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ABOVE NORMAL OUTDOOR RADON LEVELS IN CENTRAL FLORIDA: A PRELIMINARY REPORT OF SAMPLING RESULTS

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ABSTRACT

Indoor radon levels in Marion county Florida homes are reported elevated in approximately 50% of residential homes tested. In September, 2000 a sub slab depressurization mitigation system was installed in a home in the Ocala, FL area. Initial post mitigation system measurements indicated unexplained high levels with peak elevated periods in the early morning hours. Outdoor radon levels were found to be rising during the evening and early morning hours to levels approaching 40 picoCi/L. An investigation team from the Marion County Health Department and the Florida Department of Health in Tallahassee began diagnostic testing of the site and surrounding properties. Short term ambient radon testing in the area indicates an annual geometric mean level of 2.3 pCi/L. Soil analysis revealed significant Ra226 concentrations. Weather data indicated temperature inversions during most sampling periods.

INTRODUCTION

Radon is one of the most significant, silent, unseen environmental health risks we face. It is produced naturally in most soils throughout the world. It is a member of the Uranium radioactive decay series and is created when a radium atom emits an alpha particle. As a gas, it is transported by diffusion and pressure differentials into homes and other buildings where concentrations can increase to many times outdoor levels. Outdoor levels of radon are not typically considered a health issue. The national average for outdoor air radon levels is approximately 0.3 pCi/L. Elevated indoor radon levels can be lowered by installing a radon mitigation system. Radon mitigation technology in most cases achieves radon reductions below 4 pCi/L, the "action limit", and often reaches levels below 2 pCi/l. The majority of mitigation systems in Florida are Active Soil Depressurization systems, ASD, more specifically sub-slab depressurization, SSD.

In September 2000, a sub slab depressurization mitigation system was installed in a home in the Ocala, Florida, area. Initial 48 hour post mitigation measurements indicated an effectively operating system with an average below 4.0 pCi/L. However, extended testing revealed elevated periods peaking in the early morning hours. During the extended post mitigation testing, levels were seen to increase periodically in the home with no apparent failure of the mitigation system. When it was noticed that levels began to increase when the windows were opened, various system configurations and conditions were tested using continuous radon monitoring devices. Testing with the system on and off, and with windows opened and closed pointed to outdoor levels affecting indoor radon concentrations. Outdoor radon levels were found to be rising during the evening and early morning hours to levels approaching 40 pCi/L. The homeowner, mitigator and measurement specialists informed the state radon office of the situation. Representatives from the Bureau of Facility Programs/Radon and Indoor Air and Marion County Health Dept./Environmental Health visited the location. A testing plan was discussed and after meetings with the subdivision homeowners association, access to more than 20 residential properties was granted. A variety of environmental measurements were collected at these locations. Soil, water, air and weather measurements were collected, as well as geologic information. Preliminary results suggest ambient radon levels and wind speed, (temperature inversions), are closely related and expectedly, vary with the seasonal changes. Additional offsite measurements indicated elevated ambient radon levels may not be restricted to the study onsite area. Although the effect was recorded offsite, the magnitude of the offsite levels were much lower.

Testing at the subdivision focused on collecting data for use in determining 1) the source of radon; 2) extent of indoor and outdoor elevated levels and 3) potential long term health effects to residents. These three areas of focus were applied to offsite locations as well. The selection of test locations was based, in large part, on accessibility. Fortunately, a majority of subdivision residents were favorable to testing. Property owners were contacted and times were confirmed for deployment and retrieval of test equipment.

The subdivision is comprised of 43 residential properties, 9 of which are under construction or vacant. Background gamma readings were made at all outdoor sample locations. Some gamma readings were also collected from inside some homes. Sample locations were restricted to the subdivision properties initially. Later on, offsite locations were selected and tested as well.

METHODOLOGY

The subdivision was started in the early nineties and is comprised of 43 residential properties, 9 of which were under construction or vacant at the time of sampling. Prior to its current usage, the land was primarily pastureland. The area lies on the eastern edge of the exposed surfaces of the Ocala Platform in an area composed of materials from the Hawthorne group. Soil survey mapping from the 1970's indicates three major soil series on the area. These are Astatula Series, Kendrick Series, and Gainesville Series. The Kendrick Series is known to contain phosphatic materials and this particular series makes up approximately 50% of the study area.

Data was collected from four environmental areas:

Water: All the properties are on well water. Of the 34 wells in the subdivision, 28 were sampled for radon content. Samples were drawn and sent to the departments' Environmental Radiation Lab in Orlando for determination of radon concentrations. As a rule of thumb, 10,000 pCi/L of radon in water can contribute 1.0 pCi/L of radon to the indoor air. Although some wells in the state have tested higher than 40,000 pCi/L, radon from water is not considered a significant contributor to the indoor air radon levels. Samples collected contained considerably less than 10,000 pCi/L.

Soil: Soil flux measurements were made using electret ion chamber flux monitors with both short term and long term electrets. Vegetation was removed from the area of testing and the monitor was placed on the ground. At a few locations a continuous air flow apparatus was deployed that moved air at 0.75 liter per minute through an enclosed container in contact with the soil. Continuous radon monitors were placed inside the apparatus and testing ran concurrently with the regular soil flux testing. This allowed for an hourly printout of the flux/air levels. Surface soil radon flux data were collected at 11 properties. Soil samples were collected at 11 properties to determine radium concentration and to characterize the soil. Onsite soil samples were taken using a hand auger. Samples were collected to a depth of 4 feet, at one foot intervals. These samples were sent to the department's Environmental Radiation Lab in Orlando, Florida.

Air: Radon measurements were taken both indoors and outdoors. For outdoor measurements, 5 stations were used. Outdoor air measurements utilized a continuous radon monitoring device, an electret ion chamber short term device, a small heat/power source and a 5 gallon bucket. The radon monitors were attached to the inside of the inverted 5 gallon buckets to protect them from the elements. A small light source was also attached inside to provide a heat source to minimize the formation of condensation on the monitors. Figure 1. The apparatus was set up outside within 20 feet of an electrical outlet and approximately 1.5 meters above grade. Figure 2. The measurement duration was between two to five days. The range of the averages for these readings was from a low of 0.3 pCi/L, which is considered normal for ambient air, to a high of 4.7 pCi/L. Indoor short term air measurements were made by placing two monitors side by side for 2 to 5 days. Continuous radon monitors and electret ion chambers were used. Long term indoor air measurements were performed using long term electrets and alpha track devices. Electret devices were removed and replaced during each season. Alpha track devices were in place for approximately one year. None of the homes had radon mitigation systems.

Weather: Two Davis weather stations were utilized to monitor both onsite and offsite weather conditions. These stations collected data for wind speed and direction, high and low temperatures, barometric pressures and rainfall. The sampling interval could be set from once per minute for a 24 hour period up to once every two hours for a period of 120 days. Most sampling intervals were set for either 15 minutes or 30 minutes. This data was downloaded at the beginning and end of each sampling period.

The data was collected quarterly for sampling periods lasting 2-3 days. For logistical reasons, four to five homes would be sampled during one trip and another 4-5 homes would be sampled a few weeks later. Nine trips were made in all. Because the actual number of sampling days during the one year period comes to less than 36 days, long term devices were placed outdoors, on fencepost, around the area. These were retrieved in June 2002. These devices show ambient radon levels averaged over an entire year (365 days or greater), as opposed to averaging short term "snapshots" covering 36 days out of that year.

RESULTS AND DISCUSSION

Water: Water samples collected in the test area were analyzed for radon concentration. Although one well reported a concentration of 2000 pCi/L, all other wells reported less than 800 pCi/L. Well depths ranged from 65 feet to 240 feet. Radon from these wells is not believed to be a substantial radon contributor to the indoor concentration. Figure 3 shows radon concentrations at well sites, including sites involved in additional environmental sampling. During the sampling period, surficial and deep aquifer levels were dropping around the state. However, it is not believed that radon produced at the depths of these aquifers would be contributing to levels recorded during the study.

Weather Data: Weather information was split between onsite and offsite data collection. The offsite weather station was approximately 2 miles southwest of the onsite station. Data was also obtained from an offsite station in the area that was accessible from the internet. This station is located approximately 15 miles due north of the onsite station. The Davis weather stations recorded barometric pressure, temperature, wind speed and direction, humidity and rainfall. Similar, historical data was accessed from the offsite station operated by the University of Florida via the internet. Graphs of outdoor radon levels and wind speed clearly showed a relationship between the two. Figures 4a –4e show the outdoor radon levels and the wind speed during different testing periods throughout the year. Rising outdoor radon levels were closely associated with falling windspeeds, particularly windspeeds at or below one mile per hour. These low windspeeds, one mph or less, were used to define a temperature inversion event. Continuous radon monitors consistently recorded peak radon levels occurring during periods of very low wind speeds, (one mph or less), and falling temperatures in the late evening to early morning hours; which are signs that low level temperature inversions most probably are present. The highest radon level recorded peaked at 28.2 pC/L during February 14, 2001. During periods in which no inversions occurred, (the first two days of February '01 sampling, the first day of March '01 sampling, the November '01 sample period and the first day of the March '02 sampling), outdoor radon levels recorded no higher than 3.2 pCi/L.

Soil and Soil Radon Flux: Soil samples recorded radium, radon flux and general soil type. According to accounts from neighbors, a large retention pond was excavated at the site. The excavated soil was then used throughout the development as fill and for the construction of burms. The retention pond was dry during the sampling period. Soil samples collected from the bottom of this retention area ranged from 16 to 46.4 pCi of $radium^{226}$ /gram of soil. Nationally, undisturbed soils typically fall around 1.0 pCi/gram. Samples were also collected from properties where ambient radon monitors were placed. Soil radium concentrations from these locations measured from 0.77 pCi/gram to 8.9 pCi/gram within the first four feet of soil. A few additional samples were taken at depths up to 14 feet, with results falling within the same range. Contributions of radon from these deeper soil layers are not considered applicable because a clay layer was identified running beneath all the properties sampled, generally found at about 5 feet. The average radium concentration for the top four feet of soil was 4.2 pCi/gram. These readings certainly indicate sufficient radium content in the soil along with it's proximity to the surface to cause elevated indoor radon levels and, given the right environmental conditions, unusually high ambient levels.

Surface radon flux measurements were taken to determine if the radon flux from these soils could be sufficient to elevate the ambient radon levels. The average soil flux reading of all the properties tested over the entire year was 2.2 pCi/m^2 sec. Nationally, the average net flow of radon gas from soil to air is 0.45 pCi/m^2 sec. Soil flux averages ranged from 0.5 to 2.8 pCi/m^2 sec and individual readings ranged from 0.06 to 12.4 pCi/m^2 sec. Soil flux readings were not always successfully recorded. Condensation, and in some cases insect activity, interfered with some measurements, voiding those results. If ambient radon levels build up during inversion conditions, that is during periods of little to no air mixing, then the soil radium concentration and gas emanation must be sufficient to raise radon levels to those recorded by outdoor devices within the time interval of the inversion. In most cases that time interval is 11-12 hours, roughly from sundown to sunrise. In the future a model for crude estimations of ambient levels may be developed however, more information is needed to understand better the relationship between emanation and ambient radon levels.

Unfortunately, soil moisture levels were not monitored and rainfall amounts were not always available for specific sites during sampling. Due to the variability of rain shower paths in Florida, attempting to apply nearby rainfall amounts to unmonitored locations could lead to inaccurate and misleading conclusions. The results from seasonal soil flux testing indicate that environmental factors such as temperature and rainfall need to be carefully considered prior to and during sampling periods when evaluating the relationship between soil flux data and ambient radon levels.

Outdoor Radon: Individual ambient air measurements recorded values ranging from 0.3 pCi/L to 28.2 pCi/L. The average, by month, of the short term devices is shown in Figure 5. Figure 6 shows seasonal fluctuations. During the month of November no inversions were identified. This was the only month in which no measurements over 4.0 pCi/L were recorded. Short term testing averages were slightly higher than results obtained from long term devices. The geometric mean for outdoor air in the sampling area was 2.3 pCi/L. This is based on results from the short term devices used throughout the year. These results represent an actual sampling period of 36 days. Long term outdoor results from 3 alpha track devices averaged 0.9 pCi/L and represent an actual sampling period of 361 days. However, further confirmation of the AT background has not been received at this time.

Indoor Radon: All residential long term indoor radon averages were elevated, even though periodic short term measurement results ranged from about 1.0 pCi/L to more than 30 pCi/L. Seasonal measurements showed that levels varied substantially throughout the year and that single short term measurements were more likely to approximate long term averages if collected during warmer months as shown in Table 1. While elevated levels can be found indoors at any time, indoors levels were also seen to rise in conjunction with rising outdoor levels. This is more clearly illustrated in Figure 7. The graph compares indoor levels during inversions and indoor levels during the same evening hours when no inversion occurred. The months of February and March are used because 1) these were the only months in which results from both indoor and outdoor continuous monitors were obtained; 2) weather data for the testing site was obtained; and 3) both inversion and non inversion events occurred.

CONCLUSIONS

The study supports previous findings that radon gas soil transport is influenced by many physical and environmental factors, soil depth, soil moisture, source concentration, etc. Upon reaching the ground surface, radon gas levels in ambient air are significantly affected by environmental and climatic conditions. High radium concentrations in the area, the relative shallow depths of the source material, the measured flux rates and the frequency of low level temperature inversions all contribute to the abnormally high ambient radon levels reported.

The study indicates post mitigation measurements done in the colder months, which represent worst case conditions, are more likely to indicate the effectiveness of the system throughout the year. Results obtained during colder months that are less than 4.0 pCi/L may indicate more accurately that the system will maintain radon levels below 4.0 pCi/L throughout the year, given the system is properly operating and maintained. Post mitigation measurements conducted during the warmer months may more accurately represent the annual average, but may not indicate how well the system maintains radon levels during the colder months. Additionally, if a mitigation system tends to depressurize the interior, post mitigation sampling results may be 2pCi/L or more higher during an inversion than during non inversion periods. This could affect post mitigation sampling strategy. Ultimately, mitigators and homeowners should rely on long term indoor testing when defining the effectiveness of a mitigation system.

The study also indicates that outdoor levels rise significantly during temperature inversions and that the elevated ambient radon levels can increase the indoor radon levels. This effect, while measurable, is not responsible for all the homes sampled having elevated annual indoor radon levels. Soil source material concentration at relatively shallow depths, sufficient driving force and pathways for gas entry are the primary factors leading to elevated indoor radon levels in these homes, just as they are in most U.S. homes. Based on the data collected the average occupant in the study is exposed to levels above 4.0 pCi/L more than 86% of the time while indoors. In several instances, individual homeowner indoor levels never dropped below 4.0 pCi/L regardless of the outdoor radon levels. Therefore, there are significant health benefits to investing in indoor radon mitigation. Additionally, all new buildings constructed in this area may significantly benefit from applying radon resistant construction standards which are located in the appendices of the Florida Building Codes.

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Table 1.

	Short term indoor radon measurements				**Long term indoor radon measurements**				
	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	
Autio	30.4	16.8	15.1		17.3	17.3	15.3	21.6	
	25.4	16.3	12.3		17.4	17.4	15	22.5	Average lc ye
	29.5	16.1	13.2						**18.0**
Average	28.4	**16.4**	13.5		17.4	17.4	15.2	22.1	
Boutros	16.1	10.3	8.1		9.4	9.4	8.8		**Average long te**
	14.4	11.6	8.1		10.1	10.1	9.1		**9.5**
	13.3	10.4	7						
Average	14.6	**10.8**	7.7		9.8	9.8	9.0		
Galarza		6.2	8.3			5	5	6.7	**Average long te**
		5.5	8.8			4.7	4.7	6	**5.4**
		5.8							
Average		**5.8**	8.6			4.9	4.9	6.4	
Hilliard	7.4		13.3	39.6	22	7.9	7.9	22	**Average long te**
	7.3		13.3	35					**15.0**
	7.3								
Average	7.3		**13.3**	37.3	22.0	7.9	7.9	22.0	
Hudson	4.1		1.1	6	5	5.2	5.2	5	**Average long te**
	4.6		1	6.1					**5.1**
	3.9		1.2						
Average	**4.2**		1.1	**6.1**	5.0	5.2	5.2	5.0	

The results of our measurements about the characteristics of the unattached radon progeny

- electrical charge
- activity size distribution
- unattached fraction

are reported.

The neutralisation rate of the positive ^{218}Po-ions in air was determined quantitatively in chamber experiments. The experimental results show the strong influence of the ionisation rate and the humidity concentration on the neutralisation rate of the ^{218}Po-ions in air. In indoor air the neutralisation rates vary between 30 h^{-1} and 300 h^{-1}. In addition, the fraction of the positive ^{218}Po-clusters for typical indoor conditions were determined by model calculations and measurements. In indoor air 10% - 60% of the ^{218}Po are positively charged depending mainly on the ionisation rate.

The activity size distribution of the unattached radon progeny clusters as function of the particle diameter was measured using the screen technique. In general, the activity size distribution obtained from measurements under normal conditions concerning humidity and radon concentration (ionisation rate) can be approximated with three lognormal distributions with AMD-values 0.60, 0.85 nm, and 1.3 nm.

The fraction of the unattached radon progeny fp obtained from measurements at different places with different aerosol sources depends dominantly on the aerosol particle concentration Z and can well described by the semi empirical equation $fp = 414/Z(cm^{-3})$.