2) Placing the fan in such a position that the radon is pushed along the exhaust pipe rather than pulled through the exhaust pipe. That is to say, the exhaust is under positive pressure with regard to the ambient pressure of the structure, if the pipe has a leak, the radon will enter the building.

3) Placing the exhaust too close to the plane of neutral pressure. During the stack effect, the lower portion of the building is under greater negative pressure than the top of the building; at a certain point, the pressure within the shell of the structure will equal the pressure outside and the DP will be zero. This point is called the plane of neutral pressure and is typically located 5cm to 8cm below the top most ceiling in the structure. If the exhaust of the SSD system is located at or below the plane of neutral pressure, the radon can be reintrained into the building.

Furthermore, improperly installed systems can result in exposing passers-by to the exhausting radon. The following criteria should be met:

1) The discharge point must be at least 3.5 meters above ground level.

2) The discharge point must be at least 3.5 meters (line-of-site) from any door, window or other structure openings that are less than 0.75m below the discharge point.

3) The discharge point must be at least 3.5 meters away from any private or public access.

4) The discharge point must be at least 3.5 meters away from any opening into an adjacent building.

The SSD systems have also been associated with back drafting problems whereby the exhaust from other sources of combustion (fireplaces, gas fired heaters and water heaters, etc.) within the building are disrupted. Therefore, following the installation of any depressurization system a test must be performed on any building which contains combustion appliances.

Educational Videos

FACTs provides on-site training in several areas including radiation and radiation toxicology. Below is a four-part series on a 90 minute presentation on the myths of residential radon. The talk is a simple, fact-based discussion regarding the myths of residential radon. Enjoy!

[PLEASE TAKE THETIME TO COPY AND PASTE THE URLS BELOW THAT LINK TO THE VIDEOS VIEWABLE ON THE INTERNET – IT IS WELL WORTH YOUR TIME]

Radon: An Introduction to Radiation

https://youtu.be/TYZglUjLE0Y

Radon: An Introduction to Toxicology

https://youtu.be/37pCurE0nxo

Radon: An Introduction to Epidemiology and Testing

https://youtu.be/n6oD7ZiqbcI

Radon: Three Minute Wrap-up

https://youtu.be/YOGbEjLN94Q

The information on this discussion is continuously updated whenever significant or materially new information becomes available. Those who have concerns about the dates of the studies and references may be interested in reading this discussion.

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A discussion concerning myths surrounding duct cleaning, can be found by clicking here.

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