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RADON CONTAMINATION OF RESIDENTIAL STRUCTURES: IMPACT OF THE "WEATHER EFFECT" ON THE SHORT-TERM RADON TEST

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ABSTRACT

The outcome of short-term radon tests is significantly affected by weather and diurnally induced variations in radon influx. This paper details research that addresses the "weather effect" – those changes in radon levels brought about by changes in barometric pressure, winds, precipitation patterns, and differences in indoor / outdoor temperatures. These complicating factors underscore the unreliability of short-term radon assessments as predictive descriptors of long-term radon conditions.

A substantial two-year database collected in an actual midwestern residence is presented in an easy-to-understand graphical form. It illustrates and emphasizes the complexity of the radon infiltration mechanism and serves to alert and remind radon professionals of precautions that must be taken in radon risk assessment. This contribution to the literature should be of interest, not only to radon professionals, but also of special interest to Realtors, sellers, and home buyers.

INTRODUCTION

In matters of public health as they relate to the workplace and home environment, the hazards of radon have attracted substantial attention from the national media, Realtors, sellers, and home buyers. The literature, both technical (1 - 13) and popular (14 - 15), has been addressing the issue with scientific studies and general articles which lately are at variance with each other (16).

There seems to be little doubt that radon and its progeny are a threat to public health. Epidemiological data gathered from hard-rock miners in the U.S. and abroad is conclusive – radon and uranium ore dust are primary substances being blamed for the cancers found in these workers. However, there are dissenters in the scientific community (17) who are taking the Environmental Protection Agency (EPA) to task for the manner in which it has arrived at its cancer risk assessments. Data (22) derived from the Colorado Plateau miners (where cancers were detected in 356 smokers and 25 non-smokers) formed a major underpinning of the EPA assertion that there is a link between radon and lung cancers. Significant increases in lung cancer have been detected at a wide range of exposures that include lifetime levels of as little as 4.0 pCi/L (20).

The issue of whether or not other airborne deleterious substances in the mines caused the cancers will not go away (18). Some scientists target the abundant siliceous dust found in hard-rock mines as a *contributor* to lung cancers because it has been shown that neoplastic tissue forms when human culture cells are exposed to silica dust (11 - 12). Likewise, silicosis, a chronic fibrosis of lung tissue is caused by inhalation of particulate silica. Can such assaults on lung tissue be dismissed as cancer precursors? In other words, how certain are scientists that radon is the sole source of the cancers contracted by the miners? Where is the consensus? Have all non-radon factors been given enough attention in the EPA's risk-assessment protocols?

The EPA disagrees with those who maintain that radon poses a less-than-serious risk (18). It points to long-standing and current research which supports its position (19 - 24). It maintains that a linear extrapolation, from the high radon doses received by the miners to the risk attendant in the residential environment, is justified because the tissue damage has been shown to have a linear relationship to the energy delivered by the radiation (19). Also, they maintain that studies (21) support the conclusion that cancer rates do correlate with cumulative radon exposures regardless of exposure to siliceous dusts. Doubtless, more research is needed before this important public health issue is finally clarified to the satisfaction of all.

A PERSPECTIVE

Certainly, it is wise to take the radon issue seriously. However, the overall impact of the program currently fostered by the EPA is substantial, both in terms of economics and emotional stress to the public. Most radon professionals have encountered frustrations invoked by sellers who balk at mitigation costs. Some have dealt with home-buyers who would turn away from a property they really like if the radon level even slightly exceeds the EPA action guideline of 4.0 pCi/L.

Unlike the more trivial real estate aggravation posed by termites, radon is not detectable with the senses. It confronts sellers and buyers with an "invisible" threat. Perceived as frightening to contemplate and costly to remedy, the uninformed flee emotionally. If the public fails to fully understand the issues, it becomes evermore difficult to frame the radon problem in a manner that will cause it to be taken seriously.

The importance of educational programs cannot be overstated. Print and TV media are giving radon a considerable amount of coverage via public service and EPA-produced advertisements. Even so, as well informed about the radon problem as the public is gradually becoming, one wonders how many know that the 4.0 pCi/L action level is based on the assumption that one would spend 75% of a 70 year time-span in the contaminated space? Given the lifetime mobility of modern-day Americans, is it reasonable to expect that duration of exposure? Would the average person actually spend some 52 years in a radon contaminated space? Like those questions being raised within the scientific community, these are legitimate and reasonable questions being raised by angry Realtors and informed homebuyers in today's real estate market.

The radon professional is caught between a scientific community at odds with itself and a worried public who is seeking sound scientific information. As a result, the radon consultant is gradually assuming a role which transcends that of a mere analyst or mitigator. Radon professionals are increasingly being asked to do a significant amount of "radon counseling." All clients, apprehensive or not, expect and deserve as much information about the nature of radon and the testing / mitigation process as they may desire. Analysts and mitigators have a professional and ethical responsibility to keep current by engaging in a program of continuing education – and in making all such information available to clients. In that context, as the need for testing is underscored, fairness dictates that the limitations of test protocols be described as well.

THE SHORT-TERM RADON TEST

Sometimes homeowner / occupants erroneously assume the short-term radon test commonly associated with a typical real estate transaction is representative of the long-term radon situation in the tested environment. Regrettably, this occasionally occurs even though the pre-test conference, the test report itself, and the follow-up discussion clearly indicate otherwise. In matters of science which are sometimes poorly understood by the public, there is a human tendency to accept a fragment of scientific data as "engraved in stone." Somewhat dazzled by the technology, public misconception may be rooted in the ever-increasing sophistication of radon testing devices. Given the ready availability of high quality, reliable, and reproducible test devices; and due to the perceived complexities of the radon problem, homeowners and occupants sometimes give too much weight to the short-term test result. When this occurs, the aforementioned misconception takes an on an importance that can be unfair, misleading, and sometimes costly.

☐ Besides serving as a brief overview of radon infiltration factors, a major intent of the present study is to illustrate how a trustworthy short-term radon test result can be profoundly affected by conditions over which neither the radon analyst nor the homeowner / occupant, have control.

It is well-recognized that it is the overall (EPA protocol) average radon level that counts. Properly deployed and handled, a high-quality charcoal canister or E-Perm is able to provide a measure of the average radon level equivalent in accuracy to any other short-term method. Nevertheless, it is also well known that the best way to assess a radon situation is to make one or more long-term tests that span the seasons. A dilemma arises; there is a conflict between the time needed to make the preferred (and more representative) long-term test and the general impatience of buyers and sellers when the sale is imminent. As useful as alpha track monitors, E-Perms, and other long-term devices may be, they do not enjoy widespread use in the typical real estate transaction. It is, therefore, all the more important that homeowners be encouraged to have their homes tested well before sale is contemplated. Besides the important advantage of providing a healthful environment for the homeowner's family, testing early and mitigating as may be required is good insurance which can facilitate an unencumbered property transfer when that time finally arrives.

ELECTRONIC MEASURING DEVICES: GENEROUS DATA, INSTANT RESULTS

Notwithstanding its significant limitation as a long-term descriptor of radon conditions, the short-term test is, and will probably remain, the major testing method used when quick results are demanded. Here, the short-term electronic test is superior; it can provide a very revealing analytical result which goes well beyond the one-shot time-integrated average given by any measurement device able to provide a single number only. In the "hurry up" present-day real estate market, high quality electronic monitors offer the best short-term test alternative because their copious data are available immediately upon conclusion of the test cycle. The disadvantage to the radon professional is the high cost of continuous monitors. For example, a useful and functional collection of such monitors is much more costly than a comparable number of E-perms and their reader. Any analytical service able to simultaneously monitor multiple sites will have made a substantial investment in continuous monitoring detection devices. Even so, ultimate costs are recoverable as the public begins to better understand the significance of the weather effect and the superior data volume provided by the continuous monitor.

In 1993, the EPA narrowed the time-base of the test protocol for electronic radon monitors. Such devices must now be capable of reporting radon levels on a time-base of one hour. As electronic test instrumentation improves, analysts are able to make radon measurements on time-scales of ever-diminishing size. As will be shown in the next section, a radon data spectrum made over a one-hour time scale looks significantly different from one made on a different time-base.

EXPERIMENTAL

Although the effect of weather conditions on indoor radon levels has been addressed in the literature (25 - 33), none of these studies involved a time span as long nor a database as large as that used in the research presented here. Because the many variables associated with weather changes when taken individually are both subtle and minor in impact on long-term radon conditions, research has tended to neglect the impact of weather effects. Effort has been focused toward the more controllable variables such as soil composition, structural factors, and the stack effect. Even so, as will be shown in this research, weather factors working in concert can and do have a sometimes substantial impact on the outcome of the short-term radon test. Given the importance of the short term test for radon screening and real estate transactions, the weather effect should be given more attention.

All data used in this study were collected in a normally occupied midwestern residence. Data acquisition began in 1992. In order to make the data-base as large and useful as possible, collection has been continuous, and will be ongoing into the foreseeable future. Today the database is already substantial (more than 10,000 entries). It includes twice daily records of radon level, barometric pressure, indoor relative humidity, and indoor and outdoor temperature. It includes, as well, prolonged periods of continuous monitoring of radon, barometric pressure, indoor temperature, and indoor relative humidity.

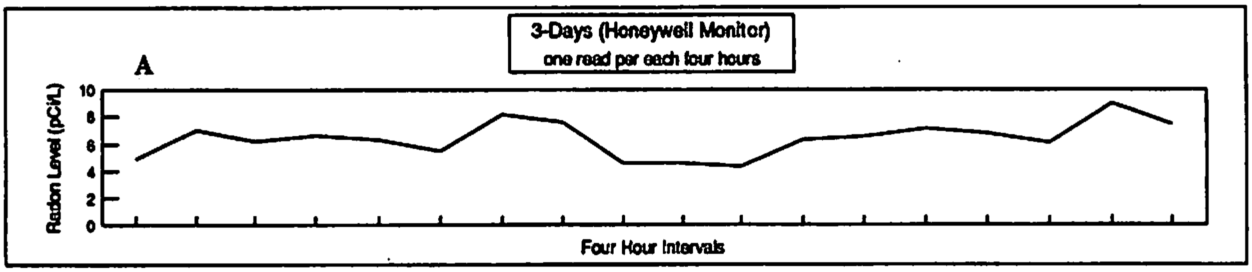
Continuous data were gathered from multiple Honeywell A9000A monitors operated side-by-side with a Genitron Instruments, AlphaGUARD 2000 Professional Radon Monitor. Data were either manually entered or directly down-loaded into a spreadsheet (Lotus 1-2-3® v.5.0 for Windows) and/or a scientific statistical graphics program (StatMost®). These two programs are the sources of graphics in included in this paper.

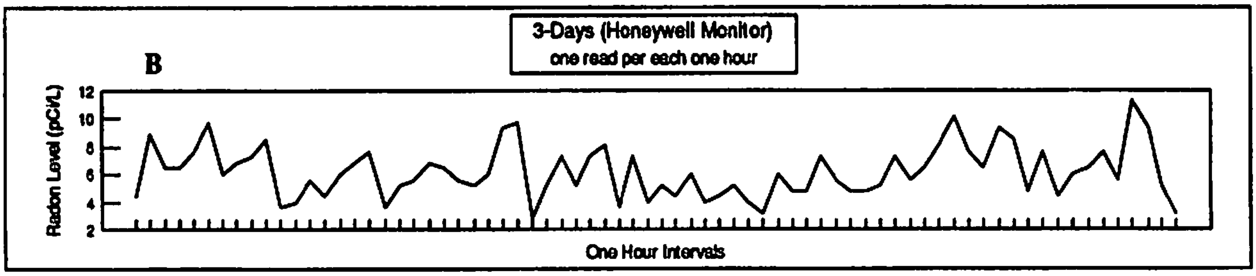
Overall, graphic images offer a view into the complexity of radon generation and influx that is otherwise impossible to visualize from the raw data. In addition, these graphic plots emphasize the inherent variability that attends radioactive decay processes. When the database is examined from the perspective of 3-D (3-axis) graphic plots, some noteworthy conclusions may be drawn. Finally, graphics help to clarify the impact of the weather effect (34) on the ubiquitous short-term radon test.

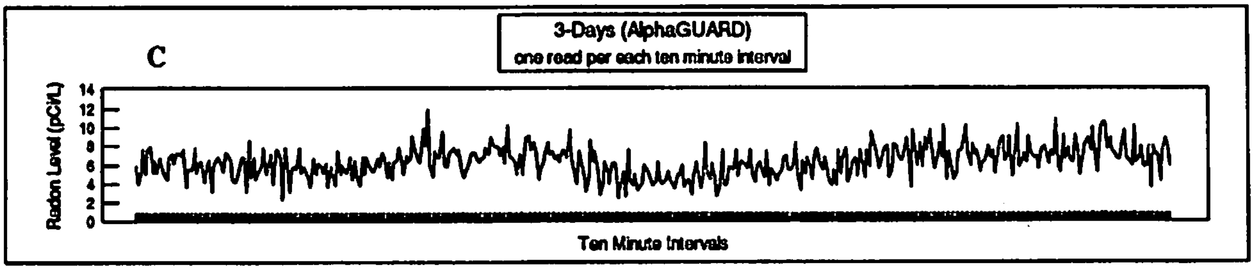
TIME-BASED VARIATIONS IN RECORDED RADON LEVELS

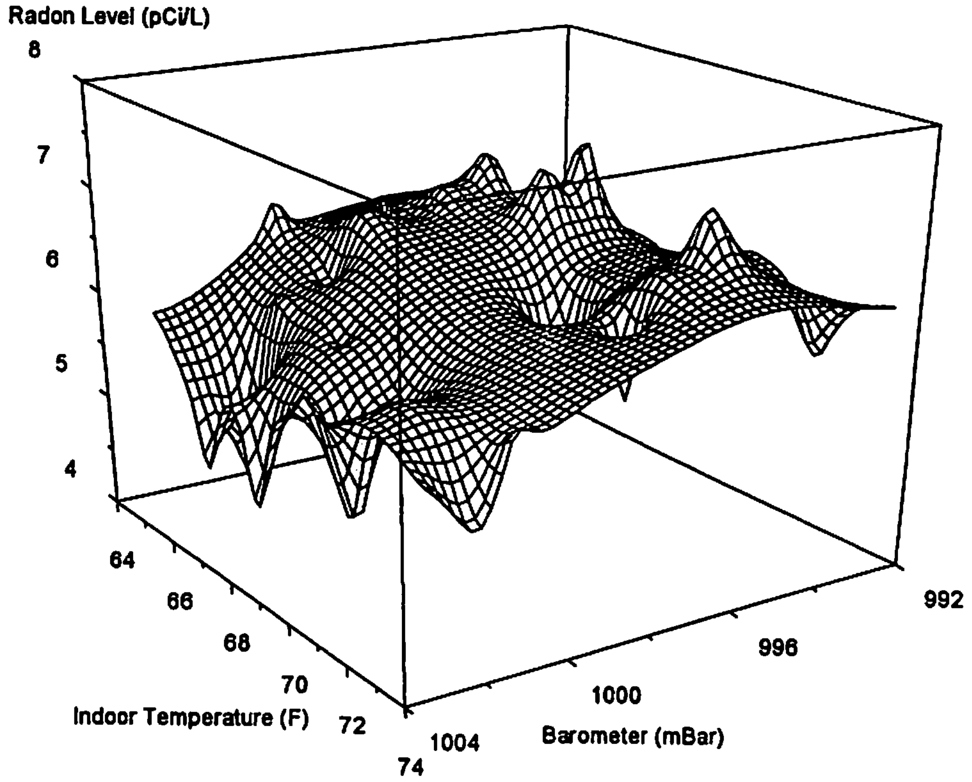
Many environmental factors impinge upon and alter the rates at which radon enters a structure. Ultimately, these factors influence the levels of radon detected. This is especially true for the results of the short-term radon test. Even the duration of a short-term test has a significant impact on the measured radon profile. Below is a continuous monitor radon spectrum (A) taken at four-hour intervals over a three day time span comparable to the duration of a typical short-term test. It is aligned for comparison with two more (B and C) that cover the same time span in the same test environment, but whose radon data were recorded in shorter intervals. All three measuring instruments logged an average radon level of about 6.3 pCi/L during the three-day test. Even so, it is clear that, although the average recorded radon levels are the same, a narrower time-base yields a radon spectrum noticeably different from that obtained over the longer counting interval. This result is emphasized to an even greater degree when the sampling interval is made shorter than the EPA interval of one hour per each logged measurement. The third graphic in the set (C) depicts the same 3-day time span and the same test environment as the pair at the top. However, the sampling interval has been reduced to only ten minutes. When it is compared to (A) and (B), note how many more times the detailed profile dipped below 4.0 pCi/L. The more detailed profiles underscore the extreme variations in radon levels that accompany its generation, influx, and subsequent radioactive decay.

When time-based radon detail is needed in order to show changing radon levels during a test, the adjustable sampling interval offered by the electronic monitor clearly illustrates the superiority of the continuous radon assay over that of any passive device delivering a single reading. In addition, more detail in the recorded profile makes the analyst better able to detect unusual swings in radon levels which may be indicative of a tampering event.

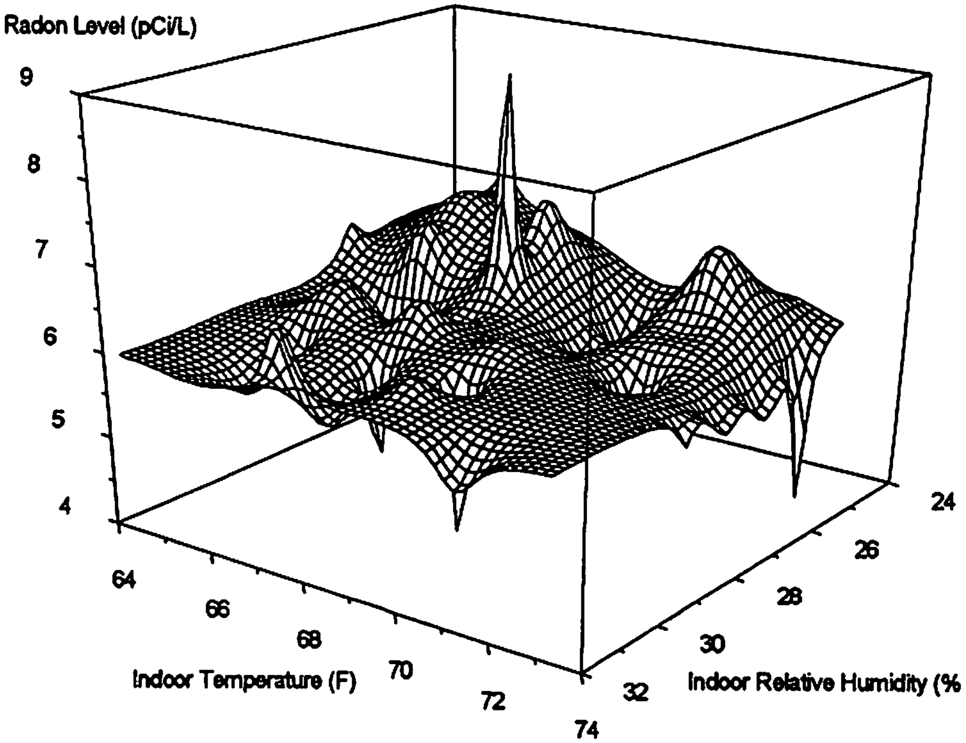






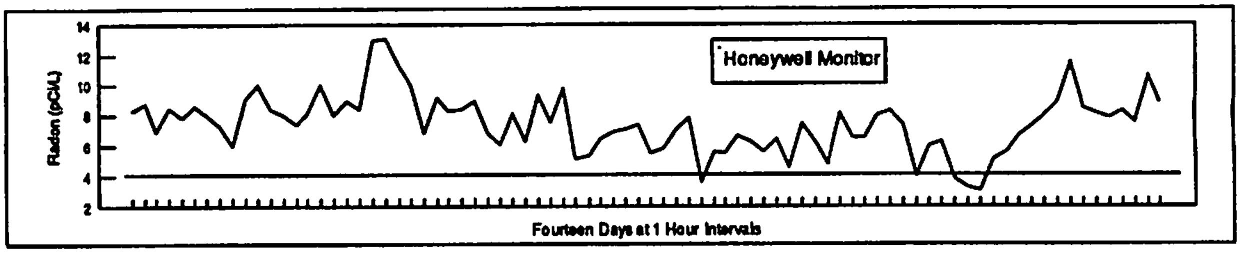


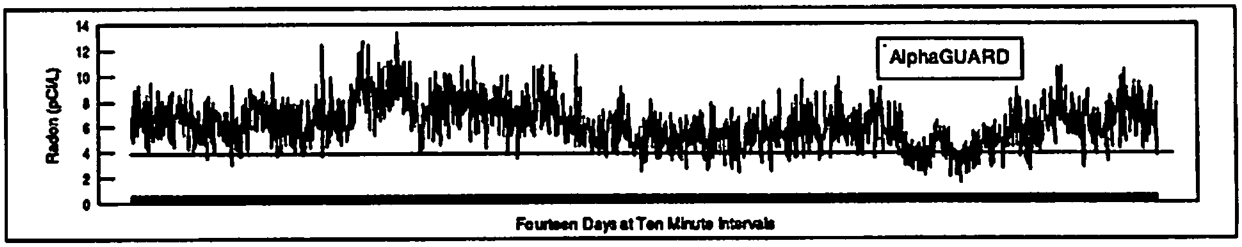
This pair of (3-axis) graphics represents the same 3-day data set shown on the previous page. However, these have been expanded to include two more parameters which also can have a significant impact on the results of the short-term radon test. The above plot illustrates the influence of barometric pressure and temperature on radon levels during the 3-day testing interval. The plot below depicts the role of relative humidity (a function of precipitation events) and temperature. As can be seen from these illustrations and others that follow, short-term radon measurements are buffeted by a host of complicating factors. The shorter the test interval, the greater their opportunity to encumber the test result.

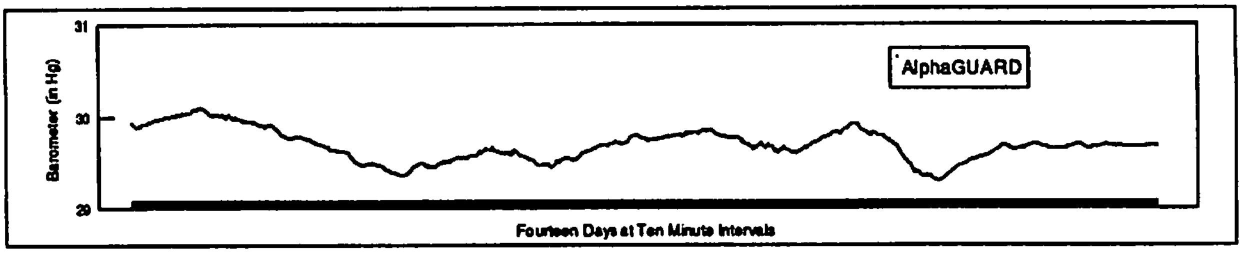


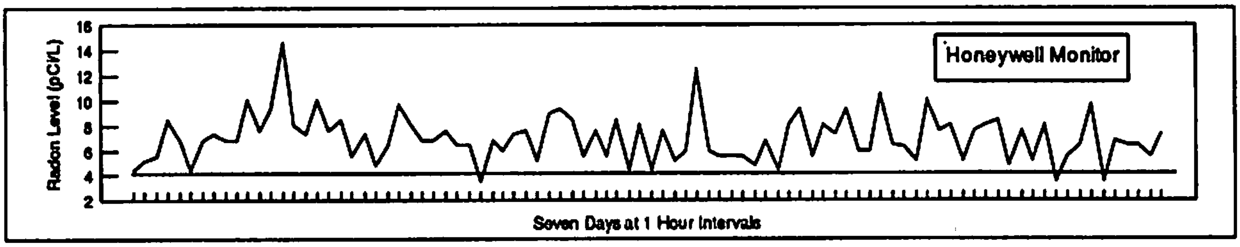
BAROMETRIC PRESSURE-INDUCED VARIATIONS IN RECORDED RADON LEVELS

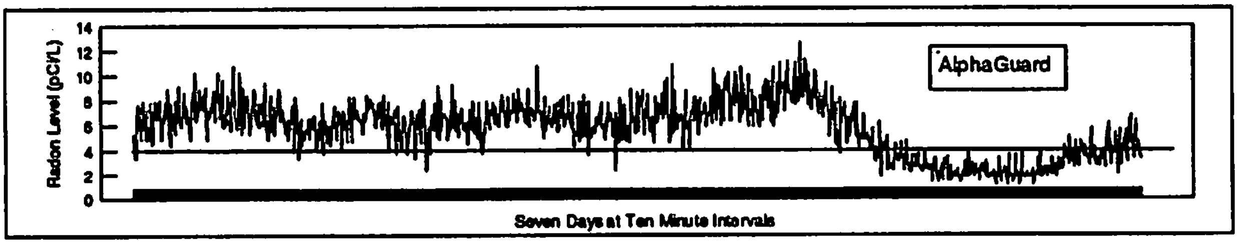
Subtle as they sometimes may be, the onset and departure of high- and low-pressure weather systems always make themselves evident in short term test results. These graphics represent two different, nonconsecutive fourteen- and seven-day time spans. Once again, note the greater detail in the radon spectrum when the sampling interval is made smaller. Note, too, how the radon level (albeit slightly delayed) tracks changes in barometric pressure. Many such plots were drawn from the full database – a sample collection is appended to this paper. They confirm the "barometer effect" – other factors equal; declining barometric pressures are associated with increases in radon influx.

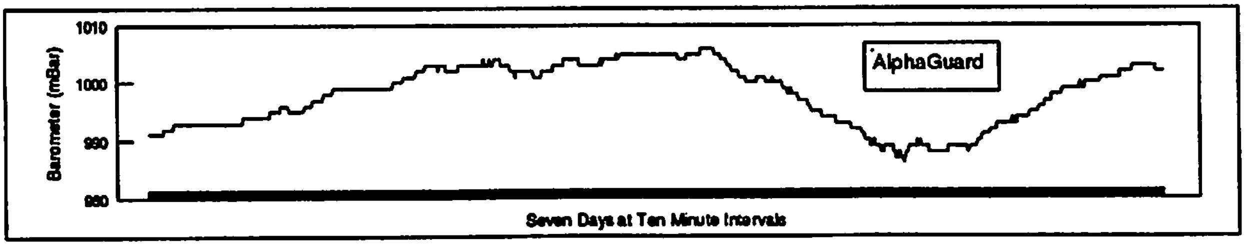






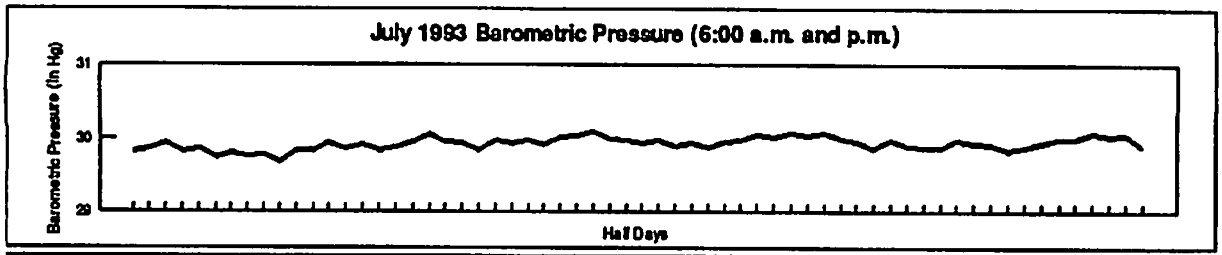


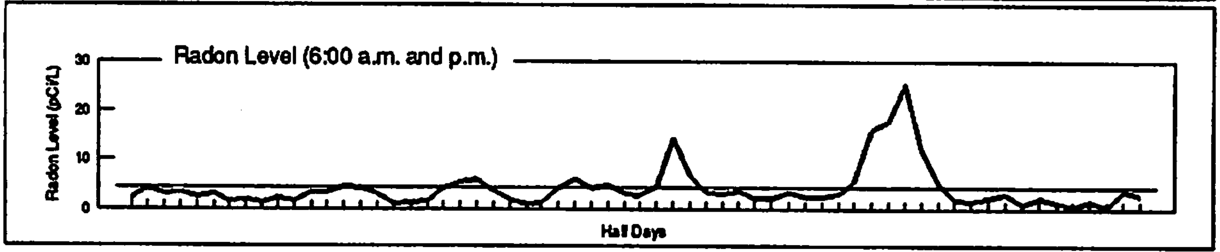


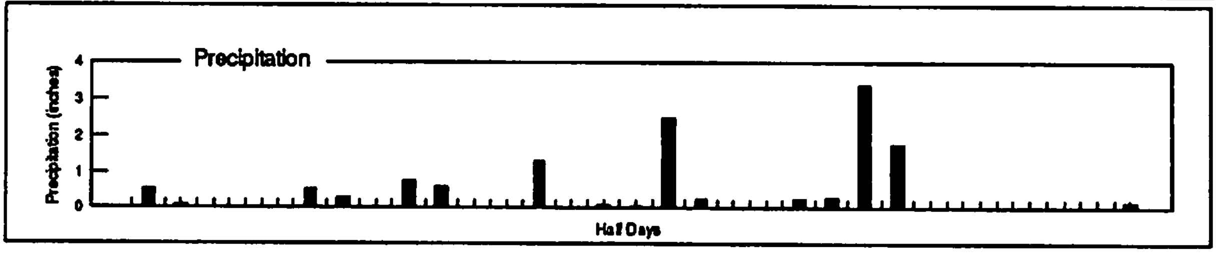


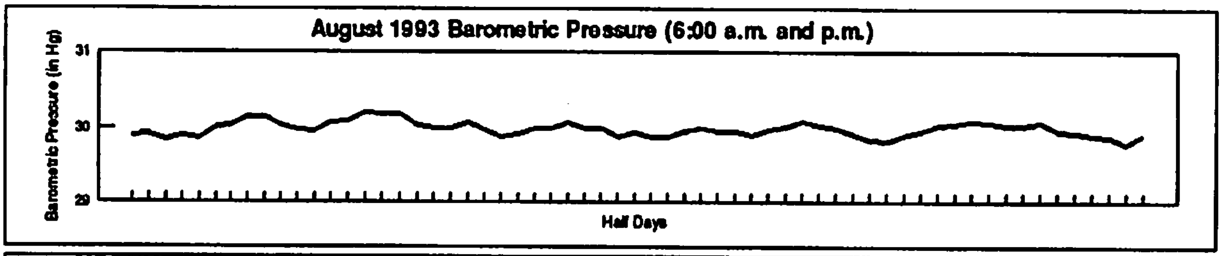
PRECIPITATION-INDUCED VARIATIONS IN RECORDED RADON LEVELS

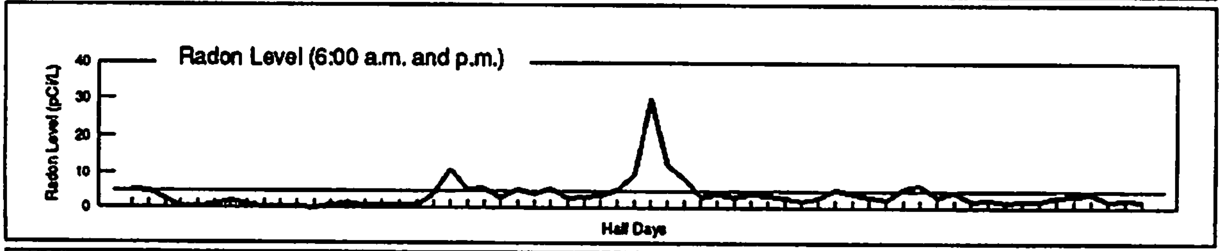
Here is a graphic sampling of the database for July / August 1993 depicting radon, barometric pressure, and precipitation. Once again, note how the radon level tracks changes in barometric pressure. Also note the correspondence between radon levels and rainfall amounts and intervals. Even small amounts of rain cause increases in radon influx. Reasons for this phenomena, focusing on a water-induced sealant effect, soil porosity, and water solubility of radon itself, have been proposed in an earlier paper (34). They will be expanded upon in the section that follows.

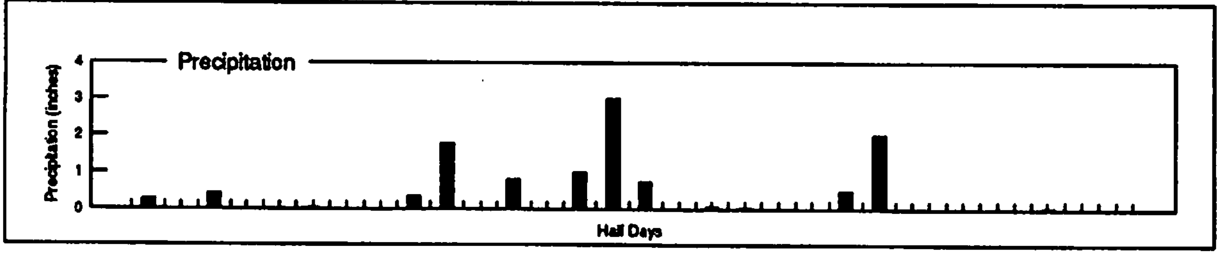












COMPLEX RELATIONSHIPS: RADON SOLUBILITY, TRANSPORT, AND WEATHER EFFECTS

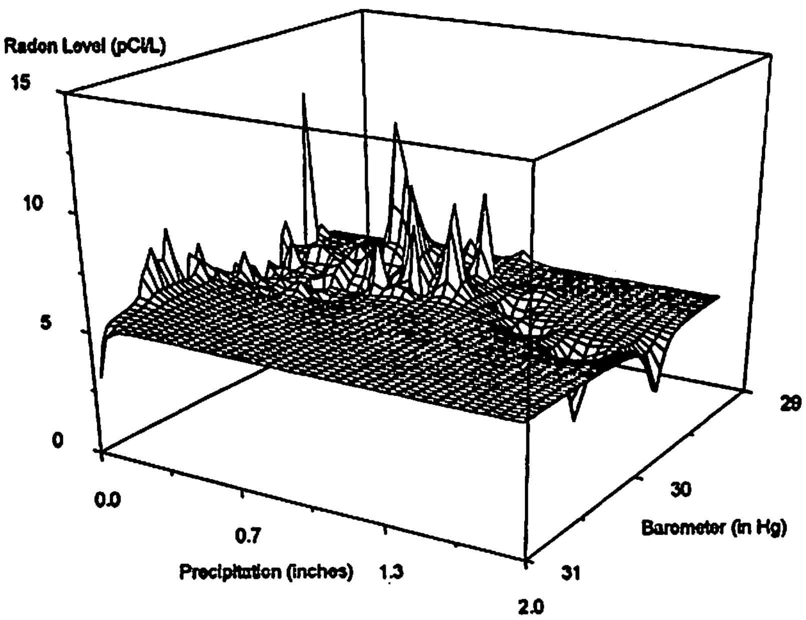
It is well-recognized that radon levels inside buildings are subject to a very complex interplay of several environmental factors. Among these are soil composition, chemistry, water content, and porosity; the season (closed-vs open-house conditions; barometric pressure changes; wind intervals, duration, and velocities; and seasonally induced indoor / outdoor temperature differences. When considering the following series of graphics, one can begin to appreciate some of the difficulties encountered by radon scientists who are attempting to create a predictive model which can serve to describe radon infiltration.

Solubility / Transport

Radioactivity, half-lives, and the decay of uranium in soil to radon and its progeny have been discussed earlier (34). A radioactive decay event may be likened to a subatomic explosion occurring inside the nucleus of an unstable atom. For example, when a radium atom (the immediate isotopic precursor of radon) decays within the soil matrix, the energetic disintegration of the radium nucleus causes the progeny radon atom to recoil from its point of origin. Recoil can have either of two results. It may embed the progeny radon atom still further into a soil grain. When this occurs, the radon atom remains trapped in the grain where it decays harmlessly. However, if the decaying radium atom is on or near the surface of the soil grain, the progeny radon atom may be ejected into the pore space between the grains where it is free to move.

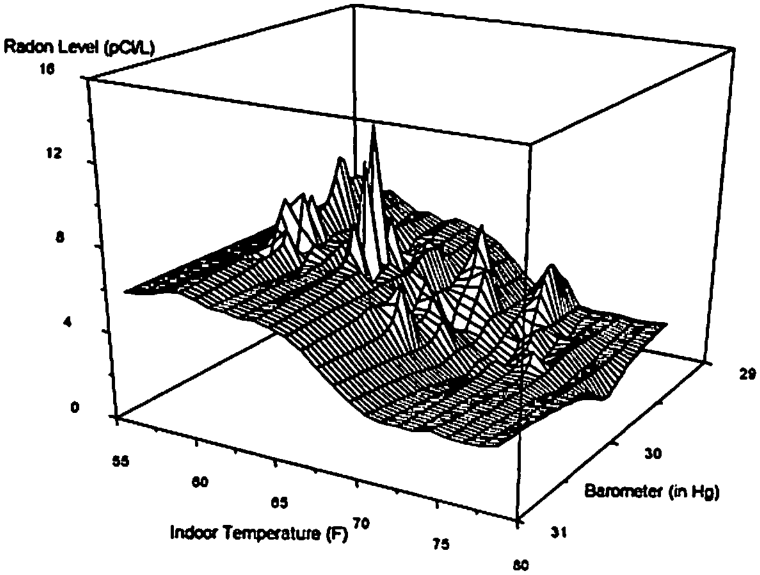
Although dry, porous soils are more permeable to radon transport than wet and / or fine-grained (clay-like) soils, some water is almost always present – both adsorbed on and between soil particles. Even though it requires about 6,000 to 10,000 pCi/L radon dissolved in water (26) to produce an indoor airborne concentration of 1 pCi/L, the high water-solubility of radon gas cannot be dismissed as a trivial means by which radon enters a basement. Because radon is about ten times more soluble in water than is oxygen (35) – it is about a third as soluble as carbon dioxide – some radon will be dissolved by interstitial water.

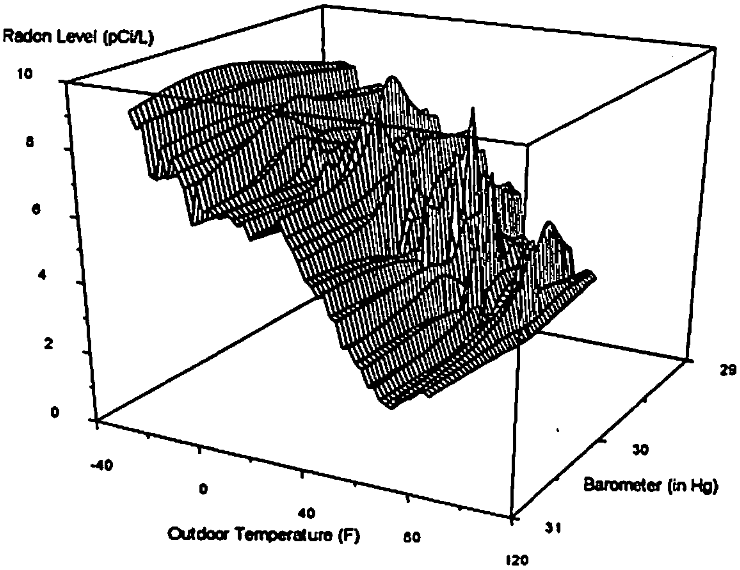
Radon's water solubility has an effect on the transport of radon from the soil into the basement. Radon becomes more water-soluble as temperature decreases (35). In periods of cold weather (when the soil is not frozen) radon presence in water percolates is even more pronounced. As radon-bearing water soaks deeper into the constant-temperature reaches of the soil, its concentration in seepage waters tends to level off to an equilibrium value. Basement walls and floor are in contact with a relatively constant concentration of radon which is proportional to its rate of generation and mode of transport. Frozen soil acts as a substantial barrier to radon movement both because ice-bound soil particles become a wall through which gaseous diffusion would be exceedingly low, and because dissolved radon would be trapped inside the ice matrix. Radon generated in frozen soil tends to build up in concentration as it accumulates in the interstitial ice. If, as is not uncommon, the soil remains frozen for ten radon half-lives (about 38.2 days), such "old" radon has all but decayed away to background radiation level. However, radon that is continuously generated in the soil is being replaced at a constant rate. When the soil thaws, trapped radon which would have moved gradually and more freely to the surface through unfrozen soil is released over a relatively short time. This accounts for the radon spikes detected in earlier research (34). In most radon-prone areas of the U.S., where the soil ordinarily never freezes more than a few feet in depth, radon generated in the deeper unfrozen soil remains free to dissolve in interstitial water and make its way inside the basement.



The graphic shown here, drawn from a part of the database September 1993 to May 1995, depicts a relationship between radon level, barometric pressure, and precipitation. It illustrates how rainfall events can cause pronounced spikes in the radon profile. At first, when a light rainfall follows a relatively dry period, the advancing water interface moving downward through the soil both dissolves and pushes the radon (and other soil gases) ahead of it into any open space it passes. However, note the marked depressions in radon level that occur when the soil is saturated by heavy rainfall. This can be understood from the solubilizing effect of water. A copious amount of water soaking into soil dissolves radon, entraps it in the liquid, and "washes" it out of the interstitial spaces between soil grains. If this radon-laden water gains access to the home, its radon problem is exacerbated.

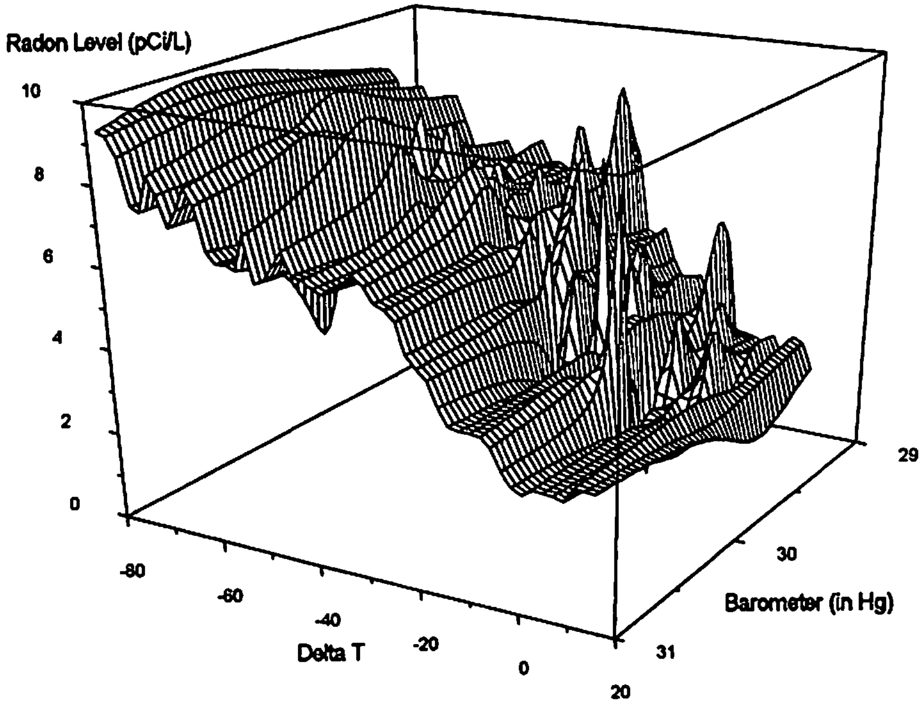
Radon-bearing sump and perimeter drain-tile waters are almost always significant contributors to a radon problem because the gas is so easily entrained by those run-offs. This is why indoor radon levels often fall when sump wells are sealed and power-vented outdoors. This same solubility factor is responsible for the radon abatement success of sealed and depressurized baseboard dewatering systems. As they divert dissolved radon safely out of the home, perimeter dewatering systems offer an additional benefit; they also vent radon which may have entered into block wall cores.





The "Stack Effect"

The "stack effect" – a temperature-induced, convective outflow of heated indoor air from above-ground-level parts of a home – reduces the atmospheric pressure in the basement to a level below that in the soil adjacent to the walls and floor. As air leaves the above-ground parts of the home, it is replaced by a corresponding inflow through all access points. If the basement walls and floors are not well-sealed, radon and other soil gases are drawn in from the higher pressure zone below ground level. This graphics pair (drawn from the same part of the data-base) illustrates how radon levels can be influenced by indoor and outdoor temperatures. When the temperature is low (winter conditions), there is a general trend toward elevated radon levels. However, the distortions (spikes and depressions) evident along the middle of the barometric pressure axis indicate a complicating factor related to a neutral (1 atmosphere, 29.92 in Hg) interior / exterior pressure equilibrium occurring at those times. Both graphics emphasize this point because heating and air conditioning effects notwithstanding, indoor temperature changes tend to track seasonal outdoor temperature variations.



The same data can be viewed from still another perspective which provides insight into the combined effect of outdoor / indoor temperature differences on radon levels. Actually, the relevant graphic shown here is just another way of illustrating the impact of the stack effect. By making the difference between outdoor and indoor temperature (Delta T) part of the graphic, it becomes clear that the radon level is highest when Delta T is large. This occurs in winter when it is warm indoors and cold outside. Under such weather conditions, above-ground outflow of lower density heated air is greatest. Thus, the stack effect plays a significant role in radon influx. The end result of a large temperature differential produced by warm interior air and much colder outdoor air is an elevated radon level. Other factors equal, radon levels are lowest when the outdoor / indoor temperature difference is least (Delta T is near zero).

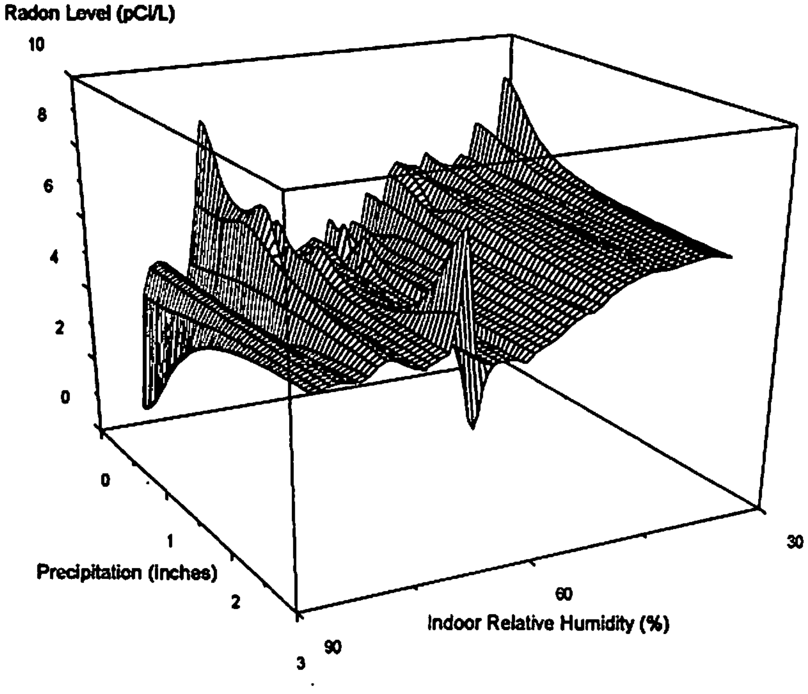
Effect of Indoor / Outdoor Pressure Differentials

Pressure differentials generated by changes in barometric pressure are largely unappreciated as significant contributors to radon influx rates. We believe they should be given greater consideration in short-term radon assessments. According to a U.S. EPA RMP training course for radon mitigation (Peoria, IL, March 13-16, 1995), the "natural" vacuum effect of a house (a manifestation of the stack effect) is of the order of 0.005 to 0.01 inches of water. During the 3-year test interval of the present study, barometer swings as wide as 1.35 inches of mercury were recorded. This represents a weather-induced pressure variation that is some 1850 times larger than the natural vacuum exerted by the house. Certainly, an effect so large cannot be dismissed. Notwithstanding the well-understood EPA protocol that discourages tests during adverse weather and periods of high winds, the overall impact of the "general weather effect" is not trivial; its effect on the short-term test can be, and often is, quite substantial. Thus, even ordinary weather changes should be recognized as factors which can seriously compromise short-term test results.

In addition, there are still other sources of pressure differentials that should at least be recognized. In summer, air conditioned interior air is more dense than warmer outdoor air. Flow-reversal due to a gravity-driven outflow of cooler air should and sometimes does tend to reduce radon influx. This occurs because outflow of higher density air sweeps soil gases out through the same cracks and pores in the foundation / floor which permits their entry. In summer, indoor / outdoor temperature differences are not nearly so great; consequently, the diminution in radon level caused by those smaller differences is also not great. This purging phenomenon is true more in theory than in actual practice. Pressure differentials generated by differences in air temperature are very small and are easily overshadowed by barometric, precipitation, and wind velocity factors. For that reason, the role of any inadvertent summertime-flow reversal as a mechanism by which the radon level may be reduced is most often negligible.

Aritficial Pressurization

In houses with relatively low radon concentrations and permeable surrounding soils, artificially induced outflow can prevent entry of soil gases (30). Basements in well-sealed homes have been successfully pressurized with blowers in order to reverse airflow through those same cracks, pores, and discontinuities which permit entry of radon. Also, pressurization tends to reduce radon levels by dilution. As promising as pressurization seems to be, it has not gained widespread application because establishing and maintaining an effective and permanent seal between the basement and upper floors of the home is difficult. And, unless blower-lost air is carefully controlled, artificial pressurization will increase heating and cooling costs by increasing exfiltration of conditioned air.



Indoor Humidity

The relationships between radon, precipitation, and low indoor humidity conditions (typical of those encountered in cold weather) are illustrated here. As discussed in this contribution and in an earlier paper (34) sometimes even a small amount of precipitation can raise the radon level. However, that particular (solubilization) effect is distinct from the effect depicted in this graphic. Low humidity conditions occur most often in wintertime when the house receives the full impact of the stack effect. On the other hand, high humidity conditions (common in weather permitting open house conditions) are accompanied by lower radon levels. In general, under (wintertime) conditions of low indoor relative humidity, the radon level is elevated.

Finally, returning to the matter of radon's water solubility, this graphic further illustrates a point brought out by the figure on page 8 and the discussion on page 9. Note the drop in radon level that accompanies the substantial (1 inch) rainfall event. Thus, radon's solubility in water has much to do with its depletion, recovery in, and transport through soil interstices.

MATHEMATICAL ANAYLSIS

Because weather effect variables are numerous and ever-changing, mathematical analysis of such effects is difficult. General radon / weather relationships cannot be constructed from even a large collection of short-term tests because most such test data focuses on the radon level to the exclusion of weather factors operative during the test period. In other words, very few radon analysts routinely log weather data. However, as weather effects become better appreciated, and weather conditions during tests are recorded along with the radon level, statistical analyses may become possible when the data-base has become sufficiently large. Although the data-base collected for the present study is substantial, it represents radon / weather conditions experienced by only a single dwelling. Many more such data-bases from widely different locations are needed before any meaningful (predictive) conclusions can be drawn. Even so, the graphics included in the present study are intriguing. They lend support to theoretical considerations based on thermal transport, diffusion, and fluid dynamics effects. In addition, they dramatically illustrate the significance and complexity of meteorological influences on the radon entry mechanism.

DISCUSSION

Because radioactive decay rates are constant, the emanation rate of radon is a constant related to the uranium (radium) content of the soil adjacent to the structure. It should be recognized that the radon which does enter a structure originates in the fill that is within a few feet of the foundation and slab. Soil composition determines its porosity and adsorptivity. Thus, the diffusivity of radon within the soil matrix is significantly affected by those factors. Given the chemistry of the soil and the tortuosity of the interstitial pathways within the soil, radon cannot diffuse very far before it decays to metallic polonium which remains almost completely immobile in the soil. It is against this backdrop of physicochemical constraints that the weather effect plays out its role.

At least in its impact on short-term radon tests, the weather effect is not a trivial consideration. A very significant body of data supports the observation that changes in barometric pressure are accompanied by changes in radon influx. Likewise, influx is significantly affected by soil moisture, precipitation frequency, and the overall quantity of water per rainfall event.

EPA protocols recommend short-term testing be avoided during periods of high winds. However, it should be noted that although winds may temporarily reduce pressures in buildings enough to draw radon inside, those same winds will thereby deplete the radon levels in the soil adjacent to the walls and floor (36). As well, this is borne out with respect to the solubility of radon in water. The overall immediate effect of high winds and / or heavy rainfall will be a surge of radon corresponding to the windy period followed by a drop in radon level until the soil gas concentration is re-established by re-emanation from the source. Even so, it should be remembered that this generalization is constrained by other factors such as soil chemistry, porosity, and moisture content. Radon professionals, realtors, homebuyers, and sellers will do well to consider the weather effect when assessing the significance of any short-term radon test.

❦❦❦

Though the U.S. EPA radon action level currently stands at 4.0 pCi/L, authorities elsewhere set the maximum permissible level much higher. For example, the U.S. Mine Safety and Health Administration allows a maximum level of 16 pCi/L for miners. Sweden permits a radon level of 22 pCi/L in existing buildings and 11 pCi/L in homes undergoing remodeling. Only new construction is required to meet the 4.0 pCi/L level adopted by the U.S. EPA. Whatever the level finally settled upon, the public has been sensitized to the radon issue; the need for testing will continue unabated.

☐ However useful and necessary as they are, short-term radon tests are fraught with uncertainties that can sometimes be misleading and/or costly to the unwary homeowner or real estate investor.

Certainly if the maximum amount of information is sought from each short-term test, there is no better alternative than that provided by high-quality electronic monitors. We are fortunate to have manufacturers who are developing and marketing superior test devices which produce reliable and accurate measurements. In times such as these, when the real estate industry is upset with the radon issue and when homeowners and occupants are fearful of environmental hazards, the generous data output provided by electronic monitors can be a real assist in understanding and explaining the variables associated with this nettlesome problem. Radon analysts should be aware and make their clients aware of the importance of the long-term test protocol.

It is not yet known whether those who support the "total cumulative exposure / linear dose" thesis will ultimately prevail over those who hold the view that no radiation dose can be considered safe. In consideration of the evidence to date, it is this author's opinion that ionizing radiation is deleterious to living systems. Thus, the "minimum possible exposure" approach seems to be the best path of action. Even so, in the meantime it is in radon professionals' interests to encourage testing and to embark upon a career of continuing education that will enable a clear presentation of analytical procedures and risk estimates to the public.

Finally, given the uncertainties surrounding the risk of radon, it is prudent to lean toward the conservative position taken by the EPA. It also wise and good business ethics to help those who seek a radon test to understand the multitude of factors that can influence the test result.

SHORT-TERM TEST DURATION AND THE WEATHER EFFECT: A SUMMARY

Much as one might want the short-term test to represent long-term radon conditions in the test site, a short-duration test cannot ever meet such an expectation. Radon generation, transport, and influx are very complex processes whose interplay can be neither quantified nor controlled. Simply put, there are "too many variables in the equation." Below is a summary of some of the "knowns" as they apply to the midwestern test site which is the subject of this paper. Each factor is coupled with general precautions the radon analyst and mitigator should consider when interpreting results of a short-term test. Also included are correlative strategies that might be employed when addressing a radon problem assessed with a short-term test.

☐ The narrower the sampling interval, the more detailed the radon spectrum.

- ◆ Such information is useful in identifying weather factors, environmental changes, and/or a tampering event which may have compromised the test.

☐ The shorter the test duration, the greater the chance of a weather-compromised test result.

- ◆ It is important to accommodate weather effect. Opt for the longest feasible test.

☐ Other factors equal, declining barometric pressures are associated with increases in radon influx.

- ◆ This is an uncontrollable factor which can sometimes bias the test.

☐ Even small amounts of rain induce an increase in radon influx.

- ◆ This factor can be insignificant only if the basement walls and floors do not permit entry of water or soil gases.

☐ Radon's solubility in water enhances its transport.

- ◆ Whether wet or dry, sump-wells should be sealed and power-vented to the outside.

☐ A radon problem is exacerbated in homes that have a "wet basement problem."

- ◆ Improve drainage. Seal cracks, pores, chases, and discontinuities in basement floors and walls.

☐ Crawl spaces are large surfaces from which significant amounts of radon can outgas during weather changes.

- ◆ The mitigation effect of sealing the crawl-space surface with plastic membrane is much improved if radon is power-vented from under the barrier.

☐ Radon levels are influenced by the difference between indoor and outdoor temperature.

- ◆ Levels are lowest when the indoor / outdoor temperature difference is least.
- ◆ In actual practice, this is an uncontrollable factor which will bias the test.

☐ Radon levels are weakly influenced by air conditioning.

- ◆ The seasonal outflow of (more dense) cooler air can sweep radon away from entry points.
- ◆ This is not to be considered a viable mitigation strategy.

☐ Radon levels are highest under conditions of lowest indoor relative humidity.

- ◆ This is a factor related to wintertime conditions. Simply humidifying indoor air will not suppress the radon level.

TECHNICAL NOTES

Radon data for this study were obtained from simultaneous, side-by-side operation of multiple Honeywell Professional Radon Monitors, model A9000A, and a Honeywell model Q901 data logger / printer. Time-base synchronized radon / environmental data were collected with an AlphaGuard 2000 Professional Radon Monitor. All monitors were calibrated in accordance with EPA protocols and periodically cross-checked against each other and against multiple Air-Chek charcoal packets testing the same environment.

Five Geiger-Mueller counters were used. The most sensitive was an Oxford-Tennelec / Nucleus 575 counter / scaler / rate-meter with a PK-2 (3.5 cm end window) G-M tube. Two were products of Solar Electronics International: a Monitor-5 G-M counter (2.86 cm end window) pancake G-M tube and a Digilert G/M counter. Two were manufactured by Aware Electronics: a RM-60 G-M unit driving a LCD-60 display and an RM-80 with (4.5 cm end window) 7313 G-M tube feeding data to a Toshiba 1850 computer running Aware Electronics AWSRAD and AWGRAPH data collection and processing software.

Time-base synchronized radon/environmental data was fed to a Hewlett Packard Omnibook 425 notebook computer and down-loaded to Hewlett Packard Vectra 486/33ST and RS/25 computers for processing with Lotus 1-2-3® and StatMost®, scientific / statistical / graphical data processing software.

Barometric pressures were monitored with a temperature-compensated Taylor aneroid barometer daily checked against pressure readings reported by the National Weather Service in Peoria, IL. Continuous barometric pressure readings were recorded on a continuing monthly basis with a similarly checked / calibrated, temperature-compensated Oakton recording barograph.

SOURCES OF ANALYTICAL EQUIPMENT, COMPUTERS AND SOFTWARE

Air Chek
P.O. Box 2000
Arden, NC 28704

Aware Electronics Corp.
P.O. Box 4299
Wilmington, DE 19807

Cole Parmer Instrument Co.
P.O. Box 48898
Chicago, IL 60648-0898

DataMost Corp. (StatMost)
P.O. Box 65389
Salt Lake City, UT 84165

Genitron Instruments Gmbh
Heerstrasse 149 D-60488
Frankfurt am Main, Germany

Hewlett Packard Company
Corvallis Division
1000 N.E. Circle Blvd.
Corvallis, OR 97330

Honeywell Inc.
1885 Douglas Drive N
Golden Valley, MN 55422-4386

Lotus Development Corp. (Lotus 1-2-3)
55 Cambridge Parkway
Cambridge, MA 02142

Oxford Tennelec/Nucleus, Inc.
601 Oak Ridge Turnpike
Oak Ridge, TN 37831-2560

Rad-Elec, Inc.
1206 East Ash Street
Goldsboro, NC 27530

Solar Electronics International
156 Drakes Lane
Summertown, TN 38483

Toshiba America Information Systems, Inc.
Computer Systems Division
9740 Irvine Blvd.
Irvine, CA 92716-9724

REFERENCES

1. Axelson, O. , *Mining, Lung Cancer, and Smoking*, Scandinavian Journal of Work and Environmental Health **4**, 46, 1978

2. Chameaud, J., *The Influence of Radon Daughter Exposure and Low Doses on Occurrence of Lung Cancer in Rats*, Radiation Protection Dosimitry 7, 385, 1984

3. Eheman, C., *Lung Cancer Risks from Exposure to Radon*, Centers for Disease Control

4. Hoffman, W., *Lung Cancer Risk at Low Doses of Alpha Particles* Health Physics 51, 457, 1986

5. Klotz, J., *Estimating Lung Cancer Risks of Indoor Radon: Applications and Prevention*, Proceedings of APCA Specialty Conference on Indoor Radon, 1985

6. Martell, E., *Alpha Radiation Dose at Bronchial Bifurcations of Smokers from Indoor Exposure to Radon Progeny*, Proceedings of the National Academy of Sciences USA, **80**, 1285, 1983

7. National Council on Radiation Protection and Measurements, *Exposures from the Uranium Series with Emphasis on Radon and its Daughters*, NCRP Report No. 77, 1984

8. Nazaroff, W.W. and Nero, A.V., *Radon and its Decay Products in Indoor Air*, John Wiley & Sons, 1988

9. Park, J. *Estimation of Lung Cancer Risk from Inhaled* PuO_2 *in Beagle Dogs*, Health Physics, 1985

10. Ringholz, R *Uranium Frenzy: Boom and bust on the Colorado Plateau*, Norton, New York, 1989

11. Amandus, H., et al, Am. J. Ind. Med. **20**, 57, 1991

12. Amandus, H., Costello, J., Arch. Environ. Health, **46**, 82, 1991

13. Saccomanno, G. et al, Cancer **62**, 1402, 1988

14. *Radon: Have its risks been overplayed?* Science News **147**, 26, 1995

15. Samuel, P., *Looking Out for Dangerous Radon Levels*, Insight, April 13, 1992

16. Samet, J., *Indoor Radon and Lung Cancer: Risky or Not?*, J. Natl. Cancer Inst. **86** (24), 1813, 1994

17. Abelson, P. *Mineral Dusts and Radon in Uranium Mines* Science, **8**, 777, 1991

18. Oge, M. and Farland, W., Science, **255**, 1194, 1991

19. National Academy of Sciences, Health *Risk of Radon and Other Internally Deposited Alpha-Emitters, BEIR* IV, National Academy Press, Washington, DC, 1988

20. Samet, J., *Risk Anal.*, **10**, 65, 1990

21. Archer, V., et al, *Silica, Silicosis, and Cancer: Controversy in Occupational Medicine*, Goldsmith, D., et al, Prager, New York, 375-384, 1986

22. Radford, E. et al, N. Engl. J. Med. **310**, 1485, 1984. Wagoner J. et al, *ibid* 273, 181, 1965

23. *Monograph on the Evaluation of Carcinogenic Risks to Humans*, vol. 42, *Silica and Some Silicates* International Agency for Research on Cancer, Lyon, France, 1987

24. Ibid., vol. 43, *Man-made Mineral Fibers and Radon*, International Agency for Research on Cancer, Lyon, France, 1987

25. Baechler, M.C. et al *Sick Building Syndrome: Sources, Health Effects, Mitigation*, Noyes Data Corporation, 1991

26. Godish, Thad *Indoor Air Pollution Control*, Lewis Publishers Inc., Chelsea Michigan, 1990

27. Hess, C. et al., *Variations in Airborne and Waterborne Radon in Houses in Maine*, Environmental International, 8, 59, 1982

28. Hopke, Philip K. editor, *Radon and Its Decay Products*, ACS Symposium Series, 1987

29. Nriagu, Jerome O., editor *Gaseous Pollutants*, John Wiley & Sons, Inc., 1992

30. Samet, J.M. and Spengler, J.D. *Indoor Air Pollution: A Health Perspective*, Johns Hopkins University Press, Baltimore, MD, 1991

31. Turk, B. et al, *Radon and Remedial Action on Spokane River Valley Residences: An Interim Report*, Proceedings of the APCA annual meeting, 1986

32. Yocum, J.E. and S.M. McCarthy *Measuring Indoor Air Quality: A Practical Guide*, J. Wiley & Sons Ltd, West Sussex, England, 1991

33. *Measurement of Toxic and Related Air Pollutants*, Proceedings of the 1990 EPA/Air & Waste Management Association, International Symposium held in Raleigh NC, May 1990

34. Hoffmann, R., *Radon Contamination of Residential Structures: Mitigation Strategies and the "Weather Effect"*, Proceedings of the 1993 International Radon Conference, AARST, Denver, CO September 1993

35. Lange's Handbook of Chemistry, 13th edition, 1985

36. Kraner, H.W. et al *Measurements of the Effects of Atmospheric Variables on Radon-222 Flux and Soil Gas Concentrations* in *The Natural Radiation Environment*, Adams, J.A.S. et al, University of Chicago Press, 1964