GAMMA RADIATION AND ITS RELATIONSHIPS TO RADON AT FOUR SITES IN WYOMING

by

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INTRODUCTION

Ground-based background gamma radiation and aerial gamma radiation maps have been used to identify the radon-occurrence potential of select areas in the United States. Duval, Reimer, Schumann, Owen, and Otton (1990) found a good correlation between ground-based gamma radiation surveys and soil-gas radon levels in Colorado. Duval (1991) was able to estimate levels of radon in soil-gas in New Jersey by using aerial gamma radiation data.

Most aerial gamma radiation surveys used in the United States were done as part of the National Uranium Resource Evaluation (NURE) program. The NURE program was conducted by the U.S. Department of Energy from 1975-1983. The program included aerial gamma radiation surveys which measured the gamma radiation flux produced by the radioactive decay of potassium-40 (^{40}K), uranium-238 (^{238}U), and thorium-232 (^{232}Th) in the top few inches of the ground surface (Duval, Jones, Riggle, and Pitkin, 1989). After the raw gamma radiation data was corrected for cosmic radiation, airborne bismuth-214 (^{214}Bi), flight altitude, aircraft gamma radiation levels, variation between systems, and Compton backscattering, the values for equivalent uranium (eU), equivalent thorium (eTh), and percent potassium (%K) were calculated. Potassium is measured directly by monitoring its gamma-ray decay. Uranium and thorium are measured indirectly by monitoring the gamma-ray decay of some of their daughter products. Bismuth-214 (^{214}Bi) is monitored to determine the equivalent uranium concentration and thallium-208 (^{208}Tl) is monitored to determine the equivalent thorium concentration. The concentration values for uranium and thorium are referred to as "equivalent" values since there may be disequilibrium between them and their measured daughter products (Pitkin and Duval, 1980). The values for equivalent uranium may be related to radon-222 (^{222}Rn) levels since radon is a daughter product of uranium-238 and bismuth-214 is a daughter product of radon-222.

In 1990, the Geological Survey of Wyoming compared published NURE data and maps for four areas in Wyoming with existing home radon data collected by the Wyoming Department of Health in 1987. Afton, Lingle, Sheridan, and Laramie were compared. Afton and Lingle both had homes that were significantly elevated in radon, although sample sizes in both areas were small. Only one home was tested in Lingle, but it had a radon level of 46.7 picocurries per liter (pCi/L). Ten homes were tested in Afton, with a maximum reading of 34.1 pCi/L and a mean radon level of 16.77 pCi/L. Sheridan had a smaller percentage of homes tested that were elevated in radon than in Afton or Lingle, but a higher percentage of homes elevated in radon than in Laramie. Sixty-six homes were sampled in Sheridan in 1987, with a maximum reading of 18.2 pCi/L and a mean radon level of 4.87 pCi/L. Eighty-five homes were tested in Laramie, with a maximum radon reading of 26.2 pCi/L and a mean radon level of 3.81 pCi/L.

Existing NURE data indicated that total gamma radiation exposure from all sources was highest in the Lingle area, with Laramie the next highest. Sheridan and Afton had the lowest total gamma radiation exposure from all sources.

The primary purpose of this project was to compare NURE aerial gamma radiation data, ground-based gamma radiation data, and current home radon sampling data for Central Goshen County (Lingle-Torrington area), Afton, Sheridan, and Laramie. For the purposes of this study, the Central Goshen County area includes Lingle, Fort Laramie, and Torrington. Very few home radon samples were conducted in Lingle itself, so the area of study was expanded. Aerial and ground-based gamma radiation data were first checked for consistency. Gamma radiation data was then compared to home radon data, in order to determine what degree of correlation exists. A secondary purpose of this project was to compare ground-based gamma radiation data with soil-gas radon data in the Laramie area. This was done to test the feasibility of using ground-based gamma radiation data to flag radon occurrence potential.

METHODS

The ground-based gamma radiation data collected by the Geological Survey of Wyoming was obtained by using a Precision Model III scintillator, a McPhar TV-1A spectrometer, or a Scintrex GAM-1 spectrometer. The Precision Model III scintillator and the McPhar TV-1A spectrometer were used to measure gamma radiation in the Central Goshen County area (Harris, 1985). The Scintrex GAM-1 spectrometer was used to measure gamma radiation in the Afton, Sheridan, and Laramie areas. The detectors were calibrated for consistent readings. One to three readings were taken each day for each area at a base locality in the area of interest in order to check for minor daily variations in atmospheric and cosmic radiation flux.

The Scintrex GAM-1 spectrometer, which was used in the Afton, Sheridan, and Laramie areas, did have some limitations. It was only able to obtain readings for a maximum of ten seconds. With the uranium window preset for a uranium peak between 1.66 and 1.90 MeV, count rates in the uranium mode were very low for some sites. For example, in the Sheridan area, uranium counts were in the 1-5 counts per second range, which are at the extreme low end of the detectors ability to discriminate values. Because of this limitation, count rates for the total gamma spectrum were utilized. In future studies, it would be desireable to differentiate the gamma radiation contribution from uranium, thorium, and potassium-40.

Nine sites were sampled for gamma radiation in the Afton area, nineteen sites were sampled within the Central Goshen County area, thirty-five sites were sampled in the Sheridan area, and twelve sites were sampled in the Laramie area. Sites sampled in the Laramie area were those that were also sampled for soil-gas radon. The Laramie area sites were sampled twice, first on November 9, 1992, and again on November 17, 1992.

Aerial gamma radiation data was derived solely from U.S.

Department of Energy National Uranium Resource Evaluation (NURE) reports. Afton data was derived from the "Aerial Radiometric and Magnetic Survey, Preston National Topographic Map, Idaho/Wyoming, Final Report" (Geodata International, Inc., 1981), Central Goshen County data was derived from the "Aerial Gamma Ray and Magnetic Survey, Powder River II Project, Torrington Quadrangle, Wyoming and Nebraska, Final Report - Volume II" (geoMetrics, Inc., 1979), Sheridan data was derived from "Airborne Gamma-Ray Spectrometer and Magnetometer Survey, Sheridan Quadrangle, Wyoming, Final Report - Volume II C" (High Life Helicopters, Inc. and QEB, Inc., 1981), and Laramie data was derived from "Aerial Gamma Ray and Magnetic Survey, Rock Springs, Rawlins, and Cheyenne Quadrangles, Wyoming, and the Greeley Quadrangle, Colorado, Final Report, Volume I" (geoMetrics, 1978).

As mentioned previously, all NURE projects contained corrected data for equivalent uranium (eU), equivalent thorium (eTh), and percent potassium (%K). The data are available in each NURE report in both tabular and graphic (map) formats. In order to determine the aerial gamma radiation levels for all of the ground-based sample sites for each study area, pseudo-contour maps for equivalent uranium, equivalent thorium, and percent potassium that were present in each of the appropriate NURE reports were utilized. Gamma radiation sample localities for each area were plotted on the pseudo-contour maps and the data were extracted. Total gamma radiation data was obtained for the ground-based study. In order to compare the aerial data to the ground-based data, the following formula (Joe Duval, U.S. Geological Survey, personal communication, 1992) was used:

$$\text{Total Gamma Exposure } (\mu R/hr) = (\%K)(1.5) + (eU)(0.625) + (eTh)(0.31)$$

eU and eTh are in parts per million (ppm)

SITE LOCATIONS AND DESCRIPTIONS

Four areas in Wyoming were analyzed for ground-based gamma radiation: Central Goshen County, Afton, Sheridan, and Laramie. Sites that were measured in each area were selected so as to represent the general distribution of surficial features, surficial deposits, and bedrock present in each area. Sample locality numbers presented below correspond to those in Figures 1-5.

Central Goshen County - Data from Harris (1985)

Site Number	Site location	Geologic Formation/Deposit
1	SE NE section 11, T24N, R61W	Quaternary Alluvium (terrace)
2	SW SW NW section 30, T25N, R63W	Brule Member of the White River Formation
3	SW SW SE section 10, T26N, R61W	Brule Member of the White River Formation
4	SE NE SE section 31, T25N, R62W	Chadron Member of the White River Formation
5	SW SW SW section 4, T24N, R62W	Brule Member of the White River Formation
6	NW NW NW section 29, T24N, R60W	Quaternary Alluvium (flood plain)
7	SE SE SE section 14, T25N, R63W	Quaternary Alluvium (flood plain)
8	NW section 28, T25N, R61W	Quaternary Alluvium (terrace)
9	SW SE SE section 15, T25N, R63W	Quaternary Alluvium (flood plain)
10	NW SW SE section 30, T25N, R62W	Quaternary Alluvium
11	NE SE SW section 5, T24N, R60W	Dune Sand
12	Center section 28, T26N, R61W	Dune Sand
13	NW NE NW section 21, T25N, R61W	Dune Sand
14	SW SW NE section 10, T26N, R62W	Brule Member of the White River Formation
15	NE NE NE section 22, T25N, R60W	Brule Member of the White River Formation
16	SE SE SE section 31, T25N, R63W	Miocene/Oligocene Conglomerate
17	SW SE SE section 4, T25N, R62W	Quaternary Alluvium
18	NW SW SE section 25, T25N, R64W	Miocene/Oligocene Conglomerate
19	SE NE SE section 6, T24N, R63W	Miocene/Oligocene Conglomerate

Afton Area

Site Number	Site location	Geologic Formation/Deposit
1	SW SE SE section 25, T32N, R119W	Quaternary Alluvium
2	SE NE SE section 30, T32N, R118W	Quaternary Alluvium
3	SW SW SW section 27, T32N, R119W	Quaternary Alluvium
4	SW SW SW section 26, T32N, R119W	Quaternary Alluvium
5	SE SE SE section 26, T32N, R119W	Quaternary Alluvium
6	SW SW SE section 30, T32N, R118W	Quaternary Alluvium (fan)
7	SW SE SW section 30, T32N, R118W	Quaternary Alluvium
8	SW SW NE section 30, T32N, R118W	Quaternary Alluvium
9	SW SE NE section 30, T32N, R118W	Quaternary Alluvium

Sheridan Area

Site Number	Site location	Geologic Formation/Deposit
1	NE NW NE section 26, T56N, R84W	Wasatch Formation (grey siltstone)
2	SW SW NW section 27, T56N, R84W	Fort Union Formation (grey shale)
3	SW SE SW section 23, T56N, R84W	Clinker rubble over Quaternary Alluvium
4	SW SW NW section 27, T56N, R84W	Fort Union Formation (Carbonaceous Shale)
5	SE NE SW section 26, T56N, R84W	Colluvium (Old Railroad Grade)
6	NE SE NW section 27, T56N, R84W	Colluvium over Fort Union Formation
7	SW NW SE section 26, T56N, R84W	Wasatch Formation
8	SE SE SW section 23, T56N, R84W	Colluvium over Wasatch Formation
9	NE SW NW section 33, T56N, R84W	Quaternary Alluvium
10	SE NW NW section 26, T56N, R84W	Quaternary Alluvium
11	SW SW SE section 22, T56N, R84W	Colluvium over Fort Union Formation
12	SE NE NW section 2, T55N, R84W	Quaternary Alluvium
13	SE SE SE section 21, T56N, R84W	Gravel-Capped Surface
14	NE NE SE section 33, T56N, R84W	Gravel-Capped Surface
15	SW SW SW section 15, T56N, R84W	Gravel-Capped Surface
16	NW NW SE section 35, T56N, R84W	Quaternary Alluvium
17	NE NW SE section 27, T56N, R84W	Quaternary Alluvium
18	NE NE SE section 28, T56N, R84W	Landslide over Fort Union Formation
19	SW NW NW section 1, T55N, R84W	Colluvium over Wasatch Formation
20	NW SW NW section 2, T55N, R84W	Colluvium over Fort Union Formation
21	NE SE SE section 27, T56N, R84W	Colluvium over Fort Union Formation
22	SE NW NW section 33, T56N, R84W	Colluvium over Fort Union Formation
23	SW NE NW section 21, T56N, R84W	Colluvium over Fort Union Formation
24	SW SW SE section 21, T56N, R84W	Colluvium over Fort Union Formation
25	NW SE NW section 21, T56N, R84W	Landslide over Fort Union Formation
26	NE NE NE section 27, T56N, R84W	Quaternary Alluvium
27	NW NE NE section 22, T56N, R84W	Quaternary Alluvium
28	NW NE NW section 21, T56N, R84W	Quaternary Alluvium
29	SE NW NW section 22, T56N, R84W	Quaternary Alluvium
30	NW NE NW section 35, T56N, R84W	Quaternary Alluvium
31	NW SE NW section 3, T55N, R84W	Gravel-Capped Surface
32	SE NE NE section 28, T56N, R84W	Gravel-Capped Surface
33	SW SE SW section 21, T56N, R84W	Gravel-Capped Surface
34	NW NE NE section 34, T56N, R84W	Colluvium over Fort Union Formation
35	NW NE SW section 27, T56N, R84W	Quaternary Alluvium

Laramie Area

Site Number	Site location	Geologic Formation/Deposit
1	NE NE NW section 9, T15N, R73W	Gravel-Capped Bench
2	SE NW SE section 1, T15N, R73W	Alluvium and Eolian over Casper Formation
3	NW NW NW section 32, T15N, R74W	Quaternary Alluvium
4	NW SW NW section 7, T15N, R73W	Quaternary Alluvium (terrace)
5	NE SW NE section 35, T16N, R74W	Gravel-Capped Bench
6	SW NW SE section 34, T16N, R73W	Quaternary Alluvium
7	SW SE SW section 31, T16N, R73W	Quaternary Alluvium (terrace)
8	SE SW NW section 27, T16N, R73W	Colluvium over Chugwater Formation
9	NE SE NE section 28, T16N, R73W	Slopewash over Chugwater Formation
10	NW SW SE section 35, T16N, R73W	Quaternary Alluvium
11	NE SW SW section 32, T16N, R73W	Quaternary Alluvium (terrace)
12	NE SW NE section 1, T15N, R74W	Quaternary Alluvium (terrace)

DISCUSSION

Aerial Gamma Radiation vs. Ground-Based Gamma Radiation

Previous research (Duval, 1991; Duval, Reimer, Schumann, Owen, and Otton, 1990; Duval, Jones, Riggle, and Pitkin, 1989) indicates that some of the NURE aerial gamma radiation surveys were not properly calibrated or analyzed. Aerial and ground-based gamma radiation data were compared for all sites in this study (Figures 1-4, Table 1). The best correlation between aerial and ground-based gamma radiation data occurred in the Laramie area (Figure 1). The Sheridan (Figure 2) and Afton (Figure 3) areas had ground-based data that were consistently and noticeably higher than the aerial data. Ground-based data in the Central Goshen County (Figure 4) area were generally higher than the aerial data, although a reasonable correlation existed for six to seven of the sites. Table 1 presents a summary of the NURE and ground-based gamma radiation data for all sites.

Table 1. Summary comparison of aerial and ground-based gamma radiation data.

Area	NURE Aerial Gamma Sample Size	NURE Aerial Gamma Mean (μR/hr)	Ground-Based Gamma Sample Size	Ground-Based Gamma Mean (μR/hr)
Central Goshen County	38	13.2	19	18.5
Afton	18	4.93	9	10.3
Sheridan	70	5.79	35	14.8
Laramie	24	7.08	24	9.82

All of the mean ground-based gamma radiation levels were higher than the aerial gamma radiation levels for all sites. Central Goshen County had a mean ground-based gamma radiation level that was 40.2% higher than the associated mean aerial level, Afton had a mean ground-based gamma radiation level that was 108.9% higher than the associated mean aerial level, Sheridan had a mean ground-based gamma radiation level that was 155.6% higher than the

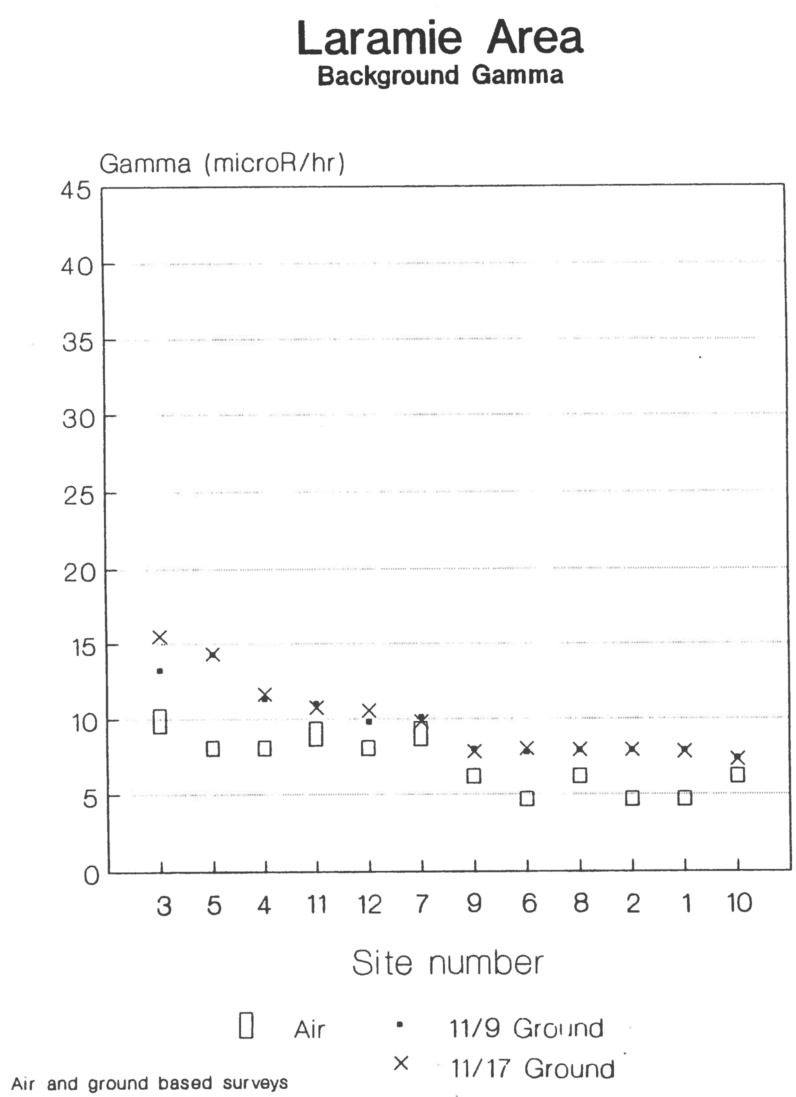

Figure 1. Aerial and ground-based gamma radiation in the Laramie area.

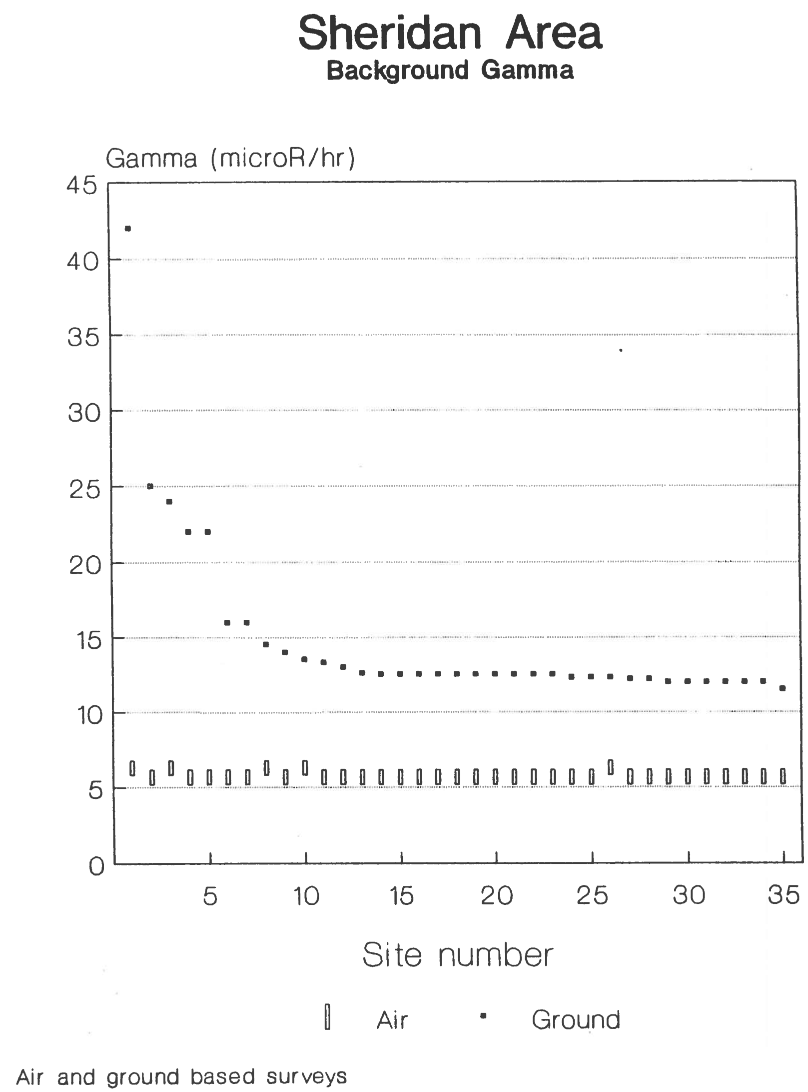

Figure 2. Aerial and ground-based gamma radiation in the Sheridan area.

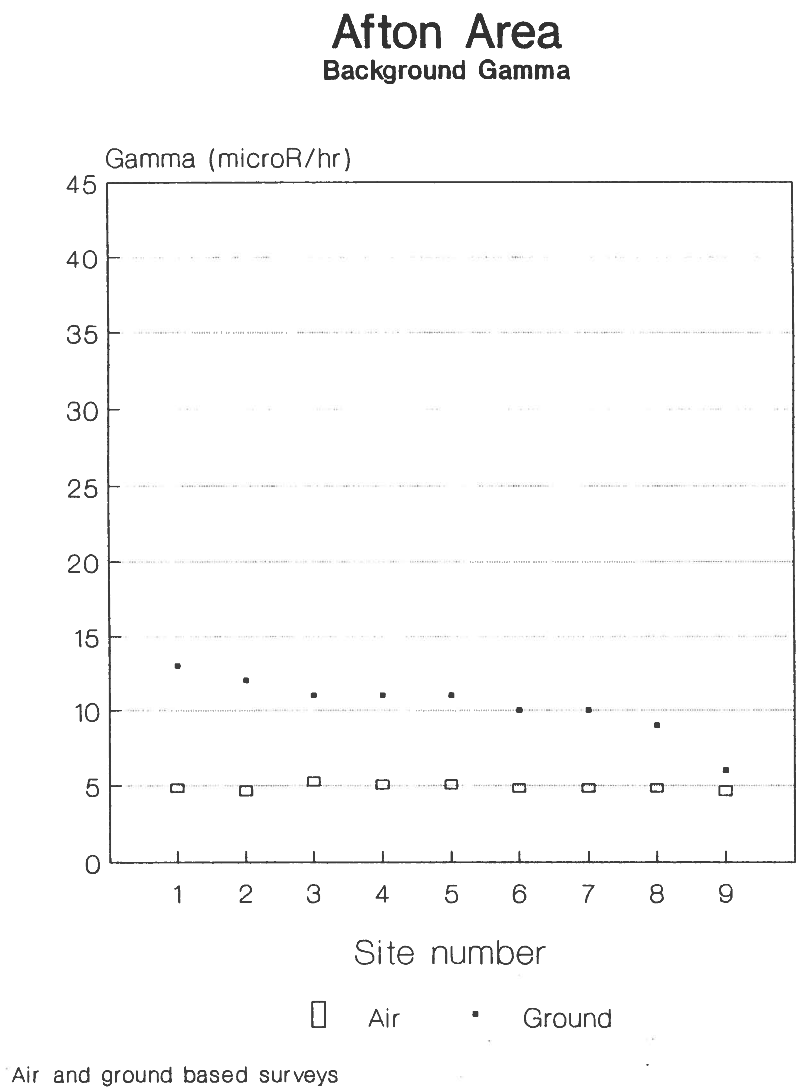

Figure 3. Aerial and ground-based gamma radiation in the Afton area.

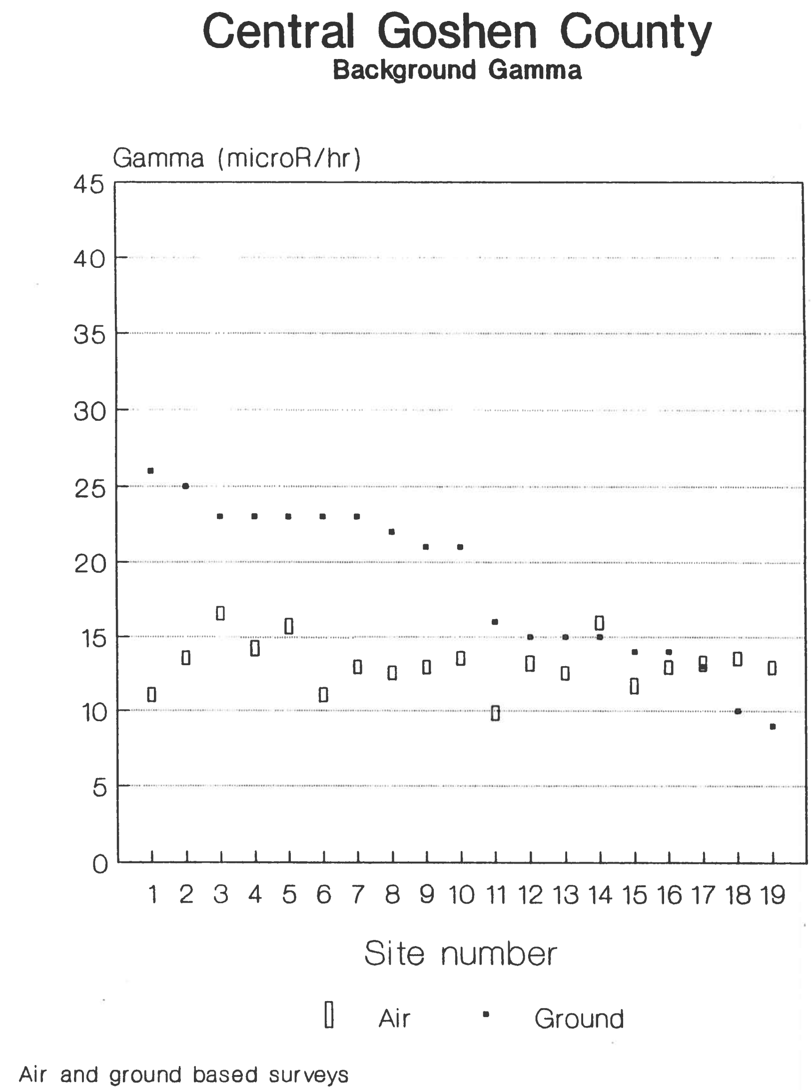

Figure 4. Aerial and ground-based gamma radiation in the Central Goshen County area.

associated mean aerial level, and Laramie had a mean ground-based gamma radiation level that was 38.7% higher than the associated mean aerial level. Due to the differences between the aerial levels and ground-based levels, ground-based levels were used when comparing observed gamma radiation with both radon present in the homes in all four areas and also soil-gas radon in the Laramie area. Newly corrected aerial gamma radiation data may lend to a better correlation, and this comparison will be done in the future.

Ground-Based Gamma Radiation vs. Radon in Homes

In 1987, the Wyoming Department of Health conducted a series of long-term radon analyses in select Wyoming homes. Charcoal canister sampling devices were used to determine radon concentrations in homes tested. In 1992, short-term charcoal canister and long-term Alpha(α)-track etch testing was done by the Wyoming Department of Health in a limited number of homes. Charcoal canister data were used in this project due to the limited number of α-track etch analyses available. A summary of home radon sampling data for all the four study areas is shown in Table 2. Afton has the highest mean home radon level, followed by Central Goshen County, Sheridan and Laramie.

In order to easily compare ground-based gamma radiation data to home radon sampling data in the four study areas, the areas are ranked from highest to lowest for both parameters (Table 3).

Table 2. Summary of home radon sampling data, 1987 charcoal canister data.

	1987 Charcoal Canister Data	
Area	Sample Size	Mean (pCi/L)
Central Goshen County	25	5.96
Afton	10	16.77
Sheridan	66	4.87
Laramie	85	3.81

Table 3. Study area rankings.

STUDY AREAS RANKED BY MEAN GROUND-BASED GAMMA (Highest to Lowest)	STUDY AREAS RANKED BY MEAN HOME RADON LEVELS (highest to Lowest)
Central Goshen County	Afton Area
Sheridan Area	Central Goshen County
Afton Area	Sheridan Area
Laramie Area	Laramie Area

The Afton area is the least consistent when comparing ground-based gamma radiation levels with home radon levels. Afton has the next-to-lowest mean ground-based gamma radiation level, and the highest mean home radon level. If the Afton site were removed from the study, all areas would have the same ordering for both gamma radiation and home radon level. Assuming that Afton is in some way anomalous for home radon sampling, ground-based total gamma radiation surveys appear to be a reasonable method of flagging relative home radon occurrence potentials. A different interpretation may result if the gamma radiation due to uranium instead of total gamma radiation was used in the analysis.

The fact that Afton appears to be anomalously high in regard to home radon levels merits further investigation. At least two topics need to be investigated - home construction/construction materials and mass transport of radon by ground water or along the Star Valley fault system. If homes are partially constructed of aggregate enriched in uranium or radium, higher radon levels could occur. If radon is being rapidly transported into a small area, such as along the Star Valley fault, such anomalies may be difficult to detect with airborne or ground-based gamma radiation surveys.

Ground-Based Gamma Radiation vs. Soil-Gas Radon

In 1992, the Geological Survey of Wyoming conducted a series of soil-gas radon measurements at twelve sites in the Laramie

Basin. Ground-based gamma radiation data was collected at each of the sites on both November 9, 1992 and November 17, 1992. A plot of the Laramie ground-based gamma radiation data is shown in Figure 5. The ground-based data appear to correlate very well from November 9, 1992 to November 17, 1992.

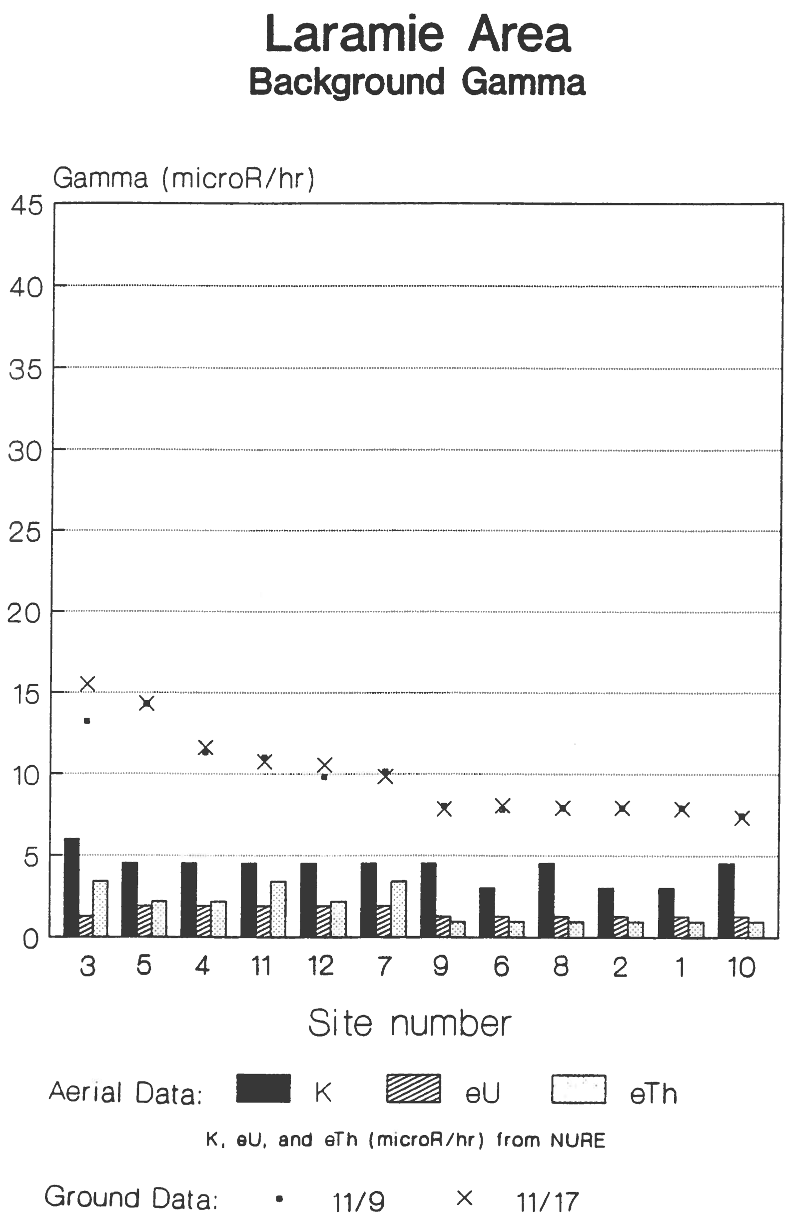

Figure 5. Aerial (K, eU, and eTh) and ground-based gamma radiation in Laramie area.

The soil-gas radon sample sites in the Laramie Basin were numbered from 1 through 12. Results of the soil-gas radon study indicated that the sites could be grouped into three soil-gas radon ranges. A low range (0-250 pCi/L) included sites 1, 2, 6, 8, 10, and 11, a moderate range (250-750 pCi/L) included sites 3, 4, 7, 9, and 12, and a high range (>750 pCi/L) included site 5.

Close examination of plots of the ground-based gamma radiation data (Figure 5) in the Laramie area indicate that three gamma radiation groupings were also present. The lowest group, composed of sites 1, 2, 6, 8, 9, and 10, has all sites in a 7.3-8.0 μR/hr range. The middle group, composed of sites 4, 7, 11, and 12, has all sites in a 9.8-11.6 μR/hr range. The highest group, composed of sites 3 and 5, has all sites in a 13.2-15.5 μR/hr range.

The ground-based gamma radiation groupings correlate fairly well with the sites in the soil-gas radon groupings, with the exception of sites 3, 9, and 11. Site 3 is in a moderate soil-gas radon group and a high gamma radiation group. This may be due to increased contributions to the gamma radiation from potassium-40 and thorium at site 3 (inferred from aerial gamma radiation data, Figure 5), which would not affect soil-gas radon. Site 9 is in a moderate soil-gas radon grouping and a low gamma radiation grouping. Soil permeability may be a factor at this site, but the actual reason for the discrepancy is unknown. Site 11 is in a low soil-gas radon grouping, and a moderate gamma radiation grouping. This may be due to an increased contribution to the gamma radiation from thorium at site 11 (inferred from aerial gamma radiation data, Figure 5), which would not affect the soil-gas radon concentrations.

With the above exceptions, the correlation between soil-gas radon levels and ground-based gamma radiation levels at the twelve Laramie Basin sites is good. The linear correlation coefficient between soil-gas radon levels and the gamma radiation levels for the two sample periods is 0.715.

CONCLUSIONS

NURE aerial gamma radiation data is inconsistent when compared to ground-based gamma radiation data. Unless the aerial gamma radiation data is newly corrected, ground-based data should be utilized.

When ground-based gamma radiation data is compared to home radon data, there generally appears to be a reasonable positive correlation. A notable exception was found in this study, however. Afton was ranked second from lowest when four sites were ranked by their associated ground-based gamma radiation levels. The town was ranked highest for mean home radon level. Ground-based gamma radiation data should be used in conjunction with other available information such as soil permeabilities, presence of faults, types of construction materials, and construction techniques when trying to rapidly assess the radon potential of an area.

Ground-based total gamma radiation data correlated well with soil-gas radon data in the Laramie area. The correlation may be better if gamma contributions from uranium were used for comparison as opposed to comparing total gamma as was done in this study.

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