MICROCLIMATIC FACTORS INFLUENCING RADON LEVELS IN SCHOFER CAVE, BERKS COUNTY, PENNSYLVANIA

Keith Williams*
Department of Geography
Kutztown University
Kutztown, PA 19530

It has been demonstrated that a high concentration of a radioactive gas such as radon (Rn 222) increases a person's chances of contracting lung cancer.[1] Radon *daughters*, which are the by-products of radon decomposition, pose a health threat because they become attached to dust, water vapor, and other aerosols and can be inhaled. As a result, the Environmental Protection Agency has set a safety guideline of 4.0 picocuries per liter (Pc/L) for indoor radon. This level is potentially hazardous in exposure situations of four to fifteen months.[2]

The majority of radon research projects has focused on the home and work place; however, a few studies have attempted to correlate radon levels of caves with microclimatic factors such as relative humidity, temperature, and distance from the nearest cave entrance. Cigna and Clemente[3] report that cave configuration, micro-meteorology and airflow patterns play an important role in radon concentration. Seymore, Ryan, and Corelli[4] note a profound winter versus summer contrast in radon levels of some cave systems; summer monthly readings were about 400 percent higher than winter monthly readings. They conclude that the variation is due to changes in airflow direction and velocity. In

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[1]J. Logue and J. Fox, "Health Hazards Associated with Elevated levels of Indoor Radon in Pennsylvania," *Morbidity and Mortality Weekly Report* 24 (March 1985): 23-24.

[2]Ibid.

[3]Arrigo A. Cigna and Gian F. Clemente, "Radiation Hazards in Natural Caves," *Proceedings of the Eighth International Congress of Speleology* vol. 2 (Bowling Green, KY: International Union of Speleology, 1981) 420-23.

[4]F.W. Seymore, R.M. Ryan and J.C. Corelli, "Radon and Radon Daughter Levels in Howe Caverns," *Health Physics* 38 (May 1980): 858-59.

addition, Eapen and Rangarajan[5] report that radon levels show a positive correlation with relative humidity levels. They also found that radon concentrations in caves increase rapidly with distances from entrances, whereas an inverse relationship exists between radon levels and wind velocity.

The preliminary nature of these studies justifies more site-specific information about the problem of radon concentration in caves. Findings from additional case studies, such the one presented here, will be of diagnostic value to future research on radon in caves in two important ways. Firstly, they will help to confirm or reject the hypothesis that radon levels can be predicted through the measurement of microclimatic conditions within caves. Secondly, they will assist in the perfection of data acquisition and, thereby, reduce the number of costly periodic radon tests in caves that are suspected of having dangerously high concentrations the gas.

STUDY SITE AND RESEARCH PROBLEM

This study was conducted in Schofer Cave, which is located in Berks County two miles northwest of Kutztown, Pennsylvania (Figure 1). Schofer Cave is a small solution cavity located in the Great Valley of the Appalachian Mountain System. It is formed in the Hamburg sequence of limestone and shale.[6] The country rock of the cave is variable and impure. Most beds are composed of Cambro-Ordovician shale-limestone, although some beds are made of limestone conglomerate and sandy limestone.[7]

Schofer Cave is located approximately eight kilometers from the Reading Prong, which is a highland composed mainly of Precambrian granitic gneiss, granite and metasediments.[8] This area is known to produce high levels of radon that seeps through cracks, fissures and pores in soil and rock.

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[5]C.D. Eapen and C. Rangarajan, "Accumulation of Atmospheric Radon in Calcite Caves," *Health Physics* 3 (August 1980): pp. 10-14.

[6]T.M. Berg, et al. *Geologic Quadrangle Maps of Pennsylvania* (Harrisburg, PA: Pennsylvania Topographic and Geological Survey, 1981).

[7]Ralph W. Stone, E.R. Barnsley, and W.O. Hickok, *Pennsylvania Caves* (Harrisburg, PA: Pennsylvania Topographic and Geological Survey, Department of Internal Affairs, 1932), p. 29.

[8]Pennsylvania Bureau of Topographic and Geological Survey, *East Half of Pennsylvania*, Map 1, Plate 1 (Harrisburg, PA: Department of Environmental Resources, 1980).

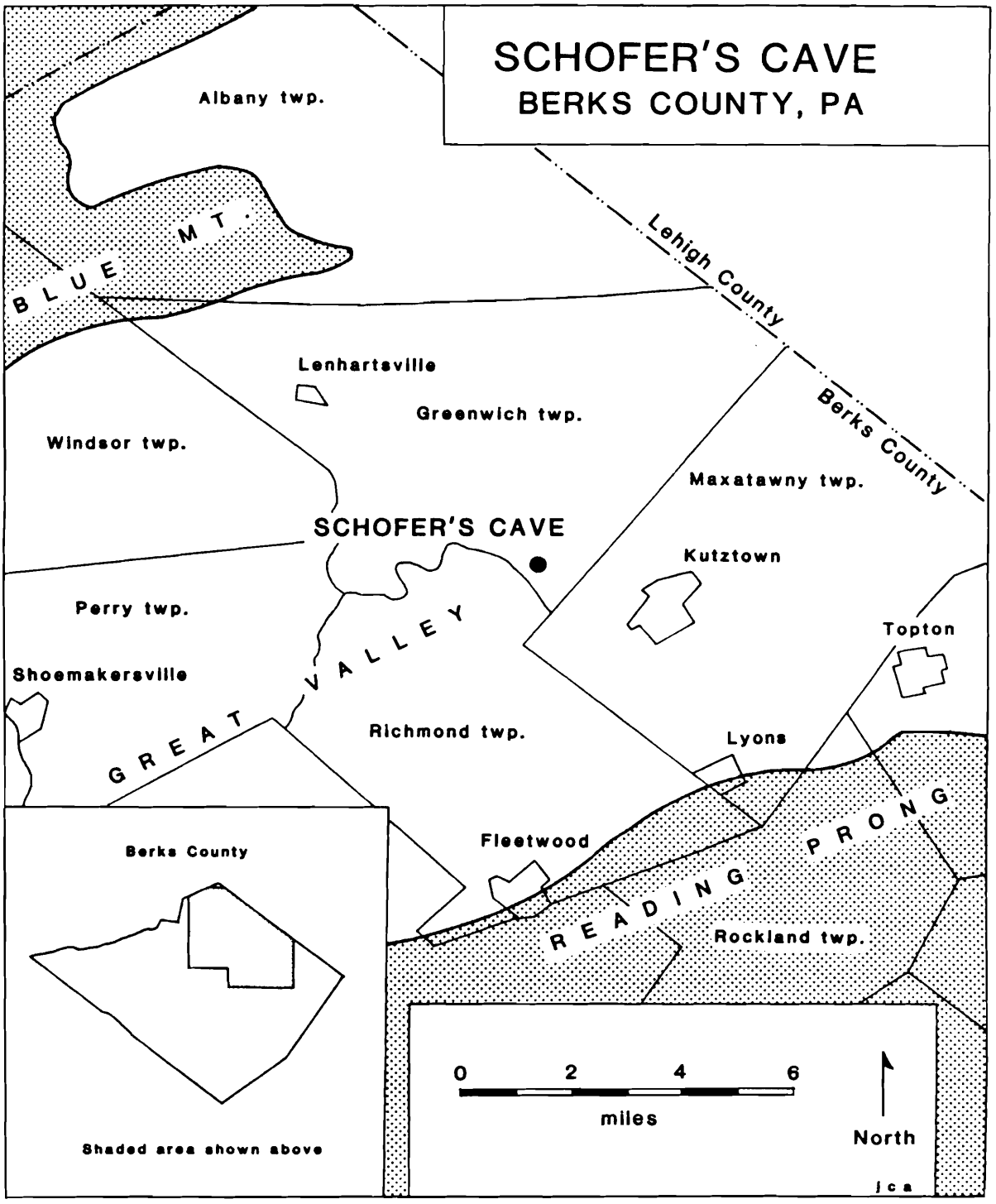
SCHOFER'S CAVE
BERKS COUNTY, PA
Albany twp.
BLUE MT.
Lehigh County
Berks County
Lenhartsville
Greenwich twp.
Windsor twp.
Maxatawny twp.
SCHOFER'S CAVE
Kutztown
Perry twp.
Topton
Shoemakersville
GREAT VALLEY
Richmond twp.
Lyons
Fleetwood
READING PRONG
Rockland twp.
Berks County
Shaded area shown above
0 2 4 6
miles
North
jca

Figure 1

The magnitude of gas transport and distance of movement depend on various factors such as interstitial water and capillary action of the gas.[9] As a result of its proximity to the Reading Prong, Schofer Cave might contain high levels of radon. However, the cave is located in different country rock, so comparable levels of radon should not be assumed.

This research attempts to answer the question, Which microclimatic factors correlate best with radon concentration in Schofer Cave? Given the findings of previous research, it is hypothesized that: (1) radon levels in Schofer Cave will increase with increases in relative humidity; (2) radon levels in the cave will vary according to temperature; (3) radon concentrations will increase with distance from the cave's entrances. This study also provides a preliminary data base that can be used to characterize the radon hazard of caves in the vicinity of the Reading Prong.

METHODOLOGY

Data collection sites were chosen to analyze the micro-spatial and temporal variability of radon and climatic phenomena within the cave. Relative humidity and temperature measurements were obtained using sling psychrometers. Charcoal-trap detectors were used to measure radon. These devices are composed of small tin canisters containing activated charcoal. Radon attaches to the charcoal, thus providing an effective means of collecting information on radon concentration. Sets of canisters were exposed for two one-week periods. The first set (10 canisters) was exposed from 7 December 1987 to 14 December 1987. The second set (20 canisters) were exposed from 4 February 1988 to 11 February 1988. After exposure the canisters were resealed and analyzed using a Canberra Multi-Channel Analyzer. Data from the two exposure periods were analyzed using scattergrams and correlation coefficients.

ANALYSIS

Graph 1 (December 7-14, 1987 data) shows a negligible .15 correlation between radon concentration and relative humidity. It also reveals an interesting pattern where the readings between

[9]"Radon Detectors, How to Find Out if Your House has a Radon Problem," *Consumer Reports* no. 9/10 (July 1987): 440-47.

0-10 Pc/L radon and 0-97 percent relative humidity are "mirrored." This type of scattergram is typical of data that have negligible or no correlation. The pattern also includes two radon values (37.2 Pc/L and 25.8 Pc/L) that are much higher than predicted by the regression equation. These readings were obtained from canisters placed in a deadend passage. According to Eapen and Rangarajan[10] radon seems to accumulate where atmospheric flow is minimal, which could explain these relatively high readings.

Graph 2 (February 4-11, 1988 data) shows an equally weak .17 correlation between radon and relative humidity. The high radon recording of 32.57 Pc/L can be explained because it was collected at the same deadend passage as the 32.72 Pc/L reading in Graph 1. The second location with a high recording in Graph 1 does not reappear in Graph 2. Presumably, this inconsistency is due to the fact that radon does not seep through cracks and fissures in rock at a uniform rate.[11] The data in Graph 2 are clustered near the 90-100% relative humidity range due to fairly uniform climatic conditions within the cave. This pattern contrasts with the cave's variable climatic pattern of the previous month (Graph 1).

Graph 3 shows the results of combining the data from the two dates shown in Graphs 1 and 2. It reveals a .20 correlation between radon concentration and relative humidity, and it substantiates further that a negligible or chance relationship exists between radon levels and relative humidity.

In contrast, the .54 correlation shown in Graph 4 (December 7-14, 1987 data) indicates that a moderate relationship exists between radon concentration and temperature. This correlation is probably affected by distance from the cave entrance, since temperature is a function of distance from cave entrances. The extreme readings (37.5 Pc/L and 25.8 Pc/L) are from the deadend passage mentioned previously.

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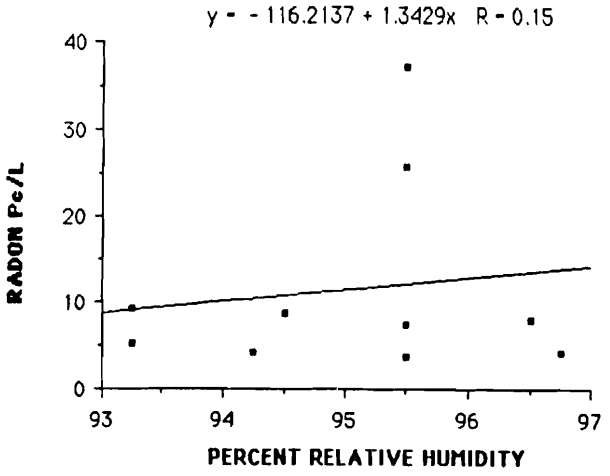
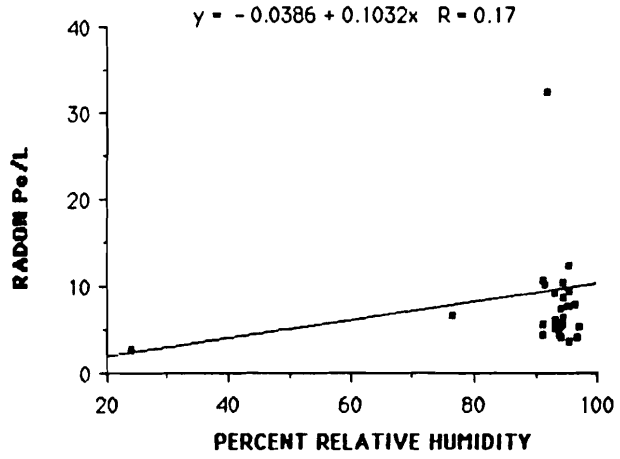
[10]Eapen and Rangarajan, op. cit., footnote 5.

[11]"Radon Detectors, How to Find Out if Your Home has a Radon Problem," op. cit., footnote 9.

GRAPH 1



GRAPH 2



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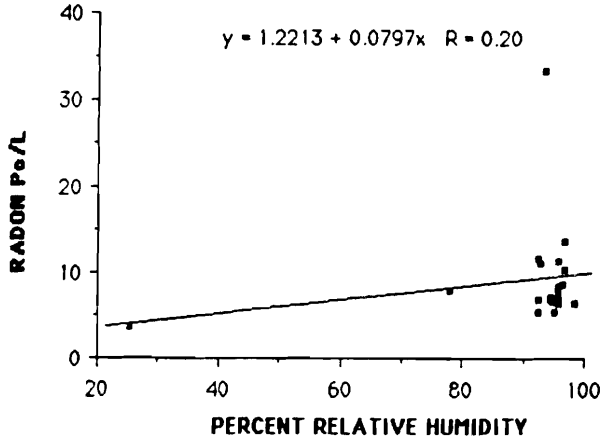

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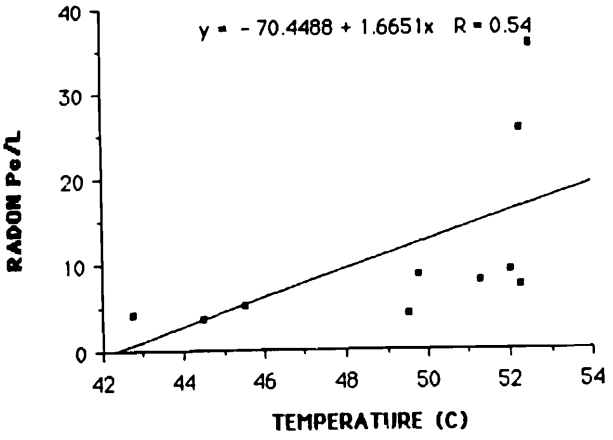
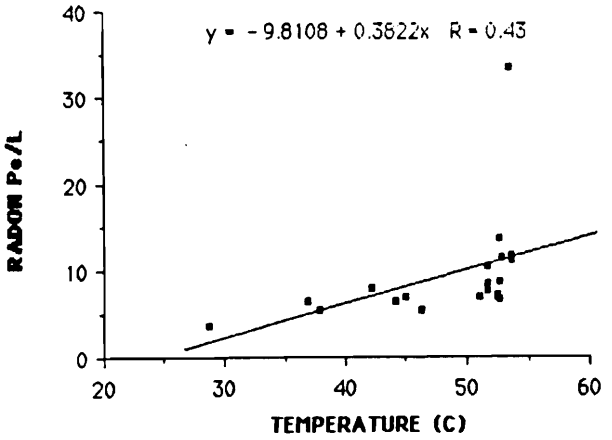
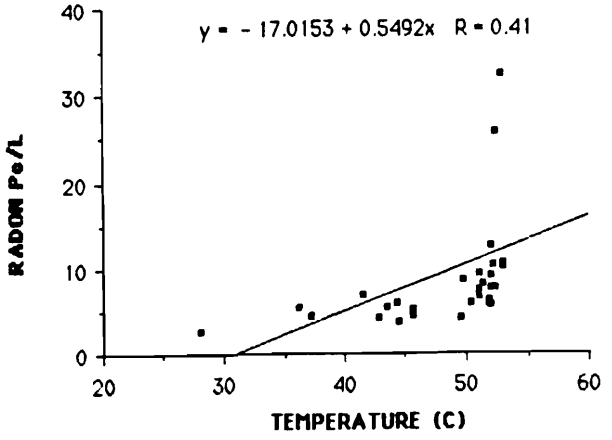


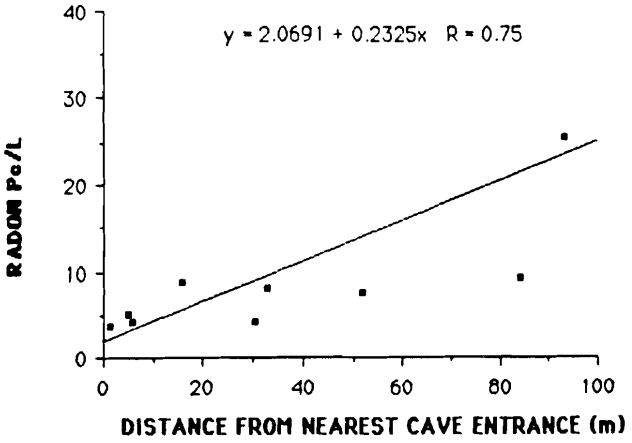
GRAPH 5



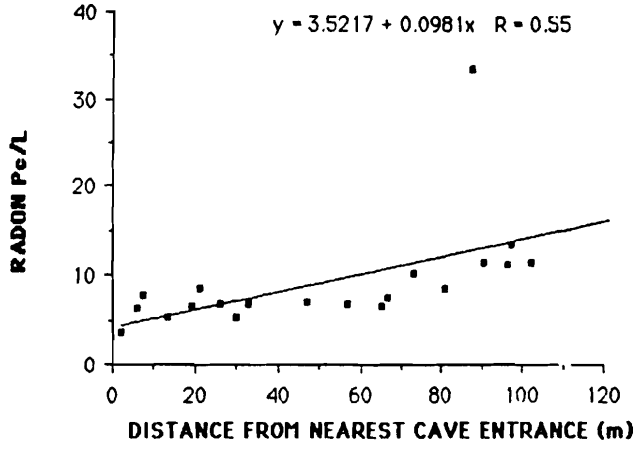
GRAPH 6



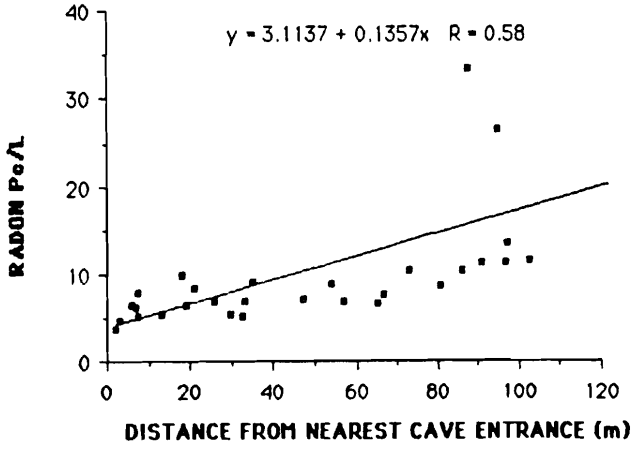
GRAPH 7



GRAPH 8



GRAPH 9



Graph 5 (February 4-11, 1988 data) shows a .43 correlation between radon concentration and temperature. The clustering of data indicates that temperature and radon levels were more uniform within the cave during this week. Once again, there is an extremely high dead end passage reading (32.57 Pc/L).

Graph 6 combines the data displayed on Graphs 4 and 5. The correlation of .41 indicates that a fair degree of relationship exists between radon concentration and temperature data collected during both weeks.

Graph 7 (December 7-14, 1987) shows a strong .75 correlation between radon concentration and distance from the nearest cave entrance. It is known that radon dissipates as wind velocity increases.[12] Therefore, a strong relationship was expected since, in closed cave systems such as Schofer Cave, wind velocity decreases rapidly as distance from the cave entrance increases.

Graph 8 (February 4-11, 1988) reveals a somewhat weaker .55 correlation between radon concentration and distance from the cave entrance. The reason for the lower coefficient could be due to the fact that data were collected from more stations over a wider range of distances from entrances.

Graph 9 combines the data displayed on Graphs 7 and 8, and it reveals a moderate correlation of .58 between radon concentration and cave entrance distance. The high radon readings depicted on the previous three graphs are from canisters placed in deadend passages where airflow is most restricted.

RESULTS

Radon concentrations in Schofer Cave are between five and ten times higher than EPA minimum safety levels, but this study suggests that the level of radon does not correlate strongly with either relative humidity, temperature, or distance from the cave entrance. Distance from the entrance exhibits the greatest relationship, but the correlation coefficient is only moderately high for the fourteen days that were studied. Thus, the results of this study do not lend a great deal of support to the hypothesis that radon levels can be predicted through the measurement of microclimatic conditions in caves.

[12]Eapen and Rangarajan, op. cit., footnote 5.

However, the high radon readings do suggest that proximity to the Reading Prong has some bearing on radon levels. Studies would have to be conducted in other caves near the Prong to determine the strength of this relationship.