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Short-term fluctuations in barometric pressure, soil-gas radon, and gamma radiation

by

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Short-term fluctuations in barometric pressure, soil-gas radon, and gamma radiation

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Abstract

Short-term fluctuations in barometric pressure that occur over periods of minutes, rather than hours, cause fluctuations not only in the concentrations of radon sampled from highly permeable soils at depths of less than 1 meter, but also cause fluctuations in the gamma radiation emitted near the ground surface. These radiation fluctuations result from fluctuations in 1.764 MeV gamma emissions after the decay of ^{214}Bi of the uranium series. Data pairs from sandy soil near the Riverside Reservoir in Colorado indicate that a positive correlation exists between the radon and radiation fluxes recorded at 30-minute intervals during a period of diurnal decrease in barometric pressure. A plot of the rates of change for barometric pressure, for radon concentration, and for gamma radiation supports a hypothesis that attributes these fluctuations in the soil-gas radon concentration and the 1.764 MeV gamma emission to fluctuations in barometric pressure.

The measured intensity of the gamma radiation from ^{214}Bi (bismuth-214)[1] has been used both for the determination of areas that are favorable for uranium exploration and for the identification of areas that may be subject to health risks caused by the presence of ^{222}Rn. Therefore, it is important to recognize the effect of short-term fluctuations in barometric pressure upon the aerial and ground radiation data frequently used for these studies.

Gamma radiation emitted after the decay of ^{214}Bi is detected in the uranium window (1.764 million electron volts, MeV) of 4-channel gamma-ray spectrometers, commonly used in aerial radiometric equipment and in hand-held spectrometers. This radiation is emitted close to the ground surface and is derived predominantly from two sources. First, it is emitted after the decay of ^{214}Bi in uraniferous or radium-bearing rock, detrital minerals, and mineral coatings that are present within 50 cm of the ground surface. A second source of this radiation results from the decay of the ^{214}Bi progeny of ^{222}Rn that has diffused and flowed upwards from greater depths into the near-surface pore space. This radon is present as a free gas, or as a dissolved gas in soil moisture, within the vadose zone. The decay of soil-gas radon within the pore space yields a chain of daughters plated to (or in liquid films on) soil particles, which remain behind after the radon-bearing soil gas has escaped into the atmosphere or has been displaced by encroaching air. The chain of daughter isotopes of ^{222}Rn (3.825-day half life) includes ^{218}Po (3.05-minute half

[1] By convention the 1.764 MeV radiation is generally attributed to the decay of ^{214} Bi, although the radiation is emitted during the resulting excited state of ^{214}Po, which has a millisecond half life.

life), ^{214}Pb (26.8-minute half life), ^{214}Bi (19.7-minute half life), and then ^{214}Po (1.6 X 10^{-4}-second half life), from which 1.764 MeV gamma radiation is emitted.

Data obtained during a study of radiation and soil-gas radon at the Riverside Reservoir in Colorado by Duval and others (1990) have been reinterpreted in this report. The soil in this area is the Valent sand, a deep excessively drained and rapidly permeable soil (6-20 in/hour in standard percolation tests) (Crabb, 1980). Soil mapping in the area has determined the water-table depth to be generally greater than 6 feet and bedrock depth to be greater than 60 inches.

Ground radiation at the E0 quality control monitoring station in the Riverside Reservoir study area (Duval and others, 1990) was measured with a 4-channel gamma-ray spectrometer that recorded emission intensities between 1.66 and 1.90 MeV in the uranium window. This uranium window records the intensities of 4 gamma-ray emissions that result from the decay of ^{214}Bi. The dominant gamma ray of this group is the 1.764 MeV emission. A large fluctuation in the gamma radiation measured by this window can only be explained by a prior fluctuation in the concentration of ^{222}Rn within the soil.

An examination of data obtained from the quality control monitoring station, site E0, at the Riverside Reservoir in Colorado by Duval and others[2] (1990, Figure 12) reveals short-term fluctuations in the soil-gas radon concentration that commonly coincide with similar fluctuations in gamma radiation (fig.1). This surface radiation is emitted from within the upper 50 cm of the shallow soil zone (Milsom, 1989, p.61). The fluctuations in gamma emission ranged from -33% to +57% of values recorded 30 minutes earlier. Further examination of this data (fig. 2) reveals that during the diurnal decrease in barometric pressure, from 10:00 to 16:30 hours, 11 of 13 data pairs detected simultaneous positive or negative fluxes in radon concentration and gamma radiation relative to the data recorded 30 minutes earlier. It is unlikely that either the random emission of radiation, or the precision of the methods for radiation and radon measurement, could be major factors in the correlation of the direction of short-term fluctuations in the radon and radiation data.

Meteorologic data recorded during the survey at the E0 sample site is consistent with a hypothesis that attributes short-term fluctuations in radon concentration and gamma radiation to short-term fluctuations in barometric pressure. This relationship is supported by a comparison of the plot for the rate of change of the barometric pressure with similar plots for the rate of change of the radon concentration in soil gas and the rate of change of the gamma radiation (fig.2). These plots are based upon data obtained at intervals of one-half hour. For this reason the apparent inflection points on these profiles do not show the actual inflection points for the barometric-pressure, radon-

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[2] Participants in the field study at the E0 sample site were G. M. Reimer, J. Been, S. Szari, and Lisa Hu.

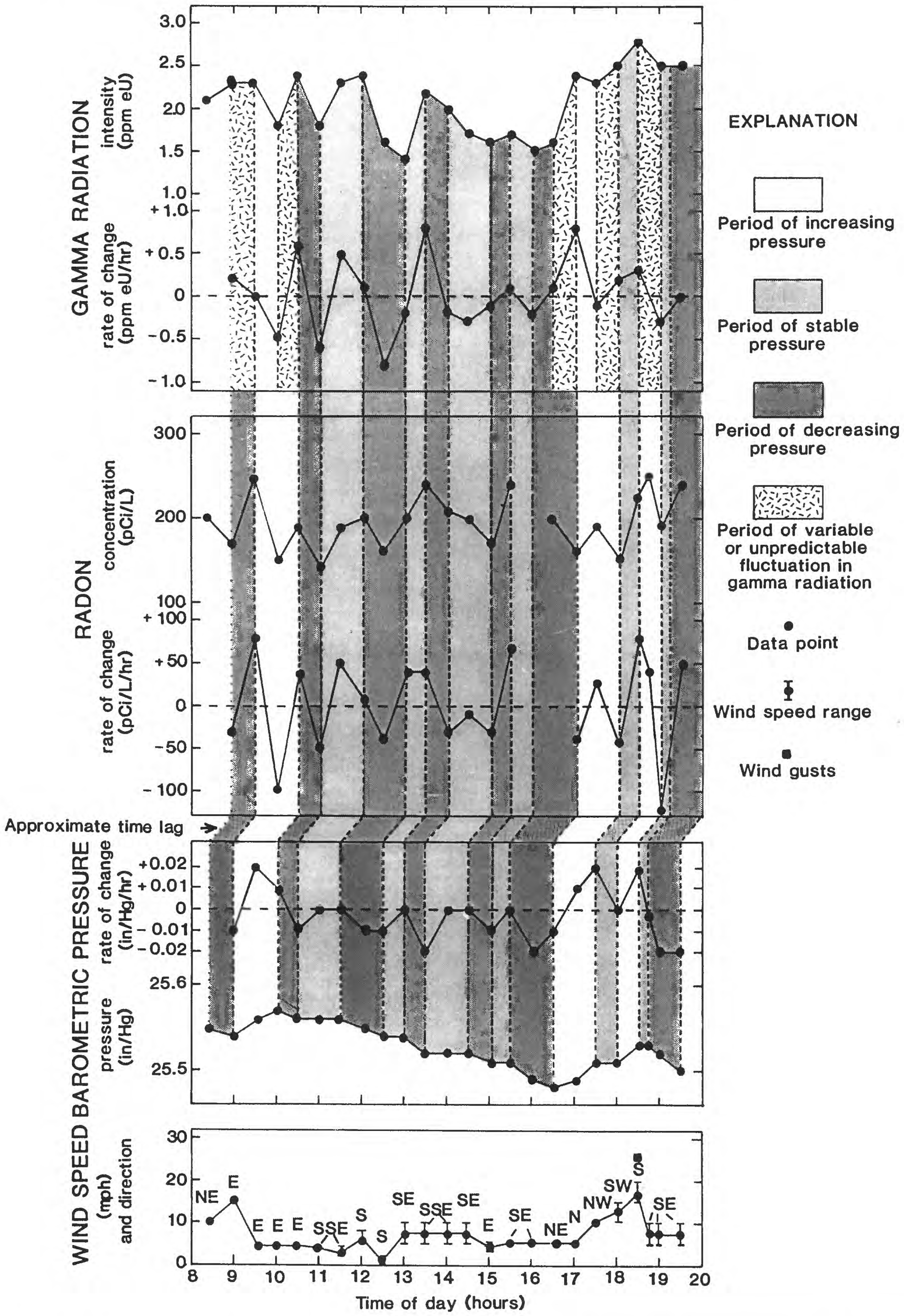

FIGURE 2-Profiles showing the effects of fluctuations in the rate-of-change in barometric pressure upon soil-gas radon concentration and gamma radiation at site E0, Riverside Reservoir, Colorado. Shading correlates periods of increasing, decreasing, or stable barometric pressure with periodic fluctuations in radon concentration and gamma radiation. Data was obtained at one-half hour intervals, therefore the actual times for the reversal of short-term fluctuations in the barometric-pressure, radon-concentration, and gamma-radiation data occur before or after the apparent inflection points recorded by this data. (Radon data for 16:02 hours is questionable and therefore is omitted from this illustration.) Wind speed and wind direction are additional meteorologic variables having an indeterminate effect upon the radon and radiation data.

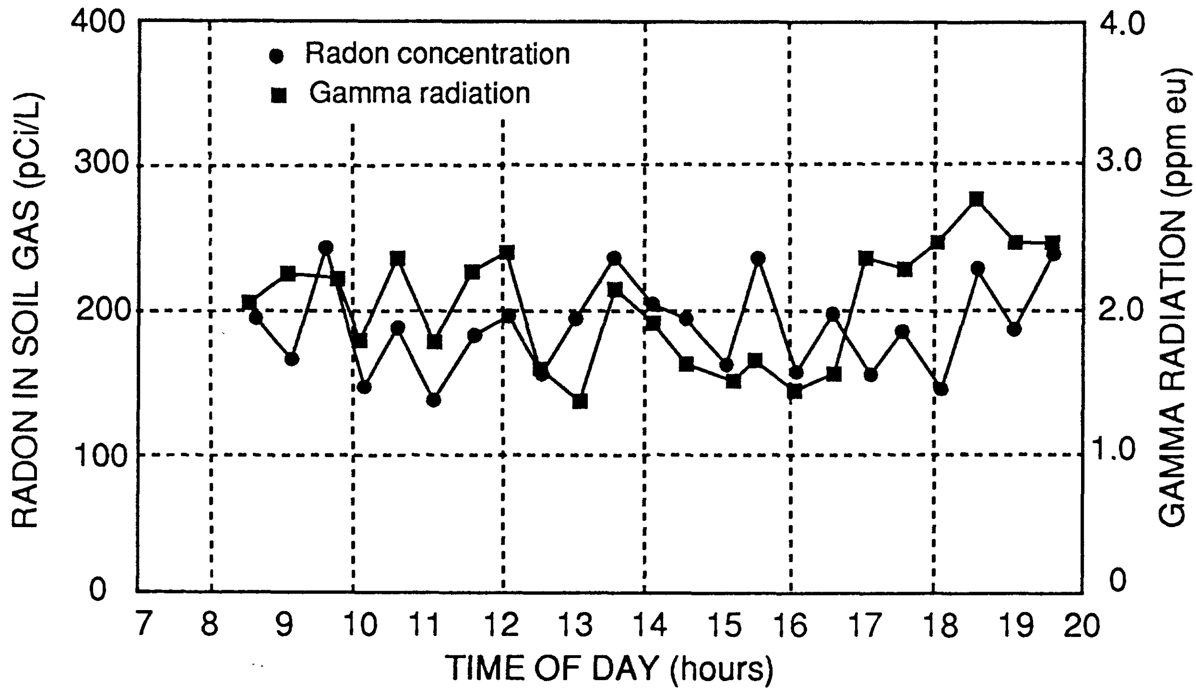

FIGURE 1-Gamma radiation measurements at sample site E0, Riverside Reservoir, Colorado reflect short-term fluctuations in the concentration of radon in soil gas. Modified from Figure 12 of Duval and others (1990).

concentration, or gamma-radiation curves. Furthermore, they do not provide an accurate measurement of the rates of change for the three parameters. Although continuous recording of data for these parameters would provide a more accurate identification of the inflection points and would yield a better measurement of the rates of change, the three profiles show a remarkable correspondence during the diurnal period of decreasing barometric pressure from 10:00 hours to 16:30 hours.

The apparent inflection points for the profiles showing the rates of change of barometric pressure and radon concentration in figure 2 generally exhibit a time lag. During this time lag the flow of soil gas equalizes the soil-gas pressure at the 0.75 meter depth (at which Rn was measured) to the barometric pressure. The concentration of radon in the soil gas reflects the fluctuations in the rate of change of soil-gas pressure. During the periods of decreasing barometric pressure a more rapid flow and escape of near-surface, radon-bearing soil gas into the atmosphere generally caused a decrease in the radon concentration at the 0.75 m sample depth.

The rate of flow of gases in the soil, and therefore the time lag for the equalization of soil-gas and atmospheric pressures, is largely dependent upon the permeablility of the soil. Sandy soil, similar to that of the Riverside Reservoir site, and gravels have the greatest permeability and permit the most rapid gaseous flow, whereas loamy soil, silt and clay have progressively less permeability and increasingly restrict gaseous flow and reduce fluctuations in the radon concentration.

A radiation fluctuation at any given depth within the soil is not simultaneous with a radon fluctuation, because a second time lag occurs as the daughters of radon accumulate and decay. Furthermore, the ratio of radon to gamma radiation does not become constant unless a steady state is established. This would require several hours of very stable meteorologic conditions, which seldom occur.

Fluctuations in barometric pressure with time and variations in the depth at which data are obtained, as well as differences in soil permeability and soil moisture, can cause variations in radon concentration and gamma radiation. When an increase in barometric pressure causes air to enter the soil and displace the radon-bearing soil gas, radiation emitted close to the ground surface will decrease at a rate determined by the half-lives and activities of ^{218}Po, ^{214}Pb, and ^{214}Bi at the time of the displacement of ^{222}Rn from the pore space. If steady-state radiation exists prior to displacement of the radon, the radiation emission from this source will be ≈98% of steady-state radiation after 10 minutes, ≈81% after 20 minutes, and ≈71% after 30 minutes (Evans, 1955, fig. 8.2). If an hour elapses without an influx of radon-bearing soil gas into the pore space, the gamma radiation emitted by ^{214}Bi derived from radon in the soil gas will be reduced to ≈51% of steady state.

At depths below 0.5 meters, which includes the 0.75 meter depth of radon sampling, the radon concentration may actually increase. This will occur if the soil-gas pressure had not previously equilibrated to the lower barometric pressure, and if the upward flow of soil gas from deeper horizons with higher radon concentrations persists. Under these conditions the radon concentration, and ultimately the gamma radiation emitted at that depth, will increase.

A decrease in barometric pressure will immediately effect a flow of soil-gas into the atmosphere from soil just below the ground surface. This will also cause the concentration of radon near the ground surface to decrease. At greater depths the reduction of barometric pressure also effects a reduction of soil-gas pressures and an upward flow of soil gas. These soil gases from greater depths may carry higher concentrations of radon. A continued upward flow of these deeper gases will later cause an increase in the radon concentration near the ground surface and, after an additional period of time, an increase in gamma radiation. All fluctuations in radon concentration at any depth effect fluctuations in gamma emissions resulting from the decay of ^{214}Bi at the corresponding depths, but only when the gamma emissions occur at depths of less than 0.5 meters are they detectable at the surface.

The rates of increase in gamma radiation following an influx of radon into pore spaces within the soil are given by Evans (1955, fig.8.1). Within the first 10 minutes after ^{222}Rn flows into the pore space of a shallow soil, the decay of ^{214}Bi will effect an emission of gamma radiation at ≈3% of the maximum rate that would be emitted if a steady state were achieved. Within 20 minutes, ≈8% of the maximum radiation level will be achieved, and ≈17% of the maximum radiation level will be achieved before half an hour has elapsed. By the time one hour has elapsed the radiation level will be ≈51% of the maximum level at a steady state.

A time lag for inflection points of the radiation data, as compared to the inflection points for radon data, is not evident in the data collected at the E0 sample site (fig. 2). The additional time lag for the radiation data is not evident in this study, because the radiation data and the soil-gas radon data are not representative of events occurring at the same depth. The surface measurements of radiation are restricted to radiation emitted from the upper 50 cm of the soil profile and are very heavily weighted by radiation emitted close to the ground surface (up to 50% from the first 10 cm). Soil gas within this uppermost zone responds very rapidly to the fluctuations in barometric pressure compared to gases at the 0.75 meter depth, at which radon samples were collected. The time lag for the surface radiation data is determined predominantly by the rate of decay of the radon daughters.

Inasmuch as both the radon concentration and the intensity of gamma radiation vary with the lapsed time following a fluctuation in the barometric pressure, a continuous recording of barometric pressure would assist the identification of the true inflection points and the evaluation of radon and radiation data. The true inflection points for the rate of change of barometric pressure could have occurred many minutes before or after the times indicated by the apparent inflection points shown in figure 2.

A repetition of this study in an areas emitting high concentrations of radon and correspondingly high gamma radiation could provide more accurate data and a better understanding of the effects of short-term meteorologic fluctuations. Data should be collected under a variety of soil conditions. The study should employ a continuous monitoring of barometric pressure and wind speed, combined with the repetitive sampling, at short time intervals, of soil-gas radon collected at several depths and at the surface, as well. It should also include the repetitive monitoring of gamma radiation at the surface and at the soil depths of the radon samples. If the above conditions are met during the study, one should be able to apply the corrective curves of Evans (1955, figs. 8.1 and 8.2) to the radiation data.

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