1993 — 47

RADON CONTAMINATION OF RESIDENTIAL STRUCTURES: MITIGATION STRATEGIES AND "THE WEATHER EFFECT"

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ABSTRACT

This discussion details two important and largely unappreciated meteorological factors bearing upon rates of radon infiltration. Rainfall and changes in barometric pressure have a significant effect on indoor radon levels. Under certain seasonal, soil, and general weather conditions, radon levels inversely track changes in barometric pressure and directly track rainfall intervals. Conclusions are based on a yearlong database of radon measurements taken at four, twelve, and twenty four hour intervals within an actual midwest residence. A qualitative mechanism for this "weather effect" is postulated. Though having a significant impact on radon influx, environmental conditions are variable. Thus, the weather effect cannot be used to predict indoor radon levels. However, other factors being equal, a decline in barometric pressure is almost certain to be accompanied by a rise in radon infiltration and vice versa. Because real estate transactions are often contingent upon radon assessment results, an understanding of these phenomena should be of much value to realtors, buyers, and sellers.

INTRODUCTION

The Weather Effect

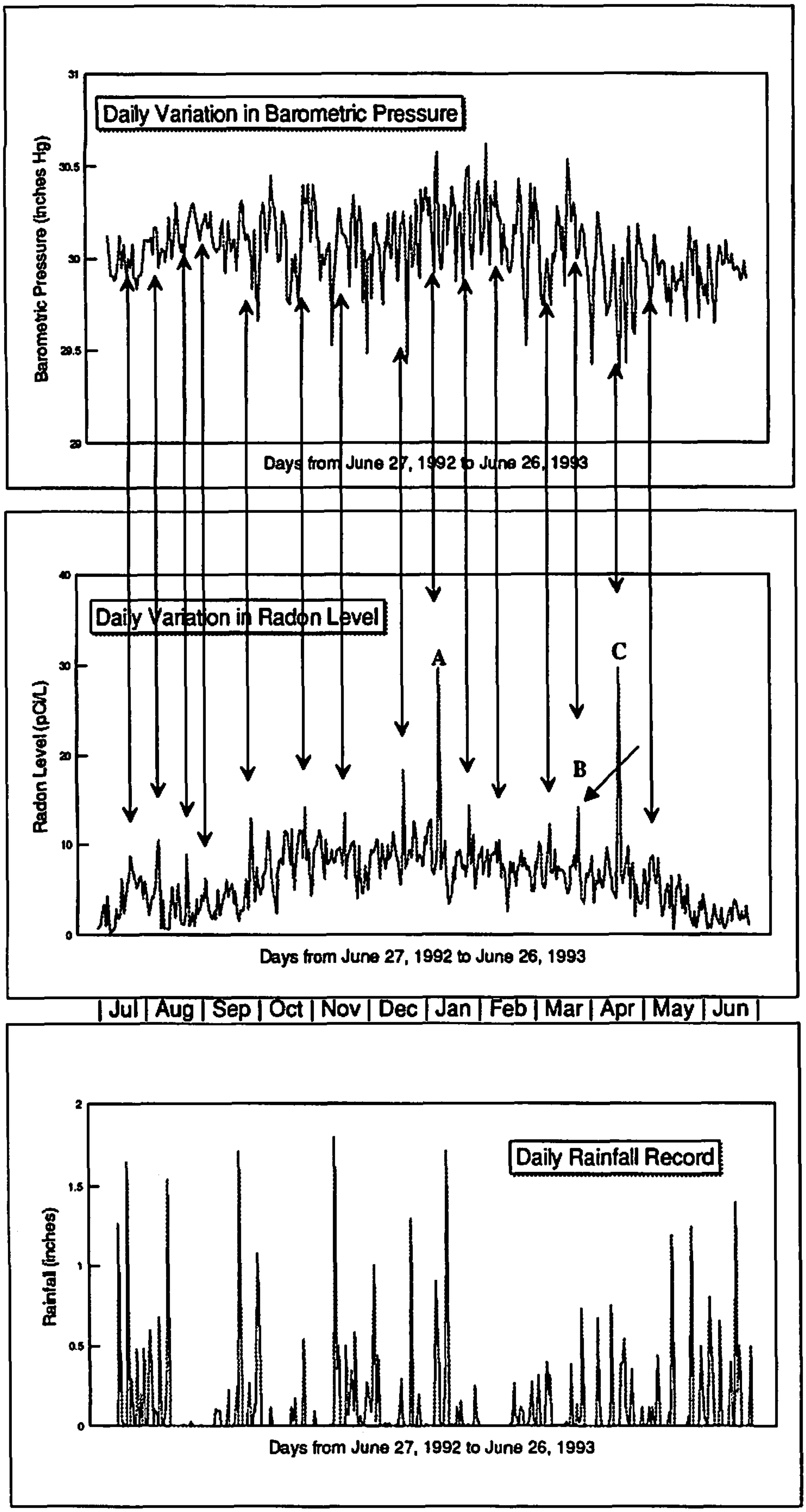
In April of 1993, the United States Environmental Protection Agency (EPA) proposed voluntary guidelines calling for builders to install protective measures that would prevent entry of radon into new construction. Likewise, it advised homeowners to ask for radon test results on properties in which they are interested, and it suggested that sellers have their homes tested before putting them up for sale. Increasingly, residential real estate transactions are becoming contingent upon the outcome of radon tests. It is the interests of realtors, buyers, and sellers to understand the various factors that bear upon test results. In so doing, it should be recognized that not all such factors are controllable. Certainly, home construction techniques and after-the-fact radon mitigation and diagnostic measures are a first line of defense over which control is possible. Nevertheless, short-term tests commonly associated with the typical real estate transaction are significantly affected by a poorly understood and little recognized "weather effect" over which there can be no control.

United States EPA reference works (1 - 15) describe meteorological effects in only broad, general terms. Both EPA sources, and other sources (16 - 22) cite the seasonal "closed house effect" which purports to account for the observation that radon levels tend to be higher in winter than in summer. Also mentioned is the "stack effect" as it relates to indoor / outdoor temperature differences which, by a convective process, draws radon into the structure. The effects of wind velocities around and over a building and the impact of rainfall on radon levels are mentioned, but not covered in detail.

There remains much work to be done in these areas; likewise, there is a great need for understandable information accessible to buyers, sellers, and real estate professionals. It is for these reasons that the current study was undertaken. This contribution to the literature is intended to both expand the radon scientific database and, at the same time, be useful to real estate buyers and sellers.

EXPERIMENTAL

Shown on the next page are graphics of a yearlong data set from an extended and ongoing investigation being made in central Illinois. Together, they represent radon / barometer / rainfall data recorded at approximately 6:00 p.m.



each day between 27 June 1992 and 26 June 1993. They illustrate how the radon level in a continuously monitored, actual residential test space changed with daily variations in local barometric pressure and rainfall.

The middle figure represents day-by-day radon levels in pCi/L. The upper graphic depicts daily barometric pressures that occurred over that same twelve month span recorded at the same time as the radon measurement. The lower plot represents the site's measured rainfall per each day of the survey.

- Data illustrate an inverse relationship between barometric pressure and radon level that has significance effect in the outcome of short-term radon tests.

To facilitate reader comparisons, some of the corresponding barometric pressure / radon levels are marked by arrows. Note the alignment of dips in the barometric pressure and spikes in the radon spectrum. The import of all this is a pointed reminder that, beyond mere seasonal effects, there is a significant and general "weather effect" which, in its impact on short-term indoor radon levels, can transcend both the closed house and stack effects.

The Effect of Local Rainfall

As can be seen from the rainfall graph, there is another significant and complicating factor that bears upon radon infiltration rates. There was a correspondence between local rainfall intervals and radon influx within the test structure which was pronounced even when the amounts of rain were relatively small. On soil that had not received rain for about a week or more, anything more than 0.1 inch of rainfall triggered an almost immediate rise in radon levels. Sometimes, when rainfall amounts exceeded about a half inch in 24 hours, the radon response was both swift and quite pronounced.

Standing water over rain-saturated soil around a structure has two effects. It seals the soil surface and prevents natural outflow of radon into the atmosphere. Soil radon is thereby diverted to the unsaturated matrix beneath the structure. Also, rain dissolves some of the radon as well, thereby diverting it to the perimeter and sub-slab drainage system, thence to the sump waters.

Rainfall has an observable effect as soon as it is sufficient to seal the uppermost reaches of the soil surrounding the structure. Unlike compressible interstitial soil gases, liquid water is incompressible. The sealant effect appears almost immediately when the downward percolation of water moves radon into accessible spaces.

- Soon after rainfall, indoor radon levels tend to rise markedly as the gas flow is diverted toward the unsaturated soil below the structure

This study indicated that when the upper reaches of the soil were water saturated (during or shortly after significant rainfall) or when the soil was frozen, changing radon levels inversely tracked changes in barometric pressure almost exactly. When the soil surface was relatively dry but not frozen, radon levels still tracked pressure changes; however, under dry or unfrozen conditions, radon levels lagged the barometric pressure changes by a few hours.

When the soil frost layer thawed (once in January and once in March, 1993) radon levels spiked markedly, as indicated by arrows A and **B** in the figures. The morning (**B**) radon reading (not shown on the graph) was 34.6 pCi/L. By late evening the level had fallen to 14.2 pCi/L, indicated by the small arrow. Three days later it had fallen to 4.3 pCi/L before commencing to rise again.

This suggests that radon is somehow accumulated in and / or trapped under or within the ice matrix in the soil. Gases are known to form clathrates (inclusion compounds sometimes referred to as gas hydrates) with water ice. Although water solubility and clathrate formation do not alter radioactive decay rates, such processes can permit radon accumulation by interfering with the rate at which radon can diffuse naturally from its point of origin in the soil to the outdoor atmosphere where it is diluted to background concentrations.

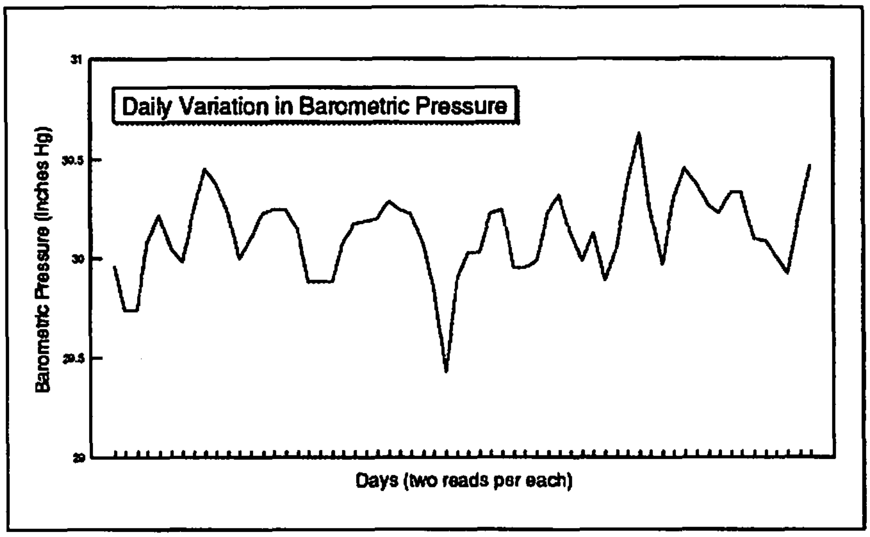
Any significant amount of waterborne radon released when the frost layer thaws, or that displaced by significant rainfall, can hydraulically force the gas into the building when it percolates down into the less saturated soil around and under its sub-structure. Note that many of the other radon spikes are also associated with significant rainfall. The prominent spike (almost 30 pCi/L) indicated by arrow C occurred on 15 April 1993 during a period of very heavy rainfall. Given the short (3.28 day) half-life of radon, water / ice induced radon spikes represent an interesting phenomenon not mentioned in the radon literature (1 - 22) examined.

In general, observed rainfall-related net increases in radon in any below-ground-level space are attributable to a combination of several poorly understood factors that include both the sealant effect and the hydraulic effect as well as the notable contribution made by radon dissolved in the sump waters. When water enters the sump and is churned about by the pump as it is discharged outside the structure, radon is released into the atmosphere within the sump-pit, thence to the interior atmosphere in the below-ground-level spaces of the structure. Such outgassing can be a significant source of indoor radon when the radon content of the sump water is high.

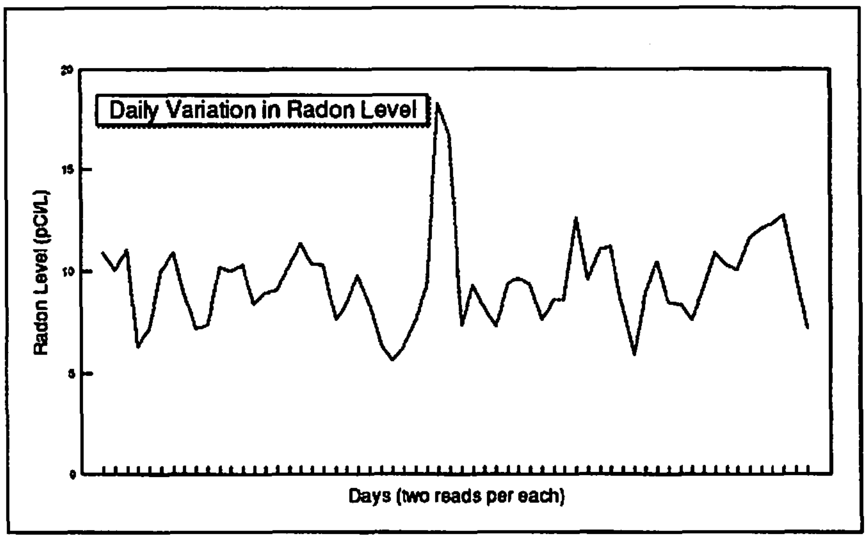
The Barometer Effect

In the expanded data set (not shown here) radon levels were measured twice each day and once each four hours per each day. Also, during the same time span, barometric pressure was recorded continuously. When the measurement interval was made shorter, under the already described conditions of soil temperature and water content, radon levels tracked pressure changes even more closely. When the barometric pressure was falling, the radon level was correspondingly rising.

The two graphics shown illustrate just how closely radon levels can track changes in barometric pressure. They represent a magnified look at the December 1992 portion of the expanded data set. A record of radon level and barometric pressure was made twice each day at approximately 6:00 a.m. and 6:00 p.m. Virtually every dip in the barometric pressure was accompanied by a rise in the radon level. Such tracking was likewise evident in the months of January and February while the soil was still frozen.



December 1992



The link between changes in barometric pressure and corresponding changes in radon level can be understood as an application of the scientific gas laws, and by an appreciation of principles of atmospheric physics. Any increase in barometric pressure, the weight of the air, over the test environment would be expected to alter the rate at which radon outgasses into the air contained within soil interstices. On its way into a below-ground-level space from its origins in the soil, radon must diffuse between soil particles and across an interstitial pressure gradient imposed by the atmosphere.

The lag-time between the rise in radon infiltration and the arrival of a low pressure air mass, the "barometer effect," may be understood by recognizing that air and radon are compressible gases. Because of their compressibility, they move as a gaseous mixture through the differing interstitial pores and pressure regions within the soil matrix. Because pore spaces within some soil types can be very small, pressure changes above ground are not instantaneously transmitted to the deeper levels alongside and under the basement. And, too, it should be noted that, in most cases, because infiltering radon is being continuously generated in the soil immediately under and adjacent to the structure's basement, the radioactive gas need not diffuse very far from its point of origin in order to enter the building. Thus, the lag and relatively short response time between barometric pressure change and the detected radon level is to be expected.

- Other factors being equal, radon levels will be higher shortly after arrival of a low pressure air mass. Correspondingly, levels will be lower a few hours after the arrival of a high pressure air mass.

It is emphasized that the infiltration relationship just described, though general for almost all soil types, will be significantly influenced by the soil composition and porosity under and around the structure. Actual lag-times attributable to soil saturation or below-freezing temperatures represent more noteworthy generalization than quantitative rule. Put another way, radon levels cannot be predicted by simply reading a barometer. However, other factors equal, a decline in barometric pressure is sure to be accompanied by a rise in radon infiltration and vice versa.

DISCUSSION

There is steadily accumulating evidence that the sump area of a home is a significant radon entry point. In conventional construction practices, water from outside the structure is brought inside before being discharged away from the building. In our experience, if a sump was present, Geiger-Mueller (G-M) count rates were always higher over the sump than almost anywhere else in the below-ground-level space.

- Because radon is relatively soluble in water, some dissolved radon degasses into the basement whenever water is churned about as it enters and leaves the sump.

Given the significance of the radon problem and the condemning evidence that the sump area is a major point of radon entry, it calls into question the wisdom of bringing contaminated water inside the structure in order to pump it away when, just as easily, it could be diverted to an outside sump. Thus, as builders become more aware of the radon problem, and in response to EPA guidelines and radon research, construction methods will change. The sump-pump and its associated basement dewatering system, when deemed necessary, will be designed to function entirely outside the structure. The pump and its discharge plumbing will be located in a below-frost-line pit. And, too, because radon cannot penetrate a seamless, plastic barrier, it also seems only a matter of time until entire basements will be built in a sealed, gas-proof plastic envelope.

A multitude of factors influence the amount of radon that might be detected in a structure. Sub-soil composition, moisture level, soil adsorptivity, and permeability; home design and construction, structural cracks, porosity, and discontinuities in the basement walls and floor; wind velocity, barometric pressure, and rainfall, as well as the radon content of the home's natural gas and potable water supply should all be considered when assessing the seriousness of a radon problem and planning a mitigation strategy.

- Whatever the technical mechanism of the "weather effect," it is clear that short term radon monitoring is, at best, only a guide toward remediation urgency.

Failure to understand the radon situation is causing a not-inconsiderable amount of confusion and apprehension in the residential marketplace and real estate industry. Often, fearful, uninformed buyers turn away from a home they really like when they discover that the radon level exceeds, even slightly, the 4.0 pCi/L EPA action guideline. Infiltration factors and the analytical consequences of the weather effect described here should be considered by all who invest in residential real estate because, in a nutshell -- in short-term tests at least -- weather factors can have a significant effect on the assessment results.

- Given the vagaries of nature, and the public importance being accorded short-term radon testing in real estate transactions, the weather effect can have a sales impact out of proportion to the actual state of contamination present in a structure.

Eager as they may be, both buyers and sellers should recognize the disadvantages of short-term and grab sampling tests. Radon analysts are well aware that the typical real estate client seems always to want instant test results. Analysts should tell their clients that grab sampling is a diagnostic measure only, and not an EPA-approved method of determining a long-term radon level. They should know that it is prudent to be as patient as may be practicable when contracting for a radon assessment. Reliable and representative data cannot be collected overnight. Homeowners and long-term occupants should follow EPA guidelines (1, 14, 15) and opt for long-term radon assessments as they plan any mitigation strategy.

Sellers should be made aware that what is today a well-intentioned EPA call for voluntary guidelines may tomorrow become a governmental mandate. It is in the economic interest of anyone who anticipates selling a home within a year to have a long-term radon assessment performed by a qualified professional using the best detector/s available. If a problem is discovered, it can be remediated before critical sales negotiations are begun. To a concerned buyer, a certificate of evidence that the property has been tested and found clean, or has been remediated to acceptable radon levels, can be a comfort factor that serves the seller's interest.

Though it may not be what buyers and sellers would like to hear: Simply put, a short-term radon test can be of questionable value when making a purchase decision contingent upon that test alone. Consider these EPA guidelines exerpted from reference (1)

- ❑ If the short-term test is 4.0 pCi/L or higher, make another short-term test immediately or (preferably, if time permits) make a long-term test to determine a year-round average level.
- ❑ If you followed up with a long term test, fix your home if the result was 4.0 pCi/L or more.
- ❑ The higher the follow-up short term test result, the more certain you can be that you should fix your home. Consider fixing your home if the average of your first and second test is 4.0 pCi/L or more.

Radon analysts and diagnosticians have an increasingly important role in clearing the confusion. Such professionals should understand the physics of radon's origins and properties. They should know as much as possible about radon detection and mitigation, be familiar with local conditions and radon data trends, and be able to explain clearly the overall picture to buyers and sellers. AARST members and other radon professionals can perform a valuable service to the housing marketplace while simultaneously using their skill, experience, and intuition as a practical guide to remediation urgency.

SUMMARY

In general, there is a paucity of weather effect information that is both accessible and understandable to those in the real estate marketplace. This contribution to the literature is intended to offer a view of meteorological effects that is straightforward, graphic, and unencumbered by statistical correction factors.

This ongoing, four-season study spanning more than a year provides an assist in understanding how barometric pressure and rainfall affects the rate at which radon enters a structure. Because its data is composed of radon levels and meteorological factors recorded in an actual lived-in residence whose occupants maintained a normal daily routine, this investigation focuses attention on the impact of ever-changing weather conditions under which radon measurements are ordinarily made. It is, in a sense, a collection of sequential short-term tests which are representative of the kinds of data that might be collected by a radon scientist or a professional radon analyst. The general effects of barometric pressure and rainfall on radon levels points the way to a better understanding of how to interpret radon levels within a structure.

An examination of the first set of graphics will reveal that although the weather effect is both a real and noteworthy phenomenon, there is only a general predictability to the relationship between the measure of barometric pressure and the radon response — when one goes up, the other goes down. This in no way enables a capacity to forecast radon levels from the weather effect. It should be appreciated that detected radon levels are a complex function of a variety of both controllable and uncontrollable parameters. Even so, weather is of significance when considered in the context of the impact it can have on short-term radon levels and its correlative aftereffect on public education and real estate transactions.

TECHNICAL NOTES

Radon data for this study were obtained from simultaneous, side-by-side operation of two Honeywell Professional Radon Monitors, model A9000A, and a Honeywell model Q901 data logger / printer. Monitors were periodically cross-checked side-by-side against multiple Air-Chek charcoal packets. Five Geiger-Mueller counters were used. One was an Oxford-Tennelec/Nucleus 575 counter/scaler/rate-meter with a PK-2 (3.5 cm end window) G-M tube. Two were by 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 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 portable computer running Aware Electronics AWSRAD and AWGRAPH data collection and processing software. Barometric pressures were monitored with a temperature-compensated Taylor aneroid barometer daily calibrated against pressure readings reported by the National Weather Service in Peoria, IL. Continuous barometric readings were recorded on a monthly basis with a similarly calibrated, temperature-compensated Oakton recording barograph.

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

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

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

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

Oxford Tennelec/Nucleus, Inc.
601 Oak Ridge Turnpike.
P.O. Box 2650
Oak Ridge, TN 37831-2560

Solar Electronics International
156 Drakes Lane
Summertown, TN 38483

Toshiba America Information Systems, Inc.
Computer Systems Division
9740 Irvine Blvd.
P.O. Box 19724
Irvine, CA 92716-9724

REFERENCES

U.S. EPA Literature:

1 *A Citizen's Guide to Radon (U.S. EPA 1992a) EPA 402-K92-001*

2 *Radon Reference Manual* EPA 520/187-20

3 Radon Research Program (1991, 1992, and 1993) DOE/ER-0488P, DOE/ER-0536P, and DOE/ER-0588

4 *Interim Protocols for Screening and Follow-up: Radon and Radon Decay Product Measurements EPA 520/1-86-014-1*

5 *Indoor Radon and Radon Decay Product Measurement Protocols (U.S. EPA 1992) EPA 520-1/89-009*

6 *Indoor Radon and Radon Decay Product Measurement Protocols (U.S. EPA 1992c) EPA 520-402-R-92-004*

7 *Indoor Radon and Radon Decay Product Measurement Device Protocols (U.S. EPA 1992c) EPA 520-402-R-92-004*

8 *Radon Reduction in New Construction OPA-87-009*

9 *Radon Reduction in New Construction* (EPA guidelines announced in April 1993)

10 *Radon-resistant Construction: Techniques for New Residential Construction EPA/625/2-91/032*

11 *Application of Radon Reduction Methods EPA/625/5-88/024*

12 *Radon Reduction Techniques for Detached Houses EPA/625/5-87/019*

13 *Radon Measurements in Schools* EPA 520/1-89-010

14 Consumer's Guide to Radon Reduction (U.S. EPA 1992b) EPA 402-K-92-003

15 *Home Buyer's and Seller's Guide to Radon (U.S. EPA 1993)* EPA 402-R-93-003

Other Sources:

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

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

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

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

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

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

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